A Dynamic Approach to Investigate Household Car Ownership and Usage

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ABSTRACT

Many features are necessary in a behavioural model of household car ownership and usage patterns. A description is given of the features of conventional equilibrium-based models, followed by a discussion of the most important dynamic issues underlying travel choice. These issues include household travel and activity budgets; state-dependent factors such as information search, cognitive processes, habits, attitudes, and inertia; and the role of the household lifecycle as a choice catalyst. Recent dynamic modelling approaches are described, followed by a description of a system dynamics modelling approach which incorporates the dynamic hypotheses discussed throughout. Finally, a direction of research is laid out, in which the model can be used to simulate household panel data as a basis for hypothesis testing.

INTRODUCTION

A detailed representation of the factors and mechanisms in household decisions to own and use automobiles is necessary in order to understand ways in which households react to transport policies or changing travel environments. For example, one might wish to design policies to reduce fuel consumption or increase the use of public transport in a particular area. In such cases, it is essential to know which types of households will adjust their behaviour, and why their reactions differ from those of other households.

The use of a car comprises several types of decisions, adjusted continuously as a household attempts to coordinate its travel patterns so that each member can participate in their desired activities within the options available. Each member will try to keep the amount of time, cost, and stress undergone in travel within a reasonable limit, but this limit may be influenced by the lifestyle, motivations, and past experiences of the individual. Within these limitations, once acceptable travel patterns are established, car use decisions appear to be largely a matter of habit.

A change in the number of cars owned by a household, on the other hand, is best thought of as a major lifestyle decision, where the purchase or sale of a car enables the members of the household to participate in their current activities more easily, or to participate in additional activities. This decision then, in turn, influences the travel patterns of the household, as each member may adjust their habits and expectations to the new situation and possibilities. This decision feedback, which is the focus of this paper, can be best represented with a dynamic, state-dependent modelling approach.

In the past, for several reasons, most analyses of car ownership and use have used an equilibrium microeconomic framework to model isolated components of the household decision process. Over time, these methods have evolved to include more and more behavioural and structural detail, as described in the following section. Over the same period, a great deal of research has evolved in areas generally overlooked in the equilibrium framework: travel and activity budgets; habit and inertia effects; and the role of the household life-cycle. Research in these areas has, for the most part, lacked a coherent framework which can easily be adapted into general models of travel and car ownership decisions. Accordingly, each of the three areas is discussed separately below.

More recently, dynamic modelling approaches have been evolved in the transport field to address issues such as car ownership and mobility. Many of these studies have arisen from the increasing availability of panel data, which allows one to test a wider range of hypotheses about the behaviour of individuals over time as a function of their past behaviour and changes in their surroundings.

After briefly describing such approaches below, I lay out the proposed structure of an alternative type of model which incorporates the dynamic issues raised throughout the paper. This model, which is based on the system dynamics approach, is essentially a descriptive model. As such, it is a departure from the usual type of model in transport research, which is based on a statistical method whereby a set of hypotheses can be tested using appropriate data. To address this difference, I describe in the final section ways in which the proposed model could be used to simulate panel data, which could then be compared to actual data sets and used to test hypotheses with various statistical methods.

EQUILIBRIUM APPROACHES

Most conventional transport model systems are based on cross-sectional data which include observations on the number of cars and licenses in particular households and/or the number, destination, travel mode, and route used for trips made by each member of the household during a specified period. These observed choices are statistically related to household profile data, general socio-economic data, land use data, and/or network travel conditions, with the aim of producing models that can be used to predict similar choices in other households, and perhaps other periods or locations. Such models are usually compensatory, assuming that individuals will attempt to maximise their expected utility by trading off among the characteristics that make up each choice alternative and will choose the one which has the optimum mix. Generally, no account is given to previous choices made by each individual, as data is only available for a single period.

One of the more representative and advanced examples of such systems is the nested logit model currently used for planning in the Netherlands (Sobel 1980). Given the shortest route available using each possible travel mode to each possible destination zone for a given trip purpose, the individual is assumed to trade off the times and costs across all possibilities. Based on the utility of each mode/destination pair, a logistic model is used to calculate the probability that the person will choose that particular pair. Then, the utilities across all possible pairs are weighted by the choice probabilities to give a general measure of accessibility for the individual. This measure is then used, along with various household and personal characteristics, to predict the frequency with which the individual will travel for the purpose in question.

It has often been noted that car availability within the household must be represented adequately in such models if they are to give reasonable forecasts in response to policies which affect car use (Bailey 1984). In the system described above, the number of cars and licenses in the household are predicted mainly as a function of income and household makeup, but are also influenced by the differences in the measured "accessibility" that would be present at various levels of car ownership, in the following manner.

An additional car in the household may increase the utility of the driver and passenger modes to each destination for each member of the household. This, in turn, increases the measure of "accessibility" for each member. These changes in "accessibility" are then added across household members for alternative car ownership levels, and input to the car ownership model. Thus, if the household is in a situation where an additional car will allow some or all of its members to reach attractive destinations or avoid greatly inferior alternative modes, the household will be treated as more likely to make this addition. The predicted car ownership is then used in the lower level choice models. In particular, the car driver mode is not possible if the household has no car or the person has no license. If this is not the case, competition within the household is represented by increasing the utility of driver versus other modes as a function of the number of cars per licensed driver.

In the preceding example, the feedback between car ownership, availability, and use has been incorporated into a quite rigid statistical framework. As a consequence, the actual feedback and adjustment mechanisms cannot be treated in much detail. So, while one might infer from such models which population segments seem to be most sensitive to certain choice factors, one cannot infer why this sensitivity might be present. In addition, since the models are based on data from a single time period, one cannot be certain if these sensitivities are completely due to mechanisms of individual behaviour, or if they arise partly out of correlations which happened to exist at the time of the survey. Concerns such as these have led to further investigations into the choice processes underlying travel behaviour, several of which are discussed in the following sections.

TRAVEL AND ACTIVITY BUDGETS

In the equilibrium economics of consumer behaviour, people are assumed to operate under given budget constraints, and to choose the mix of goods and services which will maximise their utility across the possible consequences of their set of choices (Deaton and Meullbauer 1980). Travel behaviour has often been seen in this light, with people operating under rigid time and cost budgets. Supporting evidence is given by the fact that people in several parts of the world are observed to spend quite similar amounts of time travelling each day. There remains, however, a question as to whether these aggregate patterns typify individual behaviour, and thus should be viewed as fixed constraints on choice (Gunn 1981).

In alternative economic paradigms, budgeting decisions are often seen in a different light. In one example (Earl 1984), a person is seen to budget as much time or money to a set of related activities as is required to meet their goals and aspirations while avoiding extreme risk. Thus, if the "cost" of an activity changes, people may not always change their consumption of that activity, but may remain satisfied with their present consumption and instead budget more or less to meet lower priority goals.

This type of behaviour can be seen in models which relate travel directly to the activities which it enables. Activity models may be based on direct observation of household trip patterns (Recker, et.al. 1983), or on households' stated travel patterns in hypothetical situations (Clarke 1984). In such models, the ability to reliably carry out the desired household activity patterns serves, effectively, as the constraint. If the time or cost of travel changes, but the desired activity pattern can still be carried out without infringing on higher priority activities (i.e. spending time with the rest of the household), then there will be little motivation to search for other alternatives. On the other hand, if the "cost" increases enough to inhibit the desired activities, or decreases enough to allow additional activities, it may become worthwhile to search out alternative activity patterns.

The purchase of a car is a qualitatively different decision than those involved in daily travel, but is subject to similar budgeting arguments. Mogridge (1983) found that the annual fixed costs of owning a car were inversely related to the amount people spent on operating the car, indicating a fairly stable total budget. A car, however, can be purchased to meet goals other than mobility, such as social status, investment value, or (to some) the sheer pleasure of driving. If mobility is of higher priority than these other aspirations, then people may buy less expensive cars or replace their current vehicles less often to save on fixed costs in times when operating costs are high, without compromising mobility. In the remaining discussion, cars are treated only in terms of their mobility value.

Given that car purchase and daily travel expectations involve such different budgeting decisions, but both, at least in part, with the goal of giving adequate mobility, their interrelationships do not fit easily into most analytic frameworks. For an additional car to seem necessary, households must perceive a benefit in terms of the additional activities they could undertake if the car were available. Attempts have been made to incorporate this tradeoff explicitly into equilibrium-based models (Burns, et.al. 1976).

Clearly, budget constraints are important in car ownership decisions, as some households cannot purchase a car, even when the need is perceived clearly. In other cases, however, there may be additional factors which affect peoples' perceptions of the desirability of changing their car ownership or travel patterns. These are discussed below.

HABIT AND INERTIA EFFECTS

It has been found that the most accurate way to predict a person's choice of travel mode in the future is often to observe which mode they are using today. When a person persists in making a certain choice, even after it becomes clearly inferior from an economic standpoint, the economist is left to look for explanations. Indeed, much attention in equilibrium economics has been given to ways of incorporating uncertainty, learning, and inertial and habitual behaviour into classical choice models (Deaton and Meullbauer 1980). In transport modelling, there has been a great deal of effort to find evidence of these effects, and to hypothesise their influence on travel patterns.

One of the most important issues is one of imperfect information, or bounded rationality. People may not recognise that they are making economically irrational choices if they do not know about the other alternatives. Since searching for such information is a cost in itself, and can force one to delve into an unfamiliar world, dissatisfaction with the current choice may have to become very high to warrant a search for alternatives. For example, people might endure long peak hour traffic jams before they will take it upon themselves to learn the intricacies and risk the experience of a quicker public transport system. They may not even be aware that the alternative mode is quicker.

Compounding this effect are psychological processes such as cognitive dissonance (Golob, et.al. 1979). This is the self-reassurance that one is making the right decision by subconsciously blocking out any inferiorities in one's choices. For example, if the drivers above had heard that the public transport system was quicker, they might "automatically" underestimate the amount of time they would save by using it.

A second issue involves the decision rule people use in certain contexts. For very regular decisions, such as daily travel, people may conform most to the "cybernetic" decision maker (Steinbrunner 1974), who evolves a decision pattern, monitors the outcomes of that pattern, and does not adjust the pattern unless the outcomes become noticably out of line with expectations. The longer such a pattern is continued satisfactorily, the less likely one is to learn about new alternative possibilities. If, for instance, the public transport system was improved, our drivers above may not be quick to learn about it unless a much further decline in traffic conditions causes them to look for alternatives.

Ways of incorporating these issues in conventional utility models have been hypothesised. Goodwin (1977) showed the implications of using a "habit" term for the disutility of shifting from current behaviour. Thus, an identical shift in conditions may show differing effects across individuals depending on their past conditions and behaviour. Incorporation of the information diffusion dynamics mentioned above (Lerman and Manski 1982) would magnify this state-dependence further, making the habit effect even stronger when changes only affect the utilities of alternatives not currently used. In the same line, a model based on non-compensatory behaviour rather than tradeoffs would suggest even further state-dependence, as any shift in behaviour would depend somewhat on each household's order of priority for travel characteristics, which could shift in turn as new travel patterns evolve.

Car ownership decisions may be influenced by habitual travel behaviour, but cannot be thought of as such in themselves. The perceived need for an additional car could well build up as a household searches for alternatives to bring their mobility to a satisfactory level. In such a case, the term "inertia" is often applied. The decision to buy (or sell) a car may require large changes in household budgets and priorities, and may require a search for information about cars on the market, financing arrangements, and, for a first car, about the availability of uncongested routes and parking. All else equal, it appears that these types of inertia will be less for households which already have car-owning experience. This implies a positive feedback cycle for the level of car ownership within a household- one which is constrained a great deal by external factors.

An "inertia" disutility term in car ownership utility models has been hypothesised (Goodwin and Mogridge 1981), with similar implications as for the "habit" term described above. In many ways, such a treatment is analogous to that of "transaction" costs in standard market models. A more detailed treatment of the underlying household travel patterns and perceptions, incorporating dynamic feedback relationships may go further in explaining behaviour over time.

Although the discussion above has focussed on the time and cost of travel, there may be many other factors which influence travel choice. The general term "attitudes" is often used to describe peoples' perceptions and beliefs about the more qualitative aspects of travel, such as comfort, convenience, safety, social acceptability, etc. Such subjective attributes are yet more succeptable to perception biases such as cognitive dissonance. With this in mind, much research has been done into the direction of causality between attitudes toward travel alternatives and the choice between those alternatives. Though results have varied, the relationship has often been found to be one of mutual causality, or positive feedback (Tischer and Phillips 1979). If such is the case, and if qualitative perceptions are of great importance in travel behaviour, then one wonders what might cause changes in attitudes and motivations to occur outside of this feedback loop. Major changes in household circumstances may be one such cause, as described below.

THE ROLE OF THE HOUSEHOLD LIFECYCLE

The household lifecycle can be thought of as a time frame in which the dynamic processes of travel behaviour unfold. The concept of "lifecycle" involves categorising household states according to the number of adults and their age and employment status, and to the number of very young and not-so-young children. Many of the priorities, motivations, and activities of the household will change as it moves from one category to another. Accordingly, many recent dynamic and activity-based modelling approaches have taken advantage of this concept as a way of grouping behaviourally similar households, generally using about ten distinct lifecycle groups.

Much of the recent research at the Transport Studies Unit has involved indepth household interviews to probe for the reasons behind changing travel patterns and car ownership (Goodwin, Dix, and Layzell 1985). The occurance of "life shocks", or discontinuous changes in household characteristics, have shown particular importance. Such events might be marriage, divorce, birth of a child, a change in income or the number of workers, or a change in workplace or residence location. Such an event often disrupts habitual patterns and perceptions, and necessitates the search for information about new circumstances- helping to overcome inertia. Household goals and priorities may also be changed or clarified in response to the event.

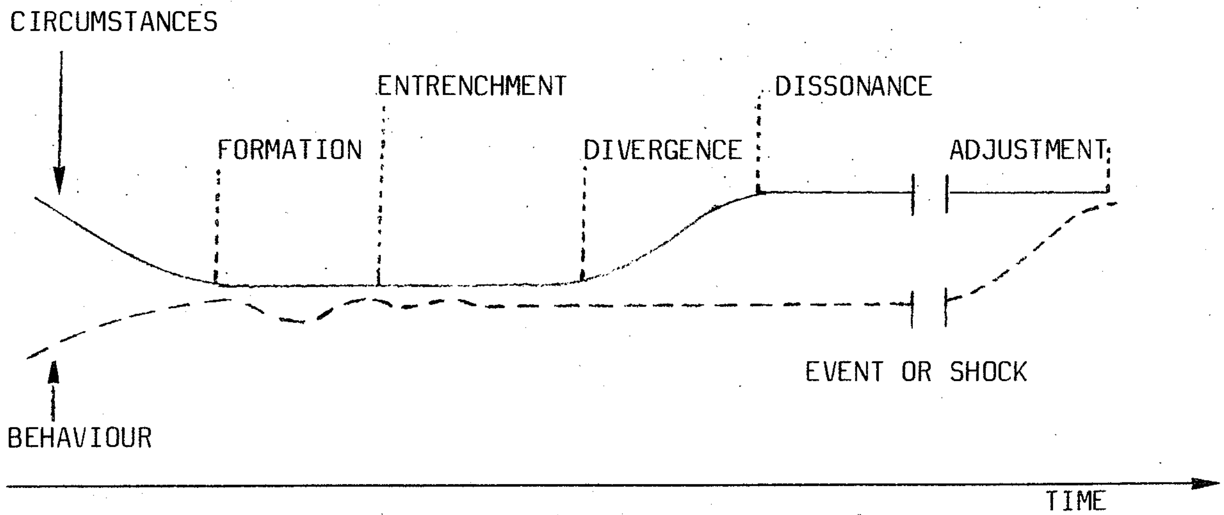


Figure 1- REPRESENTATION OF PHASES OF HABIT
(from Goodwin, Dix, and Layzell 1985)

The various phases of habitual travel behaviour can be seen in the lifecycle framework, as shown in Figure 1. During the habit formation stage, a household or individual adjusts to circumstances by gaining experience with certain alternatives within a limited range until a pattern which satisfies the priorities of the members is set. In this phase, the representation of the individual as trading off characteristics of similar options may be accurate.

In the entrenchment phase, the pattern grows to be the norm. Here, the model of the cybernetic decision maker is most applicable. If, during this phase, external circumstances, and thus the "optimal" behaviour, begin to diverge from the habitual patterns, there are several possibilities. If the change in circumstances is great enough to cause immediate dissatisfaction, the household may begin to search for alternatives. In the case depicted above, however, there is a dissonance-type response, as the household attempts, consciously or unconsciously, to rationalise the continued habitual behaviour. Information delays, budget constraints, or inertia might lead to this type of response rather than to immediate action.

Finally, a major event, or life-shock, prompts the household to adjust behaviour patterns toward current circumstances, for possible reasons listed above. In support of this interpretation, changes in car ownership often appear to accompany such events. On purely economic grounds, however, these changes may be just as rational in the period before the shock as afterwards: it is perceptions, priorities or constraints which have changed. After the adjustment, the next likely phase is "habit formation", as the household develops new travel patterns with new constraints and information.

RECENT DYNAMIC MODELLING APPROACHES

A model which could identify the relative and combined influences of each of the dynamic processes described above from observed data would be quite spectacular. Yet, the interest and possibilities in dynamic statistical models of travel behaviour have increased with the availability of panel data-multiple observations of the same households over time. Two very recent and relevant approaches are discussed here.

One major study into car purchase and usage in Australia (Hensher and Wrigley 1985) is based on the nested logit modelling approach mentioned earlier. Here, the models cascade not only through a decision hierarchy, but also through time. This means that the characteristics and past choices of each individual are taken account of, both in estimating and applying the models. The models can be used to predict the number and type of cars owned, and the total car travel distance by separate household lifecycle groups over time. In this and other panel studies, a key factor is the periodicity of data collection relative to those of the dynamic processes being modelled.

A panel to study more general and continuous changes in mobility is being carried out in the Netherlands (Golob, et.al. 1985). This study uses statistical techniques such as factor analysis to define measures of household mobility, and discriminant analysis to group households according to these measures. Then, using techniques such as linear structural relations models or cross-lagged regression, changes in mobility can be related to past behaviour, as well as to changes in household or external circumstances. Mobility, in this case, is measured by the distance and frequency of travel for various purposes using various modes, and the perceived costs to the household of maintaining this level of travel.

Both of these studies represent advances in the treatment of dynamic behaviour in a statistical framework. A useful complement is a model which does not begin from the data and attempt to discern dynamic processes, but, conversely, provides a flexible framework for simulating desired combinations of these processes and studying the types of behaviour patterns which arise. Such a model and its possible uses are described in the final sections.

A PROPOSED MODELLING APPROACH

In the past, two major transport studies have used the system dynamics methodology for simulating interrelated feedback processes. One (Adler et.al. 1980a) studied the effects of fuel price on aggregate car purchase and travel behaviour. The other (Adler et.al. 1980b), represented the aggregate feedbacks between the supply and demand for public transport. Although such aggregate models can be built on hypotheses of individual behaviour, none to date have included the explicit representation of household decision processes that is needed in this case.

The framework for this model is formed by simulating the evolution of a single household over time. A number of exogenous variables are specified which define the lifecycle stage of the household, and the general spatial characteristics of residence, employment, and the most important non-work destinations. These variable are listed in Table 1. Changes in these variables are then simulated to form a basis for car-related decisions.

Table 1
PARTIAL LIST OF HOUSEHOLD VARIABLES INCLUDED

EXOGENOUS	ENDOGENOUS
Number of adults, by:	Number of cars owned
- age category	Number of licensed drivers
- employment/income group	Weekly number of trips and related distance, time, and cost, by:
Number of children, by:	- mode (car, public transport, etc)
- age category	- purpose (work, other)
Distance from workplace(s)	Perceptions of the travel variables above
Distance from non-work attractions	
Type and cost of housing	

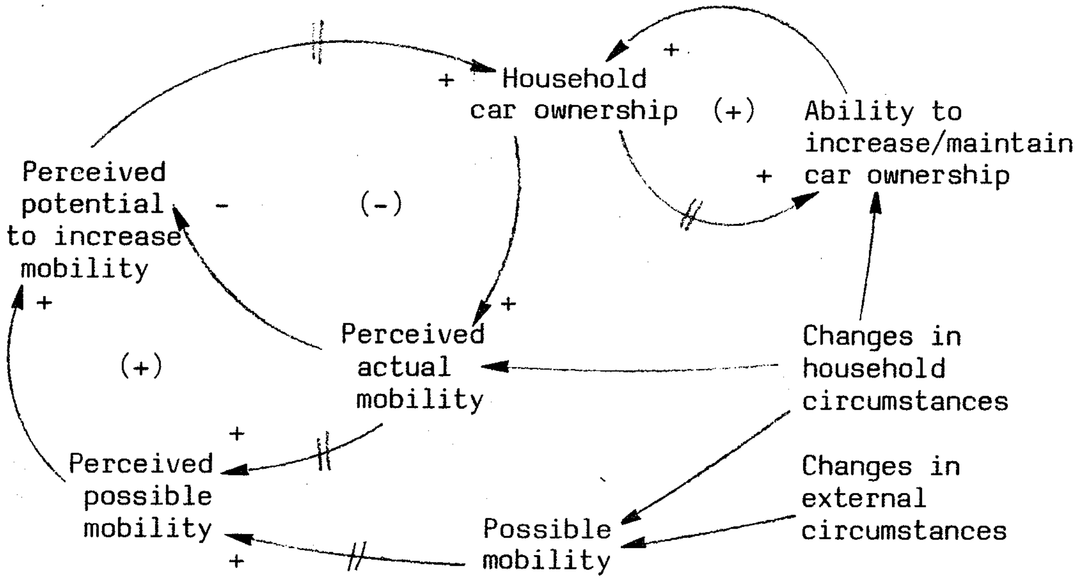
Simulation of the exogenous variables is done using conditional probabilities of the shifts from one state to another (Clarke and Dix 1981), which can be specified from standard demographic data. Aging of the household members is fairly straightforward for the likely simulation period of five to ten years.

There are two related differences between this and standard system dynamics approaches. First, the model will be used to look at behaviour patterns of isolated types of households. Therefore, at the beginning of the simulation, a random assignment will be done based on the probabilities associated with the exogenous factors. As stochastic transitions are used, "different" households can be simulated each time by varying the random numbers used. Alternatively, the evolution of a representative household can be used repeatedly for comparative policy testing.

Because of this single household approach, the transitions are not smoothed by aggregation. As a result, several "events" in the model, such as marriage, birth, or changes in income, location, etc., are treated as instantaneous. This treatment seems essential in view of the "life-shock" hypotheses above. It may also be possible to incorporate feedback between car ownership and the probability of certain household events. For example, a second income or a move to the suburbs might be more likely for households with more cars.

Using the circumstances of the household and the objective attributes of the travel network as an exogenous base, the dynamics of the endogenous variables in Table 1 are represented. Figure 2 depicts the general hypotheses regarding car ownership decisions in causal loop form. These relationships start from the assumption that the car is a superior alternative for increasing mobility. Competition from other modes is shown in Figure 3. In both diagrams, the term "mobility" is used as a shorthand for the satisfaction achieved from activity patterns. This satisfaction may be achieved at work and non-work destinations, or from returning and being at home. Travel is the means of undertaking these activities, and may detract from satisfaction as the time and cost required increases.

Figure 2



The innermost loop of Figure 2 depicts a goal-seeking negative feedback. A greater perceived potential to increase mobility tends to increase household car ownership (the plus sign indicates that both quantities are likely to move in the same direction, with the arrow giving the direction of causality). Higher car ownership then increases actual and perceived mobility, which, in turn, decreases the perceived potential to change mobility, all else equal.

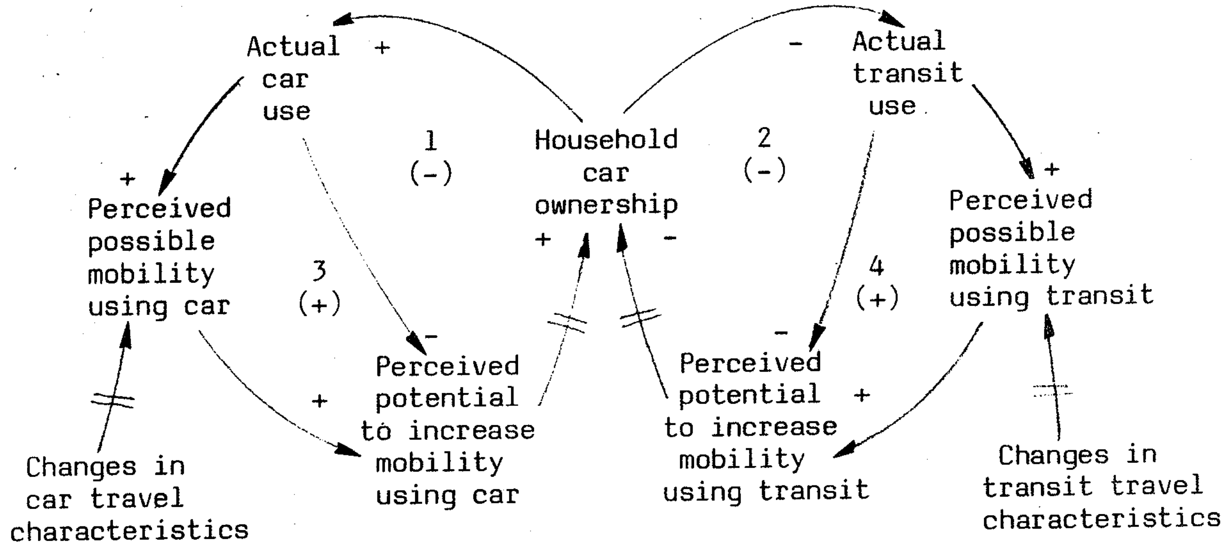
There are several complicating factors represented. The delay between perceiving a potential for greater mobility and actually doing something about it is represented by the crossed arrow in Figure 2. Such a delay will generally be due to inertia or budget constraints, which are both influenced by household circumstances.

There are additional delays which may be important. If, over time, the goal-seeking loop does not operate, due to the constraints mentioned, then the perception of possible mobility may be pulled back into line with the perception of the current state. This is an example of the eroding goal structure, which can represent behavioural processes such as cognitive dissonance (Richmond 1981). The delay indicated between possibilities to increase mobility and the perception of those possibilities also represents habitual behaviour and associated information delays.

The idea of the life-shock is also represented. Changes in external factors such as travel times and costs only affect the possible mobility of the household, while changes in the household itself also affect the ability to perceive and react to these possibilities. Whether or not car ownership changes, the event will have an effect on actual mobility as the household adjusts its habitual patterns.

Finally, there can be a positive feedback between the level of car ownership and the ability to maintain and increase this level, all else equal. The delay represents the build-up of experience in the household which will reduce the inertia involved in car ownership decisions, as hypothesised earlier.

Figure 3



In Figure 2, the car is the only mobility option considered. Figure 3 represents the longer term dynamics of choice between the car and other alternatives such as public transport. For simplicity, household circumstances are assumed to remain fairly stable.

In Figure 3, loops 1 and 2 again show the shorter term dynamics of car ownership adjusting to the potential for increased mobility. There is an imbalance, however, in that the fixed cost nature of cars makes the adjustment of car travel qualitatively different than travel by public transport. Even within the car loop, a sale may be less attractive than a purchase in terms of the recovery of fixed costs. The number of cars is also a factor, as the sale of a first car involves higher risk of immobility than the sale of a second car. These factors tend to make the loops stronger in the positive direction.

In the longer term, loops 3 and 4 show that decisions to increase mobility either through car ownership or public transport use tend to reinforce future decisions in the same direction. If conditions for one option improve, users of that option are more likely to perceive possibilities for increasing mobility than non-users. The feedback is less likely to take hold in the other direction if the current option deteriorates, because of the habit and inertia involved in changing behaviour. If changes are severe enough to trigger such a shift, however, further shifts in that direction become likely. Major household events may also trigger such shifts.

The reinforcing mechanisms just described bring out the importance of decisions made in times of household transition. Within the dynamic framework outlined above, assumptions made about choice rules, information diffusion, perception biases and inertial effects are the vital parameters for such decisions. The model is left flexible in this regard so that different dynamic hypotheses can be easily input to monitor the influence on behaviour patterns of various household types. More detail is provided in the final section.

A RESEARCH AGENDA

With appropriate tests, the model described above can provide a new means of testing dynamic hypotheses of car-related behaviour. First, the standard system dynamics procedure of robustness and sensitivity testing must be applied to ensure reasonable behaviour (Richardson and Pugh 1981). Then, the sensitivity to the various dynamic issues above can be tested, separately and in combination. In review, these issues include:

- Alternative choice rules, such as utility maximisation, priority-based elimination, and cybernetic patterns; and their role in various phases of evolving travel patterns;

- Information and perception delays and biases, and their variation with respect to current and past travel patterns;

- Inertial effects and budgeting constraints, particularly with regard to changing car ownership levels;

- The role of household lifecycle transitions in triggering behavioural changes; and

- Variations in simulated behaviour across different household configurations.

These sensitivity tests can be done by giving an adequate "start up" period for behaviour to reach an equilibrium, and then introducing one or more exogenous shocks or policies. In addition to household events, such inputs could represent changes in travel times, costs, or distances; or possibly economic factors such car prices or interest rates.

Given the range of behaviour considered, some external validation would clearly be useful. One method is to use the model to simulate household panel data which can then be compared to actual panel data sets. The way to carry out the simulation and the statistical methods for comparison will require a great deal of thought, but some of the most important issues are raised below.

The first issue is the grouping of households. Many panel data analyses are based on the household lifecycle concept. In the model, the lifecycle characteristics are mainly exogenous, and transition rates and state probabilities would have to be parameterised to match those of the panel data set.

A second issue is the initial conditions used. Actual surveys cannot be assumed to start from equilibrium, so a different simulation approach must be used. It might be possible to specify initial probabilities for the length of experience with initial travel patterns, car ownership, etc. A more practical approach is to specify exogenous inputs based on historical data for a period five to ten years prior to the survey period. This then corresponds to the start up period for the simulation, with simulated data being recorded only for the actual survey period.

To test the similarity between actual and simulated data, one is mainly interested in changes in behaviour. By comparing behavioural changes among groups of households who undergo similar lifecycle transitions, one can gain confidence in the sensitivity of the model to household circumstances. The same can be done for external circumstances by simulating economic or policy changes which actually took place during the survey period. The statistical methods used could be fairly simple. For example, t-tests could be used to compare the actual versus simulated percentages of various groups who make similar changes in car ownership or travel distances over specific periods. More involved methods such as cross-lagged regression could also be used.

With adequate validation, the model can be used as a tool for looking at the success of various statistical modelling approaches in capturing dynamic feedback processes in travel behaviour. In a method similar to that above, panel data can be simulated using varying assumptions regarding the parameters used in choice rules, perception biases, information on alternatives, survey response errors, etc. Then, a range of estimation techniques can be applied to the data to guage their relative success at reproducing the model parameters. Andersen and others (1984) used a similar approach to evaluate regression models applied in education policy. The range of techniques which could be tested could include cross-section regression or maximum-likelihood techniques to the more recent dynamic approaches described earlier.

Another application, which could also benefit model development, would be to use the simulation framework for interactive gaming. The same framework of exogenous household and external inputs would be used, but with the players deciding when to buy or sell cars or shift their travel patterns and activities. As simulated households expand, teams could split up to represent different household members. Such an approach could give more insight into the effects of household car competition on ownership patterns. Insight into habitual behaviour and information search could be gained by only giving minimal information on alternative options, and then recording which additional information people ask for and when. It would be difficult to incorporate many inertial effects, however, as there is little cost or difficulty in changing behaviour in imaginary situations. The way in which household teams are evaluated could also be important, as it would have on impact on peoples' choice rules.

In summary, several types of research could be based on a descriptive dynamic model of household car travel. The benefits would be in ways of representing and studying existing dynamic hypotheses, and in generating new ones. Further effort could also provide tests or ideas of ways to take account of dynamic processes in statistical travel demand models.

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