"The impact of curbside parking regulations on car ownership"

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Abstract

Car ownership is a major driver of household travel behavior and has a marked impact on transport demand, energy consumption, emission levels and land use. However, just how curbside parking regulations (i.e. paid parking) affects car ownership remains unclear. Here, we employ a two-way fixed effect model using panel data and difference-in-differences estimations to determine the causal impact of changes in parking regulations and the specific impact of the extension of a city-wide parking policy in Barcelona. Our results suggest that the introduction of paid parking to reduce non-resident/visitor demand has a positive impact on resident car ownership levels. Our welfare analysis suggests that the welfare loss derived from the residents' parking subsidy and their likely increase in car usage can easily offset the benefits derived from visitor-trip deterrence. This being the case, the tradeoff between efficiency and acceptability requires careful consideration.

JEL classification: H42, L91, L98, R41, R42, R48.

Keywords: parking regulations, car ownership, policy evaluation, difference-in-differences.

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1 Introduction

Expansion of cars during the 20th century has shaped cities and urban environments, giving rise to problems that are yet unresolved. The economic and health impacts of excessive traffic are no longer avoidable in densely populated areas. This has motivated cities to move on from car-dependent planning towards travel demand management (TDM), implementing different policies trying to mitigate its car related externalities and reclaim public space (i.e.: road pricing, parking management or even banning cars). Indeed, the relevance of car ownership as a key element of household travel behavior has a direct impact on transport demand (congestion), energy consumption, emission levels and land use (including urban sprawl, space occupation, and housing affordability). Thus, car ownership levels are a critical forecasting element for many stakeholders (de Jong, 2004), and the impact of TDM measures on it is of crucial relevance for cities aiming to address these problems.

Research has long focused on the determinants of car ownership, including, among others, household composition, life cycle, income, employment status, car fixed costs, population density, public transport provision, job and amenities accessibility (See Dargay, 2000; Giuliano and Dargay, 2006; Dargay and Hanly, 2007; Matas and Raymond, 2008; Potoglou and Kanaroglou, 2008; Nolan, 2010; Mulalic et al., 2016). Additionally, recent research suggests that parking is another dimension that needs to be considered, as it affects both ownership and car use (Chatman, 2013; Guo, 2013a; Weinberger, 2012; Christiansen et al., 2017a and b).

If a parking spot is difficult to find or it is costly, then owning a car becomes less attractive as both its usage and storage costs rise. However, the causal link between car ownership and parking regulations is still under-researched, despite the wide scale adoption of such policy tools to rationalize the use of cars and their externalities in urban areas. A few empirical studies have, however, sought to assess this impact and conclude that it is relevant. More specifically, drawing on data for non-densely populated areas in New York, it has been suggested that parking supply variables can have more than twice the impact of income on car ownership, depending on the household ownership level (Guo, 2013b), and that free and uncrowded curbside parking increase ownership even for households owning off-street parking (Guo, 2013c). As Guo (2013c) points out, this might suggest that curbside parking has both a supply effect (making it easier for a household to own more cars) and an amenity effect (being more convenient to use than the off-street alternative).

In a similar vein, waiting lists for parking permits in Amsterdam are found to reduce the car ownership of residents in districts where they operate (de Groote et al., 2016); while data from the US suggests that 'hiding' the cost of off-street parking in housing prices/rents reduces the odds of people being car-free compared to situations where this cost is not bundled (Manville, 2017).

To demonstrate the validity of their causal impact estimates, the above studies apply a different identification strategy to deal with the fact that households might not be randomly assigned but, in fact, sorted in accordance with their car ownership preferences. This suggests a potential self-selection bias, as residents may well take parking availability into consideration when deciding where to locate or work, so people with low parking needs will tend to opt for areas with more limited parking availability.

All studies exploring the causal impact of parking and car ownership to date have used cross-sectional data (or repeated cross-sections) and have sought to account for invariant unobservable factors. Guo (2013b and c) uses a contemporaneous, within-group comparison separating households with a car from those without that enjoy similar parking types, assuming that sub-groups share similar unobservable attributes related to car ownership preferences. In addition, he uses an instrumental variable estimation as a robustness check for his main findings. De Groote et al. (2016) propose an alternative approach using repeated cross-sectional data and a boundary-discontinuity design. Their key identifying assumption is that unobserved characteristics vary continuously over space and that parking policy is district specific, generating a sharp regulatory boundary along which they assume sorting to be continuous. Manville (2017) uses the American Housing Survey, addressing self-selection by instrumental variables, and takes advantage of different natural experiments that arise within subsamples (using recent movers, those that report their home as being the only one available and rent-regulated units). However, while each of these studies acknowledges that sorting is real, its impact, they report, is unlikely to be a problem (Cao et al., 2007).[1]

[1] Parking does not seem to be a major driver of residence location choice. The main factors reported in Manville (2017) and Chatman (2013) are financial possibilities, being close to friends and family, leisure options, access to

This body of prior research does not address the impact of curbside parking regulations (i.e. paid parking) on car ownership. As such, we have no insights into fairly common situations where non-resident parking is subsidized (with curbside charges being lower than garage fees) and all car-owning residents are granted a parking permit (with no waiting list), and where both parties compete for part of the available curbside parking supply but enjoy different levels of priority. Such regulatory schemes arise from the need to avoid what is often fierce opposition on the part of residents to curbside pricing, and to give them preferential parking treatment (subsidy). Yet, this use of cross-sectional data does not allow the temporal dimension of policy intervention to be analyzed, with previous studies measuring a 'contemporaneous impact' despite the fact that car ownership is a medium-term state-dependent variable that might only be able to change within a window of opportunity.

All in all, this suggests that gaining insights into the specific impact of parking regulation schemes on car ownership is a particularly relevant research question and a crucial one for practitioners. As such, our paper is – as far as we know – the first to assess the causal impact of curbside parking regulations on car ownership in the literature. We seek to do so by analyzing the case of Barcelona, which introduced a city-wide parking regulation policy, known as ÀREA, aimed at curbing traffic congestion by chasing out free parking for visitors and giving residents preferential parking treatment. Here, we take advantage of panel data covering the period 2006-2014 and provide panel fixed effects and difference-in-differences estimates for the policy impact in neighborhoods where the parking regulation was introduced.

Our findings indicate that increasing the number of regulated parking spaces increased neighborhood car-ownership levels, even when not specifically offering residents preferential treatment. Moreover, our analysis of the introduction of ÀREA suggests that the implementation of parking regulations in treated neighborhoods increased average car ownership at rates that were 2.9% above those experienced in control areas. Furthermore, our welfare analysis suggests that the policy implementation was welfare detrimental and that granting parking permits to residents seems to offset the gains from 'chasing out' visitor parking.

job, proximity to transit stations, public services, looks/design, proximity to schools and highways. However, while parking is not explicitly reported, it does correlate closely with some of the aforementioned criteria.

The rest of this paper is organized as follows. Section 2 describes the parking policy intervention implemented in Barcelona. Section 3 describes our empirical strategy for estimating the causal impact of parking regulations on car ownership levels. Section 4 describes our data. Section 5 presents our main results and discusses their implications and Section 6 concludes.

2 Parking policy intervention in Barcelona

The city of Barcelona is one of Europe's most densely populated cities (UN, 2015), characterized by inevitable traffic-related problems and very high competition for public space. Barcelona first introduced parking regulations in the early 1980s, when commercial curbside parking spaces (blue zones) were implemented. Tariffs and limited parking durations were set to deter long-stay parking and to increase turnover in high-demand downtown commercial areas. These regulations were successively expanded to other specifically targeted downtown areas and commercial streets in the city's outer neighborhoods, increasing from about 650 regulated spaces in 1984 to around 7,000 in 2005. These regulations were implemented at the request of business owners and users, following the technical assessment of the local authority.

Concern over increasing traffic congestion – with predictions of total gridlock by 2010 – led the City Council to explore measures to reduce the number of private vehicle trips to the downtown area. The result of their study was the ÀREA regulations which opted not to introduce a congestion charge but rather to implement parking charges for all curbside spaces (there being no free parking spaces within the regulated area).

The scheme's first wave, implemented in 2005-06, targeted the Central Business District (CBD) and 28 neighborhoods inside the city's inner ring road. The primary purpose was to reduce the number of car trips into the city center. The scheme's second wave (2009) saw regulations expanded within the already treated neighborhoods, extended to the area occupying the immediate vicinity of the CBD, and introduced in a further 13 new neighborhoods. The third wave (2010-2011) involved its extension into five neighborhoods of the city's outskirts. The implementation of ÀREA meant converting free parking spaces into regulated spaces (c. 28,500 in the first wave, 15,500 in the second and 250 in the third). Today, the overall parking supply in Barcelona is calculated at around 140,000 spaces (DB Aj.BCN, 2015), more than 50,000 of which are regulated by the ÀREA scheme.

The regulated parking spaces are assigned different dedicated uses: commercial activities (blue zones), where all users are considered visitors; mixed-use (green zones), where both residents and visitors can park, and resident-exclusive spaces ('green exclusive'). The City Council established spaces for commercial activities to encourage a high turnover in commercial areas and in the proximity of community services (hospitals, schools, etc.). The stated aim for mixed-use spaces is to prioritize residential parking over that of visitors in areas where the sum of all parking needs exceed supply. Finally, resident-exclusive spaces aim at easing what the City Council considers severe supply shortages, which in their view justifies the allocation of all curbside spaces to residents (their use being prohibited to visitors).

Commercial space regulations apply from 09:00 to 14:00 and from 16:00 to 20:00 Monday to Friday, being extended in the city center to include Saturdays and in the city's beach areas to include Sundays and holidays also. Mixed-use space regulations operate from 08:00 to 20:00 Monday to Friday, including Saturdays in the city center. Resident-exclusive spaces tend to operate 24/7 throughout the year, though some adhere to the same operation times as commercial spaces. Regulated spaces are distributed across twenty-two zones. Commercial spaces apply four fee/hour bands (€1.08 to €2.50) with associated maximum stays (from 1 to four hours), mixed-use spaces apply just two fee/hour bands (€2.75 to €3.00) and allow users to stay for maximum periods of either 1 or 2 hours.[2] Residents are allowed to park in both mixed-use and resident-exclusive spaces at a reduced rate of €0.20/day during operating hours with no maximum stay restriction, as long as they hold a valid parking permit for that zone. Resident parking permits are granted upon request to any resident paying motor vehicle tax for a car registered in the zone, there being no total number limitation and no waiting list in operation. This means parking regulation targets visitors by chasing out free parking for them; while residents receive a resident permit at a price lower than marginal provision cost (subsidy). This was used as the main instrument to overcome opposition to the policy implementation.

ÀREA is characterized by a predominance of mixed-use spaces that give residents such preferential treatment. The scheme's first wave turned some 21,700 free curbside spots into mixed-use spaces (a further 14,4000 being created in the second wave) and an additional 4,500 into resident-exclusive spaces. In the case of commercial parking spaces 2,200 free spots were

[2] Figures correspond to prices and limits established for 2016.

converted in the first wave and 1,100 in the second. The third wave also saw an increase in the number of mixed-use spaces but the total net curbside parking supply fell, with curbside space being allocated to other transport modes.[3]

A comparison of mixed-use and commercial parking spaces shows that the former are more restrictive in terms of their use by visitors; however, a previous study suggests that this difference might not be substantial.[4] The inverse does not necessarily hold for residents, as we must consider the total parking cost, which here includes cruising. Mixed-use spaces are preferentially allocated to residents who tend to park their vehicle over consecutive days, while residents and visitors are left to compete for the few available spots given the low turnover. In contrast, commercial spaces offer higher rates of turnover by limiting residential parking during operating hours, providing a greater chance of finding a spot especially at the end of the regulated period. It is not unusual for residents to selectively patronize streets with commercial spaces to increase their chances of finding a vacant spot, especially if they plan to use their car the next day.

3 Empirical strategy

In this paper, we seek to estimate the causal impact of curbside parking regulations on car ownership using a panel of 72 neighborhoods in the city of Barcelona for the period 2007-2014. We take advantage of both the cross-sectional and longitudinal variation in our data to estimate different models in our efforts to address potential econometric issues.

Our first approach involves analyzing the effect of changes in regulations at the neighborhood level over time. To do so, we specify the following general model:

$$Y_{it} = \alpha Z_{it} + \beta X_{it} + v_t + u_{it} \quad (1)$$

where Y_{it} is the number of cars owned per 1000 inhabitants in each neighborhood i and period t, and Z_{it} are the parking scheme variables (regulated parking spaces, fee and maximum length of stay). To account for the fact that systematic differences may arise between

[3] In our sample, we assume that any fall in the number of regulated parking spaces means the space was eliminated and used for new bus or bike lanes, bike-sharing stations or the expansion of pedestrian walkways.

[4] Gragera and Albalate (2016) show that mixed-use spaces can shift occasional parkers' demand towards garages, having controlled for parking fees.

neighborhoods due to households sorting according to their preferences and car needs, X_{it} is the vector of time-varying control covariates that account for average household characteristics at the neighborhood level (economic, sociodemographic and mobility related variables). Additionally, we also include v_t time-specific effects to account for time trends and specific shocks (such as the economic crisis); while u_{it} is the idiosyncratic error term. Equation (1) describes a pooled OLS model (POLS).

However, this model fails to take into account the possibility that we might not be able to control for all potential factors determining car-related neighborhood characteristics and those affecting a household's location decision. Were this to be the case, any latent heterogeneity in (1) would be averaged out and might bias our estimates. In order to account for unobserved heterogeneity, in equation (2) we include neighborhood-specific fixed effects (w_i) and so specify a two-way fixed effects model (FE). This allows us to identify the causal impact by analyzing the effect of changes in parking policy variables on changes in car ownership within neighborhoods. It exploits the within-group variation in our sample, ruling out any bias induced by unobserved time-invariant factors.

$$Y_{it} = \alpha Z_{it} + \beta X_{it} + w_i + v_t + \varepsilon_{it} \tag{2}$$

To gain insights into the specific impact of policy implementation, our second approach involves an analysis of the causal impact of the specific transformation of free parking spots into regulated spaces by taking advantage of the quasi-experimental design derived from the extension of ÀREA in the second and third waves of its implementation (2009 and onwards), as shown in Figure 1. This allows us to conduct a difference-in-differences estimation by substituting the parking spaces variables with a policy dummy (T_{it}), which takes value $T_{it} = 1$ when parking regulation extension was active in neighborhood i in period t, and zero for control neighborhoods that did not undergo any changes in their parking regulations. This allows us to estimate the difference-in-differences model (DID) specified in (3).

$$Y_{it} = \delta T_{it} + \beta X_{it} + w_i + v_t + \varepsilon_{it} \tag{3}$$

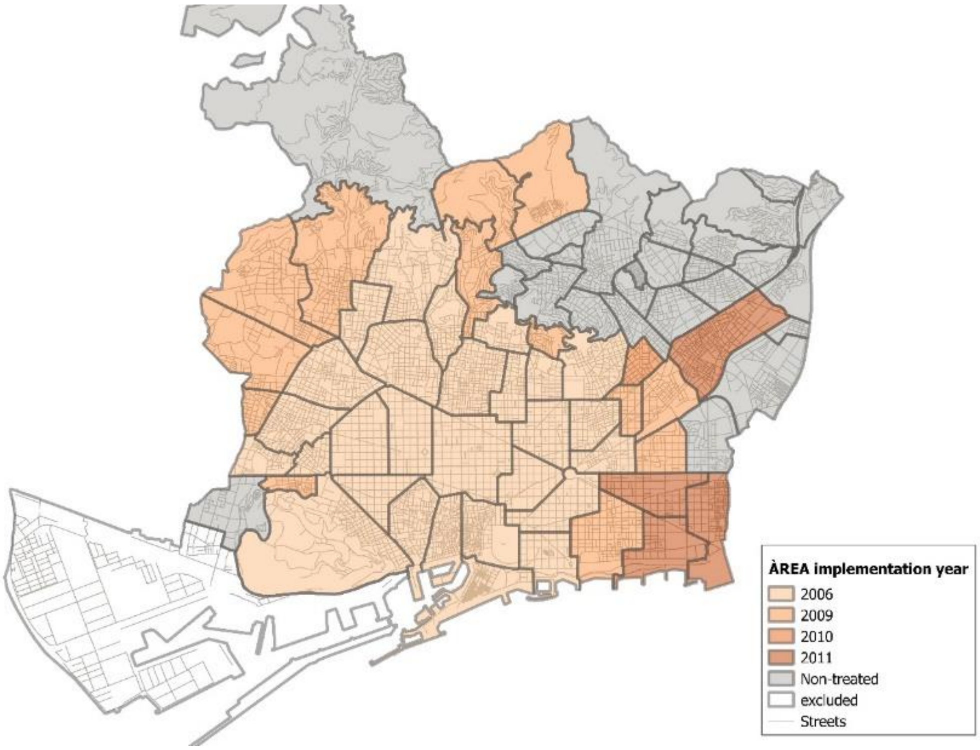
In this case, the causal impact of 'chasing out' free parking is given by the parameter δ, which measures the difference between the average change in car ownership levels in the treated neighborhoods (those to which, at some point in time, parking regulations are extended) and the average change in car ownership levels in the control group (neighborhoods in which parking regulations have never been implemented). This is formally shown in (4), where Y_B and Y_A are the car ownership levels before and after implementation, respectively, and $T = 1$ and $T = 0$ refer to the treatment and control groups, respectively.

$$\delta = [E(Y_A|T = 1) - E(Y_B|T = 1)] - [E(Y_A|T = 0) - E(Y_B|T = 0)] \tag{4}$$

The key identifying assumption in (4) is the **parallel trends assumption**, which means that average changes in car ownership need to be equal for both treated and control groups in the absence of the policy in order to obtain unbiased estimates of δ, as the control group is a good counterfactual for what would have happened to the treated group if the policy had not been implemented. Following Galiani et al. (2005), we test this assumption by using observations for the treatment and control groups during pre-treatment period. Thus, we modify (3) by substituting the policy treatment variable with separate year dummies for each group and checking whether we can reject the null hypothesis of equality between the group dummies for each year. As a further robustness check of this hypothesis, we also conduct a placebo test by randomly assigning the treatment to the population of neighborhoods during the pre-treatment period. Results of these tests are reported in Appendix 1.

Up to this point, we have considered pre-treatment changes in the outcome variables for the treated neighborhoods to be exogenous to the policy, but this assumption will be violated if households changed their car ownership levels in anticipation of changes in parking costs derived from future policy expansion or simply by demand spillover resulting from first wave implementation. Thus, we analyze the time pattern of the policy effects with respect to the year of policy implementation. We test for the validity of the previous assumption by substituting the policy dummy in (3) and introducing policy leads and lags, as a set of dummy variables that are equal to 1 for the number of years elapsed prior to or following policy implementation. The previous assumption holds whenever we are unable to reject the fact that leads are not statistically different from zero, thus rejecting potential anticipatory or spillover effects of the policy. Additionally, lags give us additional information on the effectiveness of the timing of the policy, which does necessarily only have to be contemporaneous.

Figure 1. Curbside parking regulation (ÀREA) implementation per neighborhood in Barcelona



Finally, in line with Bertrand et al. (2004), we estimate the model suggested in (3), taking into account not only heteroscedasticity but also serial correlation within neighborhoods, while allowing for an arbitrary variance-covariance matrix with cluster-robust standard errors.

4 Data

We employ a dataset with information on car ownership levels for 72 neighborhoods in Barcelona during the period 2007-2014. It also includes information on neighborhood characteristics and mobility-related indicators made publicly available by the City Council's Statistics Department (CCSD). Parking policy characteristics are computed at the neighborhood level using GIS software, based on the BSM parking regulation data maps as used in Gragera & Albalate (2016). Table 1 provides a description of the variables used in our models and its corresponding source. Table 2 provides descriptive statistics.

Our dependent variable is the car ownership ratio, measured by the number of cars per thousand inhabitants in each neighborhood and year. In order to estimate the effect of transforming free parking spots into regulated spaces, we introduce a set of parking policy variables. Our main variable of interest is the ratio of parking spaces per thousand inhabitants, which we introduce in different estimations of the model in aggregate and disaggregate terms to account for the differentiated impact of dedicated spaces (commercial, mixed-use and resident-exclusive). In this case, we aim to test whether different preferential allocations of spaces have a different impact on car ownership by restricting which demand segments compete for the same spaces. We also include the average weighted curbside parking fee and maximum stay time limit as a way to control for potential differences in visitor demand levels.

Table 1. Description of variables included in our model and information source

Dependent variable		**Source**
Car ownership	Number of cars owned per 1000 inhabitants	CCSD
Covariates		
Parking policy		
Regulated spaces	Parking spaces per 1000 inhabitant (commercial, mixed-use, resident-exclusive)	BSM
Weighted tariff	Average weighted curbside regulated parking fee	"
Maximum time limit	Average weighted curbside regulated parking maximum stay time limit	"
Neighborhood characteristics		
Economic		
Income	Gross neighborhood income (millions euros)	CCSD
Population density	Number of inhabitants per 1000 m^2	"
Sociodemographic		
Age	Average age of household members (years)	CCSD
Gender	Average percentage of women	"
Occupancy	Average household size (number of members)	"
Mobility		"
Autocontention	Ratio of resident trips within district to the total number of resident trips	ATM
Walk	Percentage of trips with the district as destination made on foot	"
Private vehicle	Percentage of trips with the district as destination made by private vehicle	"

We also include a set of variables that describe household characteristics so as to account for neighborhood differences that might arise, not as a result of changes in parking policy, but as a result of household sorting in terms of preferences and car needs. We control for neighborhood economic characteristics – income and population density – since richer neighborhoods can be expected to enjoy higher levels of car ownership while densely populated neighborhoods might be discouraged from owning a vehicle. Specifically, we use a neighborhood's gross average income (millions of euros) and the number of inhabitants per hectare.[5] We also include several sociodemographic characteristics that have been shown to be related to car preferences: namely, average age, percentage of women and the number of household members, on the grounds that younger populations, with fewer females and with

[5] Alternative measures of income and density are also analyzed, but the estimated coefficients of the main variables remained the same. We therefore opted for the measures that enhance the model's goodness of fit.

larger families might rely more heavily on the car as a means of transport. Likewise, we take into account changes in neighborhood mobility characteristics. Here, we use the autocontention ratio, measured as the ratio of resident trips undertaken within the district compared to all the trips residents undertake. This accounts for the ease with which residents are able to satisfy their needs using amenities in close proximity and so are less dependent on their vehicles. We also include the percentage of trips undertaken on foot or using public transport with the district as destination. This serves as a measure of the level of competition for public space that residents might face from visitors. In these cases, we expect lower autocontention ratios to be indicative of a lower degree of dependence on the car, while low percentages of visitors coming to the district on foot and high percentages of private vehicle trips indicate that residents might face greater competition for parking spaces.

Table 2. Descriptive statistics

		Std. Dev.		
Variables	**Mean**	**overall**	**between**	**within**
Car ownership	362.10	83.57	79.23	28.00
Regulated spaces (overall)	25.78	34.68	29.43	18.63
Mixed use	18.65	29.41	24.02	17.17
Commercial	4.70	6.78	6.46	2.18
Resident-exclusive	2.40	10.62	10.66	0.66
Weighted tariff	1.64	1.15	1.03	0.53
Maximum time limit	1.63	1.20	1.12	0.44
Income	28.474.05	12.030.81	11.811.37	2.637.58
Population density	25.33	15.22	15.29	0.88
Age	43.28	2.32	2.16	0.87
Gender	0.52	0.02	0.02	0.00
Occupancy	2.52	0.19	0.18	0.07
Autocontention	43.59	5.87	4.39	3.94
Walk	53.24	6.54	5.40	3.74
Private vehicle	17.31	4.25	3.51	2.43

5 Results

5.1 Effect of changes in regulations

We report our results for the impact of changes in parking regulations on car ownership in Table 3 based on 567 observations made in the neighborhoods of Barcelona during the period 2007-2014. Column (1) reports our estimation results based on Eq. (1). Columns (2)-(9) report our estimation results based on Eq. (2), with each sequentially building up the model to include sociodemographic characteristics, mobility related controls and cluster-robust standard errors.

These results show that regulated parking spaces are positively related to car ownership. On average, an increase of one space per 1000 inhabitants results in a 0.26-increase in the number of cars registered per 1000 inhabitants, with a relatively differentiated impact according to the type of dedicated space implemented. Thus, resident-exclusive (3.59) and commercial spaces (1.46) have a higher impact than mixed-use spaces (0.12).[6] For ease of interpretation, Table 3 shows elasticities estimated at sample mean values, with an average elasticity of car ownership to regulated parking spaces of 0.019 (ranging from 0.006 to 0.024 depending on the type of space). It is quite straightforward to see that resident-exclusive spaces offer easier parking for residents as their use is forbidden to visitors. Yet, somewhat surprisingly commercial spaces yield a higher positive impact on car ownership than mixed-use spaces, given that the latter would appear to be more restrictive for resident parking than the former. However, if we take into consideration total parking cost differences between the two types of dedicated spaces due to the amount of competition for them from within the demand segments, the explanation is clear. On the one hand, mixed-use spaces allow the two demand segments to compete for vacant spots, albeit that the preferential treatment enjoyed by residents means they tend to crowd these spaces during long parking stays. On the other hand, commercial spaces, while preventing residents from parking there during operating hours offer higher turnover rates, especially at the end of regulation periods. This tends to make it easier to find a parking place in commercial spaces than in mixed-use zones, especially for drivers who make regular use of their vehicles and who see no inconvenience in having to move it the following morning.

Our results also show that the parking fee and maximum stay time limits do not have a statistically significant impact on car ownership, additional that is to who has the right to park in a given spot (dedicated spaces). However, the main drivers of car ownership are found to be

[6] The results of the Wald test show we can reject the possibility that the coefficient for mixed-use spaces are equal to those for commercial or resident-exclusive spots, but that we cannot reject the possibility that commercial and resident-exclusive spaces have the same impact. The low variation in resident-exclusive spaces yields an estimated coefficient with higher standard errors, although the estimate points in the direction of a greater impact.

neighborhood income level and population density. Thus, increases in income levels increase car ownership, while population density presents a negative relationship that decreases as density increases (positive quadratic term). The estimated elasticities at sample mean values reported in the last column of Table 3 show that car ownership income elasticity is about 0.19 and that the elasticity to population density is -1.11.

5.2 Impact of policy implementation

To analyze the specific impact of the implementation of the parking regulations on car ownership, we exploit the quasi-experimental design derived from the extension of ÀREA in its second and third waves (2009 and onwards), which transformed free-parking into paid-parking spaces. In this case, we report the estimation results from Table 4.

Our results show that the second and third waves of the implementation of ÀREA increased car ownership levels in the treated neighborhoods by an average 11 cars per 1000 inhabitants during the treatment period compared to their counterfactual. This is equivalent to a 2.9% increase with respect to the treated neighborhoods' mean values. This is in line with the results reported in the previous section and highlights an unintended effect of the parking policy implemented in Barcelona. Paid parking was introduced to 'chase out' visitor parking, while acceptance of the policy measure relied on residents being granted preferential parking treatment, which appears to have offered them incentives to increase their car ownership levels. As we discuss below, increasing residents' welfare would seem to make parking regulations politically feasible, but the increase in car ownership might also bring welfare losses in the form of increased car journeys and the increase in their associated externalities, outcomes that need careful consideration.

Table 3. Pooled ordinary least squares (POLS) and Fixed Effects (FE) panel data results on car ownership level

	Dependent variable: Cars (veh*1000inhab.)									Elasticities
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	at $(\bar{x})$
Regulated parking spaces	-0.00801	0.275***		0.266***		0.262***		0.262***		0.019
	(0.0738)	(0.0432)		(0.0399)		(0.0402)		(0.0402)		
Mixed-use			0.134**		0.125**		0.119*		0.119*	0.006
			(0.0626)		(0.0606)		(0.0637)		(0.0637)	
Commercial			1.436**		1.452**		1.456**		1.456**	0.019
			(0.700)		(0.722)		(0.718)		(0.718)	
Resident-exclusive			3.568***		3.440**		3.594**		3.594**	0.024
			(1.337)		(1.361)		(1.396)		(1.396)	
Fee	-3.614	-3.339	-1.311	-3.755*	-1.801	-3.287	-1.168	-3.287	-1.168	
	(4.315)	(2.190)	(2.925)	(2.186)	(2.937)	(2.216)	(2.854)	(2.216)	(2.854)	
Maximum time limit	0.259	-0.376	-1.573	-0.237	-1.358	-0.912	-2.194	-0.912	-2.194	
	(2.398)	(2.707)	(3.327)	(2.823)	(3.409)	(2.757)	(3.250)	(2.757)	(3.250)	
Income	0.00422***	0.00245**	0.00251**	0.00234*	0.00239**	0.00238**	0.00244**	0.00238**	0.00244**	0.192
	(0.000462)	(0.00115)	(0.00111)	(0.00122)	(0.00118)	(0.00119)	(0.00115)	(0.00119)	(0.00115)	
Population density	0.417	-21.64***	-21.44***	-16.29**	-16.49**	-15.86**	-15.92**	-15.86**	-15.92**	-1.114
	(0.605)	(3.415)	(3.397)	(6.750)	(6.651)	(6.712)	(6.611)	(6.712)	(6.611)	
$(\text{Population density})^2$	-0.0227**	0.235***	0.235***	0.205***	0.205**	0.201**	0.199**	0.201**	0.199**	0.480
	(0.00921)	(0.0670)	(0.0675)	(0.0775)	(0.0782)	(0.0765)	(0.0771)	(0.0765)	(0.0771)	
Sociodemographic	YES	NO	NO	YES	YES	YES	YES	YES	YES	
Mobility	YES	NO	NO	NO	NO	YES	YES	YES	YES	
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	
Neighborhood Fixed Effects	NO	YES	YES	YES	YES	YES	YES	YES	YES	
Clustered Standard Errors	YES	NO	NO	NO	NO	NO	NO	YES	YES	
Observations	576	576	576	576	576	576	576	576	576	
R^2	0.645	0.233	0.245	0.236	0.247	0.238	0.250	0.238	0.250	
F-test joint significance	40.016	38.668	33.647	46.527	40.088	47.874	45.414	47.874	45.414	
Number of Clusters		72	72	72	72	72	72	72	72	

Table 4. Panel Data Difference-in-Differences (DID) estimation of the expansion of the parking regulation program (ÀREA).

VARIABLES	Dependent variable : Cars (veh*1000inhab.)	Placebo
Treatment	10.98**	-1.817
	(4.226)	(2.727)
Fee	-0.506	0.366
	(2.852)	(1.825)
Maximum time limit	-3.577	-2.366
	(3.103)	(2.871)
Income	0.00366**	0.000152
	(0.00152)	(0.000829)
Population density	-22.25**	-28.28***
	(10.37)	(8.656)
$(\text{Population density})^2$	0.257**	0.239***
	(0.126)	(0.0768)
Sociodemographic	YES	YES
Mobility	YES	YES
Year Fixed Effects	YES	YES
Neighborhood Fixed Effects	YES	YES
Clustered Standard Errors	YES	YES
Observations	352	132
R^2	0.248	0.622
F-test joint significance	13.89	22.66
Number of Clusters	44	44

Figure 2. Mean car ownership levels during pre and post intervention for treated and non-treated groups, and comparison with assumed counterfactual

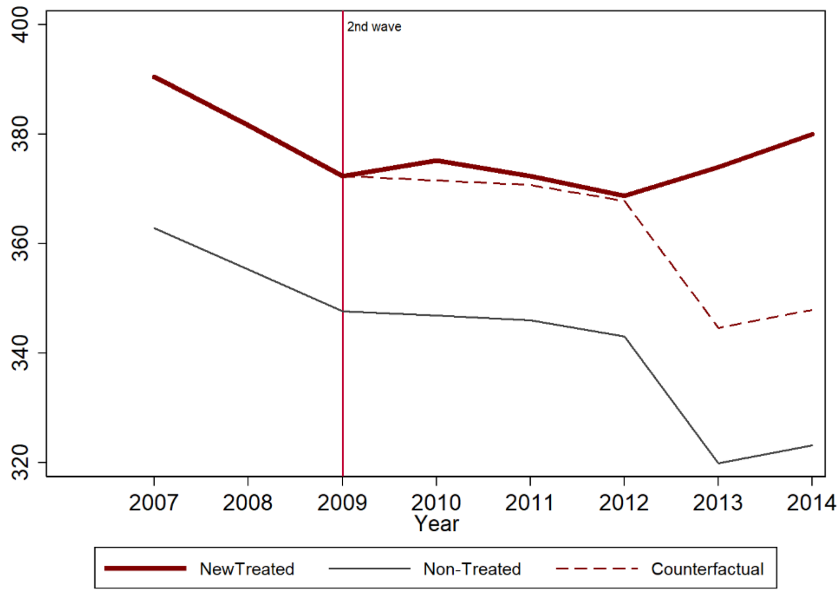
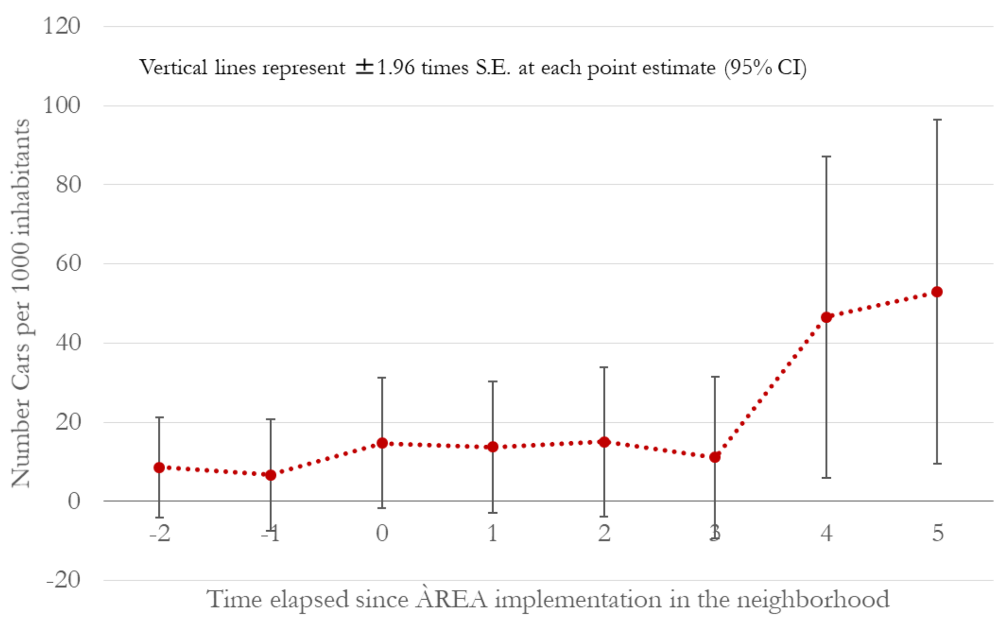


Figure 3. Leads and lags for policy implementation impact on car ownership levels in treated neighborhoods



5.3 Welfare implications

To ensure the validity of the parking policy recommendations that arise from this study, we seek to analyze the welfare implications of our findings. To do so, we compute the welfare change due to the introduction of this specific parking regulation (ÀREA expansion) and its impact on residents' car ownership levels.[7] The aim of this section is not to provide an exact estimation of the welfare change – as we have to rely heavily on plausible simplifying assumptions – but to offer guidance on the tradeoffs between parking policy efficiency and its acceptability that are typically ignored by policymakers.

5.3.1 Welfare change due to subsidy and curbside parking allocation to residents

The provision of curbside parking permits to residents implies a welfare loss if the price is kept below its marginal provision cost. Additionally, taking into account that both residents and visitors compete for the same parking spaces, a lower parking cost for residents will allocate a higher proportion of spots to them and reduce its availability for visitors. In order to clear the market, the parking costs for visitors will increase with higher search cost and some of them will give up trips. This does also imply a welfare loss derived from the interaction between both demand segments.

Thus, the welfare change induced by the policy intervention depends on the following factors: First, the total number of curbside parking spaces (N), that we assume to be equal to 52,000.[8] Second, the price of parking at the curb after the introduction of parking permits (P_r), that is at most equal to 52€/year. Third, the number of parking spaces available for residents (Q_r) and visitors (Q_v) after the policy implementation. In this case, from the data on our dataset, we know that there are 138,654 vehicles registered in the ÀREA expansion neighborhoods, from which about 30% park in the curb on a regular basis to which we need to add the increase of 4,039 vehicles we estimated as unintended impact of the policy. This means that Q_r is equal to 45,635 curbside parking spaces that are occupied by residents, leaving $N - Q_r$ just equal to 6,365 spaces available for visitors. Here we assume that parking spots allocated to residents are only used by one car per day. Fourth, the price for visitors (P_v) that we compute as their annual willingness-to-pay (WTP) per parking space using

[7] We follow the reasoning outlined in De Groote et al. (2016) and van Ommeren et al. (2014), but we deviate from their analysis in the sense that we account for the interaction between residents and visitors competing for parking spots.

[8] This is an estimate given the total number of curbside parking spaces reported by the City Council (about 147,600) and that the already treated neighborhoods deploy for certain 38,200 of them, as no free parking space is available. The remaining parking supply is split proportionally to the surface devoted to roads in each neighborhood, eliminating the logistics activity area associated to Barcelona's Port.

the total number of visitors per spot and their hourly WTP. Using travel survey data for Barcelona, we can infer that 47,300 visitors park their car in the curb, based on the number of trips and how many of them park on street (EMEF, 2013).[9] Dividing this figure by Q_v and keeping previous assumptions, we estimate that each curbside space turnover is about 7 visitors per day.[10] Additionally, to compute visitors WTP we will further assume that their hourly WTP is equal to the public garage parking fee plus the average fee differential with respect to the private operators (3.81€/hour) and that they park on average just for 1 hour each during 280 labor days a year (the figure typically employed by Barcelona's transport authorities).[11] This means that P_v is 7,468€/year, a figure that accounts both for what visitors pay in parking fees but also search time they experience, as in equilibrium the total cost of parking in a garage equates the total cost of parking in the curb.

For sake of convenience, we assume that both residents and visitors face constant-elasticity inverse demand functions given by $D_r(Q) = P_r(Q/Q_r)^{\frac{1}{\varepsilon_r}}$ for residents, and $D_v(Q) = P_v((N-Q)/(N-Q_r))^{\frac{1}{\varepsilon_v}}$ for visitors; where Q is the number of parking spaces allocated to residents and the reciprocal $N-Q$ the one allocated to visitors, ε_r is residents' price elasticity of demand for cars and ε_v is visitors' price elasticity of demand for parking. Regarding residents, we can use previous estimates to infer price-demand elasticity from the percentage change in their number of cars and the change in price induced by the policy intervention. Change in the number of cars with respect to decentralized equilibrium can be computed from the data showed above, but the market price of parking a car for residents without permits has to be inferred. In this case, we follow a similar approach to that suggested by Shoup (2005), assuming that in pre-intervention equilibrium we expect on-street and off-street parking to be equally valued. So we can infer curbside parking price using public garage subscription costs (1,368€/year), which take into account the *occupied* parking cost (capital and operating costs) and the land opportunity cost (most of them being underground facilities that are rarely used for anything other than storage).[12] Thus, each resident

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[9] EMEF (2013) shows that the city receives 1.4M visitor trips and about 50% of them have destination to the newly treated neighborhoods, where 15.3% of them are done by car and around 40% of them end up parking on the curb.

[10] This figure means an average stay length of 1.4 hours per visitor if all operating hours (10 hours per day) are fully occupied. This figure is consistent with previous data gathered in Albalate and Gragera (2018) survey to garage parkers, where those that previously searched for a curbside spot park on average for slightly more than 1.5 hours. However, we will consider that they just park on average 1 hour, as BSM data seems to point to lower parking stays for those parking on the curb.

[11] These figures are the ones typically employed by the Metropolitan Transport Authority (ATM), see *Observatori de la Mobilitat* (https://doc.atm.cat/ca/_dir_pdm/Observatori_Mobilitat/files/assets/basic-html/page-1.html)

[12] In this case, we implicitly assume that a public garage operator charges subscription prices at marginal provision costs.

permit implies an annual subsidy of 1,316€.[13] This translates into a demand price elasticity equal to -0.03 for residents. Regarding visitors, we assume a demand price-elasticity of -0.30, in line with van Ommeren et al. (2014) and consistent with recent meta-regression evidence reported in Lehner & Peer (2019).

By combining both in a single diagram, we can estimate the welfare effects of the ÀREA expansion as shown in Figure 4. The equilibrium in such a setting is attained when the allocation between residents and visitors is such that the price for both is equated, as denoted by P^*.[14] The introduction of parking permits subsidizes residential parking increasing the number of spaces blocked by newly owned cars. Thus, visitors face a tighter supply level and higher parking cost to clear the market. Thus, we can write the deadweight loss induced by parking policy (residents' permits) ΔW as the integrated difference between inverse demand functions between Q^* and Q_r.

$$\Delta W = \int_{Q^*}^{Q_r} D_r(Q) - D_v(Q)\, dQ \tag{5}$$

This ΔW does simultaneously take into account the welfare change associated to the parking permits subsidy given by setting prices below provision cost (the area enclosed by abc), and the change derived from visitors' consumer surplus reduction due to supply constraint (the area within acd), as described in Figure 4. Given previous figures we can compute the ΔW using equation (5), which yields a welfare loss of 12.5M€ per year.[15] Sensitivity analysis for previous figures is reported in Appendix 3.

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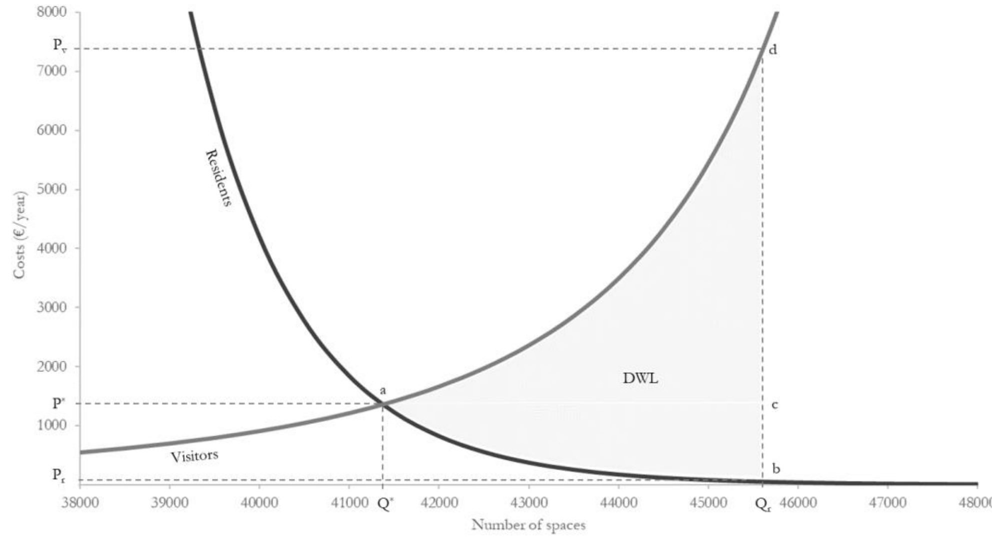
[13] This figure provides a cost estimate that is almost the same as that reported by Shoup (2005): $127/month equivalent to 1,311€/year. Changes in that figure affecting assumed demand price-elasticity are taken into account in the Appendix 3.

[14] Note that in such setting we can interpret visitors' inverse demand function as the parking supply opportunity cost for blocking a parking spot by residents.

[15] It is important to state that in this section, for sake of simplicity, we implicitly assumed that the reduction in visitors' parking demand is due to them giving up their trips, so no transfer to garage parking occurs. Note that assuming that such transfer occurs will yield both lower welfare loss due to visitors' consumer surplus reduction and lower welfare gains due external cost reduction of allocating spaces to residents in the curb.

Figure 4. Welfare loss due to parking subsidy and curbside allocation to residents



5.3.2 Welfare change due to externalities

We believe we cannot assume that external costs are internalized through optimal parking prices (De Groote et al., 2016), as in previous studies we find evidence of relevant pricing distortion in Barcelona that points to the existence of cruising externalities and non-optimal car usage levels (Gragera and Albalate, 2016; Albalate and Gragera, 2017). In this subsection, we take into account that the increase in residents' car ownership levels translates into an increase in vehicle use, which imposes an external cost on the rest of society. While, in contrast, increased travel costs for visitors cause them to make less trips and reduces the externalities they cause.[16]

In this case, we compute the net external costs associated with allocating a parking space to a resident due to parking permits (and the increased car ownership). We do that by computing the external costs of congestion, accidents, air pollution, noise, climate change, infrastructure wear and tear, and up-stream processes (pre-combustion and vehicle production) due to an increased car travel based on the marginal external cost figures provided in Table A2. We assume that after policy intervention residents' cars are used on average in the same way as they are used before, that is, the average annual distance traveled will be about 13,000 km/year in major urban areas (INE, 2008). This gives us an external cost of 722€/year for each newly owned car that we assume will block a

[16] Unlike De Groote et al. (2016) we do not assume that external costs are internalized through optimal parking prices, as in previous studies we find evidence of relevant pricing distortion in Barcelona (Gragera and Albalate, 2016; Albalate and Gragera, 2017) that points to the existence of cruising externalities and non-optimal car usage levels.

curbside parking space. Moreover, we do also assume that residents owning these extra cars will face the same cruising levels as previous ones, which can be inferred by the difference between public garage subscription costs and private garage subscription prices, which in our case is 264€/year. Here, we assume that only private operators take advantage of their localized market power to set their prices equal to total parking costs in equilibrium, also that the public operator sets subscription costs equal to the marginal provision costs, and that cruising levels or parking prices do not change with the increase in the number of owned cars.[17] Thus, the total external cost of allocating a curbside space to a resident is 986€/year.

Additionally, each parking space allocated to visitors has also an external cost associated with the car usage they make. As in the previous paragraphs, assuming that each visitor trip is 18 km long (that needs to be multiplied by 2 to make it back and forth), previously stated visitors turnover per space (see subsection 5.3.1.), and using marginal external cost figures in Table A2, we get that each space yields an external cost of 3,900€/year. The differential of external costs between residents and visitors means that there is a net benefit in terms of externalities into allocating curbside spaces to residents (2,914€/year-space). This, given previous subsection figures, implies that the reduction in visitors' trips saves society from bearing an external cost of 16.6M€/year. It is important to highlight that this is the intended impact of the policy, as this was the policymakers' goal to implement it in the first place (or at least part of it). Additionally, the increase in car ownership (and its use) increases external costs in 4.2M€/year and leaves the external costs net effect of allocating parking spaces to residents in a gain of 12.4M€/year.[18]

5.3.3 Net welfare change

Summing up previous subsection results, we can compute that the baseline welfare change for the policy implementation is a loss that is equivalent to 0.1M€/year. This means that the ÀREA expansion could have been globally welfare improving or detrimental depending on the specific figures of the inputs used in our analysis (Appendix 3 reports a sensitivity analysis for the main parameters). However, what is relevant is to compare the change in economic efficiency induced by the impact of parking regulations on car ownership. Previous sections show that parking policy did

[17] This is unlikely to be the case, but it gives us a simpler and more conservative estimate of the welfare change.
[18] Note that this welfare change is referred to the equilibrium in section 5.3.1 and not the social optimum, as externalities are not internalized for neither residents nor visitors.

help to lower transport externalities due to excessive traffic yielding relevant welfare gains, but most (if not all) is wasted due to the unintended policy impacts.

To show this we compute a relative efficiency deviation measure (eff). We use this measure to give a more straightforward idea of how much real policy implementation welfare change deviates from the policy intended one. In this case, we assume as our benchmark the welfare change induced by the reduction in the number of visitors' trips (the policy's main goal) as if the policy had no impact on the residents' car ownership levels (ΔW_o).[19] We measure the welfare deviation due to the policy having an impact on car ownership (ΔW_p) with respect to the benchmark level as $eff = (\Delta W_p - \Delta W_o)/|\Delta W_o|$. In our baseline calculation, the efficiency deviation is equal to -1.01, meaning that the policy impact on car ownership levels eats up all the gains the policymaker initially intended to get. In this regard, we can isolate the impact on the efficiency of each of the previously computed effects. The efficiency loss due to parking permits subsidy is 0.25, consumers' surplus reduction accounts for 0.51, and externalities for the remaining 0.25. In this sense, we should also stress that our baseline calculation only takes into account the average treatment on the treated (an 11-car increase per thousand inhabitants) as the policy impact on car ownership, yet the earlier analysis also shows that the impact on car ownership seems to build up over time following policy implementation. Which makes us believe that the impact can potentially be worse than what we report here.

These results suggest that the tradeoff between acceptability and efficiency are relevant when the unintended impact of parking policy that translates into an increase residents' car ownership is taken into account. Granting resident permits might help overcome political opposition to paid parking implementation, but it can also make the whole policy package welfare detrimental. Policymakers should no longer ignore this tradeoff.

6 Concluding remarks

In this paper our aim has been to gain insights into the specific impact of parking regulations on car ownership, focusing on the introduction of paid parking in a major European urban area, namely that of Barcelona, which introduced a city-wide parking regulation policy (known as ÀREA) aimed at curbing traffic congestion. We have used a panel dataset covering 72 neighborhoods for

[19] This is mainly the welfare gain derived from the reduction in external costs due to fewer visitors traveling by car.

the period 2007-2014 to estimate the causal effect of changes in parking regulations on the number of cars owned and to evaluate the causal impact of the gradual extension of the ÀREA scheme. Based on these estimates, we have also conducted a welfare analysis of the impact of the policy.

Our empirical results demonstrate that an increase in the density of regulated parking spaces increases car ownership at the neighborhood level by 0.26 cars per 1,000 inhabitants, which is equivalent to an elasticity in the sample mean values of 0.019. We find that the different types of dedicated space (i.e. mixed-use, resident-exclusive and commercial) have different impacts on car ownership, due to the way in which the allocation of parking rights facilitates competition between demand segments for the same parking spaces. Moreover, we find that the introduction of ÀREA had an average treatment effect on the treated neighborhoods of an increase of 11 cars per 1,000 inhabitants per year (an average increase of 2.9% at the sample mean values). This can be interpreted as evidence of an unintended rebound on the level of car ownership attributable to the specific parking policy introduced. This effect, moreover, appears to accumulate over time, its impact multiplying more than fourfold five years after its initial implementation. Our welfare analysis further suggests that the policy implementation has, under our assumptions, been welfare detrimental with respect to the intended policy impact. The welfare losses associated with granting residents with parking permits can offset the gains from chasing out visitors' parking. This result seems quite robust in the light of sensitivity and risk analyses.

These figures clearly reflect the relevance of an unintentional policy effect and stress the need for it to be taken into account when designing paid parking schemes in cities. From a political economy perspective, it might make sense for policymakers to give residents preferential treatment so as to maximize their welfare (as voters) at the expense of visitors who, after all, are responsible for congestion problems. By so doing, administrators might be able to circumvent opposition to parking regulations and make their introduction politically feasible, but our results highlight the need for them to be aware of the tradeoff between economic efficiency and acceptability. Parking permits and regulatory measures that ease parking conditions for residents are a subsidy that effectively lowers parking costs and increases residents' car ownership, which in turn leads to more car use and greater externalities. Our estimates suggest that the net welfare effect of the implementation of such policies is quite likely to be negative as in Barcelona.

In the light of our results, we advocate the elimination of parking subsidies in the form of resident permits. Residents should bear the full cost of owning a vehicle, including those of parking, given its status as a scarce resource. Moving in this direction might be politically challenging, but municipalities can readily change both the supply of parking and associated pricing schemes and they can impose stricter conditions on the awarding of permits, by means of quotas or rationing via waiting lists (which at least, temporarily, means users have to face market costs). We believe that the introduction of so-called 'parking benefit districts' might prove to be a sounder political strategy as it should serve to overcome resident (and retailer) opposition through the smart use of the revenues raised, allowing residents to enjoy the benefits of paid parking implementation while avoiding the distortionary effects described above.

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APPENDIX 1.

STATA output for the parallel trend assumption test

. test ntreated2007 - ncontrol2007 = 0 : F(1, 43) = 1.47 ; Prob > F = 0.2319

. test ntreated2008 - ncontrol2008 = 0 : F(1, 43) = 2.54 ; Prob > F = 0.1183

Table A1. Placebo tests

VARIABLES	(1) PLACEBO	(2) PLACEBOall
placebo	-1.817	-4.201
	(2.727)	(3.802)
Maximum time limit	0.366	-1.603
	(1.825)	(2.204)
Fee	-2.366	0.642
	(2.871)	(3.294)
Income	0.000152	0.00151
	(0.000829)	(0.00173)
Population density	-28.28***	-21.42***
	(8.656)	(6.470)
(Population density)^2	0.239***	0.188***
	(0.0768)	(0.0653)
Sex	549.0	113.0
	(456.8)	(352.4)
Age	1.888	1.602
	(3.940)	(4.383)
Occupancy	24.50	2.825
	(51.67)	(30.40)
Autocontention	-0.249	-0.323
	(0.238)	(0.287)
Private vehicle	-0.313	-0.877
	(0.483)	(0.719)
Walking	-0.326	-1.130
	(0.526)	(0.957)
2008.Year	-5.374**	-8.432*
	(2.007)	(5.058)
2009.Year	-7.241***	-13.97**
	(2.351)	(6.017)
Constant	415.8	667.8**
	(357.9)	(286.7)
Observations	132	216
R-squared	0.622	0.408
Number of C_Barri	44	72

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

APPENDIX 2

Table A2. Marginal external costs derived from the use of private vehicle in urban areas (€/vkm)

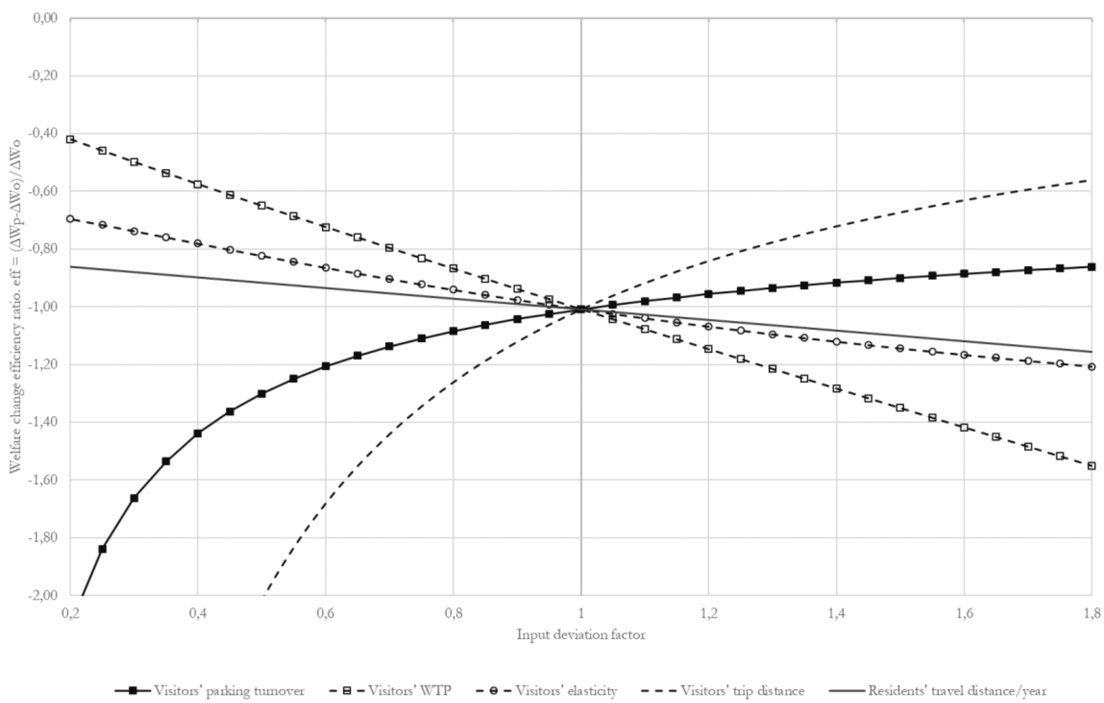
Marginal external costs (€/vkm)	
Congestion	0.009
Accidents	0.001
Air pollution	0.0189
Noise	0.0088
Climate change	0.0104
Infrastructure cost	0.006
Pre-combustion	0.0012
Vehicle production	3.852

Source: DGMOVE (2014) and SAIT (2015)

APPENDIX 3.

In order to test the robustness of our baseline welfare analysis we conduct a sensitivity analysis of our results by introducing changes in the main inputs: visitors' parking turnover, their willingness-to-pay (WTP), visitors' trip distance and demand price elasticity, and residents' travel distance. We recalculate the baseline welfare by separately multiplying each one of these inputs by a deviation factor ranging from 0 (eliminating the effect of this input) and 2 (multiplying its baseline value by 2). The outcomes of this analysis, in terms of efficiency deviation measures is summarized in Figure A3.1, which suggests that the unintended effects of the policy eat up most of the intended gains. Note that even with extreme values it is not possible to recover intended impact of the policy.

Figure A3.1. Sensitivity analysis of efficiency deviation measure (eff)



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