A New Model of Car Ownership in London: Geo-Spatial Analysis of Policy Interventions

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Abstract:
Over the last five decades there has been a tenfold increase in the number of cars in Great Britain and a steady increase in the number of cars per household. However, this national analysis hides significant regional and local trends, and in particular the fact that car ownership in London has remained relatively static over the last 15 years, resulting in London having the lowest level of car ownership of all British regions.

Developing a robust understanding of car ownership is of critical importance to policy development in both transport and land use planning, and their relationships with energy consumption, the environment, and health.

In this research, we assembled and examined a multi-source dataset to investigate car ownership in London and provide a policy-testing model to TfL. The new cross-sectional model built on previous exploratory work, by estimating a non-linear logistic function to explain trends and spatial variation across London. Statistically significant explanatory variables included household structure, income, tenure, and nationality, allowing Transport for London to forecast car ownership levels from future year demographic and socio-economic projections. Central to the model was the ability to test the impact of a range of potential policy interventions, including car cost(s), parking management, and public transport, walking and cycling levels of service. The resulting models show a high degree-of-fit to the data and have demonstrably high accuracy in forecasting car ownership at a fine-grain level.

Importantly, the new model also examined innovative use of developments in geo-spatial analysis by accounting for spatial correlations in car ownership across London. Using a technique known as Geographically Weighted Regression (Brunsdon, Fotheringham and Charlton, 1998[1]) the analysis centres on the identification of spatially specific parameter estimates – in effect providing a distribution of estimates across the study area. The method improved the goodness-of-fit and significantly reduces forecasting errors by accounting for spatial correlations; however, the functionality did not allow for the use of logistic formulations and, hence, the introduction of market saturation terms.

1 Introduction

The context of the study is that car ownership and subsequent use are critical issues in transport planning and policy-making, in terms of who travels, how frequently, where to, and by what means, and the implications for parking vehicles as well as using them. With increasing stress on the "carbon agenda", choice of the type of car is of growing interest also. Car ownership and use also have major implications for land use, energy consumption, the environment, health, and wellbeing, and consequently for policy-making in these areas too.

Car ownership per capita and household is lowest in London of all GB regions, despite the higher incomes reported in London, and has been growing at a much slower rate, as illustrated in Figure 1; concurrently car-use has also been static or declining. Consequently, there was a need for a London-specific research which considers the demographic, socio-economic, spatial and competing mode characteristics that have driven these trends, and translates into a forecasting process that is specific to the capital and can inform policy development.

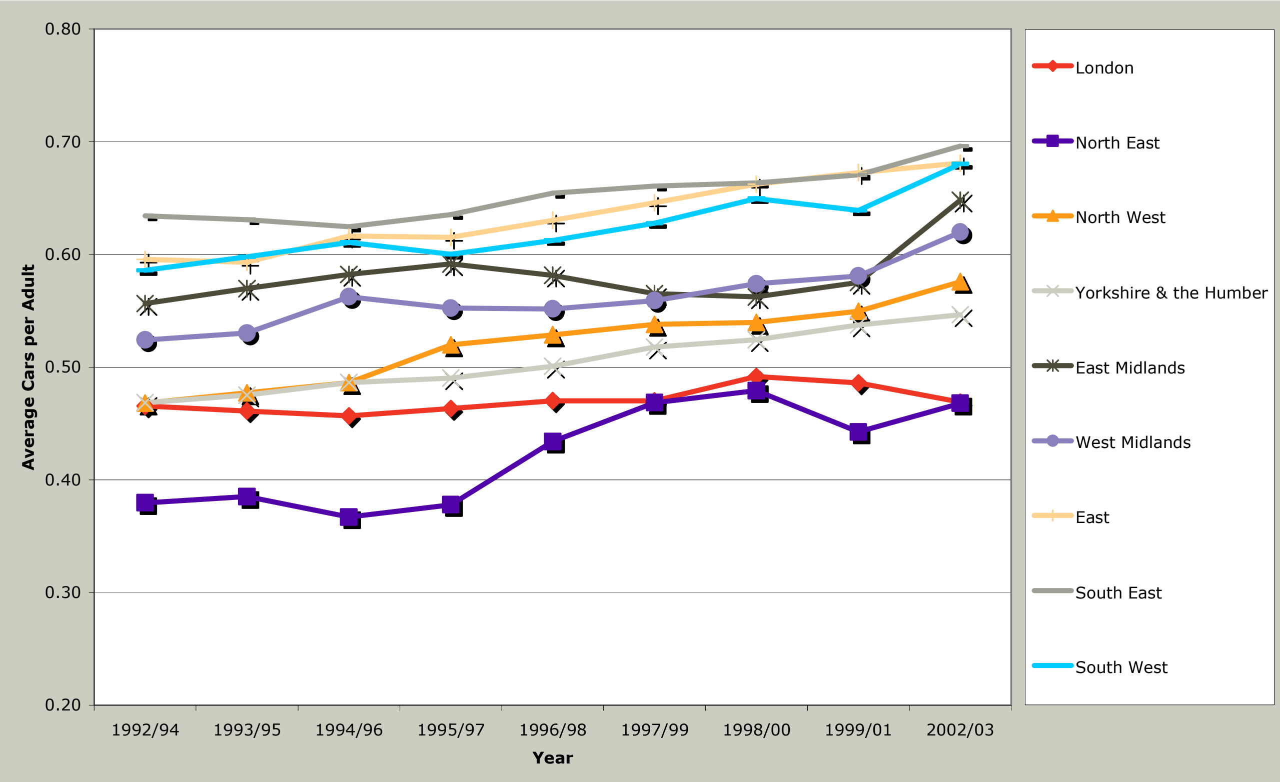

Figure 1: Average Number of Cars per Adult 1992/94 – 2002/3[1] (Source: National Travel Survey 2002/3)

In 2008, Transport for London (TfL) commissioned from MVA Consultancy an exploratory study of car ownership and use in London. Within that study, predictive models of car ownership were developed. These showed that variables not previously included in car ownership models were nonetheless statistically significant. These included whether residents were overseas- or UK-born, public transport level of service, and the living environment. The findings from this study were advanced into a fully functional piece of software that allowed for TfL to produce in-house forecasts with [very] quick turn around times. As part of this second process, the econometric analysis in the exploratory study was re-visited to test new policy variables and to (re-)examine issues regarding functional form of the relationship between car ownership and explanatory variables.

The exploratory study estimated a range of functional forms and tested a host of potential explanatory variables. These model estimates form the starting point for all subsequent models detailed within this Report. Figure 2 shows a plot of the residuals from the linear Census Output

[1] National Travel Survey is collected and analysed over a rolling period and is suitable for longer term analysis, but is not suitable for short term trend based analysis.

Area (OA) Cars per Household (CpH) model estimated in the exploratory study. There were 24,140 OA in Greater London at the time of model estimation. These exploratory models had a demonstratibly high predictive power at this fine-grain level, but did not, however, include a full suite of policy related variables that could influence car ownership. In addition, by the time of the 2011 Census, the level of granularity of the OA will become obsolete, rendering the model(s) much harder to maintain and upkeep.

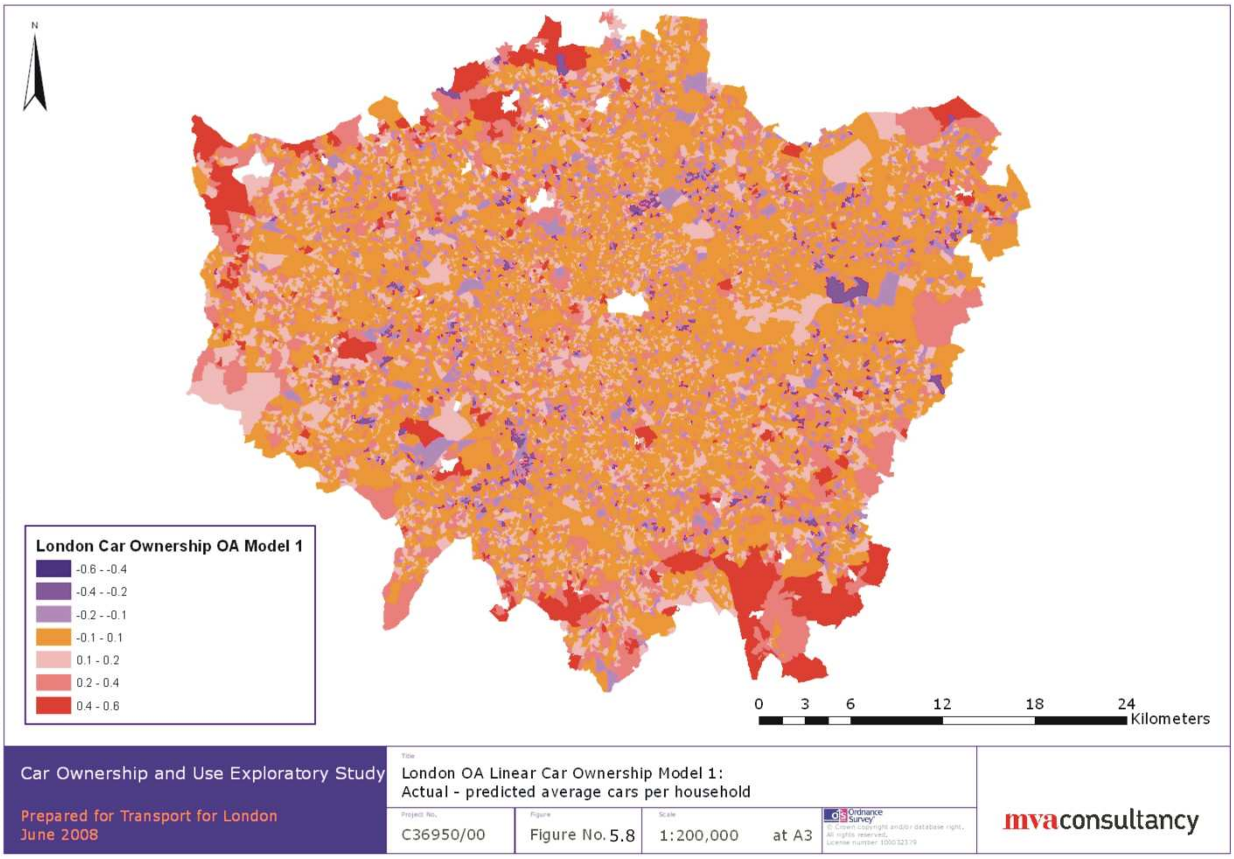

Figure 2: London Car Ownership Output Area Exploratory Model Plot of Residuals

In order to provide context to subsequent sections, Table 1 presents core forecasts from the model under the central ‘do minimum’ scenario. Key drivers such as [adult] population growth are taken from Greater London Authority (GLA) forecasts. The scale of the challenge that planners and other practitioners could face becomes clear, as unless ownership behaviour deviates markedly from the current trend and underlying relationship, then the total volume of cars is anticipated to grow by 40% from 2008 to 2036. Although driven partly by a change in Cars per Adult (CpA), of 16.2% over the corresponding period, other explanatory variables such as household structure and incomes are also leading to the increased demand.

In the next section we discuss why this central trend presents such a challenge to London, and how policy is being formulated to ensure that the capital is able to meet wider economic, environmental and social objectives.

Table 1: Central 'Do Minimum' Scenario Car Ownership Forecasts for London

Year	Adults	Cars	Cars per Adult (CpA)	%ΔAdults (from 2008)	%ΔCars (from 2008)	%ΔCpA (from 2008)
2008	6,055,875	2,915,583	0.48	-	-	-
2009	6,094,752	2,941,548	0.48	0.6%	0.9%	0.2%
2016	6,370,794	3,222,491	0.51	5.2%	10.5%	5.1%
2026	6,827,518	3,651,411	0.53	12.7%	25.2%	11.1%
2036	7,334,770	4,102,558	0.56	21.1%	40.7%	16.2%

2 Policy context

Two key policy documents for London have recently been updated providing a new framework for transport planning and policy development. The London Plan, the spatial development strategy for Greater London, has been updated and is currently undergoing examination in public with the aim for a replacement plan to be published in early 2011. The Mayor's Transport Strategy which was developed in tandem with the London Plan was published in May 2010.

One of the key goals in the Mayor's Transport Strategy is supporting the economic development and population growth of London. The draft London Plan indicates that by 2031 there will be 1.25 million more people living in London and 0.75 million more jobs. This is likely to lead to at least 3 million more trips being made in London per day.

This growth leads to three main challenges identified in the MTS; supporting sustainable population and employment growth, improving transport connectivity and delivering an efficient and effective transport system for people and goods.

The distribution of growth across London of course plays a role on the likely pressures the transport network is likely to face. Figure 3 shows the distribution of population growth across the different London boroughs and highlights the concentration of growth expected in the east London area.

Inner and Outer London are likely to see much of the growth in trips due to the increase in population and jobs. Also, the draft London Plan seeks to support development and growth of Outer London. Car travel is particularly significant in Outer London at the moment with 50% of trips made by London residents originating in Outer London boroughs made by private motorised modes[2]. Future growth in Outer London is likely to lead to additional pressure on the road network.

One other aspect of the population growth likely to influence travel in London is the change in composition. The age structure of the population will change with an increase in the younger age groups (including significant increase in school age children) and people over 60/65 and particularly among the over 90 group. London's population will also continue to diversify with strong increases in Black, Asian and other ethnic minority groups. At the same time the social trends are likely to lead to different household composition with more one person, lone parent and multi-adult but non-family based households. These changes will need to be taking into account in planning transport for the capital and developing policies to address the transport challenges.

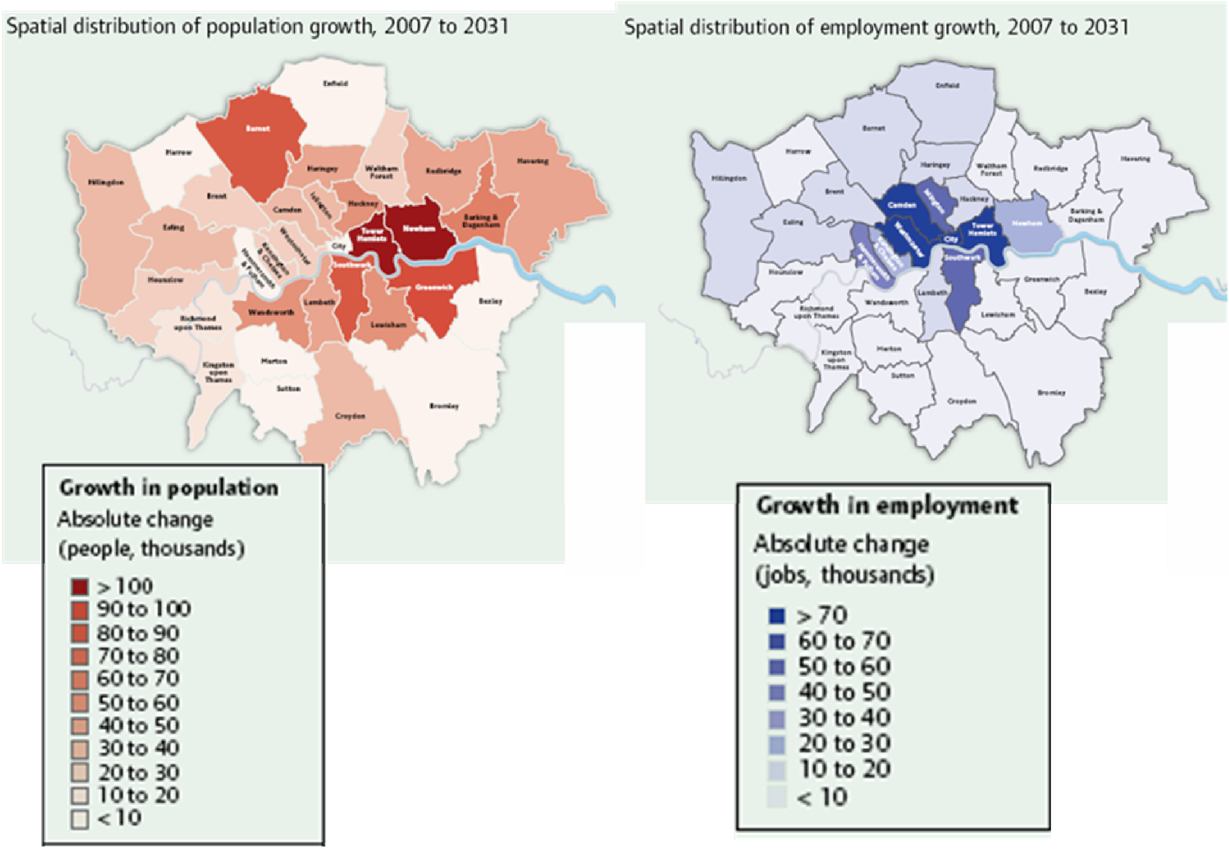

Figure 3: Distribution of population and employment growth, Mayor's Transport Strategy

The MTS sets an ambitious goal in terms of mode shift aiming to reduce the share of private motorised transport from the current 43% share to 37% by 2031. Given the predicted increase in travel overall this mode shift requires a significant decline in the number of car trips in London over the next two decades. This puts additional emphasis on improved understanding of car ownership trends and drivers. It also means that it is important to understand the policy levers available to TfL and its partners which can influence the level of ownership within London.

Within this context TfL is developing tools, such as the new car ownership model, to inform the development of policies which will assist the delivery of the MTS and London Plan goals and address the key challenges London is facing.

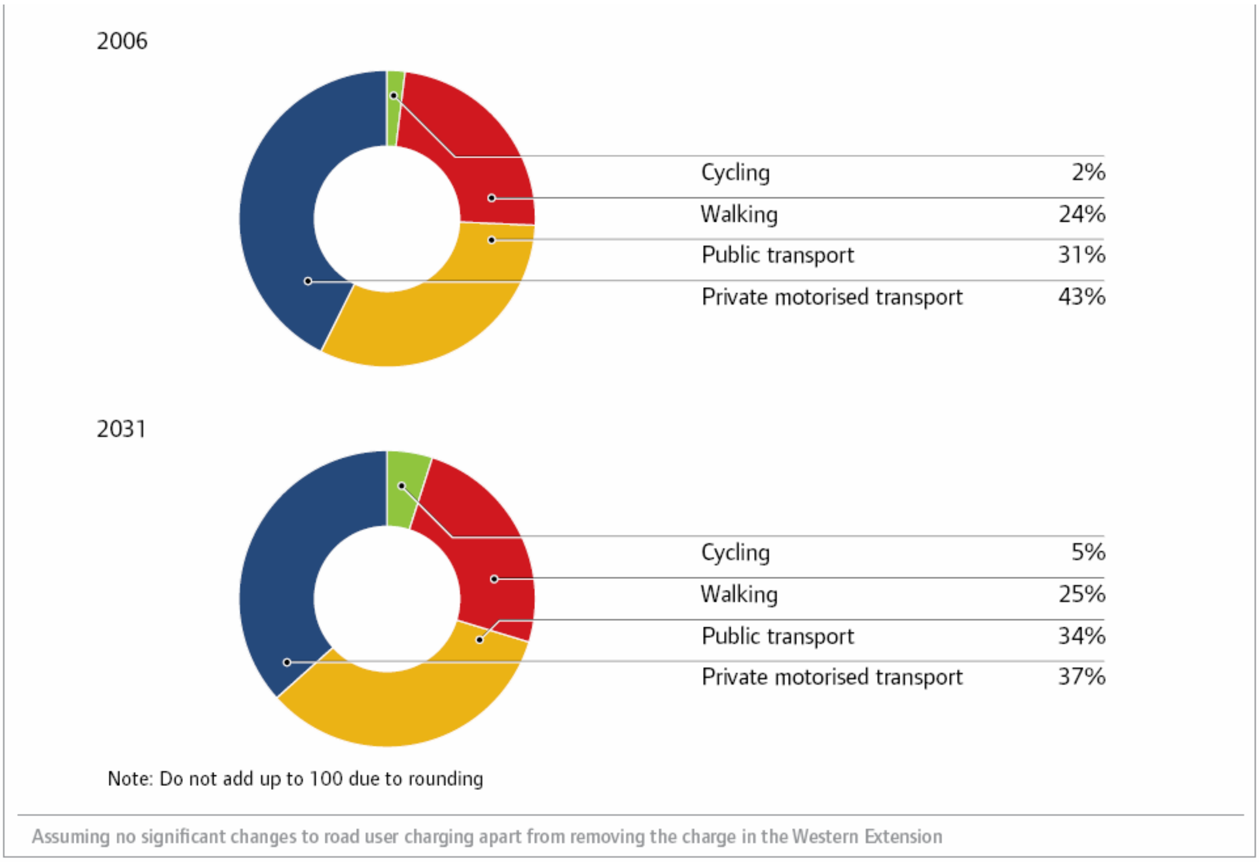

Figure 4: Mode share, Mayor's Transport Strategy

3 Factors affecting the demand for cars in London

There are clearly innumerable influences on how many cars an individual or household chooses to acquire, their type and the use that they are put to.

The car can be viewed as a typical, if not a quintessential, consumer good. As such, the range of influences on the demand for car ownership can be categorised under six headings as follows:

- **Price of Cars** – this includes the purchase price (expressed in relation to the cost and availability of finance), the fixed running costs (including time-related expenditures such a Vehicle Excise Duty (VED)), insurance) and variable running costs (including use-related expenditures such as fuel costs, congestion and parking charges, and vehicle ‘wear and tear’).
- **Quality of Cars and Highway Network** – this includes vehicle quality and functionality as well the level of service offered by the road network and parking supply (eg journey times, reliability and ride quality).
- **Price and Quality of Substitutes** – the price, availability and quality of alternative means of travel. This includes access to public transport but also the ease with which journeys can be made by walking or cycling, which implicitly relates to the spatial distribution of key services and opportunities.
- **Income** – there is a clear and well defined relationship between household/individual income and car ownership with richer households typically owning more vehicles. Clearly the

household’s ability to pay for a vehicle will be influenced by its income following deductions for essential cost of living and taxes, ie net disposable household income.

- **Need –** in most instances a consumer would not own a car unless they had a need for it. This need will be strongly influenced by the household size, structure, employment and location, and can be expressed in terms of the number and type of mandatory and non-mandatory trips that are expected to be undertaken during the period of ownership.
- **Tastes and Preferences –** these define the sensitivity of demand to changes in the influences outlined above. They include aspects of the household decision-making process as well as broader, societal trends, eg attitudes, lifestyles, values and interests (which can be collectively grouped under the term ‘psychographics’).

The consumer’s decision to own a car is likely to be a complex process which is likely to evolve over time (ie it is dynamic) and will involve interactions between vehicle ownership, vehicle type and vehicle use. Nevertheless, relatively simple mathematical/computer models have performed remarkably well in the past in explaining and forecasting ownership levels.

In contrast to past thinking, a growing consensus has agreed that car ownership can be affected by a number of influences which are, either directly or indirectly, influenced by different tiers of Government. In addition, the make-up of the private vehicle fleet in terms of propulsion/fuel type has become of increasing importance to the carbon agenda, as emphasised in Section 2. Datasets were therefore specifically sourced for the following variables which were deemed to be possible drivers of car ownership:

- car parking availability (predominantly at the home end);
- car costs;
- accessibility to public transport and key services and opportunities; and
- other policy levers set out within the Mayor of London’s Transport Strategy, which do not depend on the sourcing of additional evidence on outcomes and/or parameters, and can be specified as direct influences in the model.

Car Parking Availability

The available datasets provided a series of direct and indirect measures of likely residential (at the home end) car parking availability in Greater London. No one dataset was deemed likely to provide a complete indication of availability at the relatively fine-grain spatial detail of the Car Ownership Model for London. Instead, the available variables were assessed in isolation and using stepwise techniques to identify their predictive power, plausibility of sign and magnitude, and collinearity (or otherwise).

Tests showed that the most significant and plausible estimates were produced for:

- CPZ coverage as a dummy variable (1 if CPZ covers majority of a Lower Super Output Area (LSOA), 0 otherwise) with an associated multiplier term to capture the monetary charge for the first residents’ parking permit (RPP1); and
- total public off-street car parking spaces.

The latter variable, whilst collected as part of the parking availability policy tests, may be a better indicator of accessibility, ie, all else equal, we might assume that car ownership becomes relatively more attractive with greater parking availability at the destination end of trips. However, the principal drawback to its inclusion is the implicit assumption that any influence is a result of provision in the borough in which the adult is resident. It therefore takes no account of actual travel patterns/behaviour or the relative attractiveness of different destinations and thus cross-boundary trips.

Car Costs

Car costs can be separated into a number of different groups, including:

- Upfront Costs, including:
  - purchase
  - depreciation and/or resale values[2]
- Mid-term Variable Costs, including:
  - annual insurance
  - Vehicle Excise Duty (VED)
  - MOT(s) and service charges
  - breakdown cover
  - maintenance
  - residents parking permits
- Operating (or 'out of pocket') Costs, including:
  - fuel
  - parking charges
  - congestion charge(s)

Only certain elements of the latter two groupings can be directly influenced by TfL or the London boroughs; however, some of the others are under the direct control of Central Government at a national level and are therefore also of merit in policy tests. As these variables primarily vary in a temporal as opposed to spatial sense, prior parameter estimates were sourced from a study by Eftec[3] for the Department for Transport (DfT).

Spatial Accessibility

The exploratory models had already included Public Transport Accessibility Levels (PTALs), which reflect:

[2] One term that combines purchase cost and depreciation into a single term, is to consider the resale value after one year subtracted from the purchase cost to gain a monetary value for the true 'upfront' cost of car ownership that the individual or household can no longer (monetarily) recoup.

- access time (by walking) from the point of interest to a public transport Service Access Point (SAP), such as bus stops, rail and tube stations within a catchment area;
- the number of different services operating at the SAP; and
- level of service (average waiting time) with an adjustment for the relative reliability of the mode.

For this model development phase, two additional datasets were sourced to capture other aspects of spatial accessibility, namely:

- ATOS Origin results from TfL's CAPITAL accessibility model:
  - provides average access times by walking cycling or public transport electoral ward to six key types of attraction[3];
  - produces a composite score and allocates each ward to one of five 'accessibility' categories, where A is most and E least accessible;
  - is time based only, ie it does not include monetary costs; and
  - uses the Railplan model.
- an LTS measure of access to employment, weighted by number of opportunities:
  - based on LTS time and cost matrices;
  - taking into account opportunities within a 45 minute travel horizon; and
  - are only available for access by public transport.

Due to the relative density of attractions in Greater London, many of the accessibility calculations in the ATOS Origin results are based around walking and cycling, as opposed to public transport. It can therefore be considered as complementary to the more general measure of access to public transport, the PTAL.

The results of tests including these factors are presented in Section 6.

4 Review of functional forms

Aggregate car ownership models deal with the total or average level of car ownership in a given geographical area. They adopt a range of forms, each showing a different relationship between the dependent variable and the explanatory variables. In general:

$$C_i = f\left(\beta, X_i\right) \tag{1}$$

where:

C_i is either the number of vehicles in area/time period i or the average number of vehicles per household/ adult.

X_i is a vector of explanatory variables for area/time period i

β is a vector of coefficients to be estimated.

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[3] Primary schools, secondary schools, further education colleges, open spaces, food shopping, General Practitioners (GPs).

A common theme running through many of these models is that car ownership follows an S-shaped curve to market saturation and that growth is strongly related to income. The economic rationale used to support this practice is provided by product life cycle and diffusion theories whereby demand for new products is initially slow, then, as the product becomes more established, demand increases and finally, as the market becomes close to saturation, the rate of increased demand reduces.

Commonly adopted S-shaped forms include the logistic and Gompertz functions:

$$C_i = \frac{S}{1 + \exp(\alpha + \beta X_i)} \text{ (Logistic)} \tag{2}$$

$$C_i = S \exp(\alpha \exp(\beta X_i)) \text{ (Gompertz)} \tag{3}$$

where:

S is the saturation level

X is a vector of explanatory variables

α, β are parameters to be estimated

Geographically Weighted Regression

In "normal" regression it is assumed that the relationship being modelled holds everywhere in the study area - that is, the regression parameters are "whole-map" statistics. In many situations this is not necessarily the case, as mapping the residuals (the difference between the observed and predicted data) may reveal. Any geographic variation in the parameter estimates is confined to the error term. Many different solutions have been proposed for dealing with spatial variation in the relationship. Geographically Weighted Regression (GWR) provides an elegant and easily grasped means of modelling such relationships.

GWR is fitted by least squares, giving parameter estimates at the location (j (easting), k (northing)) and a predicted value. The (j, k)s are typically the locations at which data are collected. The weighting scheme is organised such that data nearer (j, k) is given a heavier weight in the model than data further away. Various diagnostic measures are also available such as the Akaike Information Criterion (AIC), local standard errors, local measures of influence, and a local goodness of fit.

Different model forms are possible within the GWR estimation package[4], depending on the type of response variable. If the response variable can sensibly take any value on the real line then a 'standard' Gaussian model is available. If the response variable takes the values 0/1 only (presence/absence, true/false) then a logistic (note that this is not a logistic model as described in

[4] Brunsdon, Fotheringham and Charlton, 1998, Geographically weighted regression – modelling spatial non-stationarity, The Statistician, Vol 47, Part 3, pp 431-443.

Equation 2) model will provide location specific estimates of the probability of the response variable being unity. If the data are positive integer counts, then a Poisson model may be appropriate. Consequently, it is not [currently] possible to combine the desired logistic formulation with techniques to account for spatial correlation.

Summary

There are two functional forms which provide desirable enhancements to base linear or log-linear models. The logistic/logit/Gompertz formulation and GWR can be implemented separately in isolation, but not currently in tandem. As a result, a choice must be made between the two based on the relative weight [of importance] of the two criteria. The longstanding finding of saturation in ownership levels, and its inherent desirability when key drivers such as income will produce ever higher ownership in forecasts, was deemed to outweigh the increase in overall goodness-of-fit and other desirable elements of GWR.

5 Econometric results and implications

A full suite of econometric models were developed with alternative functional forms and explanatory variables. Table 2 presents a summary of parameter estimates, goodnesses-of-fit, and statistical precision for two final formulations, namely:

- (A) with CPZ and RPP1 as a single variable (CPZ * RPP1); and
- (B) with population density and Inner/Outer London split, as a proxy for pressures on parking availability at the home end.

Table 2: London Car Ownership LSOA Level Models A and B – 2008 CpA

Variable	(A) With CPZ and RPP1			(B) With Population Density and Inner/Outer London split		
	Coefficient	t-stat	p-value	Coefficient	t-stat	p-value
Parameter Estimates (per adult level unless stated):						
Saturation – Cars per Adult (S)	1.197	30.40	0.00	1.197	30.40	0.00
Constant (β_0)	-7.21	-724.83	0.00	-7.07	-775.30	0.00
Average **Net Adult** Income in £000s (β_1)	-0.785	-12.76	0.00	-0.478	-10.04	0.00
HH Structure: Proportion One Adult (β_2)	1.468	14.26	0.00	1.107	13.10	0.00
HH Structure: Proportion One Adult with Children (β_3)	0.733	5.77	0.00	0.956	9.00	0.00
HH Structure: Proportion Two Adults (β_4)	-1.303	-9.33	0.00	-1.102	-10.04	0.00
Population Density: Number of persons per **hectare** (β_6)	*Not Applicable*			0.001	18.44	0.00

Population: Proportion aged 17 to 30 (β_7)	2.806	23.07	0.00	1.885	18.85	0.00
Tenure: Proportion Private Rented (β_8)	1.099	12.90	0.00	0.814	11.90	0.00
Tenure: Proportion Social Rented (β_9)	1.097	26.66	0.00	0.681	19.84	0.00
Nationality: Proportion Western Europe (β_{10})	-0.983	-4.48	0.00	-0.593	-3.67	0.00
Nationality: Proportion Asia (β_{14})	0.813	10.66	0.00	0.607	9.97	0.00
Geography: Outer London (β_{21})		*Not Applicable*		-0.084	-9.73	0.00
RUURB5 (β_{29})	-0.300	-6.12	0.00	-0.155	-5.07	0.00
RUURB6 (β_{30})	-0.204	-2.94	0.00	-0.060	-1.46	0.14
Public Transport Accessibility Level (PTAL) Score (β_{20})	0.029	9.68	0.00	0.054	21.65	0.00
Controlled Parking Zone; CPZ * RPP1 (β_{26})	0.000707	6.28	0.00		*Not Applicable*	
ATOS Origin Category A	0.0985	8.09	0.00	0.135	11.59	0.00
ATOS Origin Category B ATOS Origin Category C	0.067	7.27	0.00	0.082	9.37	0.00
ATOS Origin Category D	0.045	4.57	0.00	0.046	4.86	0.00
Purchase Cost (β_{36}); (6416 / 10000)	1.693	--fixed--		1.693	--fixed--	
Resale Cost (β_{37}); (5170 / 10000)	-1.174	--fixed--		-1.174	--fixed--	
Fixed Cost(s) (β_{38}); (1000 / 1000)	3.193	--fixed--		3.193	--fixed--	
Operating Cost (β_{39}) – Indexed (2008 = 100); (100 / 100)	0.641	--fixed--		0.641	--fixed--	
London-Specific Constant	1.470	--fixed--		1.470	--fixed--	
Time Series (2008) Constant	0.635	--fixed--		0.635	--fixed--	

Observations	5,299	5,299
Goodness-of-fit statistics:		
Log-Likelihood	-6569.5	-6692.35
Akaike Information Criteria (AIC)	13125.08	13372.31

Note: Variable highlighted in violet are insignificant at the 5% level

The comparable GWR result, excluding geographic-specific variables such as the Inner/Outer London split produces a global linear model with an adjusted R^2 of 0.93; however, using spatially-specific parameter estimates increases the value of this goodness-of-fit statistic to 0.96. Whilst this may be considered a marginal gain, ie there is little variation in car ownership across London through non-modelled geographically-specific, it does illustrate the merit in the GWR estimation where geographic characteristics such as residential density or urban/rural splits may play more of a role in determining variation in dependent variables.

Spatial Validation

Figure 5 and 6 illustrate the spatial precision of Models A and B by plotting the residual values. It can be seen that there is little to choose between the two variations, with Model B (with population density and the dummy variable for Outer London) displaying slightly better spatial accuracy. With reference to Figure 1, the number of outliers, particularly zones with under forecasts, has decreased markedly with the coarsening of the zone system.

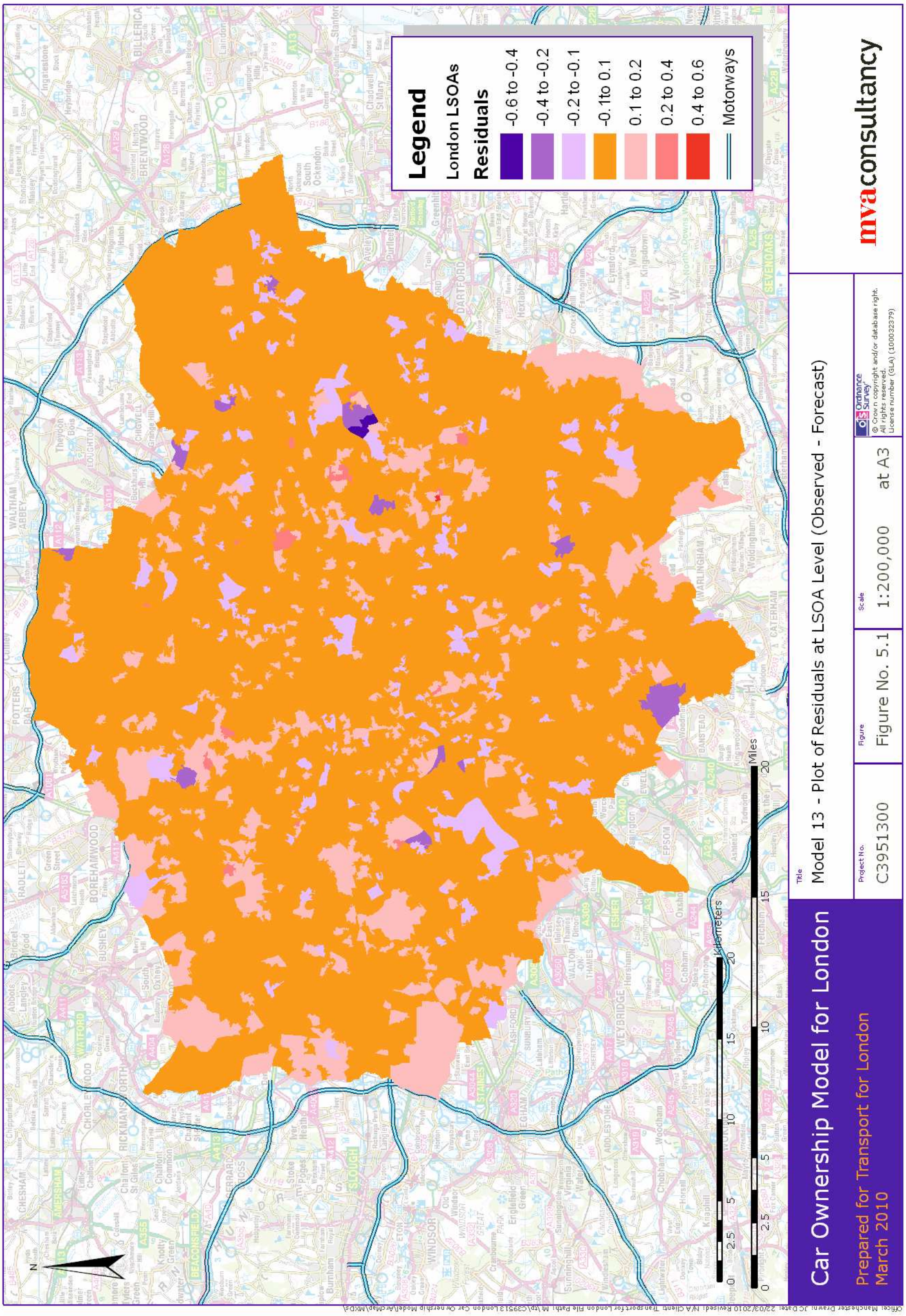

Figure 5: Plot of Model A Residuals (Observed – Forecast)

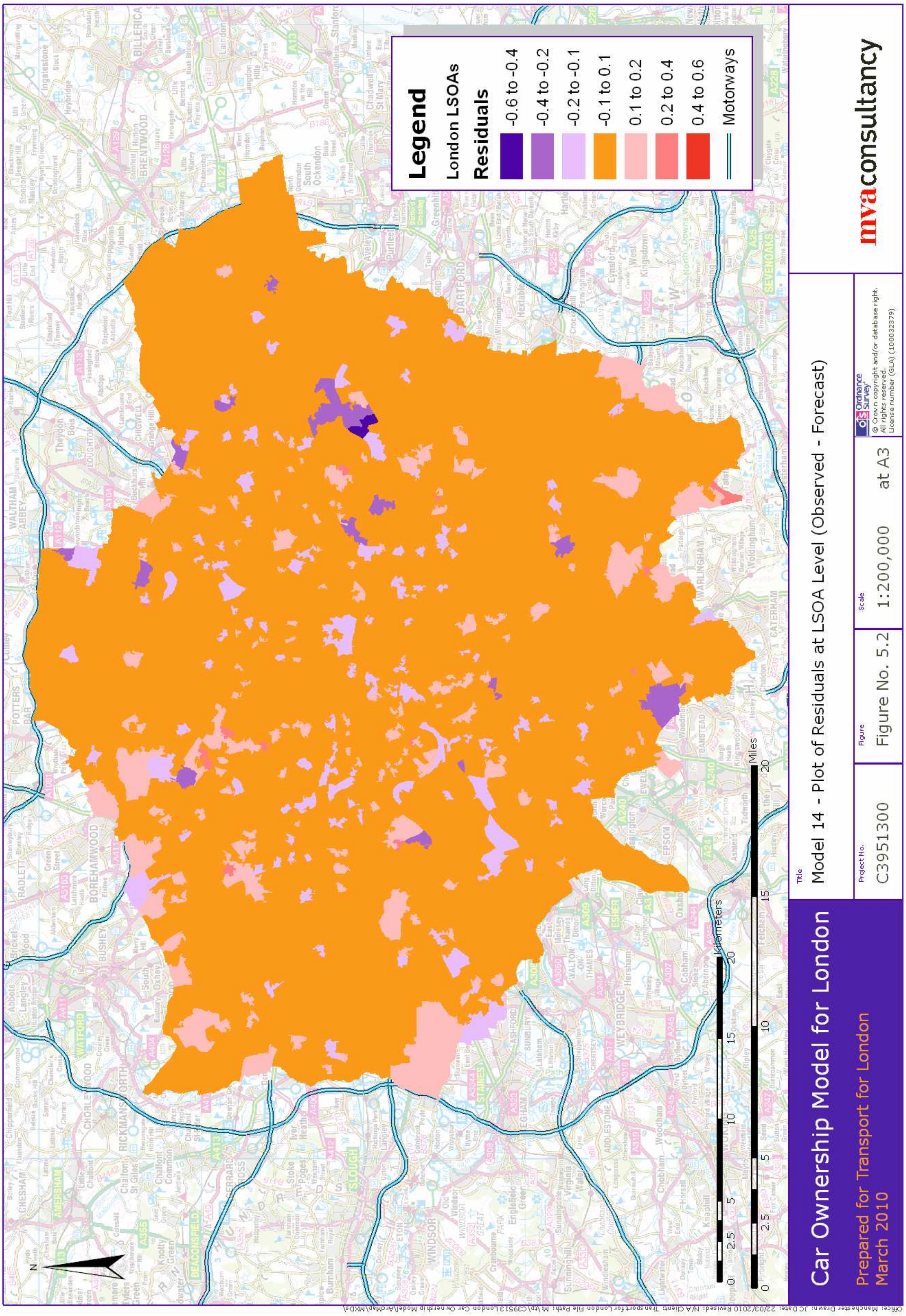

Figure 6: Plot of Model B Residuals (Observed – Forecast)

Residuals

Figure 7 shows the observed versus forecast CpA values resulting from Model A, using the CPZ*RPP1 variable [as opposed to population density and Inner/Outer London] for the London LSOAs. Figure 8 illustrates the residuals. Figures 9 and 10 illustrate the corresponding values for Model B with the population density and Inner/Outer London variables. For comparison, the linear goodness-of-fit measure R^2 and associated trendline have been added to Figures 7 and 9.

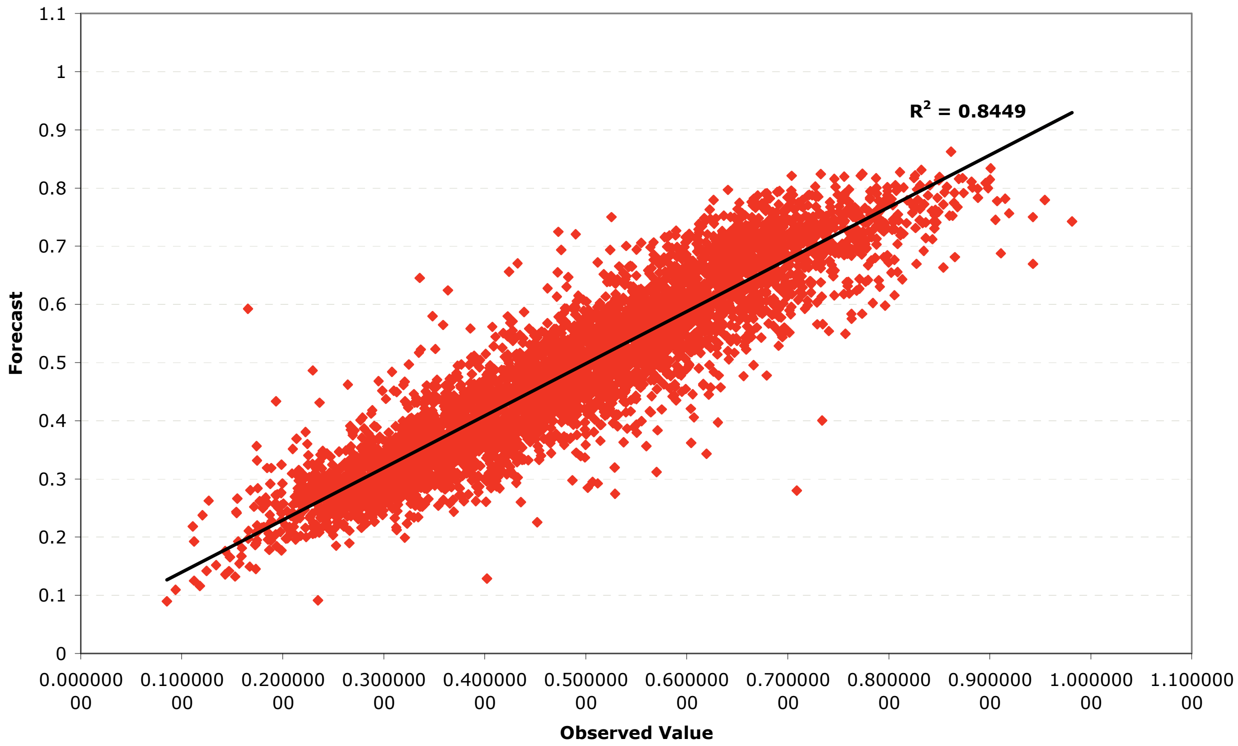

Figure 7: Observed Versus Forecast CpA Values for Model A

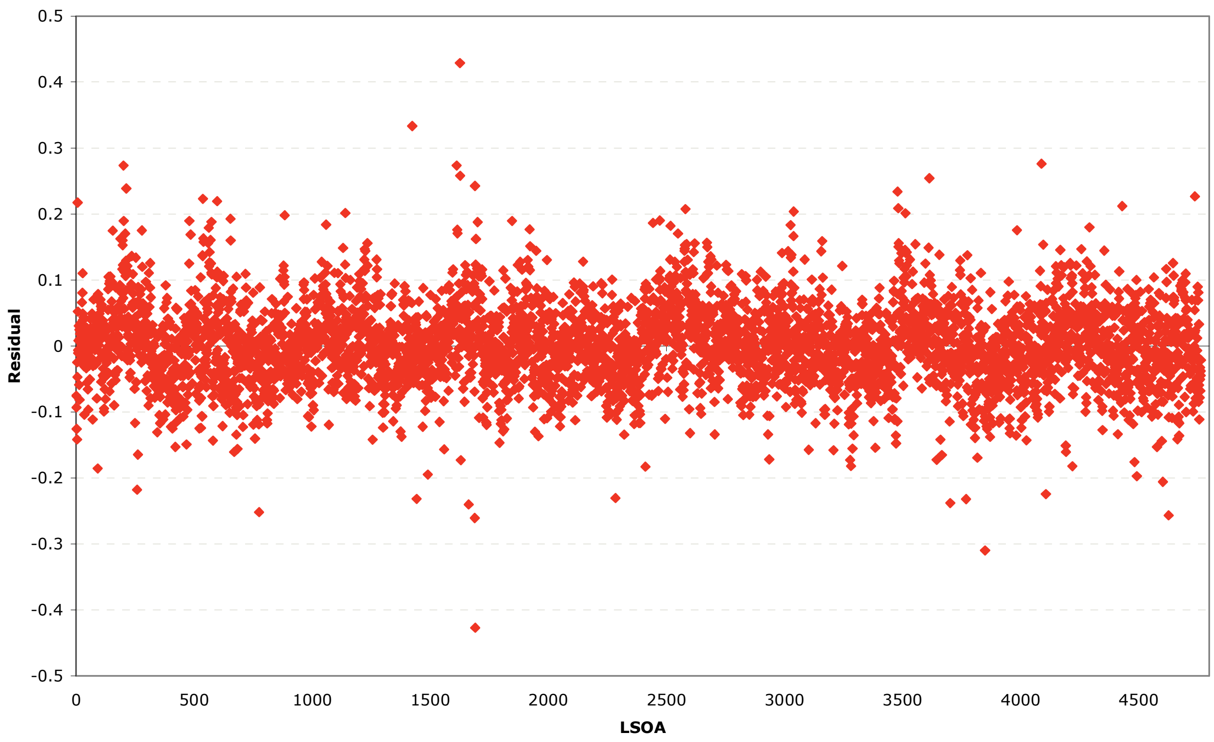

Figure 8: CpA Residuals for Model A

Figure 6 shows that the vast majority of the residuals lie within the bounds of -0.1 to 0.1.

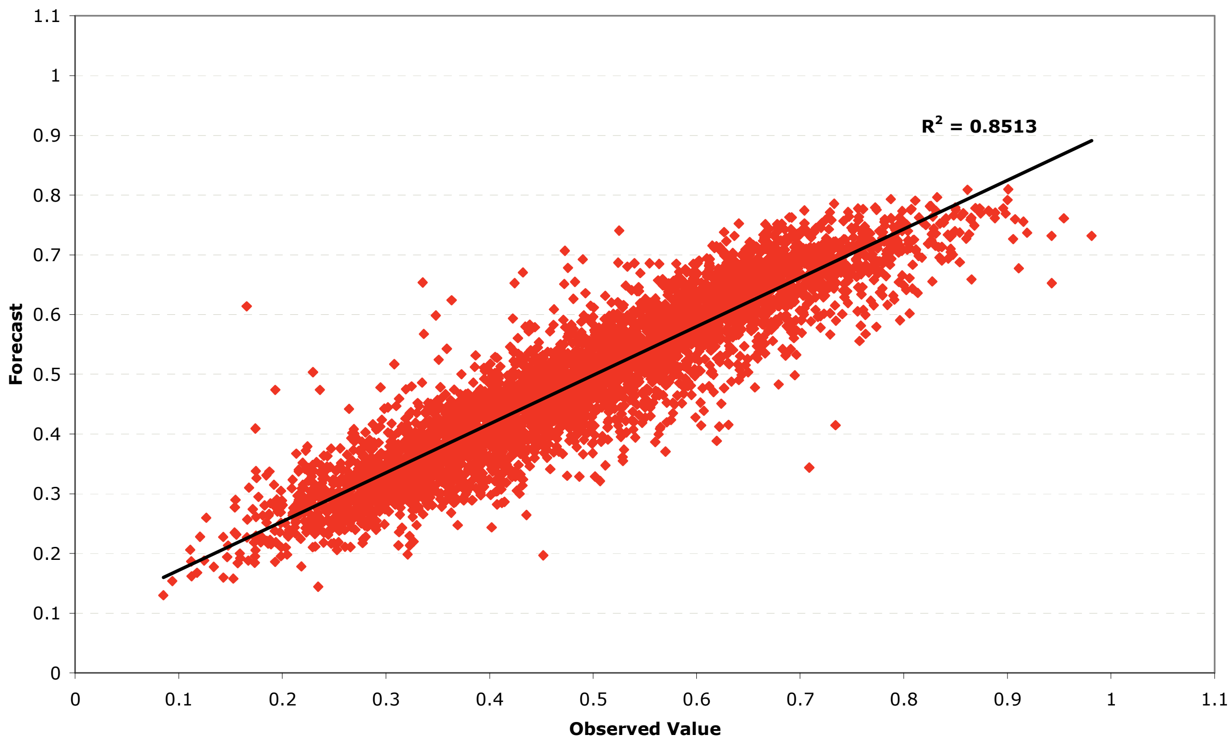

Figure 9: Observed Versus Forecast CpA Values for Model B

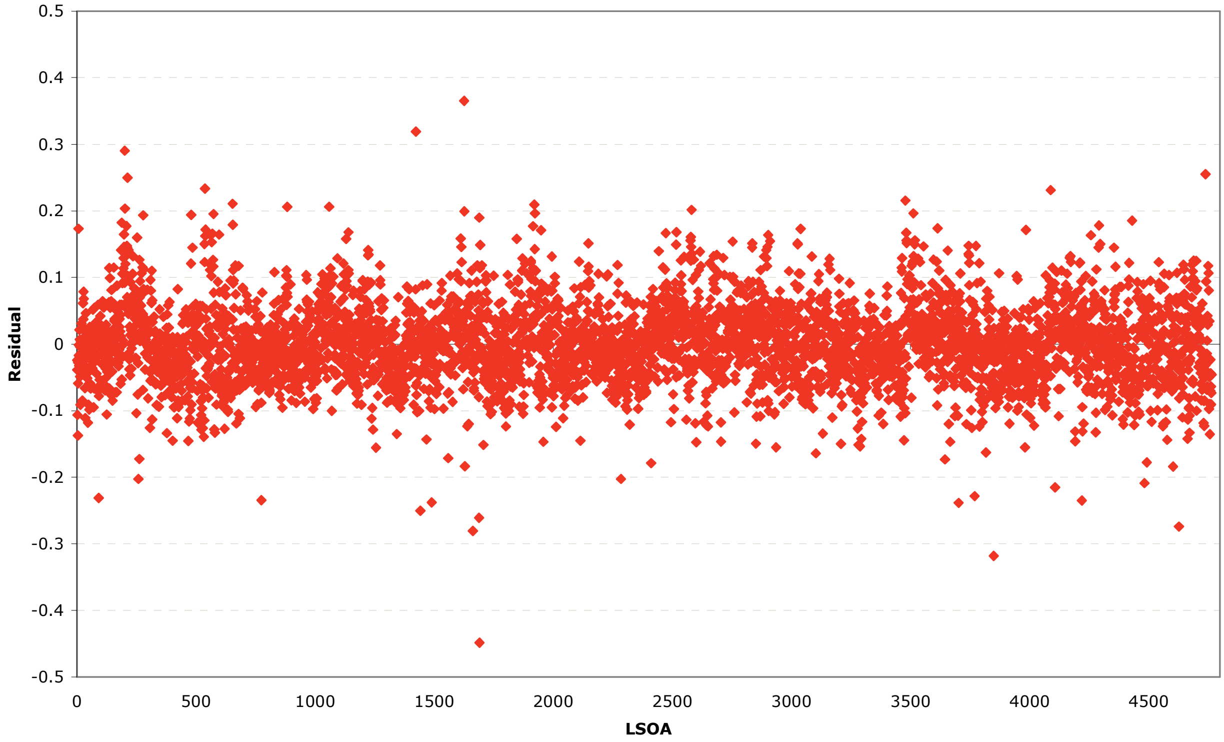

Figure 10: CpA Residuals for Model B

As already illustrated in Figures 5 and 6, there is little to choose between the alternative model specifications in terms of fit to the observed 2008 data. The choice between them therefore centres around the validity and robustness of the CPZ and RPP1 variable for forecasting purposes.

6 Car Ownership Forecasts for London

In order to test the robustness and validity of the car ownership model, a programme of beta testing was undertaken to ensure that:

- core scenarios were plausible and explainable;
- changes in explanatory variables were producing forecasts of the expected sign and magnitude, and, by implication, an appropriate implied elasticity; and
- combinations of changes in two or more variables still produced intuitive results.

Table 4 provides a high level summary of some of the internal testing to validate these requirements for 2026. The implied elasticities to purchase cost vary between -0.58 and -0.77, depending on the magnitude of the change. At the extreme scenario of a 50% increase, then a 27% reduction in total cars is forecast.

The underlying elasticity of total cars to total adults is 1.0, reflecting the assumption that, all else equal, CpA is assumed to remain static and therefore total cars will grow in line with total adults. High and low income growth scenarios, linked to GDP, are shown to affect the anticipated CpA and total cars with an implied elasticity of between 0.24 and 0.38 depending on size and direction (relative to the core scenario). Income growth at -2% per annum across the forecasting horizon was anticipated to a decrease in total cars and CpA of -10% from 2008 to 2026 figures.

As an alternative to the base public transport network, a high investment PTAL scenario was tested. In isolation this was estimated to reduce CpA and total cars by 0.7% or 25,000 less cars in London by 2026. A similar test closing some local facilities, reflected in the ATOS Origin score, resulted in a net increase in total cars and CpA of 0.8%.

In contrast to purchase costs, the elasticity to resale costs is positive, ie increases in the resale value will, all else equal, produce a positive outcome to the buyer.

Table 3: Summary of Beta Testing Results for Future Scenarios in 2026

Test	Adults	Cars	Cars per Adult (CpA)	%ΔAdults (from 2026 Core)	%ΔCars (from 2026 Core)	%ΔCpA (from 2026 Core)	Implied Elasticity
Core Scenario	6,827,518	3,651,411	0.53	0%	0%	0%	-
Purchase Costs +5% across the forecasting horizon	6,827,518	3,549,844	0.52	0%	-2.8%	-2.8%	-0.58
Purchase Costs +30% across the forecasting horizon	6,827,518	3,053,527	0.45	0%	-16%	-16%	-0.68
Purchase Costs +50% across the forecasting horizon	6,827,518	2,676,547	0.39	0%	-27%	-27%	-0.77
Adult Population +5% across the forecasting horizon	7,168,893	3,833,982	0.53	5%	5%	0%	1.00
High Income Scenario +2.89% from RPI across the forecasting horizon	6,827,518	3,757,731	0.55	0%	3%	3%	0.38
Low Income Scenario +1.25% from RPI across the forecasting horizon	6,827,518	3,557,573	0.52	0%	-3%	-3%	0.24
High investment PTAL scenario across the forecasting horizon	6,827,518	3,626,019	0.53	0%	-0.70%	-0.70%	-
VAT at 22.5% across the forecasting horizon	6,827,518	3,604,367	0.53	0%	-1%	-1%	-0.27
Resale costs +10% across the forecasting horizon	6,827,518	3,765,461	0.55	0%	3%	3%	0.32
Income growth at -2% per annum across the forecasting horizon	6,827,518	3,295,062	0.48	0.0%	-9.8%	-9.8%	0.30
ATOS Origin scenario #2 across the forecasting horizon (closure of some local facilities)	6,827,518	3,680,799	0.54	0.0%	0.8%	0.8%	-
Adult Population +5% and Purchase Costs +5% across the forecasting horizon	7,168,893	3,727,336	0.52	5%	2%	-3%	N/A

Duty costs -5% and resource costs +5% across the forecasting horizon	6,827,518	3,666,838	0.54	0.0%	0.4%	0.4%	N/A
2016 PTAL Core Scenario and high resource costs (+25%) across the forecasting horizon	6,827,518	3,537,046	0.52	0.0%	-3.1%	-3.1%	N/A
2016 PTAL Core Scenario and high resource and duty costs (+25%) across the forecasting horizon	6,827,518	3,362,376	0.49	0.0%	-7.9%	-7.9%	N/A
Adult Population +5% and Purchase Costs +5% across the forecasting horizon	7,168,893	3,727,336	0.52	5%	2%	-3%	N/A

7 Summary

The volume of cars on the road, whether they are parked or mobile, present considerable challenges to planners and practitioners. Ownership, and subsequent availability, is at the top of many models of hierarchical mode choice decision-making. Interventions that can reduce or replace the need for car ownership can therefore have beneficial impacts across a range of policy areas. In a constrained land use environment, then the demand for parking spaces, at both the production and attraction end of the trip, has significant implications for the environment and efficient movement of people, goods and services. With an increasing stress on the "carbon agenda", choice of car type is of growing interest also.

Car ownership trends in London have diverged significantly from wider growth across Great Britain, and have remained relatively static for 15 years plus, despite factors such as economic/income growth which would suggest otherwise. Whilst the UK National Car Ownership Model covers many of the factors that explain aggregate levels, an exploratory study in 2008 revealed a number of variables not previously included which were nonetheless statistically significant. These included whether residents were overseas or UK-born, housing tenure, public transport level of service, and living environment.

Extension to include delivery of an in-house model to TfL also encompassed a new round of econometric estimation alongside software design. Central to this were attempts to include potential policy interventions, such as car costs, parking management strategies, public transport level of service, and accessibility to key attractions. A tool that also allowed for spatially fine-grain analysis was also considered essential.

Estimation revealed that parking control, public transport levels of service, and walk/cycle accessibility to key attractions were all statistically significant and had parameter estimates of a plausible sign and magnitude. Findings from a recent study by the DfT on sensitivities to car costs allowed the model to respond to variables that varied in a temporal as opposed to spatial dimension.

A range of functional forms were estimated, with all showing a high degree-of-fit to the data and demonstrably high accuracy in forecasting ownership at a fine-grain level. In addition to linear, log-linear, and s-shaped formulations such as logistic and Gompertz, a technique known as

Geographically Weighted Regression (GWR) was also employed. The technique involves varying the assumptions that parameter estimates are "whole-map" statistics and that any geographical variation is confined to the error term. GWR is fitted by least squares, giving parameter estimates at the location and a predicted value. The weighting scheme is organised such that data nearer to a zone is given higher weight in the model than that further away. Whilst GWR did improve the overall goodness-of-fit, typically from an adjusted R^2 of approximately 0.85 to >0.90, the statistical relationships available within the package do not allow for saturation terms such as the logistic. This key aspect for forecasting purposes was deemed to outweigh the desirable aspects of GWR in explaining spatial variation.

Notes

1. Brunsdon, Fotheringham and Charlton, 1998, Geographically weighted regression – modelling spatial non-stationarity, The Statistician, Vol. 47, Part 3, pp 431-443.

2. Travel in London Report 2, Transport for London 2010.

3. Eftec, 2007, Demand for Cars and their Attributes, Final Report for the Department for Transport, UK.