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Forecasting Car Ownership in the Sydney Area

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Abstract

An accurate forecast of car ownership is fundamental to understanding the development of travel patterns in any area. The paper describes the development of car ownership models for the Sydney area.

The models operate at household level, allowing the full detail of the socio-economic characteristics of the household and in particular licence-holding to be taken into account. Relating car ownership to licensed drivers, rather than adults, improves the model because there remains a significant fraction of the population that does not have a licence. In particular, these tend to be women migrants to Australia, indicating that the differential between men's and women's licence-holding is likely to persist as long as migration continues, even though this difference is small among those born in Australia. Licence holding is projected using cohort analysis methods, applied separately for men and for women and for migrants and those born in Australia. The car ownership model itself represents cars held through companies separately from those privately owned. The car ownership alternatives are modelled conditional on the household characteristics and in particular on income. A variable that has been found to be significant in the case of private car ownership is the accessibility improvement given by car ownership at different levels. This variable allows the impact of costs by car and by other modes, such as public transport, to be forecast.

The paper compares the models that have been developed from 1991-1998 and 2004-2008 data, and discusses the shifts in key explanatory variables, e.g. income and age.

1. Background and motivations

The Bureau of Transport Statistics (BTS) of the Australian State of New South Wales (NSW) is required to produce information on current and likely future traffic flows by all travel modes in the greater Sydney area. Within NSW, the large majority of the population lives in the Sydney area and it is here that the majority of transport problems and congestion are also located. To assist in their task in the Sydney area, BTS commissioned Hague Consulting Group (now part of RAND Europe) to design and develop a large-scale forecasting model in the late 1990s (Milthorpe et al., 2000). In 2009 RAND Europe was commissioned to update and improve the model, extending it to include forecasts of car access to rail (park-and-ride etc.) and the prediction of traffic using the numerous toll roads in the area.

The basis for the modelling work is the high-quality Household Travel Survey (HTS) which is collected by BTS and which gives a detailed insight into the travel patterns of households in the area (Milthorpe and Daly, 2010). For the model update, the area covered was extended to include the Illawarra Statistical Division and the Newcastle Statistical Subdivision, bringing in the cities of Newcastle, and Wollongong, and including a total of about 24,000 km^2 of land, i.e. over 15 times the land area of Greater London (although its population is about 70% that of Greater London). The spatial detail in the model was also substantially increased.

The HTS began in July 1997 and is still continuing, though for the present work we use data up to June 2008. It is undertaken in 'waves', which run from July to June, labelled by the year

in which the wave begins; each wave interviews about 3,500 households. A travel diary is given to each household to record the details of all travel undertaken for a nominated 24-hour period; which may be a weekday or a weekend day. An interviewer then interviews each household face-to-face to collect the details of each trip. The details collected include: the mode of travel, trip purpose, start and end location, and time of departure and arrival. Vehicle occupancy, toll roads used and parking are recorded for private vehicle trips and fare type and cost for public transport trips. Additionally, detailed socio-demographic information is collected on the household. This includes dwelling type, household structure and vehicle details, age, gender, employment status, occupation and income of individual household members. Prior to the HTS, three major one-off household travel surveys were conducted in Sydney in 1971, 1981 and 1991/92. Combined with the HTS, these data provided a rich source with a long time series for model development.

The forecasting model, which is integrated with the Emme highway and public transport assignment systems, provides forecasts of travel frequency, mode choice and destination choice. Additionally, forecasts of car ownership are required and a sub-model to perform this task was included in the original system described by Milthorpe et al. (2000). Updating of the car ownership model was an important component of the 2009-10 update of the system and this is the work described by the present paper.

The context of providing input to a large-scale model determines the form of car ownership model that is required. The following section discusses briefly some of the extensive literature on car ownership forecasts and indicates why the specific form of model, which forecasts car ownership conditional on licence holding, was selected. Section 3 discusses the structure of the model that has been adopted and is followed by an analysis of the aggregate cohort modelling of licence holding. Section 5 discusses the results of the disaggregate choice models of licence holding and car ownership. The paper ends with brief conclusions from the work.

2. Car ownership literature

The literature on car ownership modelling is extensive and a detailed review is not possible here. We sketch briefly the key steps in the development of the methodology relevant to our work, then focus on the way in which car ownership models suitable for use in large-scale travel demand forecasting can be developed.

2.1 General overview

Econometric modelling has been applied to the issue of car ownership since at least the work of Tanner in the early 1960s. An overview of the early British work is given by Bridle et al (2004). Using aggregate national data, Tanner applied a logistic curve, in later updates including income, population density and fuel price in his model, along with a trend variable. He assumed a saturation rate of 400, later revised to 450, cars per thousand population. Also in the 1960s, Wootton and Pick published their work using data for London and for the West Midlands, which extended Tanner's work to predict the fractions of households owning no cars, one car and two cars.

In Sydney, a model was developed from the 1971 data by US analysts that can be seen as typical of practice around that date (TDC 1994, 1995). A trend term predicted overall car ownership, without reference to income and assuming an ultimate saturation of 560 cars per thousand people. Zonal corrections were made on the basis of zonal income and accessibility and the overall car ownership rates per zone were then converted to proportions of households owning 0, 1 and 2+ cars.

The application of disaggregate discrete choice methods to car ownership appears to date from the work of Lerman and Ben-Akiva (1975) in the US and Daly and Zachary (1977) and Roberts et al. (1978) in Britain. Using disaggregate incomes, rather than aggregate

estimates (e.g. zonal), greatly improves the quality of the models. The models developed in these studies were also characterised by the use of maximum likelihood estimation, the incorporation of multiple variables representing the accessibility of households, sometimes by multiple modes and an increase in the number of socio-economic variables considered in addition to income.

What can be described as a third generation of car ownership models introduced a dynamic aspect to the analysis. The early models of this type were reviewed by de Jong and Kitamura (1992), who point out the necessity in some cases for undertaking the more complicated modelling of transactions, i.e. household interventions in the car market, rather than holdings, to represent the fact that households do not (or cannot) change their cars instantaneously; therefore the market penetration of new types of vehicle has a finite rate. The effects captured by transactions modelling operate over a 2-4 year period for households and over perhaps a 10-year period for the market as a whole, as older car types are scrapped and replaced by newer types. However, for large-scale regional modelling car types, which are the main focus of these 'short-term dynamic' models, have not yet been a primary topic of interest, whereas longer-term dynamics of generations in the population are more relevant when numbers of cars are considered.

A means of approaching the population dynamics is through the analysis of the behaviour of population cohorts, probably first undertaken by van den Broecke (1988). In the cohort method, individuals are identified by their sex, age cohort, e.g. 'birth quinquennium', as van den Broecke terms it, working with 5-year grouping of age, and possibly other variables such as education. The principle of the method is that certain personal variables, such as sex and birth year, do not change over time and an important long-term dynamic aspect of the modelling can be incorporated by recognising this feature. The originality and value of this approach is not in question, but it has to be recognised that cohort processing is easiest to operate with aggregate data and obtaining the advantages of disaggregate analysis along with cohort processing is difficult. Another issue is how to deal with substantial immigration, as cohort modelling works best with a fixed population.

Other aspects of car ownership which have been included in the extensive literature cover:

- choice of car type, which is too detailed an issue (as yet) to be incorporated in large-scale travel demand modelling; and
- models estimating simultaneously the ownership and use (described only in terms of driving distance) of household cars, which can be done better in large-scale modelling because details of accessibility by all modes are available.

These aspects of the modelling are not of direct interest for the current work, for the reasons indicated above. A comprehensive review of models up to that time is given by de Jong et al. (2004), to which the reader is referred.

2.2 Car ownership for large-scale models

For the reasons discussed in the previous section, car ownership models for use in large-scale travel demand models are best developed using disaggregate methods, can better represent holdings than transactions, generally do not represent car type and can exploit accessibility by all modes of transport. Dynamic effects can be represented through identifying cohorts in the population.

An approach that has been taken in a series of studies is to restrict the cohort effects to the modelling of licence-holding and to model the car ownership of a household conditional on the number of licences held. The attractions of this approach are the following.

- Licence holding appears to be naturally appropriate for modelling by a cohort effect, since it is most often a once-in-a-lifetime decision taken before the individual is 30. The costs of maintaining a licence are small, once it is acquired.

- Car ownership, however, is a decision that can reasonably be reversed.
- The number of licences in a household is a good indicator of the household's need for cars.
- The residual cohort effect in car ownership, once licence-holding has been taken into account, appears small.
- Basing car ownership on licence holding gives a natural and credible time dependence.
- Dependence in licence holding introduces a natural saturation level (i.e. one car per licence), which certainly applies to the number of cars in use at any time, even if ownership can exceed that level.

This approach was first adopted for a regional model in the Netherlands (Geinzer et al., 1981) and it has subsequently been used for the Netherlands National Model, a model of Stockholm (Algers et al., 1996) and the model of Sydney which the current work is updating (Milthorpe et al., 2000).

In these models, the approach is to develop a cohort model to explain aggregate licence holding and a disaggregate model to predict which people will or will not have licences. The approach recognises that there is a small but significant minority of the adult population that do not have licences and that this minority is composed of specific groups: older women (for the next few years), people aged around 20 (a new trend), and migrants, for example. The models are linked by adjusting the overall level in the disaggregate model to match the prediction of the aggregate cohort model. In licence modelling a high saturation level (e.g. around 98%) can be used as there is only a very small minority of people that are not capable of acquiring a licence.

The car ownership models in these studies operate conditional on the disaggregate licence holding of the household. A simpler alternative, used in the UK National Model (NATCOP) is to base car ownership on aggregate licence holding (DfT, 2009) but the aggregate licence approach loses detail. It is possible to constrain car ownership models of this type also to match forecasts from an aggregate model and this is what is done in the Netherlands National Model. However, in the UK, Sydney and Stockholm applications the disaggregate car ownership models are used independently to make the actual forecasts.

It is also possible to introduce an overall saturation level and this can be estimated with the model (Daly, 1999). However, among the models discussed here this is done only in some versions of the UK National Model; the saturation levels in this model range are defined in terms of the fraction of households with at least one level of car ownership being at the next higher level and vary by population segment (DfT, 2009).

Accessibility measures can be derived from the travel demand models to which these car ownership models are linked. In the case of Stockholm, the logsum is derived from a complex model of collaborating household members. However, in the Sydney case, a simpler calculation is used where the logsum is derived from the travel demand models for a typical individual only. Logsums are calculated for the overall accessibility of households in each zone, conditional on car ownership level and using the home-work travel demand model. So accessibility conditional on owning no cars depends on the accessibility by public transport and slow modes, i.e. it is good for central areas but much poorer for outlying areas. Conditional on one car, accessibility increases substantially for household members who have licences, but less so for those who are dependent on lifts. Accessibility with two cars can be still better, as household car competition is reduced, but the increase is less that for the first car. Because overall accessibility is measured, the benefit of car ownership is greater in outlying areas where there may be no means of access to facilities other than by car.

The previous Sydney model predicted total car ownership conditional on the holding of company-owned cars by households. The UK National Model uses the same approach (DfT, 2009). The reason for this approach is that the mechanisms governing company car ownership may be different from those governing household car ownership. It is likely that households choose how many of their own cars they need once they have taken account of what employers provide to them.

The previous Sydney model was thus close to the most advanced practice for car ownership modelling in conjunction with large-scale travel demand models. It was therefore not proposed that the model should be greatly improved in terms of its design and specification, though a number of tests were done to confirm these expectations.

3. Model structure

Because the existing model appeared to work well and that it represented the state of practice for car ownership modelling as seen in the literature, only fairly minor changes were made for the update. Accordingly, the model structure was set up as follows.

- A cohort model predicted licence holding for 16 male and 16 female cohorts, with ages 17-20, 14 five-year groups from 20 to 90 and over 90. This model was extended slightly from the previous version, where the highest age cohort was 85+, and the treatment of young people and of migrants was revised, as described below.
- A discrete choice model was estimated to predict licence holding by the first two adults in the household. This model has four alternatives to cover all possibilities for the first two people:
    - neither has a licence[1],
    - the first person has a licence,
    - the second person has a licence and
    - both have licences.

    This structure was selected because tests in the development of the previous model had shown that the licence holding of the first two adults was correlated. Of course, for single-adult households only the first two alternatives are considered. In multi-adult households, different ways of defining the primary couple were tested, but the definition based on the first two found in the survey was found to work best.
- A discrete choice model was estimated to predict licence holding by any further adults in the household.
- A company car ownership model was estimated, taking account of the number of licensed workers in the household, predicting whether the household would own 0, 1 or 2+ company cars. For example, households without workers, or where no workers had licences, would not be considered to be able to have company cars.
- A household car ownership model was estimated, predicting choice among the alternatives of 0, 1, 2 and 3+ cars, conditional on the number of company cars held

[1] "Holding a licence" is defined as possessing a provisional or full licence, as these two types of licences give individuals independent mobility by car, People with learner licences do not have the same independent mobility, as they cannot drive a car without the supervision of someone with a full licence.

(giving a minimum of total cars) and the number of licence-holders (giving a maximum of total cars)[2].

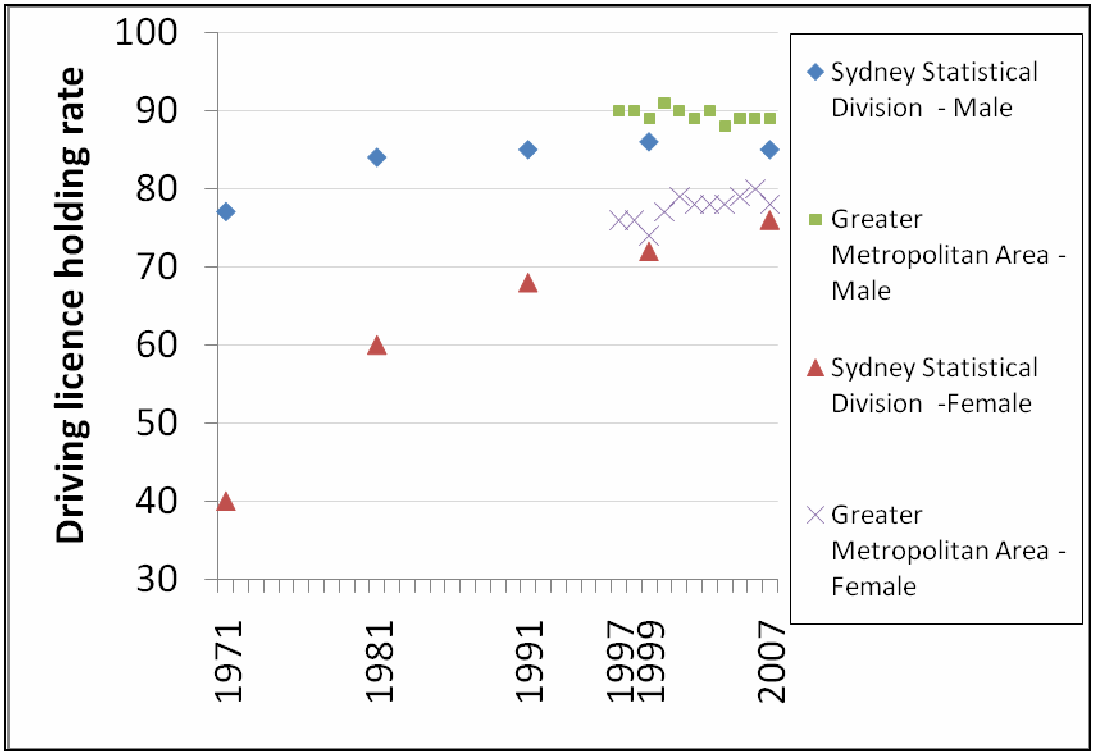
Space in this paper does not permit a detailed description of all these models. A description of the key features will be given and the interested reader can consult the detailed reports soon to be published by BTS.

4. Modelling aggregate licence holding

4.1 Development of licence-holding 1971-2007

Figure 1 shows how licence holding by gender has changed over the last 36 years. The pre-1997 data available to us covers only the Sydney Statistical Division, but not the entire Greater Metropolitan Area; therefore, we present the data as separate series (four series: male and female, for the two area definitions). As shown, licence holding increased substantially in the period 1971-1981 for both men and women, particularly for women (20 percentage points in 10 years). In the period 1981-1991, while the licence holding for men grew by only 1 percentage point, the licence holding rate for women grew by 8 percentage points. In the following period men's licence holding rate stabilised at around 85%-86% in the Sydney area and 88-91% in the Greater Metropolitan Area, while the licence holding for women continued to grow and reached 76% in the Sydney area and 78% in the Greater Metropolitan Area in 2007. Slightly higher rates are expected for the larger area which contains less urbanised development and a more stable population. It is clear that there are still significant differences between the licence holding rates of males and females, motivating the development of separate models.

Figure 1: Driving licence holding rate by gender, 1970-2007 (percent)†

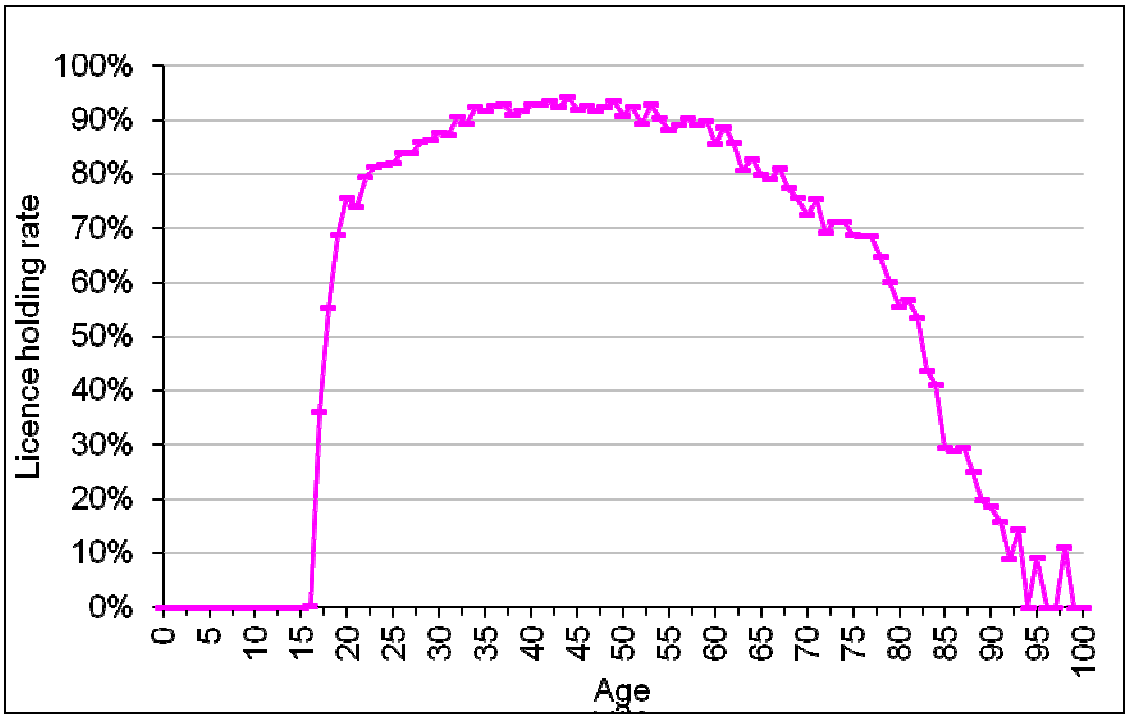


† Footnote: All values in this figure are based on unweighted values from the surveys

[2] The model assumes households must have at least one licence in order to own a car.

Figure 2 shows the different levels of licence holding across age groups (averaged over the years 1999-2007). For young people, acquisition takes place on a large scale. On the other hand, for people of working age, from about 25, the licence holding rates fluctuate only slightly around 90%. Finally, for older people, the licence holding rate declines gradually from around age 60 and more steeply from around age 75.

Figure 2: Licence Holding by Age



4.2 The cohort approach

The basic model is that the licence holding for a cohort is equal to the licence holding of the same cohort in the previous time period, plus the net acquisitions (acquisitions minus losses) that have happened meanwhile. Because acquisitions are much more common than losses, the rate is expressed as a fraction of the number of the adults who did not hold licences in the previous period:

$$P_{c,t} = P_{c,t-1} + A_c\left(S - P_{c,t-1}\right)$$

where $P_{c,t}$ is the licence-holding fraction for cohort c (defined by birth date) at time t, expressed in 5-year steps, i.e. if t refers to 2006, then t–1 refers to 2001;

A_c is the net acquisition rate for cohort c, assumed not to change over time;

S is the saturation level, which is set to be 0.98 on the basis of simple analyses of the data.

For older people, the number of licences lost is greater than the number acquired, so that the change is more appropriately calculated based on the number of people who currently have licences, rather than those who might still acquire them. This gives a model

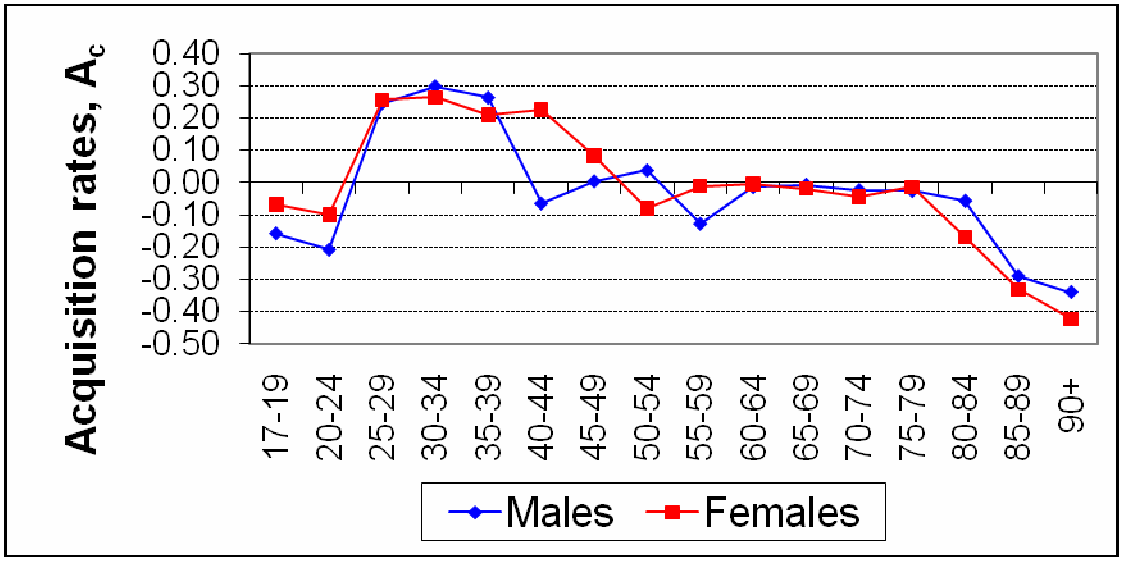
$$P_{c,t} = P_{c,t-1}\left(1 + A_c\right)$$

For these groups, of course, $A_c < 0$

For younger people, in recent years it appears that the rate of licence holding has declined (see also Raimond and Milthorpe, 2010). It does not seem reasonable to predict that these rates will continue to decline so that currently the rate of change is set to zero, i.e. $A_c = 0$.

To apply the model, the acquisition rates A_c are estimated by analysis of the historical data to obtain average acquisition rates over the period for which we have data, giving more weight to more recent information, giving the results shown in Figure 3.

Figure 3: Licence acquisition rates (unsmoothed)



Using these weighted averages gives quite reliable and stable rates of change. Nevertheless, observed acquisition rates for a few of the middle age cohorts are negative. Given the sample sizes the potential error margin in the acquisition rate is not quite enough to explain the fluctuations that are observed but we have anyway applied a smoothing procedure to the male acquisition rates, setting them equal for all the cohorts for ages 25-60. For the female rates, given that they affect the older part of the working-age population, the negative values were retained, but set equal for the cohorts 50-54 and 55-59.

The licence acquisition rates for the older people are expected to be negative and the acquisition rates did not therefore require adjustment.

4.3 Treatment of migrants

An important issue in projecting licence-holding for the Sydney area is the high rate of migration. An initial investigation looked at the countries of origin of the migrants, to determine whether cultural differences could explain some or all of the differences observed. Possibly because of the inadequacy of the volume of data for such detailed analyses, no such differences could be found and it was decided to treat migrants as a single group.

While the HTS tells us that about 36% of the population are migrants from outside Australia, it does not indicate how long people have been in Australia. Therefore, information is required on migration rates. Specifically, for any 5-year period in the forecasting period, we need to know how many new migrants there will be and how these are distributed over the cohorts. We focus on the age groups from 25 to 50, as only 2½% of migrants are over 50, while young permanent migrants up to 25 can be assumed to adapt very quickly to Australian patterns. The migration rates derived from Australian Bureau of Statistics are shown in Table 1 (ABS, 2008).

Table 1: Migration Rates and differences in licence-holding

	Prop. of migrants	Prop. of population	Migration rate per 5 years	Difference in male licence rate	Difference in female licence rate
25-29	15.7%	7.8%	8.0%	0.130	0.227
30-34	11.7%	9.7%	4.8%	0.058	0.132
35-39	8.5%	11.0%	3.1%	0.026	0.102
40-44	6.3%	10.9%	2.3%	0.020	0.097
45-49	2.5%	10.0%	1.0%	–0.011	0.127
Total	44.7%	49.4%	4.0%	0.046	0.137

Table 1 also shows the difference in licence-holding rates between those born in Australia and migrants, showing the substantial differences for women and rather smaller difference for men. The migration rates are applied for all forecast periods for both men and women, as it was found that the proportions of men and women among migrants were very closely equal. For these cohorts, the calculation of licence holding is adjusted by the fraction of migrants in each age group. After migration, the same acquisition rates are applied to the whole population, both migrants and others.

4.4 Applying the cohort model

To demonstrate the operation of the cohort model, licence projections have been calculated for the 2041 forecast year and compared to the 2004-2007 HTS data that represents the 2006 base year. These comparisons are presented in Figure 4 and Figure 5.

Figure 4: Male Licence Holding by Cohort

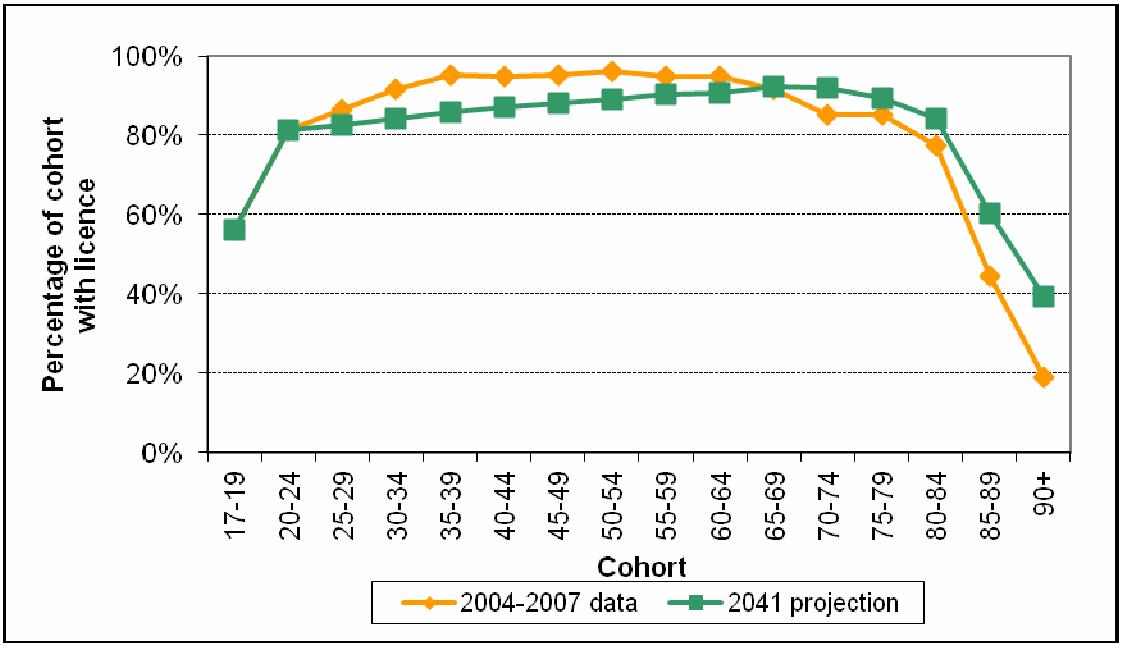
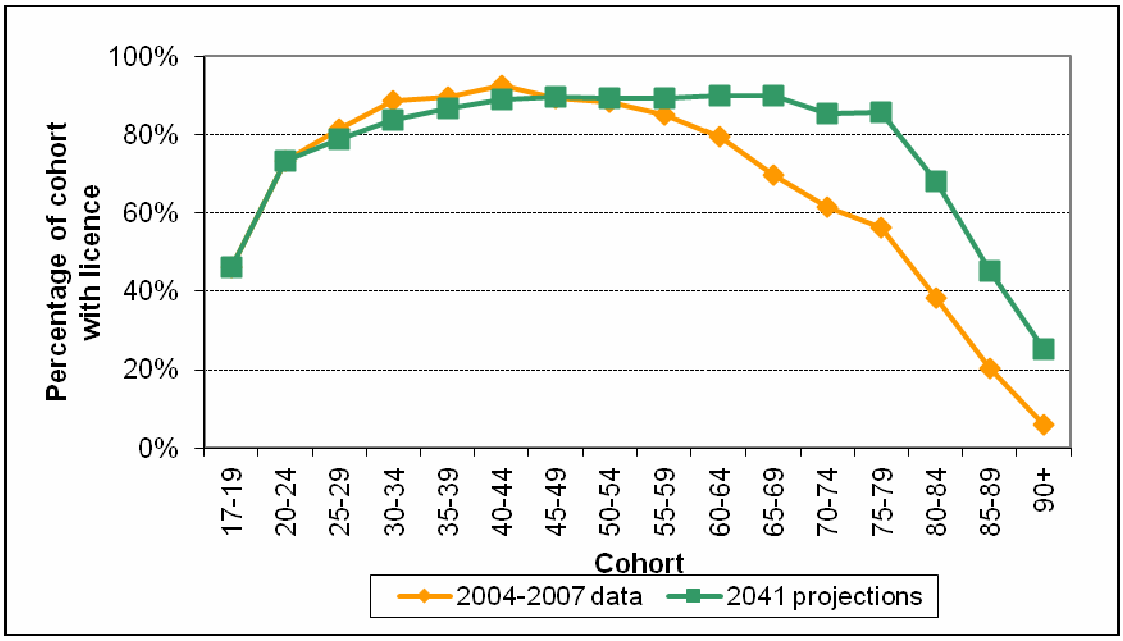


Figure 5: Female Licence Holding by Cohort



Comparing the 2004-2007 data and the 2041 projections for males, we can see that, up to age of 64, licence holding rates are projected to be lower than at present. This is due to a combination of the recent trend for individuals in the early year cohorts to acquire licences more slowly, and also the higher fraction of migrants in the 2041 population combined with the lower licence holding rates of migrants. For persons aged 65+ higher licence holding is projected due to the cohort effect of individuals retaining licences well into retirement.

For females, we also observe the effect of slower licence acquisition in the early cohorts in the 2041 projections, but the differences are not as large as observed for males. For those aged 45 and above female licence holding is projected to be higher than in 2004-2007, and in particular the overall shape of the licence holding curve is much closer to that for males as females maintain high levels of licence holding into old age.

5. Disaggregate modelling

As explained above, four disaggregate choice models were estimated. For licence-holding, models were estimated for the first two adults in the household jointly, then a model was estimated to predict the licence holdings of any further adults in the household. Then, conditional on the predictions of the licence model, a model predicts company car holdings for households with workers (0, 1 or 2+ company cars), and a further model, conditional on company car holdings, predicts the total holdings by the household (0, 1, 2 or 3+ cars, not less than the number of company cars, of course).

Space precludes a detailed presentation of these models; the detailed report of the work will be published shortly. Instead we focus on a number of the key variables affecting car ownership and licence holding and show how these influence the various aspects represented in the models.

5.1 Income

We evaluate how the effect of income has changed, by examining the change in the relevant model parameters. Notably, in the disaggregate licence holding model, the magnitudes of the income parameters have decreased by 33% for the head of household, 57% for the partner and 42% for other adults in household, comparing the 1996-based and the 2006-based

Sydney model. A large part of this decrease can be explained by the difference in price year between the Stage 1 model and the new model, as consumer prices have increased 29% during this time period (OECD, 2009). Additionally, there has been an increase in real incomes, also of 20-30%, between the data collection periods 1991-8 (with most of this data actually being collected in 1991) and 2004-8. Although there is some variation across the models, it seems that the changes in the parameters are due to inflation and real income increase.

In the company car model, the importance of income has decreased by approximately the amount of inflation and real income increase together.

However, in the total car ownership model the magnitude of the income parameter has decreased by only 8%, less than the change in consumer prices over this time period, meaning that income has become a more important differentiating factor in terms of total car ownership. It is not clear what the cause of this change might be.

Table 2: Change in the effect of income, between 1991/8 and 2006

	Disaggregate licence holding	Company car	Total car
Head	-33%		
Partner	-57%		
Other adults	-42%		
1 car		-66%	
2+ car		-68%	
all alternatives			-8%

5.2 The effect of migration

Migrant status variables are introduced into the licence holding models to represent whether the individual was born in Australia. The parameters are estimated to be strongly positive, indicating that the probability of licence holding is higher for those who were born in Australia than those who migrated to Australia. This finding mirrors the results shown in the cohort modelling but these disaggregate models also take account of other variables such as income and family status.

Similarly, in both the company car model and, more strongly, in the household car ownership model, significant parameters are found showing higher car ownership, even conditional on licence holding, for those born in Australia than migrants.

It is difficult to say whether these variables represent different a priori attitudes to cars between migrants and those born in Australia or that people move towards car ownership as they become more settled. However, it is clear that migrants have much less access to car mobility and this will remain a feature of travel in Sydney for the foreseeable future.

5.3 Effects of age

There are some significant changes in the age-related parameters. In the 1996-based licence-holding model, for individuals between 17 and 25, the parameters estimated were negative, meaning that the younger the person was, the less likely that the person possessed a licence. In the 2006-based model, we found that new terms for people aged 17 to 35 needed to be introduced. This means that the probability of licence holding continues to be lower for both the original cohort and the succeeding cohort.

For older people, increasing age continues to imply a reduced probability of licence holding, but the parameters for the decline are slightly weaker than in the previous model. A forecast

of an increasingly aged population will imply a decrease in licence holding, but not so strongly as would be implied by the previous model or by current licence-holding patterns.

Car ownership, both for company cars and household cars, is lower among people under 35 and household car ownership continues to increase after people are 35.

5.4 Accessibility

A further variable that has been found to be significant in the case of private car ownership is accessibility. This is measured by the accessibility of individuals in the household, measured by the commute mode and destination choice model, conditional on car ownership at different levels. Each increase in the number of cars owned by a household increases the car availability and thus improves accessibility for all members of the household (including those who do not have licences); however the improvements are less in areas well served by public transport, which have many attractions within walking distance, or where car use is difficult. This accessibility variable, represented as a logsum term of the commute mode-destination model, allows the car ownership impact of changing car costs, such as the price of fuel, and the accessibility and cost of other modes, such as public transport, to be forecast. This variable is highly significant.

The accessibility variable is not incorporated in the company car model or in the models of licence holding.

Additionally, we have found that total car ownership increases strongly as distance from the Central Business District increases. This variable measures a different effect from accessibility and may relate to the character of the different areas, e.g. areas further from the centre may be longer established or generally better suited for car ownership; certainly there is an increase in trip length, and a decline in public transport use, when residence is further from the CBD (Xu and Milthorpe, 2010). The inclusion of this variable meant that the variable included in the previous model representing the parking cost in the residence zone was no longer significant and was omitted. However, the company car model does include a parking cost variable.

5.5 Variation over time

One objective of the cohort modelling is to explain time-dependent variation in car ownership in terms of the dynamic process of licence holding. For total car ownership, this approach has been successful and no further variations were found. However, for company cars, it was found that there were significant variations not explained by other variables in the model that had to be represented by simple time-dependence. It is believed that these variations may relate to taxation changes.

5.6 Household structure variables

In the licence-holding models, we find a greater tendency to hold licences among those who are employed, whether full-time, part-time or even in other activities such as voluntary work. Of course there are variables expressing the lower licence-holding of women relative to men, but we also find that households that are headed by a married couple have higher licence holding. Those with children also have a greater tendency to have licences. It appears that more settled households in general have higher licence-holding.

In the model of licence-holding for other adults, we find, not unexpectedly, that those living with couples that have licences have a higher probability themselves to have a licence.

Employment is also a strong explanatory variable for car ownership. A household headed by a married couple is also more likely to own cars, as well as to hold licences, but the effect is not strong in this case.

6. Conclusions and further research

The model that has been developed mixes aggregate dynamic modelling of licence holding, using cohorts, and disaggregate cross-sectional choice models to represent the holding of licences and the ownership of cars. This approach, which has also been used in a number of other studies, including the previous model of car ownership in Sydney, appears to work well.

While licence-holding is generally high, not all adults have licences and it is important to a full understanding of mobility to know which groups are most affected by an inability to use cars. We find that migrants, older women and, increasingly, young adults are the groups most affected and these impacts can be modelled through age-sex cohorts, provided the impact of migration is added. Income and employment are also important and these are handled through the choice models.

The incorporation of dynamic effects through the cohort modelling of licences allows time-dependent variables to be omitted from the total car ownership models.

Separate modelling of company cars and total cars allows the special mobility effects of company cars (e.g. on the journey to work) to be modelled subsequently and also gives more insight into the mechanisms driving car ownership.

The key influences on car ownership, conditional on licence holding are income (of course) and employment. Additionally we find very significant accessibility and location effects, together with variables describing the household structure. The choice modelling approach used in this work, together with the size and detail of the data base, mean that a very rich model can be estimated.

Comparing the updated model with the previous version we see a change in the role of income, which is less important now for licence holding but seems more important for car ownership. There are some small shifts in the role of age variables in the model.

In summary, the application of this well-developed methodology gives a rich and soundly based model for predicting licences and car ownership, giving a good basis for the large-scale forecasting of travel demand.

The effect of rising oil prices in recent years merits further investigation. It would be interesting to investigate whether car owners would adapt to higher oil prices by owning fewer cars or shifting to vehicles that run on alternative fuels. Future research which incorporates models of car type choice would be required to understand this.

Another interesting line of further inquiry is the effect of behavioural and attitudinal changes, e.g. towards walking and cycling, environmental protection and climate change, as well as attitudes to health. These are areas for further research.

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