TOWARDS THE 5-STAGE LAND USE-TRANSPORT MODEL

Francisco J. MARTINEZ
Assistant Professor
University of Chile
Santiago - Chile

1. INTRODUCTION

The idea of modelling consumers decisions consistently and within a unified framework is theoretically appealing. Much have been done to achieve such a consistent economic model in modern transport planning, as the old 4-stage model have been subsequently replaced by highly sophisticated models which see the decision chain (destination, transport mode and route) as interdependent choices. A good example of a modern transport planning tool is the Santiago model ESTRAUS (see ESTRAUS,1989).

In our view, however, the decision chain has to be completed by two other decisions which are necessarily and mutually dependent on the rest of the chain. The first other decision is mobility (the decision of how many trips of each type would one make), normally estimated by linear trip generation models regressing trips against socioeconomic variables, though Koening (1975) and Dalvi and Martin (1976) found evidence of the relevance of accessibility in trip rates.

In this paper, however, we shall concentrate on the second decision, the location of activities in the space, normally studied as land use models. Although the interaction with transport is recognized in the so called land use-transport interaction models, some of them revised in Webster et. al. (1988), the emphasis there is placed on the development of complex land use sub-models.

Transport planning models on the other hand, normally avoid the need of a land use sub-model representing the activity system, by resorting to Williams and Senior's (1978)[1] interpretation of the double constrained trip distribution model and their location surplus concept. The key issue in their interpretation is the assumption that trip makers are either job or residential seekers, i.e. either the origin or the destination of the trip is fixed, while the other end is the best economic choice for destination or origin respectively. Under such assumption, the observation of trips provides enough information on location advantages and the expected impact of transport facilities on land rents. Nevertheless, as W&S recognize, there is no good evidence to judge which end of the trip is fixed, while, as we shall see, this judgement is crucial for the allocation of location surplus and for the interpretation of land rents and users' benefits. Therefore, an alternative approach is

---

[1] Later abbreviated as W&S.

proposed here which uses a new land use model, called bid-choice, which is able to be fully and consistently integrated with the transport model, e.g. ESTRAUS, and is seen as the first choice of an extended decision chain with five components. Moreover, most of the basic data required is already collected for the transport model or generated by its outputs, hence the extra complexity added to the transport planning tool is likely to be affordable.

The next section outlines the 5-stage consumer decision chain as an integrated equilibrium model. The land use sub-model and the relevant part of the transport model are briefly presented in sections 3 and 4 respectively, followed by a description of their interaction in the integrated model in section 5. Some relevant issues are described on section 6, which also provides some arguments supporting the need for the extension of the transport model up to the fifth stage.

2. OUTLINE OF THE 5-LUT MODEL

The 5-stage Land Use-Transport model (5-LUT) is a master model for urban transport planning and land use. It is composed by two sub-models with a common behavioral framework: the BID-CHOICE model which describes the land market, including location and rents, and a transport planning model like ESTRAUS.

The underpinning rationale of 5-LUT assumes the consumer as taking consistent location and transport decisions in order to achieve its maximum utility/profit. Therefore, consumers locate in space in order to maximise their utility (in the case of households) or profit (in the case of firms), but being aware and, somehow, taking into account the accessibility level of the site. Such accessibility is understood here as access to those complementary activities distributed in the space, i.e. access to (relevant) activities involved in their main utility/production objective for which consumers are definitely willing to pay to enjoy the benefit.

But we also require the model to keep consistency across location and transport decisions. This is obtained by reference to a unique economic framework, hence accessibility measures are defined below as revealing consumers preferences in transport, i.e. they have direct economic meaning. Consequently, the transport mode choice decision and its implicit value of time is, within 5-LUT, necessarily consistent with the consumer location choice. As we shall see, such assumption imposes further interpretation of user benefits and land rents, as well as practical advantages in the evaluation of long term transport schemes.

The structure of the 5-LUT model is shown in Figure 1 as five sub-models mutually dependent through both: the set of state variables (transport costs and accessibility) and through shared inputs/outputs (spatial location of activities, trip generation rates and trip flows).

Each sub-model may represent a disaggregate choice process, as is faced by the consumer, aimed at forecasting his/her set of decisions.

3. THE LAND USE SUB-MODEL

The theory underpinning the BID-CHOICE land use model is the result of an in-depth discussion of the economic mechanism governing the land market (Martínez,1991a,b). It integrates the basic concepts proposed by Alonso (1964), which assumes that the land market behavior follows a bid-auction process, with the popular maximum random utility (choice) model formulated by McFadden (1978) and Anas (1982) among others.

Here, we call 'consumers' all possible competitive buyers of urban land, including different types of households and firms. They are supposed to choose their best location with regards to both: a set of attributes associated with the site and their differentiated valuation.

The consumer unit taking a location decision is the household or the firm (as opposed to the independent individual), which is able to consider tastes and priorities of all members involved and affected by the location choice. The land unit is the land lot, described by a set of relevant attributes chosen according to the cultural environment of the case study. In contrast to other economic goods, we argue that land lots are <u>quasi-unique</u>, due to the fact that space is scarce and not able to be produced by human beings and also because some attributes (like view, accessibility, etc.) cannot be modified by the owner's will.

Now, we assume that the consumer's objective is to maximise the household utility or the firm production function. Following Rosen (1974) one can define the willingness to pay function WP, associated to the utility function, which allow us to formulate the maximum utility model in terms of its equivalent, the maximum consumer surplus (CS) model (see Martínez, 1991a), where CS is given by the difference between WP and the price paid p. Hence, the best choice is a location which maximises the CS (eq.1.1).

As for the land owner, we assume that he/she maximises profit. Under the assumption of quasi-unique land lots that condition is achieved if the owner simply accepts the highest bid. Notice that, in contrast to Alonso's land equilibrium model[2], so far the best bid rule generates the offer function given by eq.1.2.

The market equilibrium is then found by solving the system of equations for the consumers' and owners' behavior. Using the index h for consumers ($h \leq H$) and i for land lots ($i \leq S$), the system is:

---

[2] Martínez (1991a) shows that the difference betweew WP and bids is irrelevant in the bid choice model.

Consumer: $$\text{Max}_{i\varepsilon S} CS_{hi} = \text{Max}_{i\varepsilon S}(WP_{hi} - p_i) \quad (1.1)$$

Owners: $$p_i = \text{Max}_{g\varepsilon H}(WP_{gi}) \quad (1.2)$$

which has the typical format of the market equilibrium problem. The solution of the system is obtained replacing p_i (eq.1.2) in eq.1.1, then:

$$\text{Max}_{i\varepsilon S} CS_{hi} = \text{Max}_{i\varepsilon S}(WP_{hi} - [\text{Max}_{g\varepsilon H}(WP_{gi})]) \quad (2)$$

which represents the urban land equilibrium model.

Note that eq.2 is entirely described by WP functions, i.e. by the consumers' behavior, with land owners playing a rather passive role in the market equilibrium. This property, not normally found in other markets, is a consequence of the quasi-unique characteristic of urban land. A second property, easy to see in eq.2, is: Max CS=0, because if the highest bid (the price), is submitted by a consumer different from h, say g, then $WP_{hi} < WP_{gi}$ and $CS<0$. We can conclude then that the maximum consumer surplus occurs always at a location where the consumer is the best bidder. Therefore, the rules 'best bidder' and 'maximum utility' (or CS) are indeed equivalent.

A practical consequence of this equivalence is that one can formulate an empirical model following either the best bidder rule (bid version) or the consumer surplus rule (choice version). Note, however, that both versions represent the market equilibrium, though they have been identified separately as an offer function (eq.1.2) and a demand function (eq.1.1) respectively. As for the bid version, assume WP function having a stochastic term distributed IID Gumbel across consumers with scale parameter μ. Then, the probability that a given land lot i will receive the highest bid from consumer h is expressed by the following multinomial logit (MNL) model:

$$P_{h/i} = \frac{\exp[\mu \, WP_{hi}]}{\Sigma_{g\varepsilon H} \exp[\mu \, WP_{gi}]} \quad (3)$$

which is the Ellickson's (1981) model. Additionally, in this version the expected market price for land p_i is, by definition, equal to the expected maximum bid from potential buyers, which is given by:

$$p_i = (1/\mu) \ln \{\Sigma_{g\varepsilon H} \exp[\mu \, WP_{gi}]\} \quad (4)$$ [3]

As for the choice version, we assume the same distribution for the WP stochastic term, but across land lots instead of across consumers, and the probability that a given consumer h will choose the lot i is

---

[3] A bid version of the bid-choice model for the case of Santiago City is reported in Martínez (1991c).

estimated using the following MNL model:

$$P_{i/h} = \frac{\exp[\mu\ (WP_{hi} - p_i)]}{\Sigma_{j\varepsilon S}\exp[\mu\ (WP_{hj} - p_j)]} \tag{5}$$

Since p_i represents the inclusive value of WPs, it is clear from the random utility theory that eq.5 can be interpreted as a nested model (see Fig. 2); the lower nest imposes and satisfies the best bid rule. However, notice that if the IID condition is satisfied across consumers, as asummed in eq.3, then eq.5 is reduced to a MNL model. One can use this property to test empirically the IID condition for the stochastic term by simply allowing a parameter associated to p_i in eq.5; if the estimate is significantly different from one, then the assumption does not hold. Nevertheless, the nested model is more general than the MNL versions, so it is recommended for real applications.

4. THE TRANSPORT SUB-MODEL

The transport system is seen by the consumer seeking a location as an attribute of the site, which is intuitively easy to associate with two distinctive concepts: accessibility (acc), a measure of the relative advantage (or benefit) in reaching activities located elsewhere from the chosen site; and attractiveness (att), a measure of the potential economic profit that firms can extract from arriving travelers.

A measure for acc, proposed by Williams (1977), is the traveler's economic surplus or user's benefit. As for att, one can use a similar measure: the aggregated users' benefit across all arriving travelers, which represents the maximum surplus that economic activities can possibly extract from visitors. Both measures aggregate consumers' surplus derived from trips, therefore, they are defined for a given trip purpose/period (p) and for a given individual type (h) and calculated as:

$$\Delta acc_i^{hp} = -\sum_j \left(\int_{c_{ij}^{hp1}}^{c_{ij}^{hp2}} T_{ij}^{hp}\ dc_{ij}^{hp} \right) \qquad \Delta att_j^{hp} = -\sum_i \left(\int_{c_{ij}^{hp1}}^{c_{ij}^{hp2}} T_{ij}^{hp}\ dc_{ij}^{hp} \right) \tag{6}$$

with T^{hp}_{ij} the trip distribution model for trip purpose/period p and users type h, and c_{ij} the expected cost of the trip before (1) and after (2) the transport plan as they are perceived by consumer h in period p.

The classical example is the case where the trip demand model is the double constrained -trip distribution- gravity model, also used in ESTRAUS. In this case, following Williams (1976) we obtain:

$$acc_i^{hp} = -\frac{1}{\beta^{hp}}\ \ln(g_i^{hp}) \qquad att_j^{hp} = -\frac{1}{\beta^{hp}}\ \ln(a_j^{hp}) \tag{7}$$

with g and a the well known balancing factors associated with the constraints for total trips generated and attracted at each zone respectively, while β is the deterrent coefficient associated with trip costs, all of them estimated by the trip distribution (gravity) model. The consumer surplus acc and att in eq.7 is given in money per trip.

In order to specify acc as an attribute in the bid-choice model, one should aggregate these measures across the relevant trips made by the consumer unit: the household or the firm. In the case of att, the aggregation should be across trips arriving at the zone.

It is worth noting that these access measures are interpreted as follows: acc is the household (user)'s benefit and att measures the supplier's potential profit. They have been designed to suit location decisions by representing individuals' perceptions of access in the land use model; to be consistent with transport models and meaningful in project evaluations; to be calculated using usual transport model outputs; and, finally, to be sensitive to local and structural transport and land use changes.

5. LAND USE-TRANSPORT INTERACTION

The bid-choice model perceives transport as an attribute which, after being compared with other attributes of land, it identifies the trade-off between them by estimating the following WP functions: $WP_{hi} = WP(z_1,...z_n,acc_{hi}, att_{hi})$, with z_k the set of attributes other than access. The parameters associated to acc and att have direct economic interpretation in terms of the hedonic (or implicit) value of the attribute, i.e. the monetary value that the consumer is willing to pay per extra unit of acc or att.

Now, since acc and att are sensitive to transport changes (of any scale), the transport project will induce a change in WPs which will in turn have an impact in the spatial location of activities and land prices. That changes in land use should then feed back the transport model since population and attractive activities are modified in each zone. A new iteration of the transport model is then required and so on.

The analytical integration of the bid-choice model with the transport model is simple. Note that acc and att can be seen as the inclusive value of a transport multi-nested model, where the mobility, the trip distribution, the mode choice and the route sub-models represent lower nests or choices. Hence, acc and att in the bid-choice model are interpreted as representing inclusive values in an upper nest, the bid-choice model, i.e. location decisions are assumed to be taken subject to access conditions.

Hence, the 5-LUT model represents a master land use-transport nested choice model, which has internal behavioral, statistical and economical consistency. Moreover, an overall equilibrium routine can be performed to the whole model so as to obtain a consistent set of the system state variables: ([acc,att], transport cost), as well as to determinate the interaction between sub-models based on empirical evidence (e.g. sequence of sub-models). However, a more sophisticated mobility model is still on the research agenda.

It is worth noting that, if transport external costs (air pollution, noise, etc.) are available, they can be incorporated in 5-LUT since environmental conditions may be specified in the bid-choice model as location attributes of each location.

6. SOME ARISING ISSUES

In the introductory section, the need for a master model was partially motivated by initiating a discussion of W&S' simple method to estimate location values, which is based on a normally difficult judgement on the trip distribution model. Clearly, 5-LUT is an alternative direct method which avoids difficult judgements of the trip demand model and, we believe, is affordable with limited extra effort in transport planning. We shall now justify further this extra effort by pursuing the issue of the consequences of W&S assumptions.

6.1. Capitalization of transport benefits

Assume, only as an example, that the double constrained trip distribution model represents a labor market with travelers taken as 'residentially-fixed job seekers'[4]. In this case, the total benefit generated by the transport plan is given by the known formulae (see Williams, 1976):

$$UB = \sum_i \left[\sum_{hp} \left(\frac{1}{\beta^{hp}}\right) G_i^{hp} \ln\left(\frac{g_i^{hp1}}{g_i^{hp2}}\right) + \left(\frac{1}{\langle\beta^{hp}\rangle}\right) A_i \ln\left(\frac{a_i^1}{a_i^2}\right)\right] \tag{8}$$

$$UB = \sum_i \left[\sum_{hp} G_i^{hp} \left(acc_i^{hp2} - acc_i^{hp1}\right) + A_i \left(att_i^2 - att_i^1\right)\right] \tag{9}$$

with G_i^{hp} the total number of trips made by the population type h from zone i at period p, and A_i the total number of trips arriving at zone i. Eq.9 expresses transport benefits in terms of access measures using eq.7, though att was modified for the case with aggregate treatment of trip arrivals.

---

[4] This is the assumption suggested by W&S for the British context and used in the Santiago ESTRAUS model.

Following well established urban economic theories, W&S interpret the first term as the total travelers' (users') benefit at zone i, presumably acquired by residents, and represents the change in the generalized transport costs. The second term is interpreted as the change in location rents, generated by the 'excess profit' that suppliers can obtain from capturing the reduced transport cost of buyers but which is finally fully captured by land owners.

Note, that if one accepts the alternative assumption, with travelers assumed as 'job-fixed residential seekers', W&S's interpretation is the inverse: the balancing factor g and the attribute acc are associated with location rents while the balancing factor a and the attribute att are interpreted as users' benefits. Hence, the assumption is crucial to allocate transport benefits into users' benefits and land rents, a problem associated with the symmetry of the double constrained model, but, in our view, a direct consequence of the attempt to understand the land market solely based on information derived from the spatial distribution of trips.

Secondly, if one accepts W&S interpretation, the acc measure would represent residents direct benefit while att would represent land rents. In other words, those benefits directly perceived by residents are not capitalized by land owners, i.e. somehow the advantages of better access to residents is not transformed into differentiated rents, an assumption we believe difficult to sustain. Conversely, the fact that att is interpreted as land rents indicates that those benefits associated with better attractiveness are completely capitalized. Such an asymmetry in the market capitalization process of transport benefits, with travellers reduced costs being capitalized at one (rather arbitrary) end of the trip and kept untouched at the other, seems to lack general consistency. We understand this as a direct consequence of the interpretation given to the trip distribution model.

An alternative methodology is provided by the 5-LUT model. Indeed, the bid-choice model takes the benefits acc and att and explicitly estimates their hedonic value, i.e. the extra money consumers are willing to pay for each type of benefit. Hence, there is no a-priori assumption on the capitalization process, it is a matter left to empirical evidence. For example, applying a simplified version (without the equilibrium procedure) of 5-LUT in Santiago City (Martínez, 1991c), it was concluded that, on average, in high income areas 30% of acc is capitalized into land rents, while att is only partly but uniformly capitalized everywhere; both results oppose the usual W&S interpretation of transport benefits.

Moreover, another implicit assumption in the simplified method is that location choices are made as to minimise transport costs, usually reduced to trips-to-work only. The evidence in Santiago strongly indicates that, although accessibility is a relevant factor for some medium-high income groups, it is clearly secondary, ranking below a socioeconomic segregation attribute (i.e. average zone income). Such dominant non-transport cultural factors are expected be present in location choices everywhere, though they might largely differ between cities. It is therefore highly recommended to study the land market in each case and to avoid unrealistic assumptions.

In sum, instead of making a-priori assumptions of the trip distribution model, 5-LUT identifies two types of access benefits which are direct consequence of the need for interaction between activities. That interaction is found in the utility and production functions of consumers. Both attributes may have different impacts on land values which is a matter of empirical study using the bid-choice model.

6.2 Normalisation of accessibility measures

Another issue worth mentioning is the well known fact that the absolute value of transport users' benefits (acc) is undetermined by an unknown constant, say k. W&S recommend a normalisation procedure which, following Alonso's (1964) urban residential arguments, adjusts the lowest location rent value to the independently known marginal land price (e.g. agricultural land price).

An alternative normalisation method can be explained considering the price eq.4. The presence of a distortion k in acc and att will distort WP in, say, ΔWP inducing a further distortion in prices Δp given by:

$$\Delta p_i = \left(\frac{1}{\mu}\right) \ln\left[\sum_{g \in H} P_{g/i} \exp(\mu \, \Delta WP)\right] = \left(\frac{1}{\mu}\right) \ln\left[\sum_{g \in H} P_{g/i} \exp(\mu \, \beta^g k)\right] \tag{10}$$

with the bid probability $P_{g/i}$ given by eq.3 and β^g is the consumer g valuation of acc.[5] Note that the distortion ($\beta^g k$) is independent of the space location, hence it has the same role as the constant element (if there is any) of WP_g functions. If land prices are known, the procedure simply finds k which minimises Δp across the city, i.e. a value for k which sets the absolute value, not the relative value, of access measures by reference to the observed level of land prices.

This normalisation method accepts the same arguments of W&S procedure, but also recognizes that: agricultural land might be subject to competition from several consumers; secondly, acc and att might not be entirely capitalized (but only a fraction given by β) and thirdly, the distortion in prices occurs everywhere in the city, not only at the

---

[5] For simplicity, we have assumed that only acc is relevant in WP function. If att also appears in WP, then ΔWP is explained by the additive effect of two β parameters, associated with acc and att.

margin. But, perhaps it is conceptually more important to realize that this procedure, by explicitly modelling of the land market, eliminates the ambiguity on the absolute value of accessibility measures. That is so because consumers' perceptions are finally tied up; i.e. in the form access measures they are compelled to be consistent with the observed result of the land market equilibrium (land prices).

6.3 Net residents benefit

Finally, note that in the case of acc, hedonic prices (hp) represent the extra price that consumers are willing to pay to enjoy the benefit of better access. Given that acc represents a daily benefit for residents, the total residents' access benefit is the net present value of acc (NPVA). Therefore, the amount of benefits which remains in the hands of residents is calculated by the difference NPVA-hp. As for the case of att, that calculation is not possible because att represents a 'potential profit', not a direct benefit to the firm.

7. FINAL REMARKS

The master 5-LUT model seems to be able to clarify, both conceptually and operationally, the interaction between the activity or land use system and the transport system. It provides us with a unified theoretical framework which, embracing transport, land use and a rent theory, allows a more detailed analysis of the city performance avoiding the need of making assumptions (sometimes) unrealistic.

The complete analytical specification of the model, however, requires the development of two areas: the dynamic development of the land market and the specification of efficient algorithms for the equilibrium procedure. Nevertheless, the explorative application of the model to Santiago city, where the bid-choice model was coupled with the transport model ESTRAUS, has already shown the encouraging potential of 5-LUT.

ACKNOWLEDGEMENTS

This research was partially funded by the National Fund for Science and Technology (Chile). I am gratefull to H.C.W.L. Williams for his illuminating discussions, though I am fully responsible for the content of the articule.

REFERENCES

Alonso, W. (1964). Location and Land Use. Cambridge, Harvard University Press.

Anas, A. (1982). Residential Location Markets and Urban Transportation. Academic Press, London.

Dalvi, Q.M. and Martin, K.M (1976). The Measurement of Accessibility: Preliminary results. Transportation 5 (1), 17-42.

Ellickson, B. (1981). An Alternative Test of the Hedonic Theory of Housing Markets. Journal of Urban Economics, 9, 56-79.

ESTRAUS (1989). Estudio Estratégico de Transporte del Gran Santiago. Informe Final a la Secretaría Ejecutiva de la Comisión de Transporte Urbano, Santiago.

Koening, J.G. (1975) A theory of Urban Accessibility: a new tool for the Urban Planner. Urban Traffic Models, PTRC Summer Annual Meeting, Coventry, England.

Martínez, F.J. (1991a). The Bid-Choice Land Use Model: An Integrated Economic Framework. Environment and Planning A, forthcoming.

Martínez, F.J. (1991b). The Impact of Urban Transport Investment on Land Development and Land Values. Ph. Thesis, University of Leeds.

Martínez, F.J. (1991c). Transport Investment and Land Values Interaction: the case of Santiago City. Proceedings 19th PTRC Summer Annual Meeting, Sussex, U.K., 45-58.

McFadden, D.L. (1978). Modelling the choice of residential location, in Karlqvist et. al. (eds), Spatial Interaction Theory and Planning Models, North- Holland, Amsterdam,75-96.

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. Journal of Political Economy, Vol 82, Nr.1, 34-55.

Webster, F.V., Bly, P.H. and Paulley, N.J. (1988). Urban Land-use and Transport Interaction, Policies and Models. Report of the International Study Group on Land-use/Transport Interaction (ISGLUTI) Avebury, New Castle upon Tyne.

Williams, H.C.W.L. (1976). Travel Demand Models, Duality Relations and User Benefit Analysis. Journal of Regional Science, Vol.16, Nr 2, 147-166.

Williams, H.C.W.L. (1977). On the formation of travel demand models and economic evaluation measures of user benefit. Environment and Planning, A, Vol 9, 285-344.

Williams, H.C.W.L. and Senior, M.L. (1978). Accessibility, Spatial Interaction and the Evaluation of Land Use Transportation Plans. Spatial Interaction Theory and Planning Models, A.Karlovist, L. Lundovist, F.Snickars & J.W.Weibull (Eds.). North Holland, 253-287.

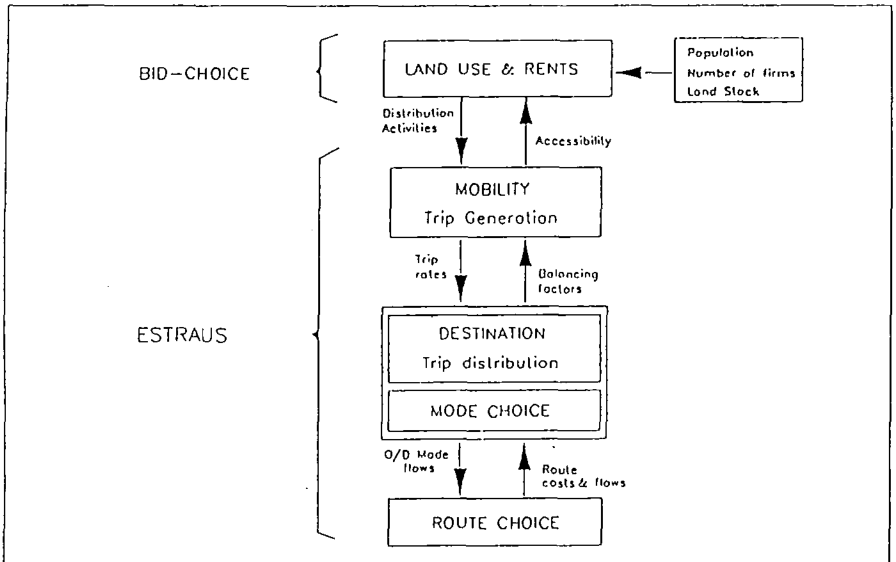

Figure 1. 5-LUT model structure

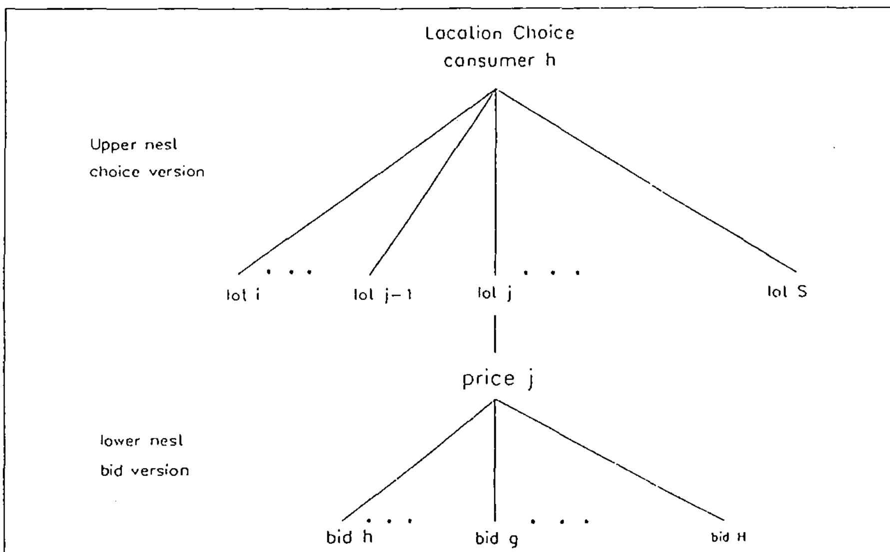

Figure 2. The Nested Bid-Choice Model