▪ report

Smartgrowth - Car Ownership Forecasting

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1 Summary and Recommendations

1.1 Purpose

This paper discusses methods for forecasting car ownership and sets out a method for incorporating a car ownership model into the Tauranga Transport Model.

Car ownership is the number of registered cars per head of population or, in the context of the Tauranga household model, the number of cars available for use by household members.

1.2 Methods of National Car Ownership Forecasting

Forecasting of car ownership at an aggregate national and regional level has been tackled in various ways. When the historic change in car ownership is studied, a very stable pattern of growth is observed over time, and the data can be fitted to a logistic (S-shaped) growth curve using only time as an independent variable and with some assumption about a future "saturation" level of car ownership – that is the market for cars is saturated and new registrations will then be balanced by vehicle scrapping. This sort of relationship is currently incorporated into the Ministry of Transport's Vehicle Fleet Model for forecasting over a 20year period, with a saturation level of 0.65 cars per head.

There have been different ways of looking at the saturation level of car ownership. One way is to assume that there can be no more cars than there are drivers, and to predict future driver numbers taking account of the age bands in the population, the minimum driving age, those unable to drive through age or disability, and those not inclined to become drivers due to other options (such as public transport). However, even this is not necessarily a top limit on car ownership if the price of cars lowers to an extent that some households take decisions to own more vehicles than can be driven at any one time. This may occur to a limited extent already.

Other factors that can be expected to influence aggregate levels of car ownership are the increasing wealth of households, expressed as increase in real Gross Domestic Product per head (GDP/capita), and the relative price of cars compared to all other goods and services.

When these are incorporated into the logistic model of car ownership they slightly improve the fit of the model. In fact, models with only GDP/capita and car price give a reasonable fit to the data without including time as a dependent variable. However, there are influences on car ownership that change gradually over time which suggest that time should be retained as an independent variable in an aggregate model of car ownership as a surrogate for these unmodelled effects. These include: changing urban form, changing availability of alternative transport modes and, thought to be of some significance, inter-generational expectations and habitual behaviour.

However, linking car ownership growth merely to time is not very satisfactory as there is no explanatory mechanism, other than the rate of new cars entering the fleet exceeds the rate of cars being scrapped.

1.3 Proposed National Aggregate Model

Previous unpublished work by Booz Allen & Hamilton (BAH) for Transit NZ in 1997 on national car ownership modelling has been reviewed and some elements have been used and updated to 2001/02. The approach suggested by BAH involved forecasting incremental changes in car ownership from year to year based on demand elasticities with respect to GDP and car price. However, this form of model does not specifically address the shape of the growth curve as saturation is approached.

We have opted to stay with a logistic model form including time, GDP/capita and car price index. This model gives the best fit to historic data at a saturation level of 0.82, which appears quite high. However, the saturation level used by MOT of 0.65 also appears to be too low. As our best estimate, we propose a saturation level of car ownership of 0.75 cars per head, equivalent to about 90% of the driving age population, with sensitivity tests to lower and higher levels of 0.70 and 0.80 cars per head.

The form of model proposed is:

$$cars / head = \frac{S}{\{1 + a.e^{b.T} G^c CP^d\}}$$

where T is the year (2001, etc), G is GDP/capita and CP is an index of car prices relative to the all sectors CPI. Coefficients a, b, c and d are constants of calibration and S is the saturation level of car ownership.

1.4 Interfacing with the Tauranga Trip Production Model

In theory, the national model of car ownership could be reproduced as a regional model using regional population, car registrations, GDP and car price. Regional GDP series are not available, apart from a short experimental series based on GST returns. Car price is unlikely to show marked regional differences and it is unlikely that a regional series could be constructed. Also a regional series is not really necessary unless the growth in car ownership rate is expected to vary significantly between regions.

The Tauranga Transport Model incorporates a category–based sub-model for household trip production, using four household size categories (1, 2, 3 and 4+ household members) and four car ownership categories (0, 1, 2, 3+ vehicles/household). For each of the 4x4 = 16 categories there is a daily trip production rate for each of the four trip purposes (home-based work, business, other and non-home based). An implicit assumption in the model is that these trip production rates are stable over time. So future trip productions can be modelled by knowing the numbers of households in each category in future years.

In the model base year there is survey data on the distribution of households into the 16 categories of car availability and household size. In future years there are predictions of changing household size from the demographic work that has gone into Smartgrowth, and of change in car availability at a national aggregate level.

The change in mean car availability at the Tauranga model level is estimated by multiplying the base year car availability by the national model car ownership projection in the future year as a factor on the car availability in the base year. A process described in the report is then followed for distributing the future household numbers into the 16 trip production categories for each traffic zone, taking account of the change in the overall persons/household and cars/person.

1.5 Effect of Incorporating a Car Ownership Model

The overall effect of the car ownership model is to increase trip productions predicted by the model in future years, particularly for home based work trips. The extent of the increase is about 7% in 2051 if the Tauranga model were to be used for projecting this far ahead.

However, there are caveats on attempting to use the model for very long range planning. These include:

- stability of the category trip rates – these will become less reliable as the time horizon lengthens
- as car ownership increases and approaches saturation, additional cars will have progressively less influence on the total kilometres driven – which implies that the trip production rates will go down

In their review, BAH suggested a concept of an “effective” saturation rate of car ownership, which would be somewhat less than the true car population but would preserve the relationships between car use and car numbers. However, it is difficult to see how such an effective rate can be established.

1.6 Alternative Approaches

There are alternative approaches to car ownership forecasting that could be considered, but involve significantly more work and are more demanding of data. These involve modelling the car acquisition behaviour of population cohorts. It has been shown in overseas work that patterns of car ownership change from one generation to the next, after all other factors of variation have been accounted for. An interpretation of this is habitual behaviour, which becomes engrained from youth and is conditioned by the transport environment at the time.

A key to changing car ownership over time may lie in influencing attitudes to car ownership and car driving in these formative years of 15 to 25 when young people first enter the car market and become drivers. Models that work with population cohort data may ultimately be more useful tools for understanding and attempting to influence car ownership, than simple aggregate predictions which carry the risk of being labelled as self-fulfilling prophecies.

However, to develop and incorporate such an approach into the Tauranga Transport Model as presently specified would require some wide-ranging change to the modelling structure.

1.7 Summary

In summary, the approach proposed allows car ownership effects to be incorporated into the Smartgrowth projections in a way that should be sufficient for short to medium range forecasting. However, it should be recognised that for longer term predictions, the time stability of the modelling relationships will become less certain and that, in particular, as the number of cars per households approaches saturation, there is likely to be a reduction in the kilometres of travel per car – that is higher car ownership will not be fully reflected in more car travel.

2 Introduction

2.1 Context and Purpose

In developing a future vision for the transport network in the Smartgrowth region, it is important to explore whether the private car will continue to be the dominant mode of transport, or whether a sea change will occur in the organisation of travel and the use of transport modes. This review of car ownership forecasting considers one aspect of this future vision.

Smartgrowth takes a long term (50 year) view of transport demand and development in the Western Bay of Plenty Region. Over such a lengthy period, factors underlying transport demand may undergo substantial change and accepted norms for forecasting demand may be called into question. There is time for the density and pattern of land development to influence private vehicle ownership and mode choice; similarly there is the time for transport technology and cost structures to influence the density and distribution of development.

This paper focuses on one aspect of land use/transport interaction, the future growth path for car ownership, and the interaction between car ownership and travel demand.

Car ownership is the term commonly used, but most urban transport modelling is based on private motor vehicles availability to households – that is cars, vans and possibly motorcycles available for use by household members, which implies parking at the household overnight.

2.2 Other Countries

New Zealand has followed a pattern of development in car ownership very similar to that of the USA, Canada, Australia and not too dissimilar from the UK and Western Europe.

Countries with lower per capita GDP show similar patterns of change in the mix of transport modes, although conditioned by their starting point. For example South East Asian countries have rapidly progressed through phases of private transport where first bicycle, then motorbike and then cars have been the dominant mode, and with similar pressures on the competitiveness of public transport. There are influences of population size, density and development controls as well as different levels of wealth and distribution of incomes that make each country's experience slightly different but overall, there has been a degree of international convergence in the level of car ownership.

2.3 Car Ownership in the Tauranga Traffic Model

Mean daily trip rates by car per household have been established for cross-categorised household car availability (0, 1, 2, 3+ vehicles) and household size (1, 2, 3, 4+ occupants), that is 16 categories in all, with a separate set of daily trip rates for each driver trip purpose (home-based work, home-based shopping, home-based other, and non home-based). The trip rates are based on sample surveys of travel at a base year and are assumed to continue unchanged into the future. The surveys indicate higher trip rates for households with higher levels of car ownership and higher numbers of household members in employment.

Changes in trip generation arise from changes in the numbers of households in each category, so a general increase in levels of car ownership over time will directly influence the numbers of modelled trips. Within a zone, changes in the distribution of household sizes will influence trip productions, with smaller average household size generally increasing the number of trip productions predicted by the model.

Car trip lengths are an output of the trip distribution model, which links household trip productions with destination trip attractions (with non home-based trips being dealt with by other trip production and attraction models). Trip attractions are modelled as linear regression relationships between trip numbers and planning data for different types of land use at the trip attraction end. Trip attractions are then scaled to equate with trip productions before application of the trip distribution model.

Travel demand (vehicle-kilometres of travel or VKT) is then modelled as the product of the household category analysis trip productions and trip lengths from the trip distribution model. Note that no direct relationship is drawn between levels of household car ownership and or travel demand.

For modelling that has so far been undertaken for Smartgrowth, future forecasts in household numbers have been distributed across the 16 household size/vehicle availability categories in the same proportions as the 1996 base calibration of the model. So forecasts have not reflected any redistribution among categories of household size.

Similarly, there has been no consideration of changes in car ownership. Forecasts so far assume that the distribution of households by car ownership category remain the same, and hence predict lower trip rates than would be expected for rising car ownership.

3 Forecasting of Car Ownership

3.1 Influencing Factors

At any point in time, there is a wide range of factors that influence the decision whether and what sort of car or other means of personal transport to buy:

- whether a personal or a company purchase
- whether a replacement for an existing vehicle or an additional vehicle
- age, family status and employment status
- residential location in relation to workplace, other destinations and alternative means of transport
- driver license status – newly licensed driver, established driver, or relinquishing a driver's license
- personal or household income (gross, net or disposable income)
- the net cost of purchase, annual costs of ownership and running costs in comparison to other goods and services, and to alternative forms of transport
- whether the 1st , 2nd or 3rd vehicle and intended use
- discretionary factors relating to the size, technical specification and features of the vehicle

If it is accepted that individuals have a notional budget that they are willing to spend on transport, (which is debatable but probably has some approximate validity within limits), for many there is a range of choice between spending on vehicle ownership and vehicle use. For example, people with young families and high outgoings but who are reliant on a private car, tend to economise on vehicle ownership by buying an older and cheaper vehicle which they use intensively, whereas those with more disposable income and fewer dependents will spend relatively more on vehicle ownership and less on vehicle use.

Annually, aggregate car purchase behaviour fluctuates more widely than changes in car ownership. Annual car sales rise and fall with economic conditions over a three to five year cycle, but these variations are not reflected in year-to-year changes in overall car ownership. This is because: only a small proportion of the car fleet is turned over in any one year; vehicle scrapping rises with new vehicle purchase; and car purchase can be advanced or postponed for a year or two depending on the prevailing level of consumer confidence.

Household car ownership at an aggregate geographic level, whether national or regional, changes only gradually, and historic data on car ownership can be closely correlated, in more or less descending order, against:

- time – the number of years elapsed from a base year;
- cost - of car ownership and use relative to other costs; that is the 'real' cost of motoring;
- incomes – personal, household or national (GDP);

- changes in the proportions of households of differing age, employment, age and relationship structures;
- the availability of public transport;
- ease or otherwise of overnight parking available at the household.

Historic growth in car ownership since the end of the Second World War can be quite closely correlated to time alone, without consideration of any other more explanatory variables. This is because many of the influences on car ownership have changed gradually and consistently over time: such as increasing incomes, reducing costs of car ownership, reducing public transport availability. So a simple regression model of car ownership with time as a surrogate for these changes will perform reasonably well.

There are other factors, not normally included explicitly in car ownership models, that are also changing gradually over time and so will inevitably correlate against it:

- socialisation processes among the young pre- and driving age population that influence attitudes and behaviour regarding car ownership and use. Once formed at a young age, early conditioning tends to stay with people through life. Someone who has become a driver and bought a car tends to stay a driver and continue to buy cars. Until now higher percentages of young adults in each succeeding generation have learned to drive
- gradual change in the density and pattern of land use and the location of activities that underlie travel demand – urban sprawl and longer commuting distances; large vehicle-based shopping centres, fewer neighbourhood shops and fewer home deliveries of retail goods; schools drawing day pupils from wider catchments
- changing and less regular work patterns put a premium on being able to vary the time that work starts and ends and travelling on demand, more people in multiple part time jobs or contracting
- less pleasant conditions for pedestrians and cyclists as vehicle traffic rises, footpaths are narrowed to make way for widened carriageway, fewer people on the streets leading to feelings of insecurity or real risk, moving people even further towards a car-borne society.
- increasing expectations of the quality of travel, with cars becoming extensions of the home where cell phone conversations can be made (hands-off of course), sound systems listened to, in a controlled climate environment.

Consequently, while models that include time as a main explanatory variable can give quite close correlation to historic data, their use in forecasting future car ownership presumes a continuation of past socio-economic and spatial development trends without understanding or questioning. While such models are likely to be accurate enough over short to medium time periods, they are of limited value for long term prediction.

3.2 The Concept of Saturation in Car Ownership

Private vehicles are consumer durable goods. Typically a new product in the market, with no close substitutes, shows a slow rate of uptake initially as there is little economy of scale and the product is unfamiliar. As the product becomes more accepted, scale economies come into play, prices reduce and the rate of uptake increases. Eventually, the market becomes saturated, when all potential buyers have purchased the product. As market saturation is approached, the pool of new buyers diminishes and the rate of new purchases reduces compared with replacement.

This pattern of purchasing behaviour gives an S-curve of market penetration over time, measured in the case of car ownership as vehicles per head of population, as shown in Figure 3.1 below.

This shape of curve is based on the assumption that the real cost of car ownership either reduces or is stable over time so that the saturation level is either constant or increasing over time. This corresponds with experience - the general trend of car ownership cost has been downward and the saturation level is likely to have increased over time with decreasing urban densities and reducing market share for public transport.

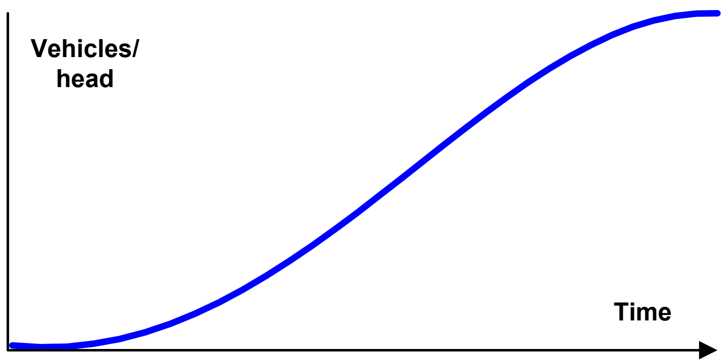

Figure 3.1 – Car Ownership vs Time, with Increasing or Constant Saturation Level

However, if the real costs of car ownership were to rise in the future and/or the saturation level of car ownership were to reduce, then a possible shape of the car ownership curve over time could be as below:

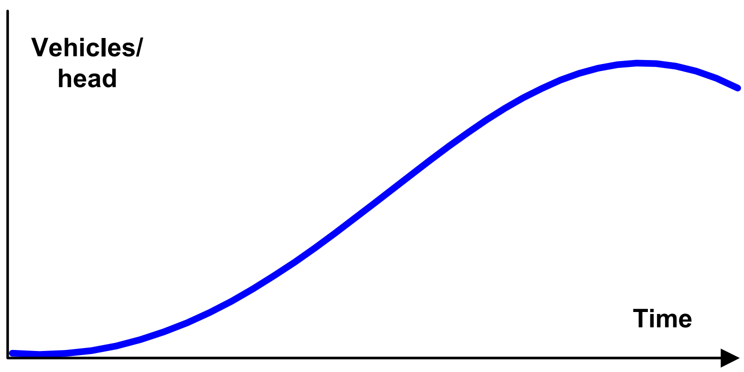

Figure 3.2 – Car Ownership vs Time with Reducing Saturation Level

3.3 Influences on the Saturation Level

There have been many views expressed on a saturation level of car ownership. One is based on the premise that no-one can drive two cars at once and that a saturation level could be one car for every person of driving age, less an allowance for the impaired, disqualified and inveterate non-drivers.

However, this ignores the fact that while many consumer products have the characteristic of one-at-a-time use, people will still own more than one. Clearly this is more likely to occur for lower price goods, such as pairs of shoes, rather than for cars but there will still be a group of households who have sufficient disposable income to afford more cars than can be driven at any one time.

While the cost of acquiring a car can be high, and the capital tied up in an asset of (normally) diminishing value is a disincentive to frivolous purchase, the changes to permit used car imports in the mid-1990s, and the earlier steep reduction in tariffs on new vehicle imports have combined to lower the cost of acquiring a car. Almost as important is the cost of annual relicencing, warrant of fitness and fixed annual maintenance costs – the costs of keeping a vehicle on the road. Some countries, such as Japan, deliberately scale the fees for annual licensing and the roadworthiness regulations (including emissions testing) to actively force older vehicles off the road. Measures to accelerate the turnover of the NZ vehicle fleet (which is very old by international standards at an average of 11 years), have been considered but not so far adopted.

Other influences on saturation level apart from the relative cost of vehicle acquisition and annual ownership are:

- changes in driver licensing; the legal driving age is unlikely to be reduced and the testing regime more likely to be tightened than relaxed;
- the proportion of population of driving age – as the population ages, with older drivers being more habituated to driving and possibly in better health than previous generations, the proportion of the older age groups who are physically and mentally able to drive will increase;
- household formation – if single person households increase relative to other household structures, then this may affect the saturation level, probably increasing it;
- urban densities, form of residential development and public transport – more compact, high density cities with higher availability of public transport will tend to reduce the saturation level of car ownership – trends in the reverse direction will tend to increase the saturation level.

3.4 Car Ownership and Car Use

At an national aggregate level, while increasing car ownership leads to increasing car use, this relationship is not necessarily linear or in equal proportion; that is a 10% increase in cars per head will not necessarily lead to 10% increase in car-kilometres travelled. As car ownership levels increase, particularly close to saturation, the average kilometres per car would intuitively be expected to fall (as additional cars in the fleet are more likely to be second and third cars in the household with lower utilisation). However, this intuitive expectation needs to be demonstrated.

Also, there are other confounding effects, particularly the real price of fuel, which reduced by 50% between 1985 and 1999. The demand elasticity of car travel distance against fuel price is of the order of -0.10, that is a 10% reduction in fuel price can be expected to induce a 1% increase in demand.

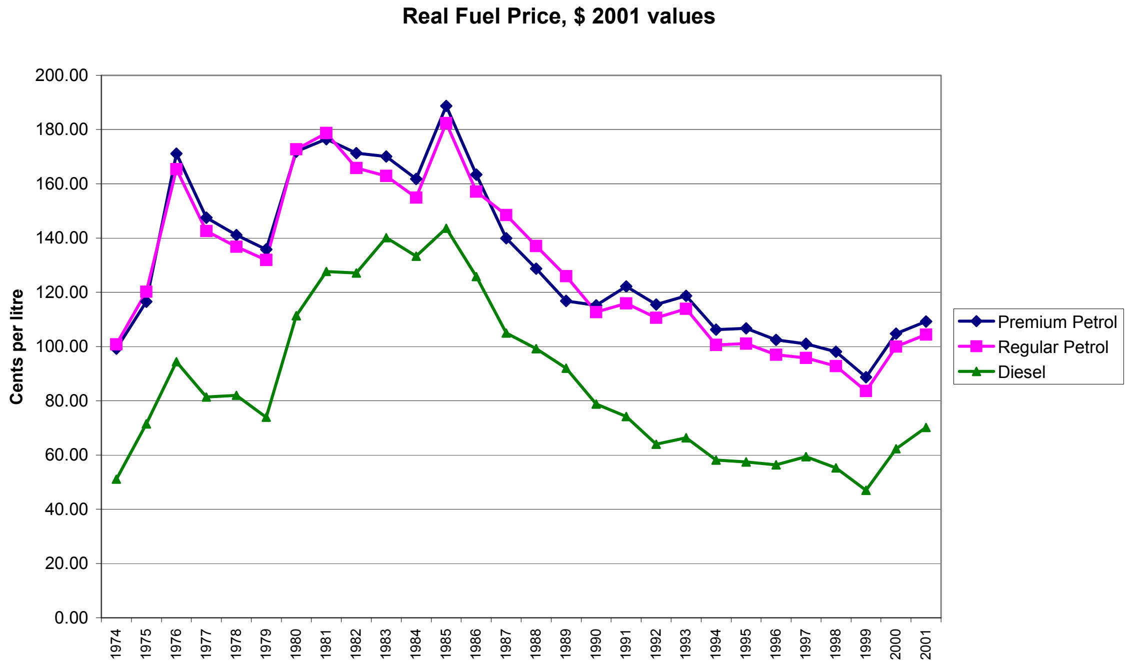

Figure 3.3 - Real Fuel Price Trends, 1974-2001

3.5 New Zealand Research into Car Ownership

3.5.1 Transit NZ Research

The most recent in-depth review of car ownership was carried out by Booz Allen Hamilton (1997) for Transit NZ. This work reviewed past trends, influences, NZ data sources and proposed a modelling approach for regional forecasting.

The BAH review noted three basic approaches to modelling car ownership that have been used since the 1960s:

- aggregate level analysis (called macro-economic approach by BAH) – a time series analysis of car ownership at national or regional level, relating observed cars per head over time to aggregate variables such as total population, gross domestic product and motoring costs;

- disaggregate level analysis (called micro-economic approach by BAH)- a cross-sectional analysis of household or personal data to correlate car ownership to other household or personal factors; the resulting model then has to be aggregated over the households in the geographic area of interest to obtain an overall projection of overall car ownership levels;
- cohort processing approach – a disaggregate approach which considers the car ownership behaviour of age and life-cycle cohorts in the population as this changes over time.

These three classes of model are discussed later in this report. BAH's conclusions were that the macro-models perform reasonably well over the short to medium term but are limited for long term modelling due to their strong reliance on statistical trend projection rather than having an underlying causal structure.

The micro-level models are based on cross-sectional analysis, at one point in time. While they remove the time-dependence, they are still based upon multivariate analysis techniques to achieve a statistical fit to observed data on variables such as income, motoring costs, household size and public transport accessibility. However, in discarding time trends, these micro-models proved not to forecast well over time, indicating that there were other unmodelled influences that cannot be readily ignored.

The cohort processing model approach provides a basis for including factors such as inter-generational change in tastes and propensity to drive, and indicated a good deal of promise. However, BAH noted that the data sets required to construct models of this form were not available in New Zealand at that time.

BAH went on to propose a national model of car ownership incorporating the following features:

- a saturation level of "effective" car ownership in the range of 0.85 to 0.95 cars per person of driving age (15 years minimum driving age to some nominal upper age – possibly 74);
- a time trend of 0.6% annual increase from 1996 reducing to zero in 2001, and thereafter responsive only to GDP and car price change;
- incorporating elasticities of annual change in car ownership with change in GDP per head (0.43) and with change in car prices (-0.17);
- low, medium and high rates of annual change on the path towards saturation based on low, medium and high rates of increase in GDP per capita (+0.5%, +1.2%, +2.0%) and low, medium and high rates of annual change (reduction) in car prices (0.0%, -0.5%, -1.0%)

This incremental modelling approach gave the following results:

Growth Scenario	GDP/Capita Growth p.a.	Car Price Growth p.a.	Cars/head 1996	Cars/head 2031	% increase
Low Growth	+0.5%	0.0%		0.551	12
Medium Growth	+1.2%	-0.5%	0.493	0.632	28
High Growth	+2.0%	-1.0%		0.734	48

A difficulty with the modelling approach is that no method for moderating growth as saturation is approached is incorporated. However, making the assuming that higher growth scenarios are associated with higher saturation levels then by 2031, the divergence between a model that includes saturation and one that does not, is relatively insignificant, so this limitation was ignored.

3.5.2 Ministry of Energy Model

In the 1980s, as part of prediction work on future fuels demand and policy analysis on fuel substitutes and conservation, the Ministry of Energy developed an aggregate Tanner model of the form:

$$\text{Car ownership} = S / [1 + a. G^{b.} \exp(c.t)]$$

where S (0.65) is the saturation level of car ownership, a b and c are constants (1814, -0.96, -0.05), G is real GDP/capita (in fact lagged by one year) and t the time in years from a base date of 1960.

3.5.3 MoT Vehicle Fleet Emissions Model

The Vehicle Fleet Emissions Model (VFEM) was developed as part of the Ministry of Transport Vehicle Fleet Emission Control Strategy in 1998, with a fleet size and composition prediction model that was developed from earlier work dating back to the 1980s. For this model, which was part of a national fleet forecasting exercise, the motor vehicle register was used as the main data source, rather than the Census data on household availability of vehicles.

The performance of the earlier Ministry of Energy model was checked against later data, and similar models with and without. The performance of the model was not significantly improved by the inclusion of a GDP/capita term, and a simple relationship against time was used:

$$\text{Car + LCV ownership} = S/[1 + \exp(a). \exp(b.t)]$$

where S is a saturation level (0.663) "t " is the number of years from the base date of 1970 and "a" and "b" are constants (respectively –0.0476 and –0.0847).

The model was calibrated for forecasting cars plus light commercial vehicles per head of population, mainly due to a strong increase in demand for sports utility type vehicles, and some uncertainty on the proportion of these that are classified as cars or light goods vehicles in the vehicle licensing records[1].

The VFEM model has since been revised and currently predicts cars/head only, with a saturation level assumed at 0.65, and coefficients "a" and "b" are –0.1793 and –0.0632 from a base year of 1978.

The prediction from this model is a national car ownership level of 0.630 cars/head in year 2030, close to that of the BAH model under medium growth assumptions (0.632 in year 2031).

3.6 Forecasting Methods and Recent Developments

3.6.1 Macro or Aggregate Modelling Approaches

In the macro or aggregate approach, car ownership is related by a mathematical function, usually of a logistic or power functional form (generating an S-shaped curve similar to Figure 3.1 above), to several independent variables and is calibrated by regression analysis of time series data. It is the least demanding on data and has been demonstrated to be capable of closely reproducing historical observation of regional or national mean levels of car ownership per head. The well-known work of Tanner (1977, 1981) in the UK epitomises the approach. Its weaknesses for prediction lie in the uncertainty regarding the saturation level in car ownership, which either has to be exogenously supplied to the model or inferred from historical data, and the inclusion of time as an independent variable to capture those other influencing factors not included in the model that are changing gradually over time. Inferring a saturation level from historical data is an uncertain process and usually pre-supposes that the saturation level is constant over time, which is questionable.

Tanner's models at their most advanced stage, included income and motoring costs as well as time in a power function. This form of model has been reproduced extensively elsewhere and across-country studies made hypothesising convergence towards a common level of car ownership.

[1] Motor vehicle registration separately classifies vehicles by body type and by a usage class, the latter determining the licence label. Some car body type vehicles are licensed as goods vehicles because of their declared type of use. Conversely, some light commercial body types are classified as cars. Published statistics of currently licensed vehicles generally show a licence label classification rather than a body type classification. At December 2001, 3.5% of passenger car licences were commercial body types and 1.5% of light goods licences were car body types. Where vehicles are used for both commercial goods and private passenger use, the owner has a choice in the type of licence to purchase. While the annual licence fees for both light goods and private passenger use are now the same, there may be other reasons related to taxation and insurance why an owner may choose to licence the vehicle in the passenger or goods category. Over a period where market conditions are changing, such as the popularity of SUVs or where there are changes in licence fees, legal changes company tax deductions, then there may be year to year changes that affect using passenger car licences alone for the car ownership data series

Wadhwa (1981) in Australia cited by BAH (1997) are an example of a logistic model form against time and income and was used for forecasting work in a number of Australian studies in the 1980s.

The ability of an aggregate model to reproduce the past growth trend in car ownership is not a guarantee of future performance, the more so where the model relies strongly on a time trend, indicating the presence of important and unmodelled influencing factors. Confidence improves the more that other explanatory variables can be introduced to lessen the influence of time in the prediction.

In a recent example Romilly, Song and Liu (2001) constructed an aggregate log-linear model of car ownership for the UK using 44 years of time series data with independent variables of per capita income, motoring cost index, bus fare index. A number of other variables were tested: number of households, road length, real interest rate and unemployment rate; but were found not to significantly improve the model's predictive ability. Of interest in this paper was the sensitivity of the model coefficients to the estimation method, attributed to the relatively small number of observations that such models are invariably based upon. Cross-sectional models have an advantage in this regard.

3.6.2 Disaggregate Cross-Sectional Modelling Approach

This approach is disaggregate, in that it models individual household or personal car ownership as a function of personal and household variables. Models of this form use cross-sectional data (that is one point in time) over a sample of persons or households and then use the resulting model relationships for prediction over time, making some assumptions about time stability of the modelling relationships.

BAH's review considered UK and Australian development of this class of models through the 1970s and 80s by Bates (1971), Bates Gunn and Roberts (1978), culminating in the model used to produce the Department of Transport update of UK National Road Traffic Forecasts (NRTF) in 1989 (DoT, 1989). These and subsequent national transport planning models in the UK have used Family Expenditure Survey and National Travel Survey data and have sample sizes in the thousands. Household income was the principal variable used, but this was progressively extended to include other variables such as household size, various measures of transport accessibility to private and public transport, and residential density. As additional variables are introduced and the level of model disaggregation is increased the importance of income as an explanatory variable falls, but remains the single largest influence.

However, the addition of these variables produced a model that seriously underestimated the growth in car ownership when applied in a predictive mode over time. Even after modifying adjustments were made to account for changes in motoring cost, through a car price index and retail price index, the models still failed to fully account for the increases in car ownership that had occurred when back-projected.

3.6.3 Later Developments of the NTRF Model – Hybrid Model

In the 1989 update of the NRTF, to remedy this problem, another variable – number of drivers licences per adult – was introduced. BAH(1997) notes that as the number of drivers licences per adult was itself modelled as logistic function against time, this extension of the model was tantamount to the reintroduction of a time variable that acts as a surrogate for various unmodelled influences on car ownership change over time.

In effect the 1989 and subsequent NRTF car ownership models are hybrids of cross-sectional and time series models.

The factors that contribute to the poor predictive ability of a model developed solely from cross-sectional data are thought to be the different habituation, taste and mores of succeeding generations to the ownership of vehicles and the use of transport. So a household/income/accessibility category in 1990 will not necessarily display the same propensity for car ownership and use as the same category household in year 2010, even after adjustment for cost differences.

In the 1997 update of the NTRF, the cross-sectional component of the model was based on eight household composition types: 1, 2, 3+ adults, with/without children, retired/not retired. Separate models were developed for five different sizes of urban area (London, metropolitan, urban, semi-urban, rural).

The probability of a household owning 1+ or 2+ vehicles (P) was estimated for each household type by income level from logistic relationships of the form:

$$P = S / [1 + \exp(-L)]$$

where S is a saturation level that must be less or equal to 1, varying by household type, and L is a linear expression of the form:

$$a + a_1 . \text{licences/adult} + a_2 . \ln(\text{household income}).$$

The number of licences per adult was predicted using a population cohort model, again with an assumption regarding the saturation level in drivers licences for different age groups. In projecting future car ownership, real GDP growth forecasts are applied to incomes, increasing the propensity to car ownership, on top of the effects of motoring costs and driver licences within the linear predictor L.

In the 2001 update of the NTRF, two further parameters were added to the linear predictor for car purchase price and car running costs, calibrated to match demand elasticities determined through separate research.

Consequently, the present method used for national car ownership forecasting in the UK is a hybrid of cross-sectional disaggregate modelling for different household and income groups, using income, prices and driver licences for forward prediction, the models calibrated to match the historic trends in car ownership.

3.6.4 Cohort Models

The more detailed cohort based models allow the propensities to acquire and to relinquish a car to be varied over time and for these propensities to be modelled as they work their way through the natural aging of the population. BAH (1997) points out that, as car ownership increases, cars are becoming more of a personal item than a shared household item, so that person-based age cohorts can be used rather than household cohorts. The key influences on predictions from a cohort model are the motivations and behaviour of people of a young driving age to acquire vehicles and, at the other end of the age range, the behaviour of those leaving the driving population. Between these extremes, behaviour is relatively stable, and consists of periodic vehicle replacement rather than totally new acquisitions or disposal.

Cohort models allow inter-generational changes in the propensity to car ownership to be identified. For example Dargay (2002), using UK family expenditure survey data, shows a pattern of increasing car ownership with age of head of household from age 19 to between 50 and 55, and thereafter a declining level of car ownership. This is not unexpected and reflects household income and workforce participation. However, when age cohorts are compared it is clear that succeeding generations show a higher level of car ownership at the same age, and higher levels than can be explained by inter-generational increases in income. Dargay (2002) also identified that car ownership increases more strongly with rising real incomes than it declines as incomes fall – the propensity to acquire a car is stronger than the propensity to relinquish. This 'hysteresis' is taken as evidence of a dependency or habitual behaviour – people become accustomed to owning and using cars.

The implication of such behaviour for transport policy is that the propensity of young adults to become car drivers and owners is a critical lifecycle stage and once taken, is likely to shape consumption behaviour through their lives.

Cohort analysis, based on longitudinal as well as cross-sectional disaggregate analysis of households and their car ownership behaviour, has the potential to bring a higher degree of understanding of the influences acting on households and their propensity to acquire and relinquish cars. More versatile models should be possible from such analysis.

However, the approach is very demanding of data and the form of predictive model that might result is unclear. An approach based on analysis of the Statistics NZ Household Economic Surveys may be considered, although the NZ sample set is relatively small (2,808 private households in 2001), and is now only conducted triennially. The BAH (1997) review considered that the data required to develop such a model were not available in New Zealand, even at a national level.

4 Evaluation of Data Sources

4.1 Introduction

There are two principal data sources for vehicle numbers and vehicle ownership or availability – the Motor Vehicle Registration (MVR) records held at Transport Registry Centre by the LTSA, and the Census data on motor vehicles available to households on Census night.

The MVR is the only data source that covers the entire vehicle fleet, whereas the Census data is the more relevant for urban traffic modelling, where trip generation relies on household vehicle availability.

There are matters of definition and coverage with both sources of data.

4.2 Census - Vehicles Available to Households

Up to 1986, the population census reported the numbers of households with 0,1,2,3,4 or 5+ vehicles available for the use of household members on Census night. Vehicles available exclude motorcycles and mopeds, but will include any household-owned four wheel (or more) vehicles other than cars that are used for personal transport.

In the 2001 Census company cars used *only* for work are excluded. The proportion of company cars that are captured therefore becomes a matter of the company's declared or implied policy on non-work use, and the honesty of the individual filling in the form. As private use of company cars is subject to Fringe Benefit Tax, there is an incentive for companies to declare personal use off-limits to carholders. Before the FBT provisions came into effect, company policies tended to be more accepting of personal use of company cars by employees. People completing the Census form would almost certainly interpret work commuting in a company vehicle as work use. This choice of definition in the Census seems unfortunate.

The Census definitions further describe vehicles as having to be operational, although not necessarily licensed or warranted – so some inactive vehicles from the MVR could be captured with this definition.

For the 1991 Census and earlier the phrasing of the question was slightly different – asking for motor vehicles "available for private use" by persons in the dwelling, rather than specifically excluding vehicles used solely for work use. While the definitions should be equivalent, there is the opportunity for some difference in interpretation.

4.3 Motor Vehicle Register

The MVR records vehicles currently holding a valid annual license (active vehicle list) and vehicles for which the licenses have expired, or have been temporarily withdrawn from service (inactive list). The active list represents the majority of vehicles in current use, although a proportion of those listed as inactive are in fact merely late in relicensing. The percentage of such vehicles has been variously estimated at up to 10% of the fleet, although tightening of the cross checks between vehicle warrants-of-fitness and licensing in recent years may have reduced this percentage.

The vehicle annual license indicates the form of use, and household vehicles available for transporting household members will almost always fall into the 'private passenger' use category. Taxis, rental vehicles, goods service vehicles and other miscellaneous uses are separately identifiable in the Register. Vehicle construction type and vehicle usage do not always match – some passengers cars/vans are used as goods vehicles and conversely, there are goods vans/trucks/utilities used for private passenger purposes.

Company-owned cars are classed as private passenger use. The majority of company cars are garaged at employee's homes, but a small percentage is parked at the workplace overnight. So, on this count, the number of cars and vans available to households will be lower than the total of these vehicles in private passenger use.

The MVR records the office at which the vehicle was licensed which may or may not be the place of domicile. Some large companies register their fleets centrally so registrations in Auckland and Wellington (as the main head office locations) will include some vehicles domiciled in other regions. For household owned vehicles the place of registration and place of domicile will almost always be the same at a regional/sub-regional level.

Prior to 1986 the MVR records were held manually. Vehicles failing to relicense during the year were not immediately purged from the records; this was done on an annual basis for vehicles whose plates had been surrendered or had otherwise failed to relicense during the year. A year later the vehicle record was removed entirely. This had the effect of exaggerating the numbers of vehicles recorded to be on-road prior to 1986. After the register was computerised, there was a period of two to three years over which the new system did not produce reliable statistics. Once the system had settled down, the numbers of vehicles apparently on the road showed a discontinuity with the pre-1986 data. The post-1986 computer records tended to under-estimate the fleet while the pre-1986 data were an overestimate. Interpretation of the historic record is also confounded by changes in legal definitions of vehicle types, in the licensing requirements and in the conventions used by TRC for reporting.

4.4 Comparison of Data Sources

A comparison of Census and MVR for Tauranga and Western BOP Districts for 2001 is shown in Table 4.1 below. In this table, the estimate of vehicles available to households from Census assumes a distribution of 3,4 and 5+ vehicles per household similar to 1991, and expands the numbers for households not reporting. Some of this non-reporting may, of course, be households with no vehicles, as well as 'don't knows' and failed to complete.

Table 4.1 – Comparison of Census and MVR Vehicle Data, Tauranga/WBOP Districts 2001

Data Source	Number
Population Census 2001	
Households with 0 vehicles	3,456
Households with 1 vehicle	19,899
Households with 2 vehicles	17,913
Households with 3+ vehicles	5,601
Households not reporting	1,896
Total households	48,765
Estimated vehicles available to households	77,076
Motor Vehicle Register – private passenger use, active status	
Cars and vans	79,958
Goods vans, trucks, utes	4,137
Motor caravans	798
Buses (small and large)	121
Sub-Total 4+ wheel vehicles	85,014
Motorcycles & mopeds	3,311
Total motorised vehicles in passenger use	88,325

The MVR total of vehicles that would be eligible for counting in the Census is 85,014 or 10.3% above the number estimated from the Census. This MVR total is probably slightly low, possibly up to 5%, due to some inactive vehicles that are operational, but unlicensed. The total of inactive vehicles for Tauranga and Western BOPis 26,531, 31% of the active total. Inactive vehicles are removed from the register after 1 year from licence expiry of the last license. Average vehicle life is approximately 20 years implying an annual scrapping rate of 5%, so the majority of inactive vehicles are either overdue for relicensing or are temporarily off the road in dealer's yards or private storage.

4.5 Reconciliation between MVR and Census Data

For statistics on the national vehicle fleet, fleet growth projections and international comparisons, the MVR data are the more complete and authoritative source, and have the advantage of continuous updating. This provides a larger number of data points when attempting to develop explanatory models based on aggregate data.

The Census data provide linkages with household income and household structure that are more useful for demand modelling at a disaggregate level. The Census data is more representative of vehicles available to households, although the omission of motorcycles and mopeds is a drawback, as there is likely to be substitution over time between two wheel and four wheel vehicles (and likewise cycles are similarly excluded). Also there is some ambiguity in the way company owned vehicles are included and, again, the potential for unrecognised changes over time if there is any variation in the proportion of business cars to private cars, or in the restrictions that businesses place on car use.

5 Proposed Approach for Smartgrowth

5.1 Short to Medium Term Modelling

5.1.1 Regional Car Ownership Forecast

For short to medium term modelling, a conventional aggregate model at a regional level, based on a saturation level of car ownership, with an income measure such as real GDP/capita and a vehicle price index as independent variables and time as a surrogate variable to capture other unmodelled influences on car ownership would be an improvement on the present absence of any vehicle ownership forecasting considerations in the Tauranga model.

It can be assumed that car prices are reasonably similar across New Zealand but regional GDP/capita may vary. However, regional statistics on GDP are not available. An experimental project by Statistics NZ has produced estimates of GST sales per region, from which an index of net GST can be constructed, which may be a useful surrogate for GDP/capita. However, with the assumption that, over the medium to long term, the percentage growth in per capita income will be relatively even across regions (that is there is no significant regional divergence in GDP/capita), a national GDP projection can be used.

Vehicles per household and vehicles per head does vary regionally, with Bay of Plenty a somewhat above the national mean (Nelson/Marlborough and Canterbury exhibit the highest levels and East Coast the lowest. From 1986 to 2001, the Census data indicate that regional levels of car ownership have shown no tendency to converge or diverge.

A reasonable translation of a forecast of national car ownership to a regional prediction for the Bay of Plenty is a simple factoring by the ratio of car ownership in the study area to the car ownership nationally.

5.1.2 National Car Ownership

For motoring costs, the movement of the CPI – private transport (SE91F1) index divided by the All Groups CPI (SE9A), provides an index of change in private motoring costs relative to general price inflation. A special analysis was carried out by Statistics NZ for the BAH (1997) study of the average prices of all cars purchased in NZ (new and secondhand) which form part of the input to the private transport cost index.

This analysis has been repeated. Statistics NZ have supplied price indexes for new and used car purchase and these have been used in a weighted form against the proportion of new and ex-overseas used car imports to give an index of car purchase for newly registered vehicles. The relative price index is then the weighted car purchase price index divided by the All Groups CPI.

Examination of the Transport Registry Centre data shows that there is a 'fuzzy' dividing line between cars and light commercial vehicles. In the past decade there has been a marked increase in sports utility vehicles used primarily for personal use although the licensing data shows many of these as commercial registrations. Vehicle ownership models based on cars + light CVs calibrate better than do models based on the apparent car licenses (see Appendix B). However, the difference is not great, and a model based on car ownership is used below.

A series of model forms have been tested with cars (or cars + LCVs) per head of population as the dependent variable over the period 1981 to 2001:

- Model 1 – linear form, GDP/capita and car price index
- Model 2 – linear form, year, GDP/capita and car price index
- Model 3 – logistic form with saturation level of car ownership, and time
- Model 4 - logistic form with saturation level of car ownership, GDP/capita and car price index
- Model 5 - logistic form with saturation level of car ownership, time and GDP/capita
- Model 6 – logistic form with saturation level of car ownership, time, GDP/capita and car price index

All models give a reasonable fit to the observed data, even Model 1 which excludes time altogether. Model 2 was a much better fit over the historic data but, of course has no upper constraint on car ownership growth, so of course by 2051 forecasts a higher level of car ownership than do the model forms that include some saturation level.

Model Form 3, which is a logistic against time alone fits the observed data well but has all the limitations previously described. Model Forms 4 to 6 give progressive improvements in fit although little difference in the future predicted car ownership level.

Model Form 6 is recommended. While its fit to historic data is only marginally better than other model forms, functionally it includes independent variables of income and relative price of cars that would be expected to influence purchasing behaviour, includes time for some unmodelled characteristics and allows for an exogenously determined saturation level.

The final model form adopted is:

$$cars / head = \frac{S}{\{1 + a.e^{b.T} G^{c} CP^{d}\}}$$

where G is a measure of real GDP per capita, CP is an index of relative car prices, and T is the year. Calibration coefficients are a, b, c and d. More details on the data series and model forms is provided in Appendix B.

In predictive mode, the model requires the following parameter values:

- Saturation level of car ownership
- GDP per capita forecast
- Relative car price forecast
- Year of forecast

5.1.3 Saturation Level of Vehicle Ownership

Without going to the sophistication of cohort models working with generational change in propensity to become car owners and driver, some assumptions have to be made on car ownership.

The logistic models gave the closest correlation to historic data at a saturation level of about 0.82 for cars/head and about 0.92 for cars + LCVs per capita. This is considerably above the saturation level of 0.65 currently used in the Ministry of Transport Vehicle Fleet Model, and above the 1980s/90s urban transport models. In Australia, the Bureau of Transport and Regional Economics has recently increased its saturation expectation from 0.57 cars/head (which NZ has almost reached already), to something around 0.65, about a 15% increase.

The BAH report for Transit NZ argues for saturation levels between 85% and 95% of the driving age population (15+), on the basis that around 5% are unable to drive through age or disability, up to 5% do not buy a car through inclination, and that up to 5% do not buy a car because of public transport options. In mid-2002, there were 2.64 million licensed drivers and a driving age population of 3.05 million, that is 78% held licences and there were 24% more drivers than cars.

In 2051 the driving age population is forecast to be 84% of the total population, so this range of saturation levels is between 0.71 and 0.80 of the population.

A saturation level below 0.70 cars/head now looks unlikely on present trend, but a level as high as 0.80 makes no allowance for any brake at all on personal vehicle ownership in future years. We propose a nominal level of 0.75 cars/head as a central projection, with sensitivity to 0.70and 0.80 as low and high bounds.

5.1.4 GDP per Capita

An analysis of GDP per capita data over the past 32 years shows that incomes grew unevenly over the period, periods of firm growth being followed by periods of relative decline. Overall there was an upward trend, but not of a progression to support other than a linear growth projection.

The trend corresponds to a 0.7%per annum linear growth in GDP per capita based on the 2001 GDP/capita value. From the range of variation, we suggest that a central projection of 0.75% per annum linear be used with an upper and lower range of 0.5% and 1.0% for sensitivity testing.

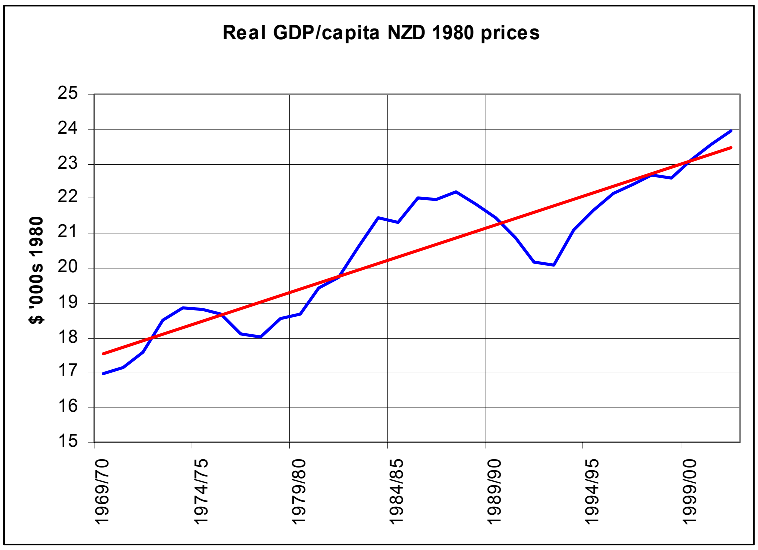

Figure 5.1 – GDP per Capita 1969/70 to 2001/02

5.1.5 Relative Car Price Index

The cost of car purchase has come down over the years with the removal of import duties and imports of used cars from Japan. The change in the price index is shown below:

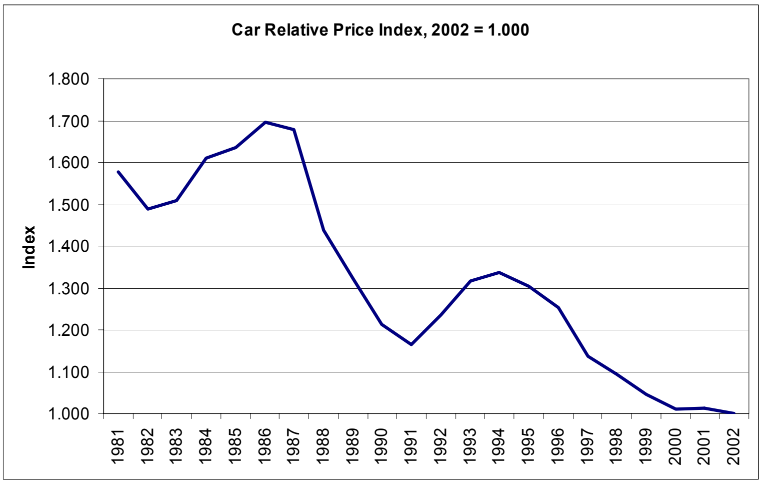

Figure 5.2 – Relative Car Price Index

It is debatable whether there is scope for further downward movement in this index, as the drop that has occurred is through one-off factors that could be reversed if Government policy were to change. As a base assumption we suggest that a value of 1.00 be assumed over the forecasting period. As an upper and lower bound range we suggest a real rise of 50% and fall 25% over the 50 year period.

5.1.6 Resulting National Car Ownership Projections

National car ownership projections for the three saturation levels and showing sensitivity to GDP/capita and car price growth are shown below. Saturation level has the largest effect, followed by GDP and then car price.

Figure 5.3 – National Car Ownership Model, Projections and Sensitivity

5.1.7 Incorporation in the Model Structure

The national forecast of car ownership has then to be incorporated into the category analysis model for trip productions at a traffic zone level.

This requires, for future years, that the households in each zone be redistributed over the 16 persons/household x vehicles/household categories. TDC has estimated future population and households per zone. While these imply small changes in the mean persons per household in each zone over time, the generality of the forecasting process does not really allow such a level of detail. Accordingly, while the car ownership model provides for changes in household structure, it has been assumed that zonal persons per household remains unchanged in the future. Redistribution is therefore across the vehicles/household categories only.

For this redistribution of households by car ownership, the approach taken is to analyse the 2001 Census data of car availability and household size and derive relationships at Area Unit level between:

- percentage of households in each size category modelled on average household size
- average vehicles per household in each household size category modelled on average vehicles per household over all household sizes
- percentage of households in each vehicle availability category within each household size category modelled on the average vehicle availability for the household size category

Synthetic trip productions for base and future years are then developed using these relationships and used to develop growth factors for application to the base year trip productions using the observed distribution of households for the base year.

Details of this procedure are given in Appendix A.

5.1.8 Effect of Car Ownership Changes on Regional Trip Productions

The effect of car ownership changes on trip productions from the Tauranga model for future years and trip purposes is estimated as the following percentage increases (see Table 5.1). Note that this is before considering any increases in trip production due to increasing zonal population or households.

Overall, increases in car availability lead to around 7% increase in trip productions over the 50 year period, most of this increase occurring (in a medium car ownership growth scenario), in the first 25 year period. It is notable that the trip production category model forecasts very little change in home-based shopping and home-based other trip purposes, but a larger increase in non home-based trips, and the largest of all (20% over 50 years) in home based work trips.

Table 5.1 – Percentage Increase in Trip Productions from Car Ownership Growth

Year	HBW	HBS	HBO	NHB	All
1996	0.0%	0.0%	0.0%	0.0%	0.0%
2001	4.4%	0.1%	0.2%	2.5%	1.6%
2006	7.3%	0.4%	0.4%	4.0%	2.7%
2011	9.7%	0.5%	0.7%	5.3%	3.6%
2016	11.8%	0.6%	0.8%	6.4%	4.4%
2021	13.5%	0.6%	1.0%	7.2%	5.0%
2026	15.1%	0.6%	1.1%	8.0%	5.5%
2031	16.3%	0.6%	1.2%	8.7%	6.0%
2036	17.4%	0.6%	1.2%	9.2%	6.3%
2041	18.3%	0.6%	1.3%	9.6%	6.6%
2046	19.1%	0.6%	1.3%	10.0%	6.9%
2051	19.7%	0.5%	1.3%	10.3%	7.1%

5.2 Long Term Modelling

The relationships discussed above should be adequate for modelling say over a 10 to 15 year period.

However, the stability over time of the trip production category analysis model is unknown, and will become more uncertain as time goes on.

As car ownership approaches saturation, additional household cars will translate into fewer trips per car. While the category analysis model already predicts this to some extent, the effect is likely to become more pronounced and the reliability of this model will become less over time.

On an aggregate level, vehicle-kilometres of travel (VKT) per head of population can be modelled directly from income level (GDP/capita) and fuel price, without the intermediate step of car ownership. That is, the number of cars and car use are only loosely related and are likely to become less so as cars become cheaper and car ownership levels rise.

Also, over the long term, inter-generational change in the propensity to own cars has time to influence both car ownership and car use. Different modelling structures, such as disaggregate modelling of population cohorts, should be explored (see 3.6.4).

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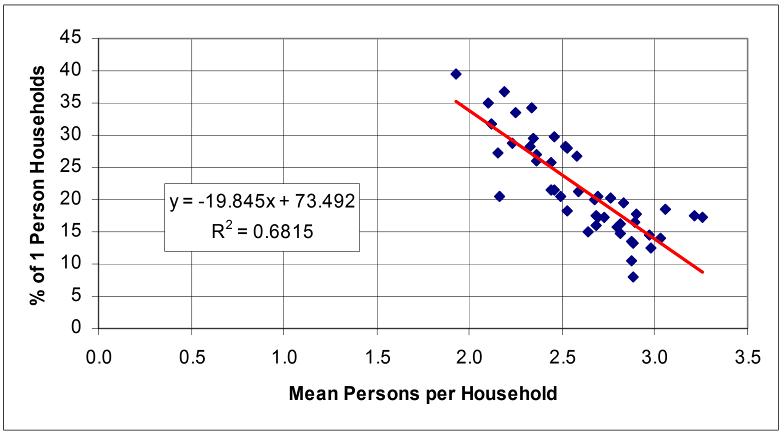
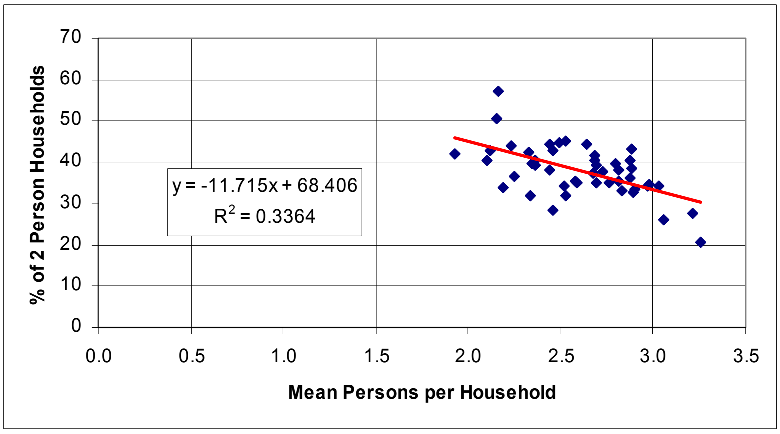
Appendix A - Analysis of 2001 Census Data on Household Size and Vehicle Availability

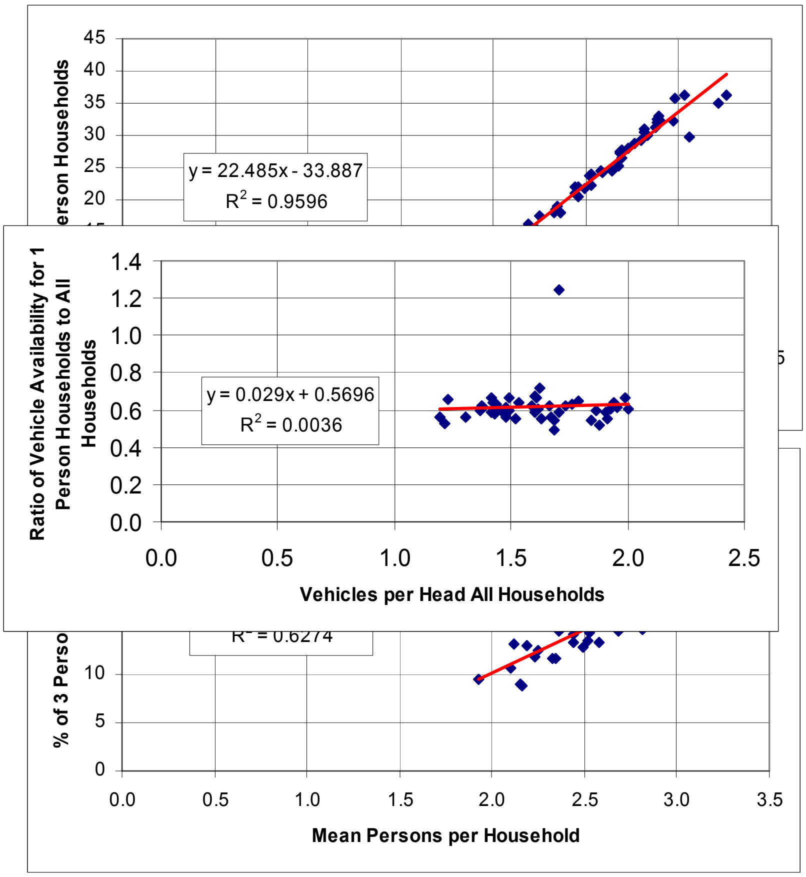
Census data for Area Units (AUs) was obtained for Tauranga and Western Bay of Plenty Districts from Statistics NZ 2001 Census information base. The data preserves the three's-rounding confidentiality but the AUs are generally of sufficient size for the effect of this to be insignificant.

The relationship between percentages of households in 1,2,3,4+ size categories (persons per household) with mean household size was examined using scatter plots, and linear best fits obtained. These are illustrated below:

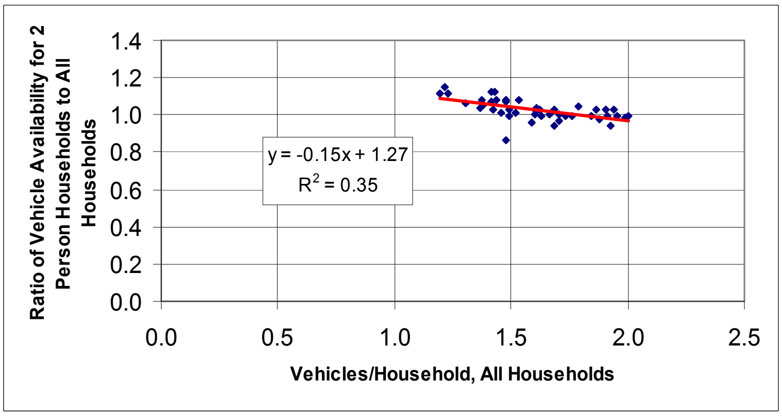


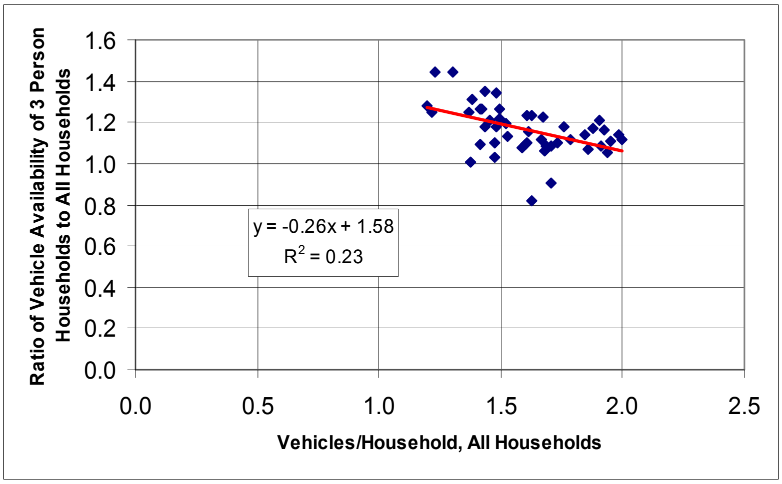


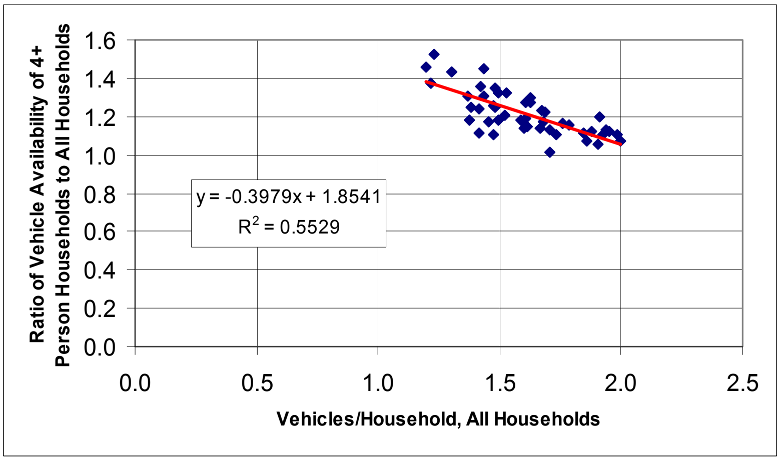
The relationship between the ratio of mean vehicles per household for the household size category to the mean vehicles per household for all households in the Area Unit was explored in similar fashion, resulting in the diagrams shown below.



For single person households, this ratio shows no correlation with the mean vehicles per household for all households. In this case, vehicle availability for single person households can be modelled as a fixed proportion of that for households as a whole. As household size becomes larger, the mean over all households becomes more significant in estimating the vehicles per household for the household size category.

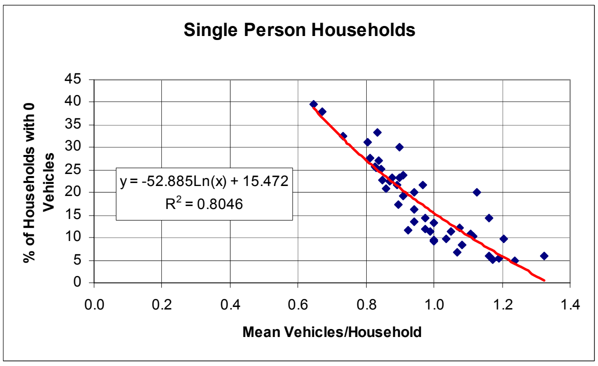


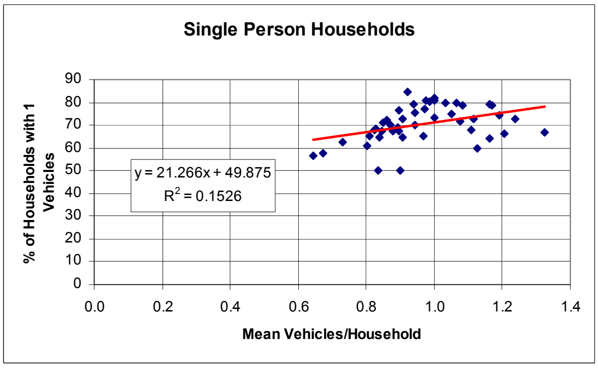


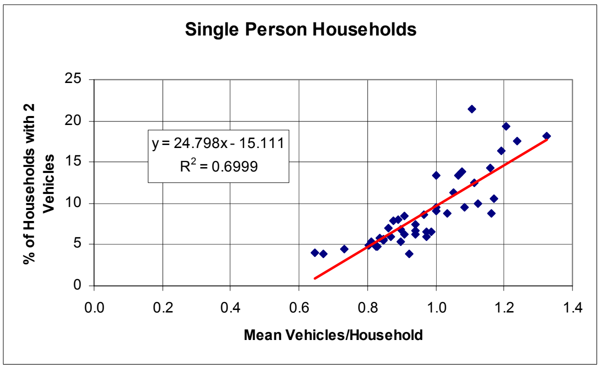


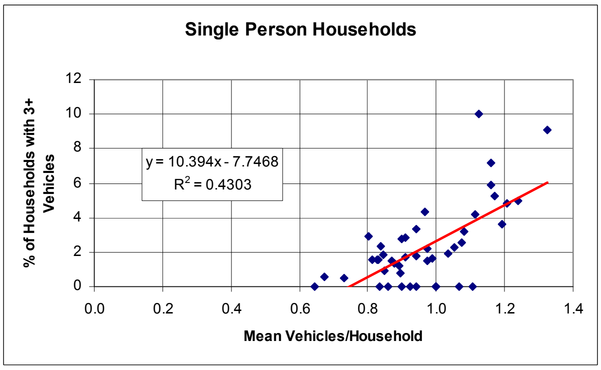
Within each household size category, the distribution of households into 0, 1, 2 and 3+ vehicles per household was plotted against the mean vehicles per household for the household size category, generating a further 16 scatterplots to which linear or logarithmic relationships were fitted as shown below:

Percentages of Households in Vehicle Availability Categories, Single Person Households:

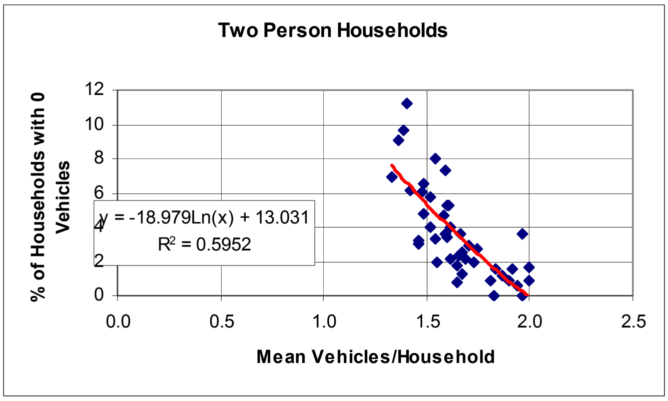


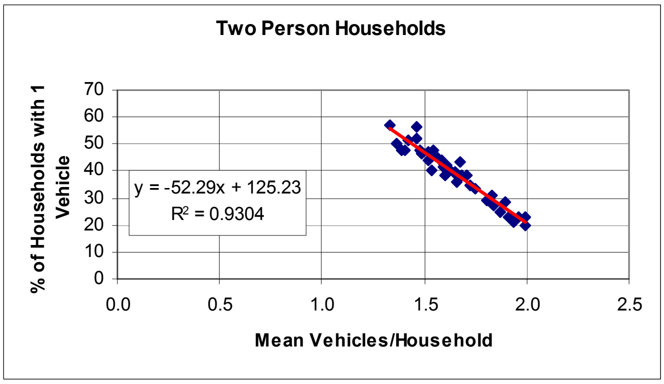


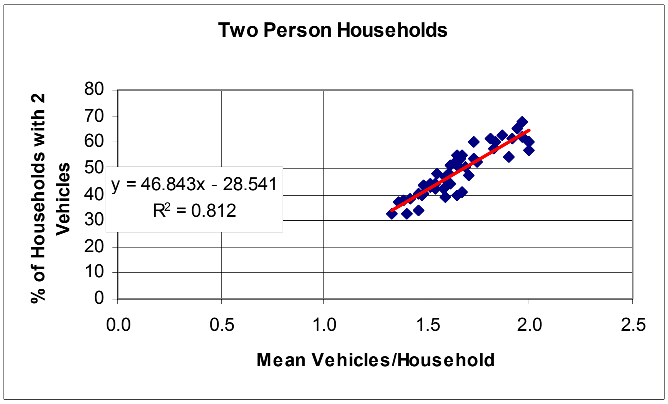


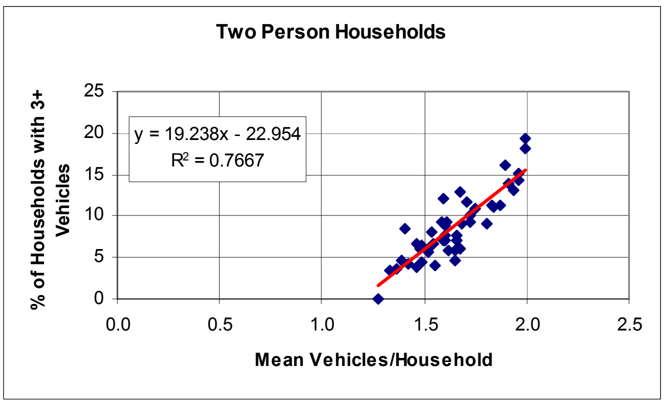


Percentages of Households in Vehicle Availability Categories, Two Person Households:

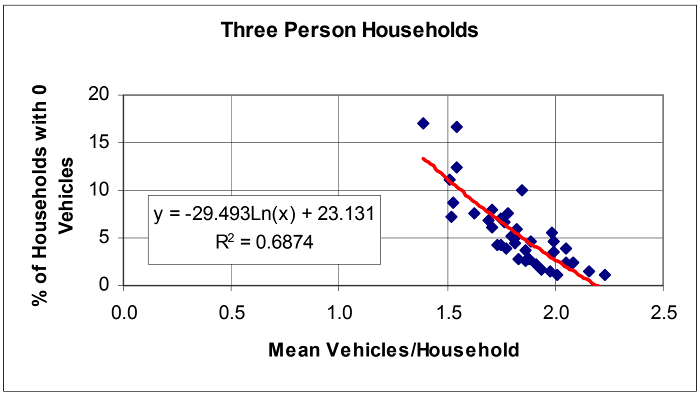


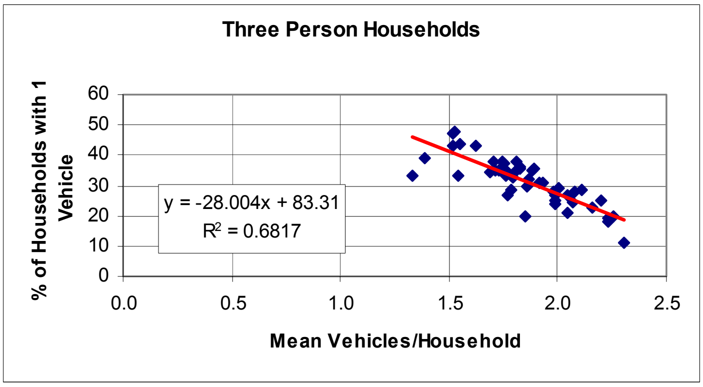


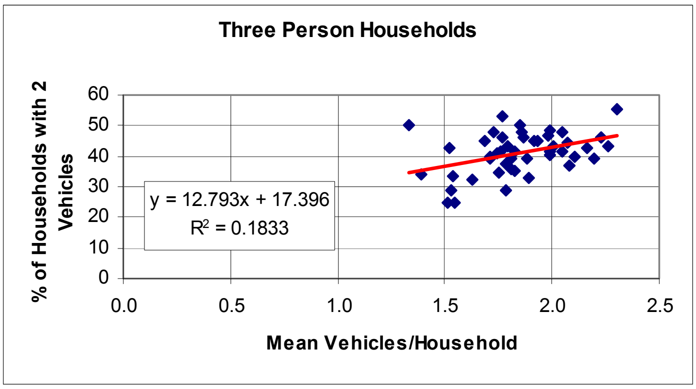


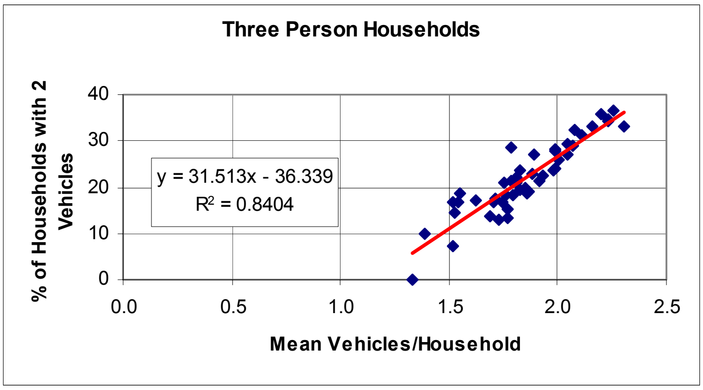


Percentages of Households in Vehicle Availability Categories, Three Person Households:

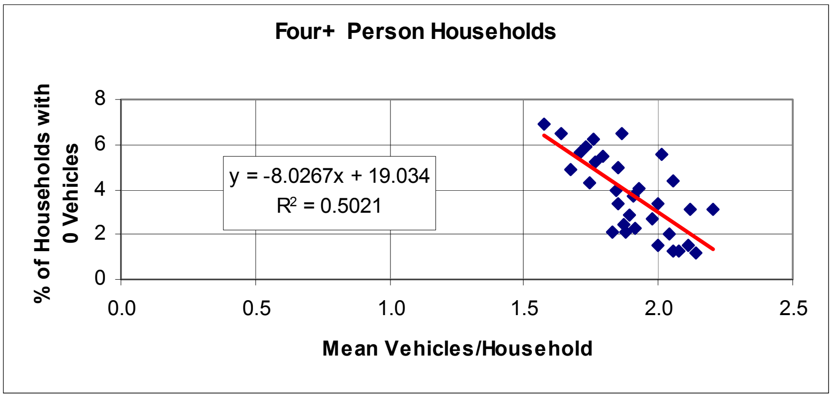


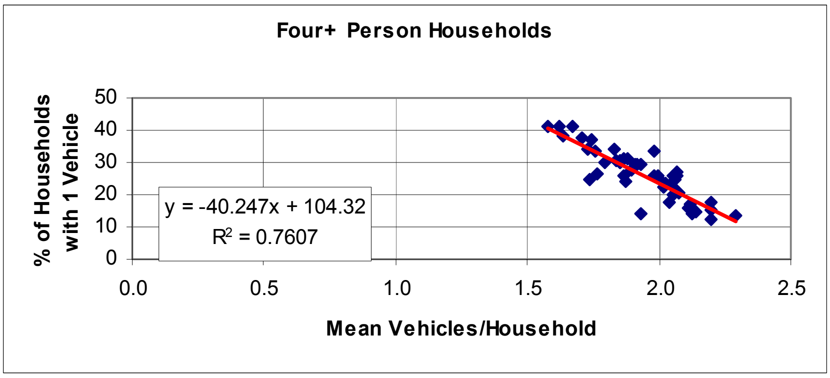


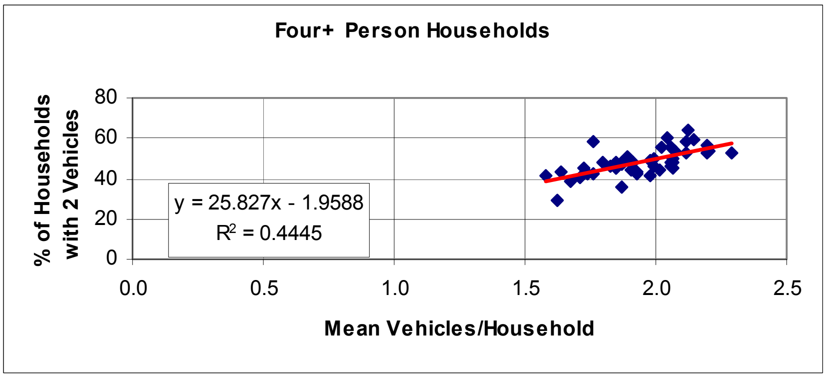


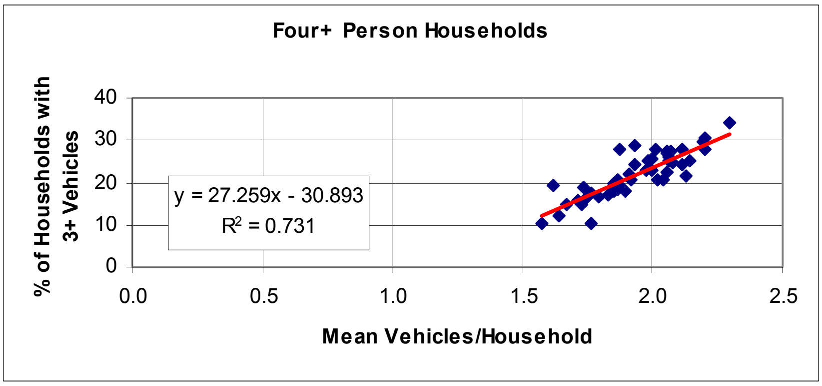


Percentages of Households in Vehicle Availability Categories, Four+ Person Households:









Bearing in mind that there is a good deal of scatter in the data, it would be unwise to rely on a completely synthetic estimate of trip productions based on a distribution of household categories using future year predicted vehicle availability and household size vehicle availability. Also, while the relationships provide a reasonable fit at Area Unit – and Smartgrowth zones are this size or larger – at a finer zoning, individual characteristics of each zone will take on an even larger effect.

A comparison of the synthetic household distribution with the observed household distribution in the base year gave an acceptable fit.

The method adopted is therefore to base the zonal trip productions on the 1996 base distribution of households in each of the 16 categories but to use synthetic distributions to develop growth factors for future years.

The process is as follows:

1. Obtain a factor for general growth in car ownership as the future year national car ownership level divided by the base (1996) year;
2. Apply this factor evenly across all Smartgrowth zones – this makes the assumption that growth in vehicle availability is not significantly influenced by geographic, economic or demographic differences across the region[2];
3. Use the 1996 base year car availability and household size for each zone to produce a synthetic distribution of household to the 16 trip production categories;
4. Apply the growth factor in car ownership to all zonal cars/household for the future year;
5. Derive a synthetic distribution of households for the future year in the 16 trip production categories.
6. For each trip purpose, derive synthetic productions for the base and future year and obtain growth factors;
7. Apply the growth factors to base year trip productions using the actual household distribution to give an estimate of future year trips

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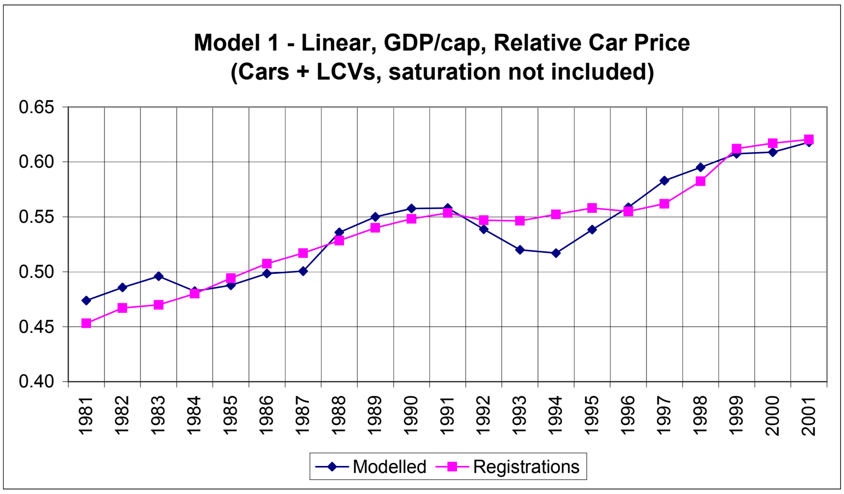
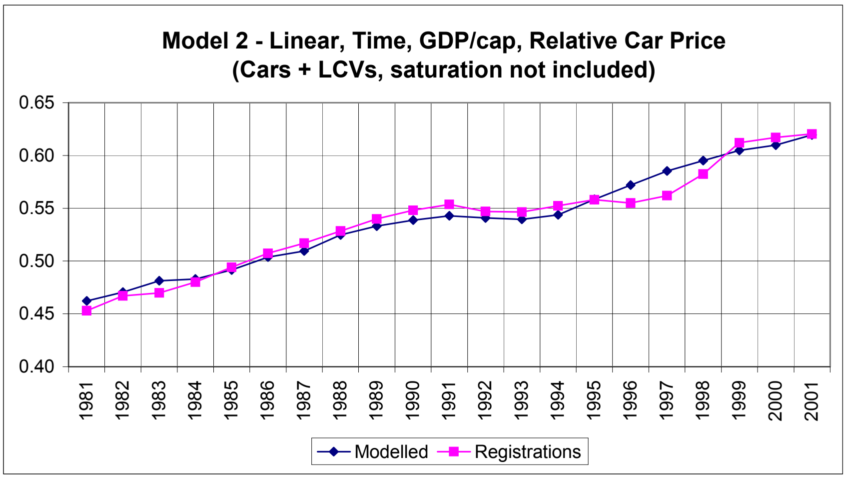
[2] The assumption that vehicle availability can be assumed to grow at the same rate over all zones could potentially be influenced by possible differences between higher density urban zones or zones positioned on transport nodes due to public transport and urban accessibility influences on car ownership

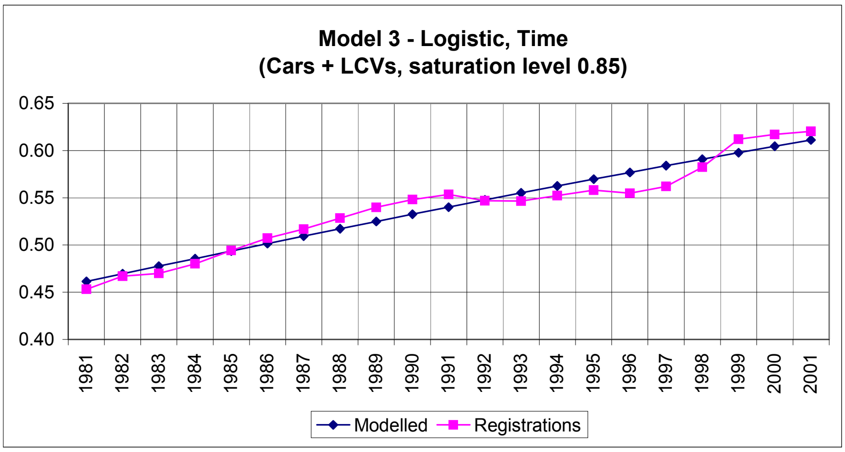
Appendix B – Vehicle Ownership Model

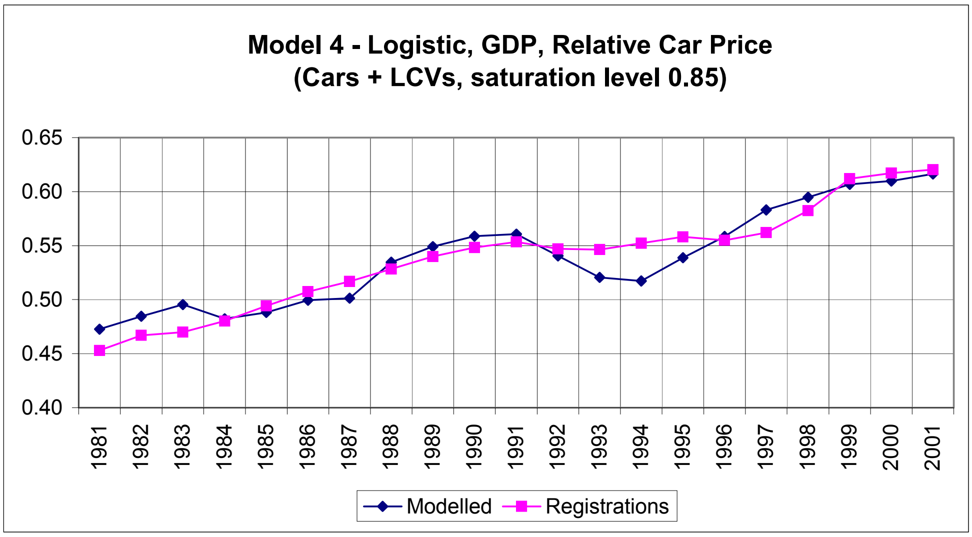
Model Functional Forms and Fit to Historic Data

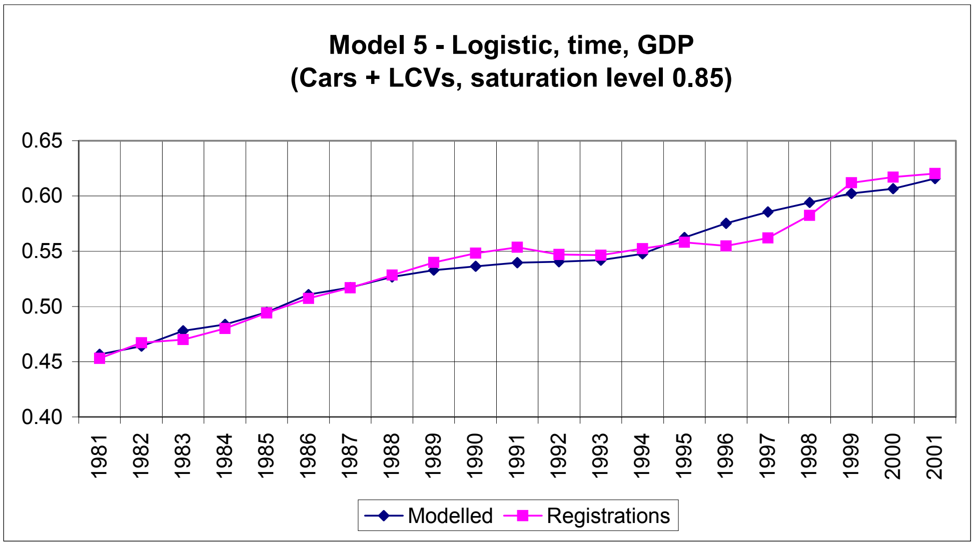
A – Models based on (Cars + Light CVs) per head

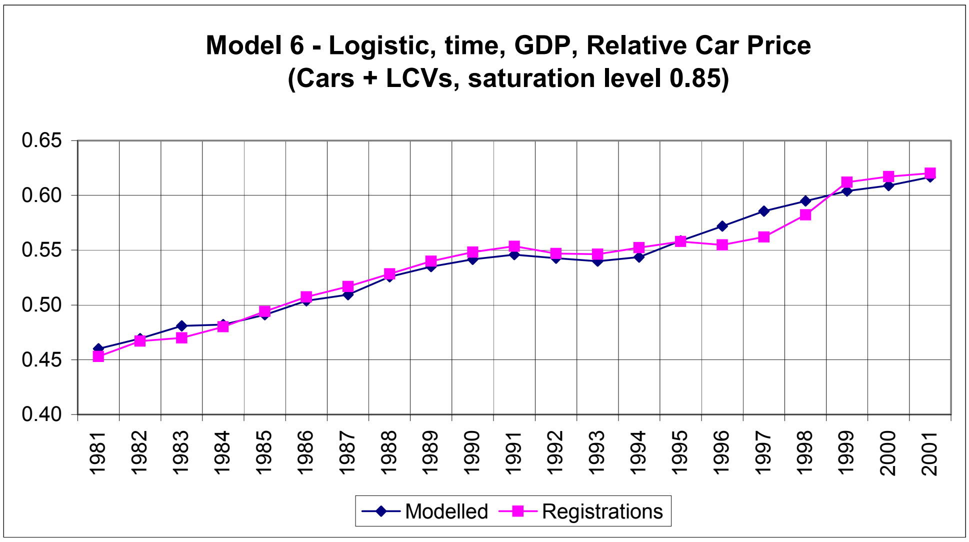




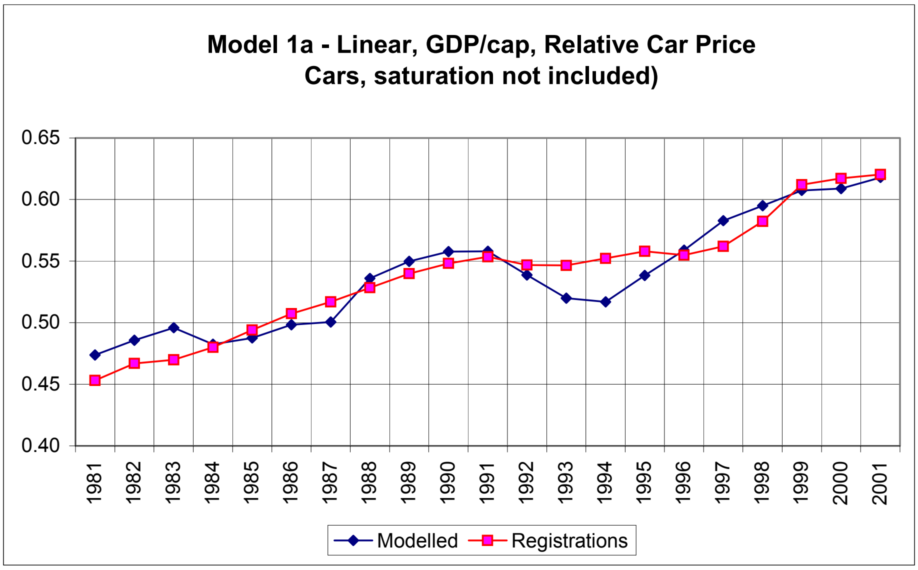


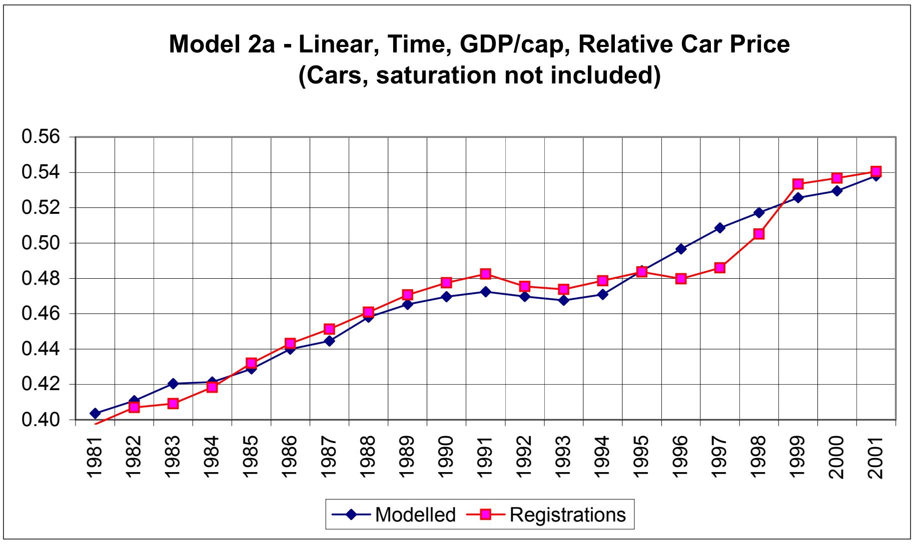

Model 4 - Logistic, GDP, Relative Car Price
(Cars + LCVs, saturation level 0.85)
0.65
0.60
0.55
0.50
0.45
0.40
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Modelled
Registrations

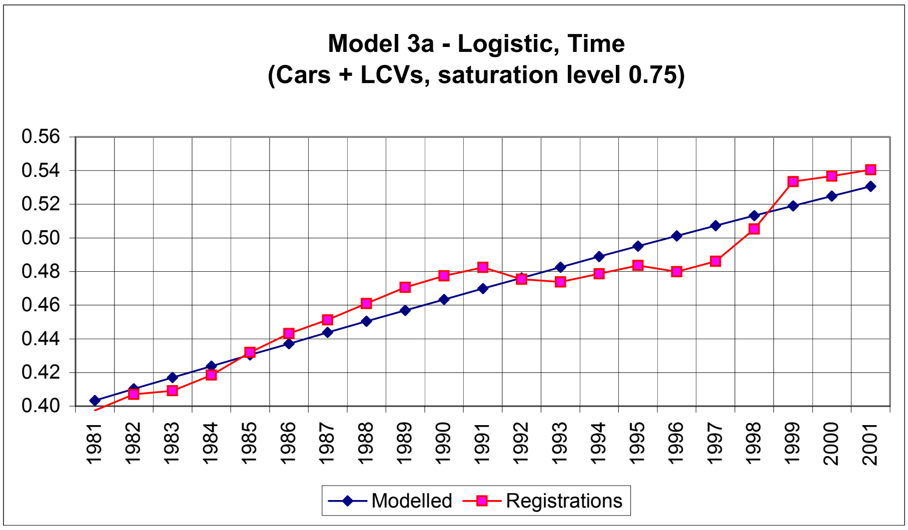

Model 5 - Logistic, time, GDP
(Cars + LCVs, saturation level 0.85)
0.65
0.60
0.55
0.50
0.45
0.40
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Modelled
Registrations

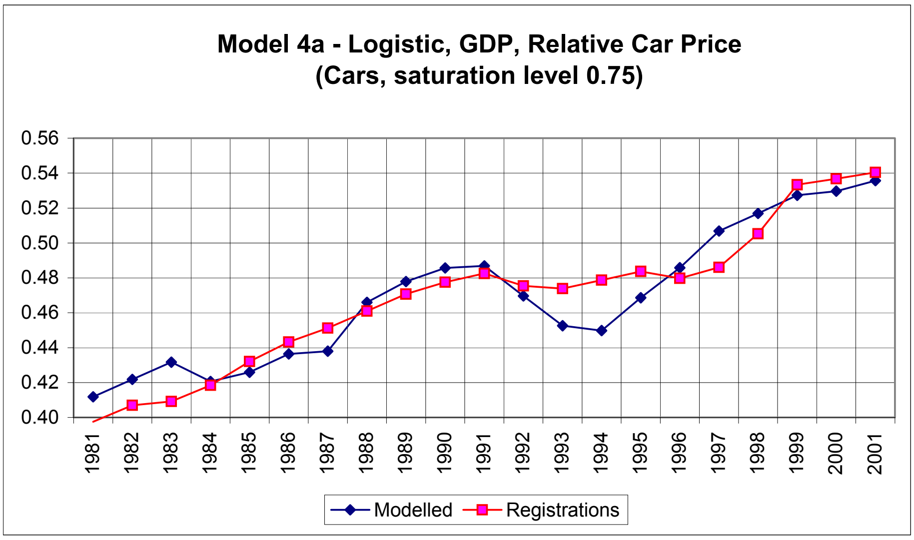

Model 6 - Logistic, time, GDP, Relative Car Price
(Cars + LCVs, saturation level 0.85)
0.65
0.60
0.55
0.50
0.45
0.40
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Modelled
Registrations

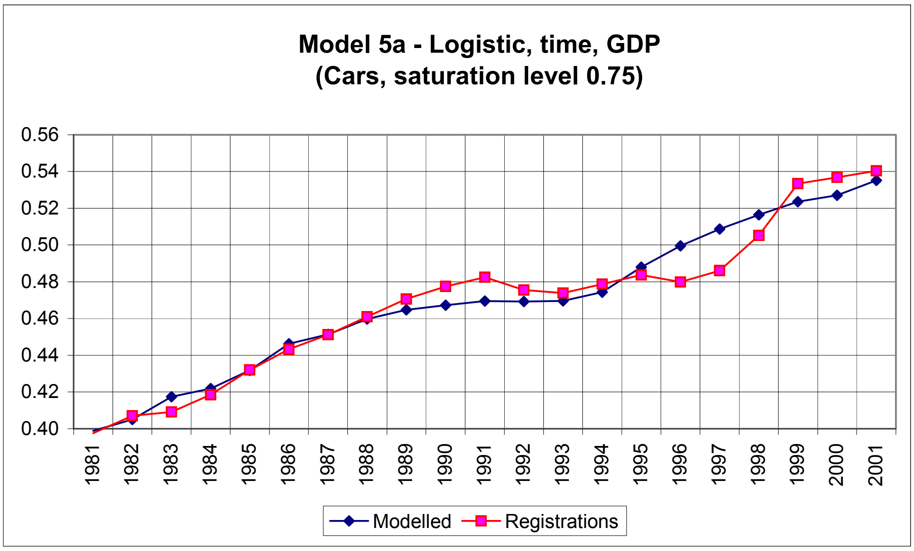
B – Models based on Cars per head

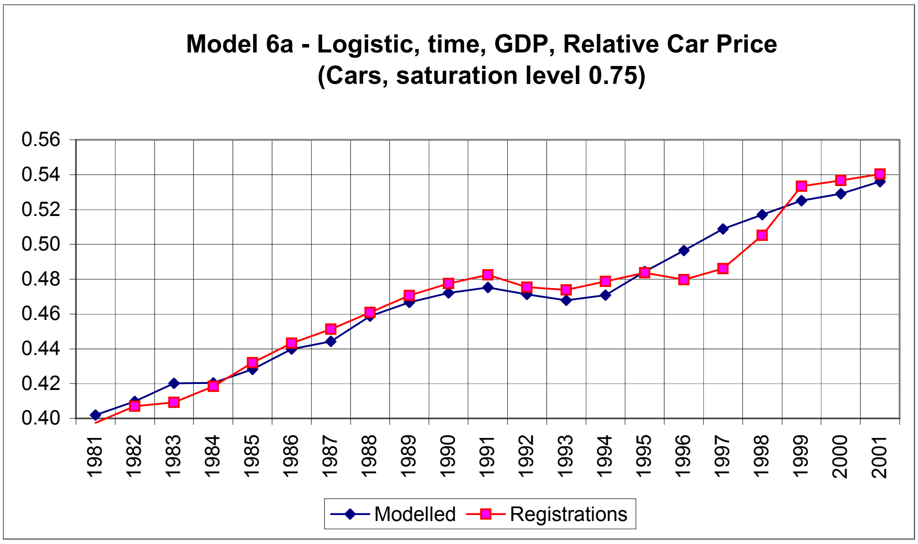







Model 4a - Logistic, GDP, Relative Car Price
(Cars, saturation level 0.75)
0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Modelled
Registrations


Model 5a - Logistic, time, GDP
(Cars, saturation level 0.75)
0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Modelled
Registrations


Model 6a - Logistic, time, GDP, Relative Car Price
(Cars, saturation level 0.75)
0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Modelled
Registrations

Data Series

Year	Car/head	Cars + LCVs/head	Real GDP /Cap	Car Price Index
1981	0.3974	0.4531	19.50	1.577
1982	0.4070	0.4671	19.58	1.488
1983	0.4092	0.4700	20.27	1.509
1984	0.4184	0.4801	20.19	1.610
1985	0.4320	0.4942	20.65	1.636
1986	0.4432	0.5073	21.64	1.697
1987	0.4512	0.5169	21.64	1.679
1988	0.4610	0.5284	22.00	1.438
1989	0.4706	0.5399	22.00	1.322
1990	0.4775	0.5481	21.71	1.212
1991	0.4825	0.5536	21.41	1.163
1992	0.4754	0.5469	20.82	1.235
1993	0.4738	0.5464	20.33	1.317
1994	0.4787	0.5523	20.29	1.337
1995	0.4836	0.5580	21.25	1.304
1996	0.4798	0.5549	22.05	1.254
1997	0.4860	0.5620	22.60	1.137
1998	0.5052	0.5823	22.99	1.095
1999	0.5334	0.6120	23.34	1.046
2000	0.5367	0.6171	23.20	1.011
2001	0.5404	0.6204	23.71	1.013

Real GDP per capita is based on a one year lagged series of March year GDP expressed in 1991/92 constant values

Model Functional Forms and Calibration

Y = (Cars + LCVs)/population

Ya = Cars/population

G = real GDP/capita

CP = relative car price index

T = year (2001 etc)

S = Saturation level of (cars + LCVs)/population

Sa = Saturation level of cars/population

a,d,c,d are coefficients of regression

R^2 = multiple correlation coefficient

Model 1: $Y = a + b.G + c. CP$

Model 2: $Y = a + b.G + c. CP + d.T$

Model 3: $Y = S/\{1 + a. \exp (b .T)\}$

Model 4: $Y = S/\{1 + G^c. CP^c\}$

Model 5: $Y = S/\{1 + a. \exp (b .T). G^c\}$

Model 6: $Y = S/\{1 + a. \exp (b .T). G^c .CP^d\}$

Models 1a to 6a are similar form with Ya and Sa substituted for Y and S

Calibration Parameter Values

Parameter	*Model 1 Linear*	*Model 2 Linear*	*Model 3 Logistic*	*Model 4 Logistic*	*Model 5 Logistic*	*Model 6 Logisitc*
Cars + LCVs:						
Saturation S			0.85	0.85	0.85	0.85
a	0.3080	-10.0090				
Ln(a)			75.8795	4.8708	64.3687	**52.6066**
b	0.0182	0.0088	0.9623		0.9694	**0.9751**
c	-0.1197	-0.0281		-1.8484	-0.9992	**-0.9738**
d		0.0052		0.8661		**0.2511**
R^2	0.9415	0.9799	0.9669	0.9466	0.9773	**0.9805**
Parameter	*Model 1a Linear*	*Model 2a Linear*	*Model 3a Logistic*	*Model 4a Logistic*	*Model 5a Logistic*	*Model 6a Logistic*
Car:						
Saturation Sa			0.75	0.75	0.75	0.75
a	0.2536	-8.0010				
Ln(a)			72.2615	4.9208	59.6699	**47.5046**
b	0.0162	0.0086	0.9641		0.9719	**0.9777**
c	-0.0991	-0.0257		-1.8469	-1.0930	**-1.0667**
d		0.0042		0.8084		**0.2597**
R^2	0.9418	0.9755	0.9585	0.9464	0.9721	**0.9758**