Do Parking Standards Matter?

Evaluating the London Parking Reform with a Matched-Pair Approach

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ABSTRACT

Minimum parking standards, which require developers to build a certain amount of off-street parking spaces, are increasingly criticized for leading to excess parking supply and automobile travel in recent years. However, due to the difficulty in identifying the policy effect, few empirical studies have directly and accurately estimated the effects of parking standards on parking supply. The present study examines a parking reform in London, UK, where minimum parking standards for residential developments were replaced with maximum standards in the early 2000s. Using planning application records, we match neighboring pre-reform and post-reform developments to estimate the effect of the parking standard switch and further identify the "binding" and "capping" effects of minimum and maximum parking standards. It is found that the parking reform in London has led to a reduction of approximately 0.76 parking spaces per unit in residential development applications, or 49% of the pre-reform level. Minimum parking standards seem to have a larger impact than maximum ones on parking supply that fell more upon inner city developments, while maximum parking standards have more influenced suburban neighborhoods. Market forces have played a major role in the decline of parking supply. The findings provide strong evidence for the market distortion effect of minimum parking standards.

Keywords: parking standards; minimum parking requirements; residential parking supply; London

Highlights

- We examine how the parking standard reform in London has affected parking supply
- We match and compare neighboring developments before and after the reform
- The reform has led to a 49% reduction in new residential parking supply
- Minimum parking standards have a greater and wider influence than maximum ones
- Off-street parking control is not essential to an efficient parking market

1. Introduction

There have long been discussions on how urban form factors, such as sprawl and job-housing balance, can contribute to car usage and dependence (Handy et al., 2005; Ewing and Cervero, 2010). It is less recognized, however, that automobile-oriented built environments are often not designed by pro-car planners, but rather dictated by technical, seemingly neutral, planning guidelines and standards (Guo and Schloeter, 2013). Parking standard, an important but often overlooked planning regulation upon urban developments, is one of these "invisible" automobile policies.

The *parking standards* discussed in this paper refer to the clauses in planning codes that regulate the provision of off-street parking spaces. Traditionally, these clauses require a minimum amount of parking spaces provided along with new developments to accommodate subsequent parking needs. Therefore, the term *parking standards* is often used interchangeably with *minimum parking standards*, *parking requirements*, or *minimum parking requirements*.

Regarded as a necessary amenity for decades, the off-street parking supply created by minimum parking requirements has become controversial in recent years. Opponents argue that these requirements are often arbitrary and excessive, and that they distort both real estate and car markets, leading to higher car ownership and housing costs (Shoup, 2005). The debate has led to a series of reforms of parking standards: In Europe, many countries have started to use *parking maximums*, which limit the amount of parking developers can provide, together with or in place of parking minimums, including but not limited to Belgium, France, Germany, Italy, Switzerland, the Netherlands, and the United Kingdom. In the United States, major cities such as New York City, San Francisco, and Portland have also applied maximum parking standards and/or relaxed minimums ones in downtown areas. Nevertheless, in most of these cases maximum parking standards are only applied to city centers and non-residential uses, and minimum standards remain the norm for residential parking in both European and U.S. cities, as well as in developing countries that are facing increasing levels of car ownership, such as China, India, and Philippines (Barter, 2011).

Despite the general agreement that parking requirements could lead to market distortion, few have empirically studied the consequences of parking standards, or the effects of initiatives that relax or eliminate minimum parking standards. The lack of empirical evidence is likely due to the difficulty in identifying the effect of parking standards on parking supply. Apart from parking standards, parking supply is also influenced by parking needs, site circumstances and housing market dynamics. Since not all these factors are easily measurable and controllable, cross-city comparisons are often subject to omitted variable problems and unlikely to generate accurate estimates of the effects of parking standards. In cities that have partially relaxed parking

requirements, the impact of minimum parking standards could be confounded with self-selection effects: Developments with lower parking needs may concentrate in the exempt areas, leading to superfluous or overestimated "policy effects".

The aim of this study is to fill the research gap and to expand the knowledge on how parking requirements affect parking supply, which could further affect housing affordability and car-owning decisions. It examines a policy change in London in the early 2000s, when all minimum parking standards were replaced with maximum ones in the entire Greater London. The London parking reform offers an opportunity to circumvent the above-mentioned identification problem and directly estimate the effect of parking standards on parking supply. In evaluating the parking reform in London, this study intends to answer the following questions: Has the shift from minimum to maximum parking standards reduced parking supply, as the decision makers and advocates expected? How do minimum and maximum parking standards, respectively, affect parking supply in residential developments? Did the citywide reform cause similar effects in all areas of London? How did local planning policies and market conditions shape the reform at the borough level?

Using a matched-pair approach to compare neighboring pre-reform and post-reform development applications, the study finds that the parking reform has lowered parking provision in residential developments, on average, by 0.76 spaces per dwelling unit, or a 49% reduction. Moreover, the removal of minimum parking requirements might have played a stronger role than the establishment of parking maximums. Minimum parking standards had larger and more universal binding effects across the city, while the maximum ones have mostly curbed parking supply in suburban areas. The results shed light on the rarely studied residential parking market and provide valuable evidence for future designers and students of parking management policies.

The paper is structured as follows. Section II reviews the literature, focusing on the three approaches to parking regulation and relevant empirical studies. Section III describes the London parking reform in detail. Section IV introduces the datasets used in this study. Section V explains the estimation methods. Section VI presents the empirical results, and Section VII discusses the conclusions and policy implications.

2. Literature Review

An important theme in transportation research is how to address the negative externalities of automobiles. Various policy remedies have been discussed and explored around the globe, most of which can be classified into two broad categories: land use strategies and pricing strategies. The former seeks to reduce the demand for car travel by increasing density and diversity, as well

as producing environments that induce alternative travel modes, while the latter try to correct the externalities by making drivers bear the real costs of driving. Empirical studies have shown that both land use and prices influence travel behavior, though no one single policy is likely to solve the problem in its entirety (Ewing and Cervero, 2010; De Grange et al., 2012; Givoni, 2012; Guo et al., 2011).

Despite the close linkage between parking and driving, it is not until recently that the role of parking policies in automobile regulation becomes widely noticed. In his iconoclastic book "The high cost of free parking", Donald Shoup (2005) discusses how excessive minimum parking standards, together with free curb parking, have reinforced the automobile dependence, congestion, and urban sprawl in the United States. Bad parking policies distort both land use and prices: the oversupply of parking spaces contributes to generate urban environments that are unfriendly to pedestrians, cyclers, and transit passengers; underpriced non-residential parking induces car usage; moreover, minimum residential parking standards bundle the costs of parking with housing prices, thus lowering the marginal cost of owning a car and leading to inefficiently high car ownership levels.

As Barter (2010) puts it, the ubiquitous use of minimum parking requirements represents a "conventional approach" to parking policy that intends to control the spillover of parking needs to common parking spaces (e.g., curb parking). By requiring buildings to provide sufficient on-site parking for their users, parking demand is internalized, or at least ideally so. However, since parking requirements seldom accurately reflect parking needs, and "parking needs" *per se* are usually endogenous to available parking spaces, the result is often that buildings end up with too much parking. Shoup therefore advocates a pricing approach to the parking problem: optimally priced on-street parking will cease to be a common good, eliminating the overcrowding issue as well as the rationale for minimum parking requirements. Market forces will adjust both parking demand and car usage to efficient levels, and no off-street parking standards will be needed (Shoup, 2005).

In reality, however, multiple barriers may hinder the formation or functioning of an efficient parking market (Barter, 2010). On the one hand, increased costs on parking that was traditionally free or underpriced could meet with substantial political resistance. Actually, local governments and developers may intentionally oversupply parking as a means to compete for residents and consumers, which partly explains why fundamental parking reforms, like the London parking reform, have to be initiated at a national or regional level. On the other hand, since car usage has significant external costs, market outcomes may not be socially optimal. This point of view justifies further parking controls such as maximum parking standards and comprehensive management of on-street and off-street parking.

Barter (2010) describes and contrasts these three major approaches to parking policy: the conventional approach as represented by the use of minimum parking requirements, the market approach as suggested by Shoup (2005), and comprehensive parking management that aims at controlling car ownership and usage (Litman, 2006). The three approaches differ in their basic assumptions about parking supply, that is, whether the residential parking market is an efficient one without regulation. In other words, will developers provide the "right" amount of parking on their own, or do they tend to undersupply or oversupply parking so that either minimum or maximum parking standards are necessary?

Although empirical evidences on the relationship between parking standards and parking supply or market demand are very limited, the few studies available do suggest that minimum parking standards, at least those in North America, tend to be higher than actual parking needs and push up the supply of parking. In a case study on 10 office buildings in southern California, Willson (1995) finds that in the five "typical" suburban office developments, the amount of parking minimally required and that actually provided are almost twice the parking spaces used during peak time. Also targeting non-residential uses, Engle-Yan et al. (2007) examine parking supply under minimum parking standards in Toronto, Canada, and predict that general office and retail uses will probably provide fewer parking spaces if the parking requirements were relaxed.

A few studies have focused on residential parking standards. After Los Angeles adopted the Adaptive Reuse Ordinance that exempted old downtown buildings converted into residential use from parking requirements in 1999, Manville (2013) find that converted projects generally provide less parking than required by original standards. McDonnell et al. (2010) examine 38 residential developments that were approved under minimum parking requirements between 2000 and 2008 in Queens, New York, and find that almost a half provided parking exactly at the required levels, implying that parking requirements had probably affected the developers' decision on parking provision. None of these studies, though, provides an estimate of the magnitude to which parking requirements lift parking supply. More recently and relevantly, Guo and Ren (2013) look at the London parking reform and estimate that the reform has led to a substantial drop in residential parking supply. Nevertheless, the conclusion is only at the aggregate level and based on a crude comparison between 216 pre-reform developments and over 10,000 post-reform developments without properly controlling for sampling biases or further exploring how the shift of parking standards has played out at the local level. Built upon their work, this study probes deeper into the operation and implementation of the London parking reform, uses a larger dataset and refined methods to estimate the policy effect, and discusses how the reform worked differently in inner city and suburbs due to varied local implementation and parking demand.

3. London Parking Reform

The parking reform in London was initiated by a series of national policies adopted in 2000 and 2001 that intended to restrict car usage and promote alternative transport modes (see *Planning Policy Guidance (PPG) 3: Housing*, 2000*; Planning Policy Guidance 13: Transport*, 2001). The two PPGs have led to a wave of parking standard changes across the nation, while London led the tide by shifting all existing minimum parking standards to maximum ones[1]. The standard shift was dictated by the 2004 London Plan, accompanied by initiatives to encourage "car-free" developments[2] and strengthen on-street parking management through Controlled Parking Zones (CPZs[3]). In a few years afterwards, local planning councils in London removed all minimum parking standards, apart from those for disabled vehicles and bicycles, from their updated planning policy documents.

The shift of parking standards did not take place simultaneously across all boroughs under the Greater London Authority (GLA). As local authorities review and revise local plans on their own schedules, some updated their parking standards as early as 2001, whereas some did not formally reflect the change in adopted planning documents until 2008. Nevertheless, the implementation of the parking reform did not solely depend on formal revision of local plans. Both regional and local planning policies, including drafted plans that are under review, are considered in practice, with more weight given to the more recent ones. From survey and interviews with local planning officers in London, it is inferred that the shift mostly occurred between 2001 and 2004 (See Guo and Ren, 2013 for more details of the London parking reform).

While local plans have to conform to the London Plan, local planning councils maintain considerable autonomy in setting and applying parking standards. The 2004 London Plan has set guideline parking maximums at 1.5 spaces per unit for houses with one to three bedrooms, 2 spaces per unit for those with four or more bedrooms, and 1 space per unit for housing in town centers or areas with high Public Transport Accessibility Levels (PTALs[4]). The 33 boroughs in

[1] The standard shift in London mostly applied to residential uses, as non-residential uses were already subject to maximum parking standards prior to 2000. For a more detailed discussion of the consequences of the two PPGs in other parts of England, see Barter (2013).
[2] Residents of car-free developments will have no access to either off-street or on-street parking.
[3] Controlled Parking Zones are areas within which all roads are subject to certain parking restrictions. In London, CPZs are typically designated to ensure the priority of parking for local residents (except for those in car-free developments, who cannot apply for resident parking permits).
[4] PTAL (graded 1-6) is defined by the Public Transport Accessibility Index (PTAI), which is calculated on the basis of the walking distance from a location to nearest subway stations and bus stops, as well as the service level (frequency or waiting time). The higher the PTAL or the PTAI, the better the location is served by public transport.

London have their own standards for varied categories of housing, as low as 0 and as high as 3 spaces per unit[5].

A scan of the local parking policies suggests that parking standards vary considerably across the boroughs, especially between Inner London (urban) and Outer London (suburban) boroughs. Inner London boroughs have generally lower parking standards, and some of them explicitly require new developments to be car-free in certain areas. Outer London boroughs are more lenient in parking maximums, and although minimum parking requirements have been removed from the official planning documents, there is a sense that developers are still more or less expected to provide a certain amount of parking in low-density, low-PTAL areas. The borough of Brent, for example, states in its 2004 Unitary Development Plan (UDP):

> Residential developments should not provide more parking than the levels as listed in standard PS14 for that type of housing, with its maximum assigned parking levels. Lower standards apply for developments of affordable housing and for units in town centres with good and very good public transport accessibility. Where development provides or retains off-street parking at this level then on-street parking will not be assessed. (Policy TRN23, p. 129)

Such expectation is revealed in the lower parking standards for affordable housing and the indication that an on-street parking assessment is needed where parking provision is below the standard level. In our email survey, a planner in Greenwich also mentioned: "In some cases where the site has a poor accessibility by public transport or majority of development consists of family units, the Council would require the maximum level be achieved." Therefore, it could be imprudent to assume that minimum parking requirements have been completely eliminated in London. Local authorities tend to set parking standards at levels where they deem "right", and they may continue to ask developers to conform to these guidelines to ensure sufficient parking supply. In these cases the current parking standards serve as both parking caps and parking requirements, although not as stringent and obvious in the latter sense.

The different approaches to parking regulation reflect different parking demands and local planning priorities in Inner and Outer London. While Inner London features high density, high PTAL, low car ownership, and high housing prices, the suburban boroughs have less public transport coverage and are more car-dependent, and thus planners have reasons to apply maximum parking standards with precaution. To understand how the parking reform has played out in different parts of London, it is important to recognize the role of market demand and local policy implementation as intermediates in the process.

[5] Local parking standards, in general, should not exceed the maximally allowed level in the London Plan. Newham, which updated its parking standards in 2001, set the maximum parking standard at 3 spaces per unit for houses with five or more bedrooms. In the new Core Strategy adopted in 2012, it changed the parking standards to conform to the London Plan.

A further analysis of the parking reform would require a comparison between current parking policies and the previous ones with minimum parking requirements. However, most of the pre-reform planning documents expired long ago, and not all of them are still obtainable. Due to the restricted availability of planning documents and development data (explained in the next section), this study focuses on 12 out of the 33 London boroughs, 7 of which are Inner London boroughs. This selection is largely based on the technical structure (e.g., the availability of digitized documents and search functions) of the online planning database from the 33 boroughs (see later) and therefore exogenous to parking policies. Figure 1 shows the studied boroughs in Greater London.

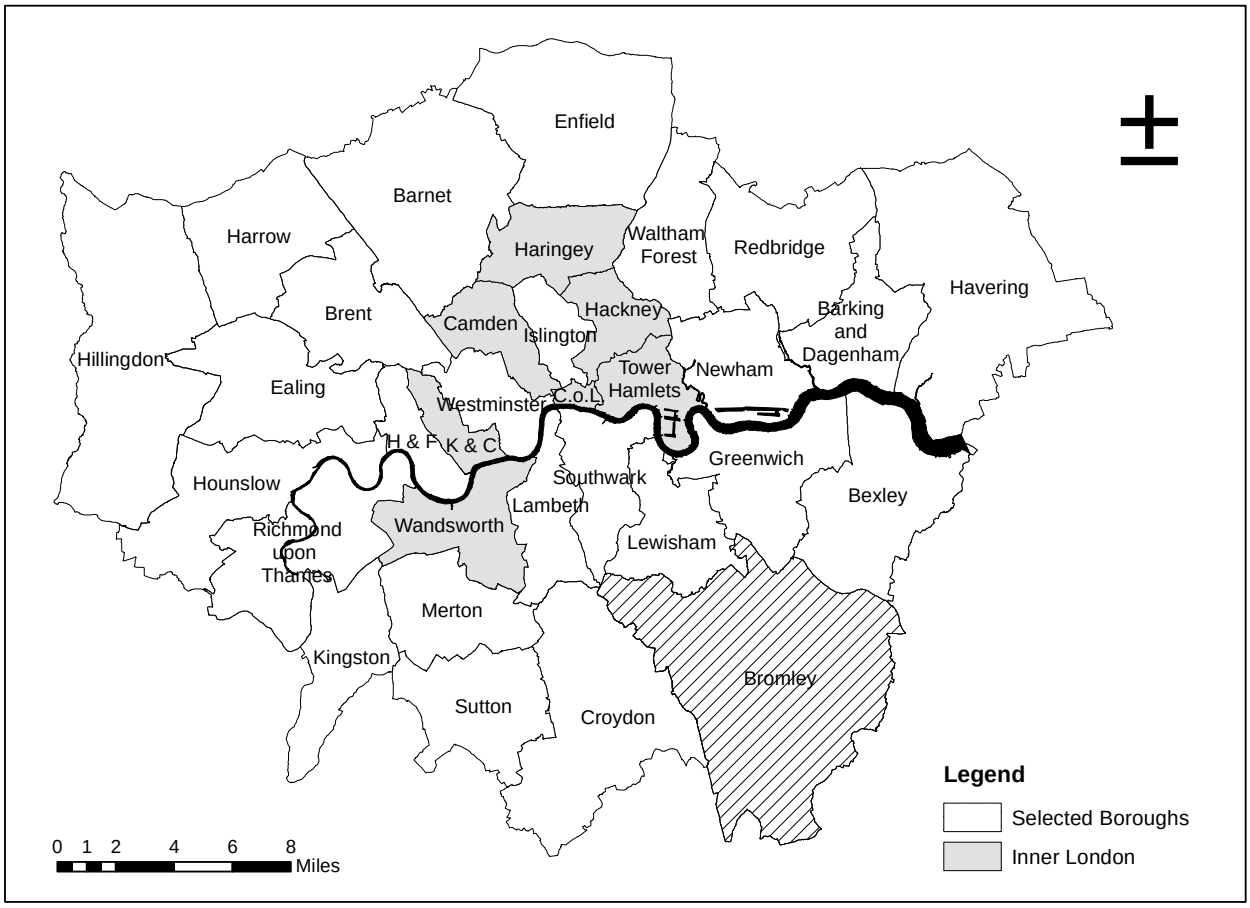

Figure 1. Boroughs in Greater London and the studied areas

Table 1 compares the pre-reform minimum and post-reform maximum parking standards, as well as the levels of car ownership and usage in 2001 and 2011, of the 12 studied boroughs. As described above, the Outer London boroughs set their parking standards, both minimum and maximum, at higher levels, which are probably justified by their higher levels of car ownership and larger shares of workers commuting by car. Those in Inner London, by contrast, have much

lower car ownership levels, half or more of the households without a car, and very few people driving to work in 2011. Lewisham and Newham (and to a lesser extent Brent and Greenwich), which are at the fringe between Inner and Outer London, fall between the most central and the typical suburban boroughs. Still, the general pattern is clear: car dependence increases as one goes from the center to the suburbs, and so do parking standards.

The parking reform resulted in different standard changes in the selected boroughs. All of the 5 suburban boroughs set lower maximum parking standards than their former minimum ones, probably in order to conform to the London Plan (see footnote 4). The responses of the 7 Inner London boroughs varied: two of them (H & F and Lewisham) simply changed minimum parking standards to maximum without adjusting the numbers, three (Islington, Lambeth and Southwark) lowered standards for some categories while raised others, one (Newham) reduced the lower limit of parking standard, and one (Westminster) raised the upper limit.

Table 1 also shows that the use of car among commuters has declined substantially from 2001 to 2011, which probably results from the rising petrol prices, the economic downturn, and policy initiatives such as the congestion charge, on-street parking control, and improvement of public transit services. Since residential parking more directly affects car ownership than trip making, the London parking reform may have played a less significant role in the decline of car usage in the past decade. The dip in car ownership could be a hint that the parking reform has worked; however, since parking standards only apply to new developments, the short-term effect of the reform on car ownership might at best be modest. In fact, the decline of car ownership between 2001 and 2011 has been much smaller than that of car usage, with little or no changes in the Outer London boroughs.

Table 1. Parking standards, car ownership and car usage in the 12 boroughs[a]

	Borough	**Parking standards[b] (# of spaces per unit)**			**# of cars per household**		**No-car households (%)**		**Commuting by car (%)**	
		Min (Pre-reform)	**Max** (Post-reform)	**Change**	**2001**	**2011**	**2001**	**2011**	**2001**	**2011**
Inner London	Hammersmith and Fulham (H & F)	1-1.6	1-1.6	None	0.65	0.54	48.56	55.25	19.00	8.73
	Islington	0-1	0.5	Mixed	0.51	0.41	57.62	64.65	16.82	6.39
	Lambeth	0-1	0.25-1	Mixed	0.61	0.51	50.94	57.85	20.07	9.12
	Lewisham	1-1.5	1-1.5	None	0.74	0.66	42.77	48.15	30.82	15.29
	Newham	1.5-3	1-3	Reduced	0.63	0.60	48.86	52.06	29.25	12.67
	Southwark	1.1	0-2	Mixed	0.59	0.50	51.93	58.39	21.84	8.66
	Westminster	1	1-1.5	Increased	0.54	0.46	56.43	62.90	14.43	6.48

Outer London	Bexley	1.33-2.5	1-2	Reduced	1.13	1.17	23.72	23.67	50.75	33.43
	Brent	1.2-2.16	1-2	Reduced	0.88	0.80	37.29	43.00	36.11	18.67
	Bromley	1.5-3	1-2	Reduced	1.16	1.18	23.00	23.48	45.23	28.91
	Greenwich	1-2	1	Reduced	0.79	0.77	40.83	42.02	36.59	18.71
	Richmond upon Thames	1-3	1-2	Reduced	1.09	1.06	23.70	24.74	40.70	24.40

[a]Data sources: local planning documents; 2001 and 2011 UK Censuses

[b]The range of minimum (pre-reform) or maximum (post-reform) parking standards for all sizes and types of housing

4. Data

The study uses planning application data to examine how parking standards function in practice. All developments or constructions in the UK are subject to approval by local planning authorities. Application materials contain detailed site plans and thus provide a reliable source of parking supply in proposed developments. After 2004, all planning applications for residential developments are archived by the GLA in a London Development Database (LDD). Prior to that, the information was separately maintained by borough councils.

The LDD provides a complete database of post-reform residential developments in the 12 selected boroughs, which contains 12,474 applications with 155,350 units from April 1, 2004 to March 31, 2010. A similar dataset of pre-reform developments, though, is not readily available. We define the pre-reform period as the years before 2000 (included), as 2001-2003 is considered to be a transition period during which local authorities gradually revised their parking policies. Unfortunately, application records in the 1990s are often not digitized, and given the large numbers of applications for non-residential uses and minor alteration, a scan of the original documents would be infeasible. We had to resort to the online application databases built in local boroughs' websites, and the richness of information and the restrictions on searching or browsing of these online records became an important consideration in the selection of the 12 boroughs. Within the 12 boroughs, we have focused on the applications for single-use residential developments with some new units gain between 1997 and 2000. While early application records are often incomplete, we strived to collect all cases with information on location, development type (whether it was a new building or conversion), housing type (whether it was a house or apartment), unit size (in terms of the number of bedrooms), and the number of parking spaces provided[6]. For some of the cases, we were able to utilize Google Maps and commercial real

[6] Most boroughs' online databases do not distinguish residential developments from other uses or allow searching by multiple criteria. Over 100,000 application records were returned by the date specified (1997-2000), the majority of which are non-residential, mixed-use, or minor alterations that do not involve new units or parking construction. To efficiently find out eligible applications from the vast number of records, we have relied on keywords such as "parking", "space", or "car" to select those records that contains detailed parking information. Many earlier records

estate databases (www.zoopla.co.uk and www.mouseprice.com) to complete the missing details. The resulting dataset contains 607 pre-reform applications with 5,847 units[7].

Table 2 shows the average parking supply, standards, and parking-to-standard ratios[8] for the pre-reform and post-reform developments. The drop in parking supply is significant. While the average parking standard per unit has not changed as much, the parking-to-standard ratio has declined significantly. Before the reform, average parking supply was close to or slightly above the required level, especially in Inner London, where the parking-to-standard ratio was almost 1, implying that many developments were bound to provide parking at the required level. The post-reform developments, in contrast, on average provide parking well below the standard level. The simple comparison intuitively suggests that the parking reform might have caused substantial reduction in new residential parking supply.

The study also relies upon qualitative data drawn from multiple planning documents of the 12 boroughs, as well as local planners in London. We communicated with 15 planners through email and conducted 6 face-to-face or telephone interviews. Not all of them are from the 12 selected boroughs, but their input provides useful contextual information for understanding the parking reform and its consequences.

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do not include such information, so it narrows down the usable sample. However, we believe the filtering criteria have not led us to disproportionately select developments with parking. First, according to the planning documents and interviews with London planners, minimum parking standards were rather strictly enforced, and car-free developments were very unlikely in the pre-reform era. Second, the few pre-reform developments that provided no parking might also have indicated that in the application record, as the 5% car-free pre-reform developments in Inner London did. Third, the lack of parking information in many application records are likely due to incomplete digitalization, since other attributes are often missing as well. Therefore, the study assumes that there is no systematic difference between pre-reform applications with and without parking information, other than the completeness of electronic records.

[7] Not all planning applications were actually built; some could have been rejected, some lapsed or replaced with new proposals. Nevertheless, the proposed parking supply in these applications, built or not, represents the developers' response to parking policies at the time. Unfortunately, no information is available regarding whether an application was dismissed due to violation of parking standards. According to the interviewed planners, parking standards should not be a major reason of application dismissal, as developers are usually aware of the amount of parking they need to or can provide, and pre-application negotiation is a common practice for developers to adjust their plans to maximize the chance of getting approval. We do find that, in the pre-reform sample, the rejected applications tended to provide less parking than the approved ones (1.59 vs. 1.72 spaces per unit), but the applications that were lapsed after approval or voluntarily withdrawn provided even less (1.25 spaces per unit). Since it is unclear whether the difference was systematic, we keep the rejected and lapsed applications to preserve the sample size (these cases amount to 196 observations in the pre-reform sample). Similarly, we do not exclude the lapsed or superseded applications in the post-reform database, which provide more parking than the completed or started applications (0.96 vs. 0.80 spaces per unit). If some of the cases were actually rejected on the basis of parking standards (which is quite possible), then our estimates would be an underestimation of the practical effect of the parking reform in London. It is assumed that most developers build houses according to the approved plans. Violation of planning permits could be subject to enforcement measures including modification and demolition.

[8] The parking-to-standard ratio is the ratio of actual parking supply to parking standard (minimum or maximum). The average parking-to-standard ratio per development, as given in Table 2, is the average of this ratio over all developments. Another way to calculate an overall parking-to-standard ratio would be dividing the total amount of parking spaces provided by the total amount of parking spaces required (or allowed).

Table 2. Parking supply and parking standards of the pre- and post-reform developments

	Inner London		Outer London		Total	
	Pre-Reform	Post-Reform	Pre-Reform	Post-Reform	Pre-Reform	Post-Reform
Average parking supply (spaces per unit)	1.05	0.19	2.21	0.93	1.63	0.44
Average parking standard (spaces required/capped per unit)	1.1	0.95	1.68	1.3	1.39	1.06
Average parking-to-standard ratio	0.96	0.19	1.34	0.64	1.15	0.34
# of developments	*304*	*8315*	*303*	*4159*	*607*	*12474*
# of units	*3827*	*107309*	*2020*	*48041*	*5847*	*155350*

5. Estimating Methods

While Table 2 shows notable difference in new residential parking supply before and after the parking reform, it should be noted that the pre-reform dataset is not a complete sample of all residential applications between 1997 and 2000 as the post-reform dataset is during 2004-2010, and such a crude comparison could be subject to unobserved sampling bias. To obtain a robust estimate of the effect of the London parking reform, we use a matching procedure to select from the post-reform dataset developments that are comparable to the pre-reform ones. The matched-pair approach also allows further investigation into how the policy effect varies across different areas and types of developments.

A possible challenge to this strategy is that other changes that occurred at the same time, such as the adoption of the congestion charging scheme and the expansion of bus services, could have also influenced parking supply. We believe that these factors will not substantially bias our analysis. First, minimum parking standards restrict the ability of developers to respond to market changes, such as shifts in parking demand. Even if other policies had resulted in a shift in parking demand, parking supply may not necessarily change without the relaxation of minimum parking standards. The effect of the parking reform, therefore, reflects the difference between the formerly required and the underlying "efficient" level of parking, or the extent to which minimum parking standards could have distorted the parking market. Second, the efficient-market level of residential parking is determined by construction costs and the levels of car ownership. While the congestion charging scheme and the improvements in public transit have probably had a significant effect on car usage, their association with car ownership levels and residential parking demand is more likely weak and indirect. In the following analysis, we have

controlled for pre- and post-reform levels of car ownership and public transit accessibility to rule out potential confounding effects.

5.1 The Matched-Pair Approach

We match pre- and post-reform developments by development type and location. Specifically, new developments are only matched with new developments, while conversions, extensions, or change-of-use applications are matched among themselves, as these are often subject to different site conditions and parking policies. Matching on location balances geographical heterogeneity in housing and parking demands, neighborhood characteristics, and local planning regulations. Arguably, matched developments should face the same time-invariant local policies, housing market conditions, and parking needs.

While other development attributes, such as density or housing type, may also affect parking provision, they are not used in the matching process for two reasons. First, these development attributes tend to be homogenous within neighborhoods, so unless the nature of a neighborhood has changed dramatically during the parking reform, matched pairs of neighboring pre- and post-reform developments should be similar in these regards. Second, as discussed by Shoup (2005), these attributes themselves could be affected by parking policies. Since using endogenous variables as matching variables violates the basic assumption of matching and could bias the estimates (Cochran, 1968), we choose to use them as controls in the regression analysis instead of matching criteria.

We use the smaller sample of pre-reform developments as base and seek match(es) from the post-reform dataset through two ways: nearest neighbor and caliper matching (Dehejia and Wahba, 2002). The former matches the nearest one or several post-reform developments, in straight-line distance, to each pre-reform development. It utilizes all pre-reform developments, some of them possibly with far matches beyond the neighborhood scale. The latter method finds all post-reform developments within a searching radius of each pre-reform development, thus excluding those pre-reform developments that have no match in the set radius and reducing the sample size. Considering the advantages and limitations of the two methods, we apply both methods, run the analysis across six different matching schemes and present the results in parallel. Three of them use nearest neighbor matching, with respectively 1, 3, and 5 nearest neighbors. The other three use caliper matching, with 100m, 300m, and 500m as the searching radiuses[9]. Table 3 presents descriptive statistics of the six matched datasets. The 500m caliper matching dataset (*500m*) has the greatest distances between matched pairs of developments, 312

[9] In all matching procedures, matches (post-reform developments) must be located in the same borough as the pre-reform development. Matches are selected with replacement, i.e., they can be matched more than once to different pre-reform developments.

meters, which is about 5 minutes' walking distance. We are thus confident to assume that most of the matched pairs are located within same neighborhoods and face similar parking demand.

Table 3. Statistics of the Matched Datasets

Matching Schemes	Nearest Neighbors			Caliper		
	Near1	*Near3*	*Near5*	*100m*	*300m*	*500m*
Pre-reform developments used	607	607	607	252	531	587
Post-reform developments matched	487	1288	1929	459	2251	4140
n (weighted sample)[10]	607	607	607	268	561	581
average # of matches per pair	1	3	5	2.1	5.9	12.4
average distance (m)	157.8	233.3	292.7	59.1	189.6	311.7
median distance (m)	121.2	186.9	239.1	61.3	204.2	326.5
std. of distance	139.0	185.0	223.8	25.8	78.1	128.2

5.2 Identifying the Policy Effect

We use two strategies to measure the effect of the London parking reform on new residential parking supply. The average effect is estimated in a combined sample of matched pre- and post-reform developments, while individual effects are measured by pairwise difference within each matched pair.

In the combined model, the actual parking supply of a pre- or post-reform development is determined by project specific factors P_i (housing type, unit size, etc.), location specific factors L_i (density, transit accessibility, etc.), and relevant parking standards (minimum or maximum)[11]:

$$Y_i = \alpha L_i + \beta P_i + \delta Z_i + \gamma S_i + \varepsilon_i \quad (1)$$

where Y_i is the parking supply per dwelling unit in development i, S_i represents local parking regulations applied to the development, and Z_i is a dummy variable denoting the reform status, that is, $Z_i = 1$ if i is a post-reform development, 0 otherwise. The coefficient δ gives the average reform effect on parking supply. The model may also include interaction terms of the reform dummy and location or project attributes to examine how the reform has affected different types of developments and neighborhoods:

$$Y_i = \alpha L_i + \beta P_i + \delta Z_i + \gamma S_i + \varphi Z_i L_i + \phi Z_i P_i + \varepsilon_i \quad (2)$$

[10] In all but the 1st nearest neighbor (*Near1*) dataset, each pre-reform development has more than one match. These matches are weighted by the inverse of the number of matches for each pre-reform development.
[11] The model is estimated by Weighted Least Squares (WLS) regression with weights as explained in footnote 10.

If the reform effect is correlated with unobserved factors, pairwise comparison would provide more precise estimates of individual outcomes (Rubin, 1973). The pairwise difference estimator can be derived from Equation 1 with unmatched neighborhood and development characteristics controlled for[12]. As unobserved factors remain in the residual ε_i, the pairwise different estimator for a pair of matched developments i_{min} and i_{max} can be expressed as:

$$E_i = Y_{i_{min}} - Y_{i_{max}} = \varepsilon_{i_{min}} - \varepsilon_{i_{max}} - \delta \quad (3)$$

E_i should be greater than zero if the parking reform has led to a reduction in parking supply.

5.3 Binding and Capping Effects

The pairwise difference estimator not only accounts for heterogeneous effects, but also allows a closer scrutiny on the relative importance of minimum and maximum parking standards. Since the reform did not include a deregulation period, we cannot directly compare the parking supply under minimum or maximum parking standards with that in a free market. Nevertheless, a lower-bound estimate can be made through looking at the developments that provided exactly the same amounts of parking as standards dictated. By definition, minimum standards are only binding when they are higher than the free market equilibrium, in which case developers would have to provide parking at the required level. Similarly, maximum standards can only "cap" parking supply if set lower than the market level, in which case developers would provide exactly the maximally allowed parking. Upon such assumption, in areas where parking standards are too high, pre-reform developments would provide parking at the required level, while post-reform developments would provide parking at the market level. In contrast, if parking standards are too low, pre-reform developments would provide parking at the market level, while post-reform developments would provide parking at the maximally allowed level.

The pairwise difference estimator gauges the "binding" effect of the minimum parking standards in the first case and the "capping" effect of the maximum parking standards in the second case. Specifically, a pre-reform development is subject to the binding effect of parking requirement when the parking-to-standard ratio is 1 and the pairwise estimator E_i is greater than 0 (that is, the market equilibrium level of parking supply as suggested by its matched post-reform developments, after controlling for covariates, is lower than the pre-reform parking requirement). Likewise, a post-reform development is bound by parking caps when the parking-to-standard ratio is 1 and the pairwise estimator is greater than 0 (that is, the market equilibrium as suggested by its matched pre-reform development is higher than the post-reform parking cap).

[12] We also tried a model specification without the reform dummy, which theoretically could bias the estimator towards zero, because omitting Z would result in part of δ being picked up by other regression coefficients. The results were generally 0.05-0.1 spaces per unit smaller than those presented in Table 6.

It should be noted that other complications may exist in practice. Local councils exercise various levels of flexibility in the implementation of parking standards, and developers might negotiate with the planning boards for higher or lower levels of parking supply. Therefore, even those developments with parking-to-standard ratios lower than 1 might have been bound to provide more parking than they wanted. Still, to the extent that parking standards are strictly enforced, pairwise comparison provides a viable approach to identify and compare the respective effects of minimum and maximum parking standards on residential parking supply.

6. Results

6.1 The Average Policy Effect

Table 4 and Table 5 present a brief comparison of pre- and post-reform parking supply in the matched pairs. The six matching schemes produce consistent results: There has been a sharp reduction in new residential applications' parking provision after the parking reform, both in Inner and Outer London. The overall difference amounts to 0.73-0.82 spaces per dwelling unit, not as large as that between unmatched pre- and post-reform samples (Table 2), a substantial reduction nevertheless. Developments with no parking, which were rarely possible before 2000, prospered after the reform: nearly 60% of the post-reform developments in Inner London are car-free.

We estimate the average policy effect δ using Equation 1, with the following covariates:

STD: number of parking spaces required/capped per unit under current standard;

AVGBR: average number of bedrooms per unit;

SGUNIT: 1 for single unit developments, 0 otherwise;

FLAT: 1 for flats or apartment complexes, 0 otherwise;

CONV: 1 for conversions, extensions, or changes of use, 0 otherwise;

DIS_C: distance to the city center in kilometers

DEN: population density in the Output Area[13] (persons per hectare);

INC: average weekly household income in the Ward;

CAR: average number of cars per household in the Output Area[14].

PTAI: Public Transport Accessibility Index, larger values implying higher accessibility;

[13] Output Area (OA) is the smallest census unit in the UK. The recommended size of an OA is 125 households.
[14] Time variant neighborhood characteristics (*PTAI*, *DEN*, *INC*, and *CAR*) are measured in 2001 for pre-reform developments and in 2011 for post-reform developments.

CPZ: 1 for developments within a street Controlled Parking Zone, 0 otherwise.

Table 4. Average number of parking spaces per dwelling unit

Matching Schemes	Inner London		Outer London		Total	
	Pre-reform	Post-reform	Pre-reform	Post-reform	Pre-reform	Post-reform
Near1	1.05	0.39	2.21	1.25	1.63	0.82
Near3	1.05	0.42	2.21	1.24	1.63	0.83
Near5	1.05	0.41	2.21	1.21	1.63	0.81
100m	0.97	0.33	1.94	1.10	1.43	0.70
300m	1.04	0.40	2.09	1.19	1.52	0.76
500m	1.05	0.39	2.15	1.25	1.58	0.81

Table 5. Percentage of developments with no parking

Matching Schemes	Inner London		Outer London		Total	
	Pre-reform	Post-reform	Pre-reform	Post-reform	Pre-reform	Post-reform
Near1	4.6	56.3	0.0	15.5	2.3	35.9
Near3	4.6	58.0	0.0	17.7	2.3	37.9
Near5	4.6	59.8	0.0	18.7	2.3	39.3
100m	6.8	64.0	0.0	18.6	3.6	42.4
300m	4.8	58.9	0.0	17.1	2.6	39.8
500m	4.6	59.5	0.0	16.6	2.4	38.7

Table 6 presents the modeling results. The estimates of δ are negative and strongly significant in all six samples, averaging -0.76. Considering that an average development in the pre-reform dataset provided about 1.6 parking spaces per unit, the reform effect amounts to a near half reduction in the parking supply of proposed residential developments.

Most of other coefficients have the expected signs. Understandably, parking provision increases with the standards and unit size (in terms of the number of bedrooms). Single unit developments have more parking spaces, while multi-family buildings and conversions tend to provide less. As for the location specific factors, distance to the city center is a primary indicator of parking supply, following by neighborhood income and car ownership levels. In general, there is less parking provision in central, dense areas, and higher provision in suburban, wealthy, and high car-ownership neighborhoods. When these factors are all controlled for, public transit levels (*PTAI*) and controlled parking zone (*CPZ*) seem to have little impact on parking supply.

Table 6. Estimates of the average policy effect

	Matching Schemes					
Coefficients	*Near1*	*Near3*	*Near5*	*100m*	*300m*	*500m*
(Constant)	-0.1671	-0.3129	-0.2667	0.2446	-0.1878	-0.2340
	(0.1829)	(0.2054)	(0.2069)	(0.2507)	(0.2074)	(0.1956)
Z	**-0.7730*** **	**-0.7647*** **	**-0.7760*** **	**-0.7728*** **	**-0.7406*** **	**-0.7346*** **
	(0.0532)	(0.0613)	(0.0614)	(0.0761)	(0.0615)	(0.0574)
STD	0.2285***	0.2503***	0.2444***	0.1470	0.2548***	0.2027***
	(0.0649)	(0.0754)	(0.0757)	(0.0896)	(0.0744)	(0.0699)
AVGBR	0.1885***	0.1902***	0.1911***	0.1326***	0.1847***	0.2101***
	(0.0295)	(0.0345)	(0.0346)	(0.0422)	(0.0349)	(0.0321)
SGUNIT	0.2919***	0.1875***	0.2191***	0.2583***	0.2126***	0.2493***
	(0.0594)	(0.0678)	(0.0678)	(0.0817)	(0.0697)	(0.0644)
FLAT	-0.1229*	-0.2421***	-0.2263***	-0.1587*	-0.1799**	-0.1598**
	(0.0631)	(0.0741)	(0.0747)	(0.0913)	(0.0744)	(0.0695)
CONV	-0.0524	-0.0732	-0.0760	-0.2813***	-0.0982*	-0.0852
	(0.0496)	(0.0576)	(0.0574)	(0.0704)	(0.0586)	(0.0543)
DIS_C	0.0529***	0.0570***	0.0577***	0.0443***	0.0503***	0.0575***
	(0.0070)	(0.0081)	(0.0080)	(0.0104)	(0.0082)	(0.0076)
DEN	-0.0014***	-0.0003	-0.0004	-0.0015**	-0.0008*	-0.0005
	(0.0005)	(0.0004)	(0.0005)	(0.0007)	(0.0005)	(0.0004)
INC	0.0004**	0.0005**	0.0005**	0.0005**	0.0004**	0.0003*
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
CAR	0.2485**	0.2670**	0.2271*	0.1454	0.3032**	0.2731**
	(0.1049)	(0.1200)	(0.1209)	(0.1597)	(0.1226)	(0.1138)
PTAI	0.0004	0.0017	0.0018	-0.0020	0.0004	0.0015
	(0.0035)	(0.0041)	(0.0040)	(0.0046)	(0.004)	(0.0038)
CPZ	-0.0276	-0.0281	-0.0199	-0.0067	-0.0355	-0.0335
	(0.0513)	(0.0590)	(0.0590)	(0.0702)	(0.0586)	(0.0553)
R^2	0.5469	0.4828	0.4827	0.5501	0.4858	0.5116

(*: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$. Figures in parentheses are standard errors.)

We further test 3 alternative model specifications in Table 7. Column 1 repeats the coefficients δ in Equation 1, as shown in Table 6. Model 2 controls for borough fixed effects. Model 3 includes quadratic terms of *DIS_C*, *DEN*, and *PTAI* to take into account nonlinear relationships between parking supply and geographical factors. Model 4 includes both fixed effects and nonlinear terms. The estimates of δ become larger in the fixed effect models, while

the inclusion of nonlinear terms produces little difference. On average, the policy effect remains approximately 0.76-0.8 spaces per unit and is consistent across different matching algorithms.

Table 7. The average policy effect in alternative models

Model	**Baseline**	**Fixed Effects**	**Quadratic Terms**	**Fixed Effects & Quadratic Terms**
	1 (Table 6)	**2**	**3**	**4**
Near1	-0.7730	-0.7936	-0.7772	-0.8001
	(0.0532)	(0.0558)	(0.0549)	(0.0574)
Near3	-0.7647	-0.8122	-0.7683	-0.8227
	(0.0613)	(0.0643)	(0.0631)	(0.0661)
Near5	-0.7760	-0.8233	-0.7786	-0.8307
	(0.0614)	(0.0647)	(0.0634)	(0.0665)
100m	-0.7728	-0.7702	-0.7755	-0.7941
	(0.0761)	(0.0816)	(0.0802)	(0.0857)
300m	-0.7406	-0.7883	-0.7593	-0.8099
	(0.0615)	(0.0649)	(0.0638)	(0.0670)
500m	-0.7346	-0.7630	-0.7454	-0.7777
	(0.0574)	(0.0604)	(0.0591)	(0.0620)

(Figures in parentheses are standard errors. All coefficients are statistically significant at the 0.01 level.)

Equation 2 is then used to examine how the parking reform has influenced different types of housing and neighborhoods. As Table 8 shows, the interactions between the reform dummy and development attributes are stronger than those with neighborhood attributes. Specifically, single unit developments and redevelopments have seen greater cut down in parking supply, though there are little discriminating effects between small and large units or between houses and flats. As for the location specific factors, the reform has had somewhat larger effects on suburban areas, which is consistent with the descriptive results that the magnitude of parking reduction is larger in Outer London (although Inner London has a lower initial level of parking provision). The interaction effects with density, car ownership, *PTAI* and *CPZ* are mixed and generally insignificant.

6.2 Pairwise Comparison

Using the pairwise difference estimator given by Formula 3, Table 9 compares the policy effect between Inner and Outer London. While the magnitude of parking reduction is greater in Outer London, Inner London developments have seen a higher percentage of reduction. Post-reform developments in Inner London on average provide 66.6% less parking than neighboring pre-reform developments, while those in Outer London provide 31.7% less. The overall percentage of reduction is around 49%.

Table 8. Interaction effects

Coefficients	Matching Schemes					
	Near1	*Near3*	*Near5*	*100m*	*300m*	*500m*
Z	-0.3058	-0.4643	-0.4015	-0.2217	-0.1160	-0.5976
	(0.3130)	(0.3534)	(0.3569)	(0.4354)	(0.3603)	(0.3395)
Z*AVGBR	-0.0088	-0.0080	-0.0166	-0.0001	-0.0551	0.0092
	(0.0528)	(0.0617)	(0.0617)	(0.0771)	(0.0632)	(0.0582)
Z*SGUNIT	-0.6871***	-0.8605***	-0.8189***	-0.5521***	-0.7039***	-0.6678***
	(0.1178)	(0.1348)	(0.1351)	(0.1638)	(0.1395)	(0.1294)
Z*FLAT	0.0996	-0.1608	-0.1345	0.0703	-0.0921	-0.0436
	(0.1238)	(0.1465)	(0.1476)	(0.1819)	(0.1478)	(0.1388)
Z*CONV	-0.2827***	-0.3193***	-0.3261***	-0.1162	-0.2172*	-0.1941*
	(0.0958)	(0.1118)	(0.1119)	(0.1376)	(0.1143)	(0.1068)
Z*DIS_C	-0.0257**	-0.0118	-0.0113	-0.0183	-0.0235	-0.0078
	(0.0130)	(0.0150)	(0.0150)	(0.0191)	(0.0154)	(0.0144)
Z*DEN	-0.0005	0.0012	0.0010	-0.0006	-0.0002	0.0010
	(0.0009)	(0.0010)	(0.0010)	(0.0013)	(0.0010)	(0.0010)
Z*CAR	0.2335	0.2406	0.1613	-0.0509	0.1789	0.1740
	(0.1878)	(0.2154)	(0.2169)	(0.2880)	(0.2236)	(0.2073)
Z*PTAI	-0.0053	-0.0015	-0.0022	-0.0098	-0.0069	-0.0011
	(0.0068)	(0.0080)	(0.0079)	(0.0092)	(0.0078)	(0.0075)
Z*CPZ	0.0265	0.0261	0.0394	0.1040	0.1001	-0.0342
	(0.0963)	(0.1111)	(0.1112)	(0.1350)	(0.1110)	(0.1051)
R^2	0.5751	0.5109	0.5096	0.5719	0.5083	0.5289

(*: p < 0.1; **: p < 0.05; ***: p < 0.01. Figures in parentheses are standard errors.)

Table 9. Pairwise estimates of the policy effect

	Inner London		Outer London		Total	
Near1	0.7161	(66%)	0.8300	(29%)	0.7730	(47%)
Near3	0.7106	(66%)	0.8190	(30%)	0.7647	(48%)
Near5	0.7053	(66%)	0.8469	(31%)	0.7760	(49%)
100m	0.7303	(73%)	0.8196	(35%)	0.7728	(55%)
300m	0.6864	(63%)	0.8053	(31%)	0.7406	(48%)
500m	0.7053	(65%)	0.7657	(29%)	0.7346	(47%)

(Figures in parentheses are the average percentages of reduction in pre-reform parking supply.)

Table 10 and Table 11 estimate the binding and capping effects based on the pairwise difference estimator. The first column in each panel shows the percentage of developments bound or capped by parking standards in Inner/Outer/entire London, and the second and third columns show the average effect size and percent reduction among the affected developments. One may multiply the second or third column by the first (as percentages) to obtain an average binding or capping effect among all developments.

Almost 30% of the pre-reform developments, either in Inner or Outer London, had been bound to provide parking at the required levels by minimum parking standards. Unlike the overall policy effect, the binding effect was greater in Inner London in both absolute and relative terms. When minimum parking standards were removed, post-reform developments neighboring to the bound pre-reform ones provide less than 20% of the previously required parking, an average 0.88 spaces per unit reduction. In Outer London, in contrast, post-reform developments provide over 60% of the previously required parking. It shows that minimum parking standards had led to greater market distortion in Inner London.

Table 10. Binding effects of the minimum parking standards

	Inner London			**Outer London**			**Total**		
	Bound (%)	Average Effect		Bound (%)	Average Effect		Bound (%)	Average Effect	
Near1	27.3	0.9074	(86%)	28.7	0.6948	(38%)	28.0	0.7986	(61%)
Near3	28.2	0.8899	(84%)	28.1	0.6657	(38%)	28.1	0.7782	(61%)
Near5	28.7	0.8761	(83%)	29.0	0.6628	(38%)	28.8	0.7691	(60%)
100m	26.4	0.9668	(89%)	40.1	0.7553	(43%)	32.9	0.8441	(62%)
300m	29.8	0.8397	(80%)	33.6	0.6812	(39%)	31.5	0.7628	(60%)
500m	28.4	0.8185	(78%)	29.9	0.6755	(39%)	29.1	0.7472	(59%)

Table 11. Capping effects of the maximum parking standards

	Inner London			**Outer London**			**Total**		
	Capped (%)	Average Effect		Capped (%)	Average Effect		Capped (%)	Average Effect	
Near1	9.2	0.5363	(33%)	21.1	0.7850	(28%)	15.2	0.7093	(30%)
Near3	7.8	0.4505	(36%)	24.1	0.7831	(27%)	15.9	0.7017	(29%)
Near5	7.8	0.4463	(35%)	24.2	0.8464	(29%)	15.9	0.7488	(31%)
100m	4.6	0.9939	(51%)	26.0	0.7483	(28%)	14.8	0.7884	(32%)
300m	9.3	0.4911	(34%)	24.4	0.7571	(28%)	16.2	0.6738	(30%)
500m	8.2	0.4784	(35%)	23.2	0.7318	(28%)	15.5	0.6629	(30%)

The capping effect is smaller than the binding effect in both scope and magnitude, and it disproportionately falls upon the suburbs. Maximum parking standards are binding for less than 10% of the inner city developments, for which they have forced 38% reduction of parking supply. In Outer London, over 20% developments are capped by parking maximums, which leads to 28% reduction in parking provision. Although the overall binding and capping effects are similar in size (as shown in the third panels in Tables 10 and 11), the capping effect is much smaller in relative term as it mainly affects areas where the pre-reform parking supply was high. Moreover, minimum parking standards have bound almost twice the share of developments that maximum parking standards have capped. The average binding effect among all developments is 0.23 spaces per unit, or 18% reduction, while the corresponding capping effect is 0.11 spaces per unit, or 5% reduction in parking supply.

Logistic regression is performed to test which factors affect the bound/capped status of a residential development. Apart from all the development and neighborhood attributes in Model 1, we also include the number of units in a development (*UNIT*). The results are shown in Table 12. To simplify the presentation we only present the coefficients for the two largest samples, *Near5* and *500m*. Understandably, more restrictive standards (high minimums or low maximums) ones are more likely to be binding, and redevelopments are less bound by parking standards than new developments, especially under parking maximums. Other factors often have different, even opposite, effects on pre-reform and post-reform developments. Minimum parking standards tend to bind developments with larger unit sizes or fewer units, or those close to the city center, while the capping effect of maximum parking standards disproportionately affects single family developments, houses, and suburban areas. Interestingly, pre-reform developments in richer neighborhoods have been more subject to the binding effect, which might indicate that minimum parking standards could be utilized as an "exclusionary zoning" tool to deter the construction of affordable dwellings in affluent areas.

7. Conclusion and Discussion

This paper have found substantial decline in new residential parking supply after the parking reform in London. The average effect is 0.76 parking spaces per dwelling unit, or 49% reduction of pre-reform parking provision. The absolute effect is slightly larger in suburban boroughs, but Inner London has seen a greater percent reduction and a stronger trend of car-free development after the parking reform. Single unit developments and redevelopments (conversions, extensions, and changes of uses) have cut down parking supply more than larger and new developments. The results are rather consistent across the six matching schemes, except for the *100m* sample in some cases, which has a much smaller sample size.

Table 12. Developments that have been bound or capped by parking standards

	Pre-reform		**Post-reform**	
	Near5	*500m*	*Near5*	*500m*
(Constant)	-1.0338	-0.8606	-2.4339**	-2.1143*
	(0.8511)	(0.8539)	(1.2203)	(1.2295)
STD	1.2150***	1.0845***	-0.7345*	-0.9413**
	(0.2757)	(0.2758)	(0.3962)	(0.3950)
AVGBR	-0.4212***	-0.4008***	0.0379	0.1098
	(0.1359)	(0.1366)	(0.1510)	(0.1514)
UNIT	-0.0234**	-0.0216**	-0.0379	-0.0307
	(0.0101)	(0.0099)	(0.0235)	(0.0207)
SGUNIT	-0.0992	-0.2060	0.2621	0.5743*
	(0.2837)	(0.2864)	(0.3015)	(0.3203)
FLAT	-0.2271	-0.3184	-0.7874**	-0.8001**
	(0.2810)	(0.2827)	(0.3636)	(0.3786)
CONV	-0.4901**	-0.3882	-0.9256***	-1.2411***
	(0.2376)	(0.2398)	(0.3446)	(0.3900)
DIS_C	-0.1007***	-0.0854**	0.0701*	0.0714*
	(0.0333)	(0.0334)	(0.0406)	(0.0418)
DEN	0.0016	0.0012	-0.0043	-0.0027
	(0.0023)	(0.0023)	(0.0033)	(0.0032)
INC	0.0020**	0.0020**	0.0012	0.0008
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
CAR	-0.2401	-0.4244	0.7660	0.6266
	(0.5040)	(0.5144)	(0.5651)	(0.5828)
PTAI	-0.0029	-0.0039	0.0238	0.0259
	(0.0177)	(0.0179)	(0.0227)	(0.0243)
CPZ	-0.2808	-0.3242	-0.4503	-0.6407**
	(0.2313)	(0.2313)	(0.3075)	(0.3239)
Percent correctly predicted	72.8	71.5	84.3	84.3

When decomposing the policy effect into binding and capping effects, we find that a larger part of the parking reduction can be attributed to the elimination of minimum parking standards than the implementation of maximum parking standards. Nearly 30% of the pre-reform developments have been bound by parking requirements, with greater binding effects in Inner London boroughs. Maximum parking standards, in contrast, have capped just over 15% of the post-reform developments, most of which are located in Outer London. The overall capping

effect is about half the size of the binding effect, only accounting for 15% of the total parking reduction.

While the binding effect is estimated as the reduction of parking supply when minimum parking standards are removed, it also indicates the additional parking that has been created by minimum parking standards. The overall binding effect is 0.23 spaces per unit among all developments, or 0.78 spaces per unit for those developments that are directly affected. We see that minimum parking standards particularly affect small units, small developments and inner city neighborhoods. The inflexibility of minimum parking standards proves inefficient in such cases.

It should be noted that the "binding effect" here is a rather conservative estimate for the market distortion caused by parking requirements. When minimum parking standards are a norm, homebuyers, often unaware of the hidden cost of parking, would expect for large garages and driveways. Developers or even local authorities could be forced to provide more parking than they would like to keep their homes attractive and competitive in the market. If the general equilibrium dynamics is taken into account, the effect of parking standards could be much larger.

These findings lend some support to the deregulation, or market approach to parking management. The elimination of minimum parking standards is found to play a major role in the London reform and consequent parking reduction. The adoption of parking maximums has had less prominent impacts, especially in Inner London, where only 8% of the developments are actually "capped" by maximum parking standards. It might suggest that London planners have allowed sufficient slack or flexibility in setting and applying maximum standards so as not to overly distort the market. In that case, however, the parking maximums would be more of "guidelines" rather than "standards". Certainly, a bigger impact can be expected if lower maximums are set and enforced strictly, but in that case the planners would be faced with a similar problem as with minimum parking standards: Due to the imperfect information they have, they can neither gauge nor reflect parking needs and parking costs accurately in setting parking standards. Considering the potential political resistance, especially in more car-dependent cities and suburbs, maximum parking standards may not be the most efficient approach towards parking and traffic issues.

Shoup (2005) has argued that an efficient parking market needs not only the deregulation of off-street parking, but also the proper pricing of public parking. In the case of London, on-street parking is constantly monitored and managed through controlled zones, parking permits, and dynamic prices that are adjusted on the basis of usage, which facilitates the implementation

of the parking reform without creating or exacerbating severe on-street parking problems[15]. Nor does it seem to result in insufficient parking supply: While the building costs of parking are substantial, developers often need to consider the market acceptance before they decide to build homes without parking. The concern is most relevant in Outer London, where both planners and developers tend to take account of the lower public transport coverage and higher car ownership levels.

The London parking reform provides a good lesson for both city centers with extensive public transport networks and suburban communities with greater parking demand, in both developed and developing countries. It shows how the parking market can adjust for itself under parking standards that are less restrictive and more responsive to local needs. Nevertheless, the deregulation of off-street parking should be supported by better management of on-street parking, particularly in dense urban areas. We expect to see more innovative parking management policies in different parts of the world as well as the longer term effects of the London parking reform on the parking and housing markets.

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[15] Four out of the six interviewed planners believe that on-street parking is not a problem in their jurisdictions, while the other two expressed that on-street parking occupancy had always been high in their boroughs. They generally agree that residential permits and dynamic parking fees are effective measures to manage on-street parking.

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