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MICRO-SIMULATION IN SOCIO-ECONOMIC AND PUBLIC POLICY ANALYSIS.

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1. INTRODUCTION.

In this paper we discuss the potential for the application of micro-simulation to the analysis of socio-economic and public policy issues through a series of examples drawn from urban and regional planning. Although the general approach is not new and indeed dates back to the study of household dynamics by Orcutt and his colleagues in the late 1950s (Orcutt *et.al.*, 1961) the number of such applications, particularly those involving a spatial dimension, is to our knowledge very small, and spread sparcely across several fields (see the overview by Clarke, Keys and Williams, 1980).

The approach was originally motivated by a desire to consider in more detail the characteristics or attributes of individuals (or households, firms, etc.) as a basis for the analysis and explanation of particular socio-economic phenomena. An explicit recognition of the high degree of heterogeneity in a population when each member is characterized by the values of several attributes, and the requirement to confront the aggregation problem directly, prompted a consideration of an efficient representation of the state of a system (Orcutt *et.al.*, 1961; Wilson and Pownall, 1976; Kain *et.al.*, 1977). It became apparent that the computational listing and manipulation - *list processing* - of samples of micro-units (individuals, households, etc.) multiply classified by the various demographic, social, economic,and activity attributes relevant to a particular context, was highly preferable to the manipulation of a large and typically very sparce occupation number matrix. The elements of the latter are the number of individuals cross classified by the various attribute levels of interest. That is, if the values $\underline{x}_i = \{x_i^1 \ldots x_i^\mu \ldots x_i^M\}$ of M attributes are associated with each of N individuals (i = 1, ... N) in a population P, then the storage of the NM elements associated with the N vectors $\{\underline{x}_1, \ldots, \underline{x}_i, \ldots, \underline{x}_N\}$ will typically be very much smaller than the number of elements in the occupation number matrix. This quantity is given by $\prod_{\mu=1}^{M} \alpha^\mu$ where α^μ is the number of classes associated with the μ^{th} attribute. Recent work (Wilson and Pownall, 1976; Clarke, Keys and Williams, 1980) has emphasised that micro-level inter-dependency, or more formally the structure of correlation in the joint distribution of attributes $\rho(\underline{x})$ over the population, is a crucial determinant of the efficiency and advantage of the 'list processing' method.

Within this micro-level representation, models representing the statics or dynamics of the population P are embedded. Applications of micro-simulation combine a number of methodological features which tend to become intertwined in the discussion of a particular problem, so that different applications tend to appear idiosyncratic. While they may be mutually influential, the processes of: model specification; estimation; solution; and aggregation, should be clearly distinguished, and a general discussion of these may be found in Clarke, Keys and Williams (1980). Although we shall attempt to draw out some methodological features in the following discussion, our main intention in this paper is to emphasise, through a series of examples the motivation for the approach. For this reason we have selected specific and developing areas in our own and related work at Leeds. They include applications in the analysis of: the transportation policies; housing expenditure and finance; public sector housing allocation and dynamics; local authority service provision; and the interaction of certain economic and demographic processes. These will now be discussed in turn.

2. THE AGGREGATION OF TRANSPORTATION MODELS ESTIMATED AT THE MICRO-LEVEL.

Although pioneering work on the specification and estimation of travel choice models using individual data took place in the early 1960s (Warner, 1962) it was not until the early 1970s, in the United States, that an effective challenge to "aggregate" travel forecasting methods materialized. This challenge was aided considerably by the emerging requirements to assess a broader range of policies for which conventional methods were not designed.

The initial claims of the so-called "second generation" of models were considerable, and included: their increased policy sensitivity; their data efficiency; a lack of aggregation bias in the estimation of elasticity parameters; and the ease with which behavioural postulates could be interfaced directly with a representation of consumer choice. There was a related and important motivation involved, namely that the development of an appropriately specified micro-model based on behavioural principles would prove to be practically transferable in both space and time. This major prize would result not only in the rapid and economical development of travel response forecasts, but also in an increased confidence in model results.

Although it is now recognised that some of the original claims associated with "disaggregate behavioural" models were exaggerated and the difficulties of their application to general policy analyses understated, the micro-analytical framework has stimulated a number of theoretical innovations, and allowed several important problems of forecasting to be confronted (see, for example, the review by Williams, 1980). Not the least of the benefits was a far greater appreciation and understanding of the problems of aggregation itself.

This process may be summarized very simply in terms of the relationship between a probabilistic choice relationship $P(A_j|\underline{x}_i)$ estimated with micro-data, and the aggregate quantity $N(A_J|X_I)$

$$N(A_J|X_I) = \sum_{A_j \varepsilon A_J} \sum_{\underline{x}_i \varepsilon \underline{X}_I} P(A_j|\underline{x}_i\ \underline{\theta}) \qquad (1)$$

in which

$P(A_j|\underline{x}_i\ \underline{\theta})$: is the probability that an individual i with a vector of characteristics $\underline{x}_i$ will select an alternative (transportation mode, location, etc.) A_j,

$N(A_J|X_I)$: number of individuals in the population P with characteristics falling into the class $\underline{X}_I$ who select an alternative belonging to the class A_J,

$\sum_{\underline{x}_i \varepsilon \underline{X}_I}$: denotes summation over all individuals i who have characteristics $\underline{x}$ which fall in the range of the attributes specified by $\underline{X}_I$,

$\sum_{A_j \varepsilon A_J}$: denotes summation over all alternatives A_j belonging to the set of alternatives A_J.

The vector of characteristics $\underline{x}$ in say a mode choice context would contain variables relating to an individual and the associated household, and location variables in terms of which transport level of service variables of competing alternatives - substitutes - could be determined. The model $P(A_j|\underline{x}_i\ \underline{\theta})$ would typically be of multinomial logit form, in which the parameters $\underline{\theta}$ are estimated from revealed preferences.

We shall rewrite this equation for aggregate demand in terms of the distribution of the independent variables $\underline{x}$ over the population P, such that

$$N(A_J|X_I) = \sum_{j\varepsilon A_J} \underset{\underline{x}\varepsilon X_I}{S} P(A_j|\underline{x}, \underline{\theta})\, N(\underline{x}, \underline{\phi}) \quad (2)$$

with

$N(\underline{x}, \underline{\phi})$: denoting the number distribution of the attribute vector $\underline{x}$ over the population P of size N in terms of which the density function $\rho(\underline{x})$ will be defined by

$$\rho(\underline{x}) = N(\underline{x})/N.$$

$\underset{\underline{x}\varepsilon X_I}{S}$ denotes general summation (summation Σ over discrete variables and integration over continuous variables).

The process of producing aggregate outputs consists then of estimating the parameters $\underline{\theta}$ of the micro-model from stated or revealed preferences, and "weighting" each contribution within the relevant aggregate class according to $\rho(\underline{x})$. We have assumed here that the alternatives A_j are discrete. It is straightforward to present necessary modification for continuously distributed options, although we shall not pursue this issue here.

There are many approaches to the evaluation of the aggregation process embodied in Equations (1) and (2), and Koppleman (1976) and Koppleman and Ben-Akiva (1977) have catalogued a taxonomy of different procedures with varying information requirements. The challenge is one of designing a method which is both accurate and computationally efficient.

One approach is that of direct numerical integration by Monte Carlo simulation in which a (typically parametric) density function $\rho^*(\underline{x}, \underline{\phi})$ is synthesised, or obtained directly from observations, and a random sample P^* of size N* taken from it in order to perform the necessary summation

$$N(A_j|X_I) \simeq \alpha \sum_{A_j\varepsilon A_J} \sum_{\substack{i\varepsilon P^* \\ \underline{x}_i\varepsilon X_I}} P(A_j|\underline{x}_i, \underline{\theta}). \quad (3)$$

In this expression $\sum_{i\varepsilon P^*}$ denotes summation over individuals in the sample P^* and α is a scaling factor relating P^* to P. The accuracy of this method depends on the accuracy with which the density function is synthesized and the numerical evaluation performed.

This process of forming a random sample and aggregating micro-relations by Monte Carlo simulation is a general strategy and should not be associated exclusively with travel demand modelling. An example of its use in the latter is given in a car pooling model developed by Peter Bonsall in the Institute for Transport Studies at Leeds. Details of the study may be found in Bonsall (1979). Here we shall comment briefly on one of its components in so far as it relates to the aggregation process.

The nature of the transport policy to be assessed makes it desirable to examine car sharing as a process in which the mutual decisions of driver and passenger determine whether a "match" will or will not be made. It is known that a potentially large number of demographic, social and activity variables of driver and passenger attributes will determine whether individuals, having applied to a pooling scheme, will in fact share a ride. In Bonsall's model the demand (passenger) and supply (driver) dises are confronted in a matching process, in which individuals, randomly drawn from synthesised populations P_1 and P_2 respectively determine the benefit of match. The total number of effective matches may be written

$$N(\text{share ride}) = \sum_{i \varepsilon P_1^*(\underline{x}^1)} \sum_{j \varepsilon P_2^*(\underline{x}^2)} P(\text{share ride}|\underline{x}_i^1, \underline{x}_j^2, \underline{\theta}) \tag{4}$$

in which $P(\text{share ride}|\underline{x}_i^1, \underline{x}_j^2, \underline{\theta})$ is the probability that a driver i with attribute $\underline{x}_i^1$ drawn from a population $P_1^*(\underline{x}^1)$ will share a ride with a passenger with attributes $\underline{x}_j^2$ drawn from a population $P_2^*(\underline{x}^2)$.

The probability is actually expressed in terms of a random utility function, estimated by stated preferences, and the outcome of the matching algorithm which is designed to take account of "competition" due to potential mis-match of supply and demand, is at the individual level a 1 or 0 according to the success or failure of a match.

This micro-level matching of lists is not uncommon to micro-simulation applications in which it is necessary to examine the interaction between demand for and supply of a commodity. We shall meet it once again in a housing example to which we now turn.

3. HOUSING MODELS AND MICRO-CONSIDERATIONS.

In the development of housing models through the 1960s and 1970s there has existed a clear divide between aggregate econometric studies estimated with time series data, and typically applied at the national level, and those studies of stratified housing markets applied at the metropolital/urban level and estimated at the cross section. The former have been used to analyse and explore the dynamics of demand, supply, prices, and mortgage institution behaviour as a function of macro-economic and demographic variables, while the latter of which the models developed at the Urban Institute, Washington (deLeeuw and Struyk, 1976), the National Bureau of Economic Research (N.B.E.R.: Ingram *et.al.*, 1972; Kain *et.al.*, 1977) and in Stockholm (Holm *et.al.*, 1978) are among the more prominent, concentrate on the problems of allocation and the general equilibrium (or disequilibrium) between demand and supply.

In spite of the large number of theoretical and empirical investigations on the housing systems, there do not exist, as far as the authors are aware, at the local or national level models which embrace the full dimensions of variability in expenditure, and incorporate an adequate recognition of:

(i) the nature of housing as an asset,

(ii) the effects of control and metering on allocation and dynamics of the institutions of tenure and finance.

These are fundamental and contentious issues and it would be quite wrong to be over critical of the state-of-the-art. However, we would suggest that in theoretical developments, particularly in the treatment of space and tenure, the conventional paradigm of information theory and random utility theory, particularly as used in transportation studies, have been too closely adhered to. Of course, models should be 'context dependent' but it is not always possible or necessary to attempt a causal approach. The changing emphasis in activity-travel demand research to reflect behavioural constraints in quantitative analyses does not however appear to be forthcoming in housing model research, although there is a considerable and growing literature on the general role of housing organization in social stratification.

Because institutional arrangements in housing systems are very specific to individual countries, we shall limit our comments now to a British setting which is characterized by large public and owner occupier sectors, and a declining private rented sector. Their relative sizes (and the importance of Housing Associations) vary considerably over the country. It is one of the peculiar and important features of the housing system in Britain that individuals who live in very similar houses (for example in adjacent semi-detached properties) can have very different housing expenditures, while because of local rent pooling arrangements and cross subsidisation in the public sector, households who live in rather different properties can have very similar (or identical) rents. While the problems of: asset accumulation, the effects of the large reserve purchasing power of exchange buyers, differential subsidisation; the sensitivity of household expenditure to the movement of macro-economic variables and taxation policies are widely recognized; these features have yet to be captured in a "causal" model of a national or local housing system. In the technical papers of the recent Housing Policy Review (H.P.R., 1977), for example, in which the issues of equity and subsidy were discussed at some length, sketch calculations were directed at the subsidy to *houses* (ie. stock in different tenures) over a nominal sixty year period (see also the discussion by Webster, 1978).

We feel that there is a logical, and arguably pressing, need to attempt to quantify the flows of money in the housing system between the relevant 'spatial actors' and in particular: central and local government, building societies, and *individual* households, in order to bring out clearly the changes over time, and under different policies, of the variability in expenditure between households

(i) over space (both intra- and inter-regional),

(ii) who are 'first time' and 'exchange' buyers,

(iii) between and within different tenures,

(iv) with different socio-economic and demographic characteristics.

This is the principal motivation for a micro-simulation study.

A model is currently under construction to draw out the above dimensions of variability, with particular reference to the subsidy issue. In order to do this it is necessary to generate a population $P^*(\underline{y})$ of households with attribute list $\underline{y}$ which is given for the j^{th} household by

$$\underline{y}_j = \{\underline{x}_{j1}, \underline{x}_{j2}, \dots \underline{x}_{jn_j} : \underline{x}^*_j\} \tag{5}$$

in which $\underline{x}_{j\mu}$ is the vector of attributes for the μ^{th} member of an n_j membered household. $\underline{x}_j^*$ refers to specifically household attributes. $\underline{x}_{j\mu}$ includes demographic and economic characteristics of individual members, while $\underline{x}_j^*$ includes household summaries, housing characteristics (house-type, tenure, age, etc.) and financial characteristics, including details of a mortgage, if held. By storing the price of a house when bought, it is straightforward to embed the notion of assett accumulation.

It would clearly be desirable to have micro-level housing information for different parts of the country in different years in order to provide accurate bases on which to construct population $P^*_{(\underline{y})}$. Because of data limitations, and this is obviously why more progress has not been made in the examination of micro-level housing behaviour, we have been content to synthesise $P^*_{(\underline{y})}$ from secondary data sources (that is from the conditional and marginal distributions of the various attribute values in $\underline{y}$).

Having constructed these populations in a base year we can subject members to the interval (eg. life cycle and economic) and external (fiscal and monetary) changes, to which each is subject, and modify attribute values accordingly.

Essentially this operation may be seen in terms of the solution of a set of differential equations, which govern the demographic and economic dynamics of the system, by means of Monte Carlo simulation. The relative values of a random number and the probability that an event will occur (eg. the formation of a household) will determine whether a transition between individual micro-states is actually made.

We are resisting the temptation to attempt to build a very complex "behavioural" model because of data restrictions, and are settling for a sensitivity analysis of the time dependent behaviour of the population $P^*_{(\underline{y})}$ under the various processes of interest

$$P^*_{t(\underline{y})} \rightarrow P^*_{t+\Delta(\underline{y})}. \qquad (6)$$

In particular we are not here attempting to model details of the interaction between supply and demand, but are allowing prices (and rents) and other macro-parameters to be "imposed" on the system. It is then straightforward to extract from the updated list of individual households information on both current and past expenditure on the one hand, and the streams of costs and benefits flowing between spatial actors on the other.

We wish to conclude this section with reference to the dynamics and allocation in the public sector, which is also the subject of a modelling effort.

Underpinning the whole micro-representation is a very fundamental theoretical question, namely: how does an individual or household come to be associated by a particular set of attributes - that is, what dynamical processes are responsible for the structure of correlation between the attributes of individuals in the population $P^*_{(\underline{y})}$? A very particular but important case in point is the association between household characteristics and house type attributes including tenure. In both the private and public sectors, the probability of a match between particular attributes on the demand and supply side at the micro-level is powerfully determined by constraints imposed by the institutions of tenure.

We are currently attempting to examine within the micro-simulation framework the interaction between supply and demand, in order to draw out a number of particular features of the housing system namely: the interaction between the public and private sectors; captivity effects, both within the public sector and in its queues; and the variation of allocation policies (eg. between different local authorities).

It is not difficult to document and account for the various transitions of households - again using Monte Carlo simulation to solve equations for household formation/dissolution. In the housing system and in the labour market the *external* movers caused by households leaving the sector, and the new supply triggers a series of internal moves which must be accomodated in much the same way as an input-output system. The solution algorithm for this model thus combines the processes of transitions directly with an allocation policy. The public sector, in many ways operates as a multi-line queueing system with pre-emptive priorities. Priority rankings and decisions are sensitive to a number of attributes of individual households and associated houses "released" in any time interval. The list processing approach is partiuclarly amenable to the high information requirements of the allocation. At the moment we are, again due to data restrictions formulating the problem of allocation and dynamics as a "game" in which the preference structures and constraints of both potential tenant and housing manager interact in a "multi-criterion" matching process. That potential tenants do show discrimination is evidenced by the co-existence and often proximity of highly sought after and vacant stock in the public sector.

4. LOCAL AUTHORITY SERVICE PROVISION.

The state, both at a national and local level, provides a wide range of services, such as education, health care, social services and benefit packages that are consumed by a large and heterogeneous client group. The field of service provision has given rise to a number of policy related issues that fall into several related categories. Amongst these are: determining existing and forecasting the future need for services; the allocation of finite resources between sectors and individuals (determining priorities); monitoring the efficiency, effectiveness and equity of service provision; and questions pertaining to ways of financing the cost of this provision. Current policies also demand that the effects of cuts in levels of provision can be assessed. With local authorities often being the largest single employer in an area, the role that the authority plays in the local economy is also an important topic.

Determining the need (or perceived demand) for services is a key aspect of planning in a local authority. In areas of social, economic and demographic change and where considerable capital investment is required over a number of years (eg. schools, hospitals, housing, transport, infra-structure) then there is a strong incentive for producing detailed and, as far as possible, reliable forecasts of future need. A suitably specified micro-simulation model that produces detailed cross-classified information pertaining to a number of socio-economic attributes deemed appropriate by the policy analyst should be of considerable use. Planners may be interested in changes in the number of individuals with certain types of attributes between given time intervals. For example, to provide appropriate care for the elderly it is necessary to have detailed information on individual characteristics. Formally we can determine this number in the following way

$$N^{\mu_1,\mu_2,\mu_3} = \underline{G}^{\mu_1,\mu_2,\mu_3} = \bigcap_{i=1}^{N} \{\underline{x}_i^{\mu}\} \qquad (7)$$

$$\mu_1,\mu_2,\mu_3$$

where N^{μ_1,μ_2,μ_3} is the number of individuals in the matrix G^{μ_1,μ_2,μ_3}, which contains all indiviudlas having attributes, μ_1,μ_2,μ_3. This is determined by establishing the intersection, $\cap$, of all individuals, $i = 1, \ldots, N$, with attributes μ_1,μ_2,μ_3. The policy analyst may thus be interested in N_t, N_{t+T}, G_t and G_{t+T} for a suitable time period T. The updating of the files of households and individuals may be performed in the manner outlined in Section 3. Used *in conjunction* with appropriate macro-models, that say produced aggregate forecasts of migration, changes in the demand for labour, and so on, micro-models have a wide potential application for producing forecasts and monitoring progress. Housing issues have been discussed above, but obvious applications exist in social services, where a large number of attributes of individuals are of interest, such as the elderly with respect to health care facilities, and in economic support for the unemployed, where there is often a mis-match between the skills and qualifications required by employers and those obtained by individuals.

The provision of services is traditionally based on the assumption of need rather than the ability to pay. It is therefore an interesting research quesiton to assess how much of an income redistribution between individuals of different incomes is being effected by service provision. This needs not only consideration of what services individuals receive, and how much they are valued by individuals, but also how much individuals contribute to the financing of these services, through property taxes, income tax, charges and so on. Traditional concern has focuessed on income band groups, where all those individuals or households whose income lies between two points are considered together (for example, Nicholson, 1964). This is clearly unsatisfactory, as very disparate groups under aggregation lie in the same class. For example, pensioners, young single persons, unemployed persons with several children may all fall into the same income group, yet the service consumption pattern of their household will clearly differ (see Webb and Sieve, 1971). A micro-simulation approach affords a way of surmounting this difficulty by considering the baisc micro-units, individuals and households. The approach involves an extension of the attribute list, $\underline{\mu}$, to incorporate variables relating to service consumption, transfer payments and contributions to financing this, such as domestic rates, and other taxes. Aggregation in a variety of ways is then possible, and alternative aggregation schemes compared. If there is to be change in levels of service provision it is important that the effects of these changes can be assessed. Using the approach outlined in this paper it is possible to determine what these changes are and what type of individuals gain or suffer from these changes. Two models are currently being developed at Leeds relating to these issues. The first is concerned with assessing the impact of reductions in public sector employment. It is clear that if the person made redundant does not find employment then the burden to the state in welfare payments may approach the savings made by making that person redundant. Whether the person finds employment will depend on his or her attributes and also the type of vacancies existing in the local labour market, which will vary from region to region.

The second model being developed is concerned with fiscal interactions between individuals/households and the local authority. Equity issues are of interest here (between individuals, over time, and between authorities) as well as examining the impact of alternative local government finance schemes.

In many cases we do not have primary data sources, and we resort to the synthetic population generation methods outlined earlier. Clearly for detailed policy analysis in a local authority primary data may be deemed essential and this would necessitate a survey being undertaken. Orcutt *et.al.* (1976) suggests however that the size of the sample in such a survey need not necessarily be very large and hence prohibitive to the adoption of this method.

5. THE EFFECT OF DEMOGRAPHIC AND SOCIO-ECONOMIC FACTORS ON INCOME DISTRIBUTION.

The previous modelling efforts discussed in this paper have been concerned with a partial analysis of the system of socio-economic variables in a given urban area or region. An implicit assumption in the making of a partial analysis is that any effects between the part of the system which is modelled and that which is not can be ignored for the purpose of analysing the problem at hand. The problem of how to close the system being modelled, that is which parts to omit from the modelling exercise, is dependent upon the relative strength of the interactions between the modelled and non-modelled parts of the system. It is also dependent upon the types of policy impact to be analysed using the model.

In order to illustrate the way in which these factors determine model specification an outline of a dynamic model of income distribution at the micro-level is presented. In particular our concern lies with the processes which give rise to this distribution over time and the impact upon it of various labour market policies and the role of the state.

Household income is derived from various sources. For the majority of households income is primarily earned by certain members of that household or is derived by benefits received from government. For a smaller proportion of households this is supplemented, to a greater or lesser degree, by unearned income from investments. In order to understand more fully the process by which different incomes are received by different households it is necessary to consider then the flows of the money through the system. In particular it is of interest to investigate the transfer from rich to poor of money by means of the tax system, and the costs and benefits received via the local authority by different households (as described in the previous section). The need to consider benefits received and monies paid to the National Exchequer automatically forces one to consider the different expenditure of households on commodities such as transport, housing and consumer goods, the taxation on which helps Central Government raise the money to pay for benefits. This may be done by a macro-economic model if this were all that was of concern. However the way in which different households spend and receive money is dependent upon their activity in the labour market, their position in the housing market and other factors such as the age and number of individuals in the household. These factors also affect the income of money from various sources: benefits, wages and non-monetary income via services. By considering the system as a set of micro-level units, households and individuals, the decisions and processes underlying the flows of money may be explicitly incorporated into the model. Further when these are present the impact of different policies upon the income distribution, may be examined.

It can be seen from this discussion that many processes are involved in a complete model of income distribution. These spread over the whole socio-economic system and include effects peculiar to the demographic, labour market, housing market and transportation sub-systems. These do not act independently to determine the money flows but interact in different ways, particularly through the household budget. Decisions made in the labour market, concerning say a change of job of an individual, may affect the residential location of the household of which he is a member. This will then affect the transportation characteristics of that household and also the expenditure on items such as energy, food etc. due to a changed income. There is, therefore, a variety of interactions present in the system which require consideration. Those which are of sufficient importance, on their own accord or because they cause other effects, should be included in a model. A model built on the basis of micro-level representation has the potential to incorporate the richness and wealth of interactions is limited by data availability, but the micro-simulation approach at least allows all possible interactions, in theory, to be included.

It is the lack of micro-data at the urban level which constrains the type of model which can currently be implemented. It is possible to build, as described in Section three, a model of the housing market in which transitions and allocations are explicitly considered. A model of the labour market can be conceived along similar lines and linked with the housing market model to provide a central basis for an income-expenditure model. Demographic changes may also be considered in the framework of Monte Carlo simulation and these can again then be linked with labour and housing market transitions by individuals and households. Housing costs and wages provides only part of the household budget and transfers between household and its members and central and local government, as a function of labour, housing and demographic characteristics, need to be included. A model such as this based at the micro-level allows the variability and uncertainty present in the system to be included in the model and also more aggregate outputs, such as total levels of transfers paid, to be obtained for different classes of households, individuals and spatial areas.

6. CONCLUSION.

In developing the micro-simulation models outlined in this paper we have confronted a number of important questions, both of a theoretical and practical nature. Issues of aggregation are seen as of central importance to model building particularly in attempting to embed both micro- and macro-models into a coherent hierarchical framework for policy analysis. The combination of several modelling techniques in approaches to problem solving is particularly desirable. We must view the problem at hand and attempt to solve it in the most efficient way and not assume that any one technique holds a monopoly over others.

On a practical level the information requirements of the type of models described above are often seen as problematic. We recognise the paucity of longitudinal micro-data does constrain the model builder, as it has and continues to do in our own work. However, the list processing representation presents an excellent way of *organizing* information in this way may well be a necessary precondition if the full potential of the micro approach is to be realised.

Our own attempts to develop the approach are modest in scope, but we believe that if certain types of policy related questions are to be fully confronted much more research needs to be directed towards the design and construction of models using a micro-level representation.

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