A review of the MEPLAN modelling framework from a perspective of urban economics

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1 Introduction

MEPLAN is a mathematical framework and software package for modelling the spatial economies of cities or regions. It is called a "model of land-use/transport interaction" (ME&P, 1989) since it contains a fairly detailed and comprehensive transportation planning model and the influence of transportation conditions on the location of various land uses are core to the function and purpose of the model.

Urban economics is a discipline of study concerned with the allocation of resources in an urban area, and in particular on the spatial arrangement of activities and the consumption of land and floorspace.

This paper is a review and critique of the MEPLAN framework from an urban economics perspective. It is based primarily on a reading of "Modeling in Urban and Regional Economics" by Alex Anas (Anas, 1987). Anas does not mention MEPLAN in his review, although he mentions a variety of models that are similar to MEPLAN in various ways.

This report compares the taxonomy of models in Anas (1987) with MEPLAN in section 2, and offers conclusions in section 3.

2 MEPLAN and the taxonomy of models

2.1 Monocentric models

2.1.1 Basic Theory

Monocentric models are models that assume a single "market" or commercial node where all goods are exchanged. Land outside of this single point can be used for a variety of purposes. The original formulations of the monocentric theory were agricultural in nature, and the "market" corresponded to an actual agricultural market, while the land radiating outwards from the market was allocated to the production of different types of agricultural goods (von Thunen, 1826). This established the base theory, under which the activity with the highest bid for any parcel of land would occupy that land, leading to an orderly arrangement of activities according to the various bid curves, with the bid curves related to the production function of the activity and the cost of transporting the goods to market.

In applying this agricultural theory to urban economics, the "market" is taken as the central business district where all labour occurs. Households are the consumers of land outside of the CBD, and their "production function" involves preferences of how much land they are willing to consume at what price. Their indifference curves for different amounts of land at different distances is related to their ability to consume "other goods and services" with the budget that is leftover after paying rent for the land and paying for the transportation necessary to commute to the CBD.

The utility functions of households are normally taken to be identical, and the willingness to pay for land at different distances is related only to different budget constraints due to different incomes. This leads to a spatial arrangement of households according to income. Under most assumptions and in most studies the wealthier households are able to purchase more land at greater distances because they have the money available to pay for larger commutes, while poorer households have little choice but to compete for small amounts of space near to their workplaces.

If a time budget as well as money budget is imposed and if some household members are not employed, then households with high salaries and few dependents will also successfully compete for the most central locations, leaving the more distant locations to households with more dependents and to households with large amounts of income from non-wage sources.

The contribution of monocentric analysis to urban economic *theory* is strongly stressed in Anas (1987).

2.1.2 Comparison to MEPLAN

MEPLAN adopts many of the fundamental concepts of monocentric theory. Most importantly, MEPLAN includes travel time and cost, land costs and elasticity of demand for land, and income as fundamental variables, and so can recreate the scenarios that have been investigated in the monocentric theory.

The one aspect that has been included in some of the monocentric literature that can not be directly represented in MEPLAN is a time budget. MEPLAN can include the disutility of travel in the utility of households, but this is always a linear relationship that can not represent the diminishing marginal returns that a time budget does.

Households are typically divided into categories according to income, allowing MEPLAN to model the spatial segregation by income that occurs, but not in a continuous way.

Various actors compete with the different household categories for space in MEPLAN, but the different budgets and 'average' utility functions control which activity is more likely to outbid for space, and so the arrangement of activities and the market rent for land is still determined by a process similar to bidding process in the monocentric theory. The main difference in this respect is that although MEPLAN models aggregate totals of activity, it does so using random utility theory by assuming that the aggregate activity consists of a large number of individual actors each with an individual utility function. The wide range of utility functions is expressed by a random variable, and the mean of the random variable is assigned to a function. Thus although each actor in MEPLAN is given a single "utility function", the MEPLAN utility function is actually the mean of a very large number of utility functions. This means that at any one location type there will be certain portions of different activities that are the "highest bidders", and MEPLAN begins to simulate the actual randomness that occurs in real cities.

Perhaps the most important difference between MEPLAN and the monocentric literature is that MEPLAN *is not monocentric*. That is, no predetermined central economic location is defined in MEPLAN. All types of economic activity is allowed to occur in all zones. Thus MEPLAN could at least in theory converge to a multicentric city consistent with central place theory (Christaller, 1933) or a completely mixed configuration [Anas p 37]. (Note, however, that Central Place Theory is related to optimum firm size and agglomeration economies. Since MEPLAN has no representation of individual firms and firm sizes it does not embody Central Place Theory).

2.2 Non-Economic Beginnings

This category includes some of the earlier attempts to build urban models without a strong economic background. These models are typically very practical in that they are designed to address certain problems that needed to be analysed given certain data that was available.

2.2.1 Forrester dynamic model

An urban dynamic model was constructed by Forrester (1969). This model is based in control theory, and describes the dynamic relationship between variables. Different variables can respond at different rates to the levels or rates of changes of other variables. In a sense this model is a numerical simulation of a system of differential equations with time discretised. It is not an equilibrium model although with proper coefficients markets could tend to equilibrium. The markets represented include housing markets and labour markets. Anas does not mention the time discretisation level, but presumably time is discretised into 1 year or smaller increments, giving enough resolution to tune the dynamic nature of responses to actual data. Forrester's model is interesting, in that is shows how dynamic relationships can be modelled without direct recourse to economic theory. But without a strong economic theory the model absolutely needs to be very carefully calibrated to observed relationships, and there is no evidence that Forrester's model has ever been calibrated to any data at all other than Forrester's own expectations.

MEPLAN models the land and labour markets in equilibrium at any one time period. Usually land markets are "constrained", meaning that the supply is fixed in the time period and price adjusts so that demand matches supply; while in other markets price chains are adjusted so that the price of outputs (and ultimately exports) are determined from input prices. This is distinctly different from Forrester's model where market prices (and indeed prices in general) are not specifically modelled, but in any one time period the "markets" neither need to clear nor have prices based on input costs.

MEPLAN has a facility for representing dynamics, and because of this certain comparisons can be made with Forrester's model. The incremental nature of MEPLAN and specifically those processes that are modelled in the incremental model can be directly compared with Forrester's model. MEPLAN could be run in 1 year or shorter time steps, and various rate-of-change variables could be maintained in the incremental model. This would allow a more direct representation of the dynamics in an urban system than is typically done with MEPLAN. In Forrester's model the differential equations are modelled using "implicit" modelling, where variables can be functions of other variables in the new time period. In MEPLAN those variables updated by the incremental model can only really be functions of variables in the previous time period, leading to an "explicit" method of solving differential equations. The explicit method is much less stable and in general requires a careful consideration of the relationship between the scales of spatial disaggregation and time disaggregation. Theoretically, the explicit nature of MEPLAN *requires* small time steps for stability, and it is has never been shown that MEPLAN's typical 5 year time steps are small enough to be stable, let alone represent the underlying dynamics.

2.2.2 EMPIRIC

The EMPIRIC model (Hill, 1965) is similar to Forrester's model in that it represents a numerical solution of differential equations. The main differences are:

- The coefficients in EMPIRIC were meant to be estimated using two-stage least squares estimation (or similar techniques) while Forrester's model never had any defensible estimation techniques, and
- Forrester's model is aspatial while EMPIRIC uses a standard zone system, although in EMPIRIC, each zone is independent so spatial interactions are not represented.

2.2.3 Lowry model

In 1964 Lowry published an urban economic model that has been extensively imitated and extended. Lowry's model is based on economic base theory, where a certain amount of employment is "exporting" or "basic", and this exporting activity drives the economy. The employees in the basic industries demand housing and other services, and other employees are necessary to fill these demands. These other employees also have needs, of course, and so an infinite but converging chain of demands are created all from the "basic" industry.

Lowry's contribution was to extend economic base theory to a spatial system divided into zones. This is done by using gravity model type formulations to allocate the secondary employment to zones based on the distance to other zones and the population in the other zones, and to allocate the population to zones based on the distance to other zones and the employment in the other zones. Lowry first examined trip distributions for shopping trips and work trips to find the coefficients for his gravity models, then simultaneously estimated all remaining parameters.

MEPLAN has many similarities to Lowry's model - in fact MEPLAN claims Lowry's model in it's pedigree (Hunt and Echenique, 1993). Both are based on economic base theory, although the input-output model in MEPLAN is a more comprehensive extension of the theory. Both use gravity type models to allocate secondary employment based on travel difficulty to households and to allocate households based on travel difficulty to employment locations. The spatial allocation models in MEPLAN are based on logit random utility models, which makes them more behavioural and easier to interpret than strict gravity models, and also allows the inclusion of price information (see below). Lowry's model does not include a direct preference for greater land consumption, instead using an upper bound constraint on density.

The other major differences between MEPLAN and a Lowry model appear to be:

- MEPLAN is more comprehensive, with multiple types of land, floorspace, industry, employment and households; and with a choice of functions for most of the relationships. Inter-industry and inter-household dependencies are also represented.
- Travel impedences in MEPLAN's spatial allocation models are congested travel times from a multi-modal transportation model
- MEPLAN's constraints on land and the elasticity of land consumption give a market clearing price for land. These prices are combined with the input-output relationships to give a price for every other factor, and all these prices are used together with the travel impedences in the allocation models. The prices can also be used to adjust the consumption and production functions that are implied in the coefficients of the input-output model. All this makes MEPLAN a much more *economic* model, while Lowry's original model is "not economic but physicalistic in nature" (Anas).

- MEPLAN includes the incremental model for adjusting the constraints on space and the arrangement of basic activity, and uses travel impedences from a previous time period, making it quasi-dynamic.
- MEPLAN allows for demand coefficients that vary with price, and for households this can be consistent with utility maximising behaviour.

2.2.4 Wilson's statistical gravity model and Random Utility Theory

Wilson (1967) provided a statistical interpretation of the gravity model, showing that the logit form of trip distribution corresponded to the most likely statistical arrangement of trips given constraints on the total amount of travel. This corresponded to other developments at about the same time, most clearly enunciated by McFadden (1973), giving the random utility theory of the logit model, and corresponding measures of utility and of user benefit over a range of choices. These developments made multinomial logit, and nested logit, the formulations of choice for discrete choice modelling and provided both a statistical and economic theory for understanding and interpreting the properties and results of models.

MEPLAN uses multinomial logit and nested logit models extensively, making it consistent with the theories as developed by Wilson and McFadden. The only weakness here is in an incomplete use of the log-sum as the aggregate measure of the cost or utility of choosing from a range of goods. According to Random Utility Theory, when a firm or household chooses to consume from a zone that is sub optimal according to the utility functions, it is because the unique nature of that firm or household is different then the average nature expressed in the utility function, and the chosen zone is in fact optimal for that firm or household. For this reason the log-sum measure needs to be used as a measure of the average costs or utility associated with a range of options - to ensure that a larger number and a wider variety of options corresponds to a lower average cost and/or a higher average utility.

To express this in an input-output framework would require that the efficiency of each type of firm increases when a wider range of input zones are available. Unfortunately, input-output theory typically works in terms of fixed efficiency. To get around this MEPLAN uses weighted average costs instead of log-sum costs, and a major benefit of travel (allowing more variety and choice) is lost in MEPLAN's monetary accounting (but not in its spatial allocation). This inconsistency makes user benefit and supplier benefit analysis difficult.

2.3 Mathematical Programming

2.3.1 Traffic equilibrium models

Traffic equilibrium models are included in this section of Anas (1987) because they use a non-linear constrained optimisation to assign traffic to a network according to Wardrop's user-optimal conditions. Anas includes a discussion of stochastic congested assignment algorithms by Daganzo and Sheffi (1977) and Fisk (1980). Anas complains that the use of *flow rates* to describe congestion is unrealistic, since flow varies by time of day and as vehicles move through a network different links will become more congested at different times. This is an argument for a more modelling of arrival and departure times, and for modelling of vehicle movements through the network.

MEPLAN uses a stochastic congested assignment algorithm, but uses Dial's algorithm rather than the more theoretically appealing Fisk algorithm. A major advantage of Dial's algorithm is that it analyses almost all possible paths (except those that involve "backward" steps, where backward is determined from the minimum path to the final destination) in a simple algorithm that can consider all origins at the same time for a single destination. A problem with Dial's algorithm is that it is dependent on network coding, and paths through areas where shorter links are coded will be more likely to be chosen then paths involving longer links. The determination of "backward" steps is also rather arbitrary and dependent on network coding. From the evidence in Anas's book it would appear that MEPLAN could use some updating of it's travel assignment model.

Anas's argument for more dynamic modelling of departure time, arrival time and vehicle movements is convincing on its own, but in a large scale urban model designed to predict the dynamics of spatial change over 30 year or more it is hard to imagine that the detailed dynamics of traffic movement on a single day are important. It may be appropriate to look at better ways of abstracting traffic characteristics beyond a single "flow rate" number for each link, but for the purpose of urban economic modelling it seems hard to believe that full dynamic assignment is the answer.

2.3.2 Spatial price equilibrium

Spatial price equilibrium problems were developed by Samuelson (1952), who investigated spatially separated markets. With the demand and supply of each commodity at each point being a function of the price at that point, and any price differences between two points being equal to the cost of shipping between those points (for those pairs of points between which shipping occurs), a spatial price equilibrium model will determine the shipments that will occur and the prices at each point. This can be integrated with transport models to simultaneously determine the cost of shipping.

The spatial price equilibrium problems are similar to MEPLAN in that the price of each factor at each point includes the cost of transporting that factor. The main difference is that in MEPLAN factors are not commodities but classifications of goods and services, and the great variety of goods and services means that random utility theory is appropriate. This means that some commodities will be shipped from points that are sub optimal according to the average utility functions, because the individual commodities and businesses vary about this average in a probabilistic way. The unfortunate part of MEPLAN is that its calculation of average costs is based on trade-weighted averages that would be consistent with commodity flows, rather than the log-sum averages that are consistent with MEPLAN factors.

2.3.3 Network design models

Anas includes a mention of network design models, where mathematical programming approaches are used to select a subset of links from a set of feasible links to achieve certain travel cost objectives. When the problem is extended to include variation in link capacity it becomes non-convex, making the mathematical minimisation extremely difficult. This suggests that some of the more recent heuristic search algorithms (genetic algorithms or simulated annealing) would be more appropriate ways to solve for optimal network designs.

For the network design problem, it seems that MEPLAN is destined to be a tool in various *ad hoc* explorations of networks, rather than a submodel in a network design model. This is largely because the complexity of MEPLAN makes it unsuitable for use in an inner loop of an even more complicated problem. The economic nature of MEPLAN and it's inclusion of complete consumption and production functions means that using MEPLAN for the network design problem, even in an *ad hoc* way, is probably more appropriate then using a simpler model that only includes travel costs.

2.3.4 Herbert-Stevens model

The Herbert-Stevens (1960) model of land use allocation simulates bidding for land by maximising the total revenue obtained by land owners. As such it can allocate activity to land in an economically efficient manner. Anas uses the Herbert-Stevens model to introduce the concept of an open city, where the utility level of the populace is set exogenously, and the population of the city will adjust so that the utility level will equal the exogenously set level. Anas also introduces the concept of land-use sequences, looking at the price of land through time and optimising the time-discounted revenue. In other works (e.g. Fujita, 1989) land-use sequences are examined in a monocentric context.

A direct comparison between the Herbert-Stevens model and MEPLAN is difficult, because the Herbert-Stevens model assumes equal utility functions and MEPLAN uses random utility theory. The constraints on land availability in the equilibrium model in MEPLAN and the elasticity of land consumption in MEPLAN are consistent with the Herbert-Stevens model, however. The open city concept is not directly comparable to MEPLAN. In MEPLAN it is possible to fix the utility level of the citizens exogenously, but the population is also fixed exogenously. This would lead to over constraint in the Herbert-Stevens model, but in MEPLAN the extra degree of freedom is in the cost of labour, which then feeds up through the model to contribute to the costs for every other good or service and ultimately defines the costs of exported (basic) goods and services.

The concept of landowners maximising the time-discounted rent by choosing a land-use sequence can not be directly implemented in MEPLAN because MEPLAN can not have variables in previous time periods as functions of variables in later time periods. The best that can be done is to manually experiment with multiple runs of MEPLAN through time to find the myopic developer behaviour functions that best approximate the time-sequence optimum.

2.3.5 Mills linear programming model

Mills linear programming model (Mills, 1974) is based on Leontieff constant coefficient technology describing the relationships between various goods and services. The quantities of export commodities are set exogenously, and the constant coefficients on land, labour and capital correspond to the production of floorspace. An important feature is that the amount of land allocated to roads is determined endogenously for each area, by minimising the total cost of the urban area including transport congestion. This is a normative model, in that it does not account for the fact that most congestion costs are externalities. Households in the Mills model are cost minimisers, rather than utility maximisers. Mills model centres activity around a central location where the basic goods are exported from. Hartwick and Hartwick (1974) included intermediate goods and services, and investigated the relative location of different activities. It has been extended to a multi-modal system by Kim (1979), showing that as cities get larger and central land becomes more valuable it is efficient to build transit systems and subways in central areas because they make more efficient use of land. Mills model is a linear model, with the non-linear congestion functions represented by piece wise approximations. To preserve the linear nature, the urban area needs to be described using a grid or other regular geometry, which makes the model difficult to use in practice.

The Mills model and MEPLAN are similar in that both represent various factors in an input-output framework and both take into account congested travel times. Mills model fits the entire problem into a linear mathematical programming framework, making it less realistic and more difficult to apply. MEPLAN, on the other hand, can not solve for such things as optimal land allocation to roadways and optimal time-series-use of land. One could say that the Mills model is more theoretical and the MEPLAN model is more practical.

2.3.6 Koopmans-Beckmann quadratic assignment

The Koopmans-Beckmann model (1957) involves assigning a certain number of plants or facilities to an identical number of sites to minimise transportation costs between the sites. The assignment is done by maximising net rents, simulating highest bidding for land, and the question that is asked is whether this assignment represents a market equilibrium. The answer seems to depend on a number of factors, but allowing profits to vary across plants or making the problem more continuous by allowing more than one plant at a site seems to help make the optimum solution market sustainable.

MEPLAN has a more direct simulation of markets and with variable densities and elasticity of land consumption is more directly suited to modelling a large number of independent actors. The Koopmans-Beckmann model seems to have been relegated to use by operations researchers who are actually interested in assigning plants to sites to maximise profits. That is to say the use of profit maximisation to represent efficient markets has fallen out of favour; direct market simulations have been accepted as more appropriate.

2.4 Econometric Models

Econometric models combine empirical data and forecasting concerns with the urban economic theory that developed in the 60's.

2.4.1 The Urban Institute Model for housing market analysis

In 1975 deLeeuw and Struyk published the Urban Institute Model. The model contains four factors: households, dwellings, builders and government. Builders supply housing at a horizontal supply curve, providing any housing that is demanded above a certain cost point. Government's involvement includes housing standards, taxes and housing subsidies. Households have a utility function, with terms for housing services, other goods and services, leisure time and the wealth and racial composition of other households in their home zone. Housing services are provided from both land and capital inputs, allowing the model to include investment into housing stock by landlords directly, with landlords looking to maximise expected discounted profits. The model is run in 10 year time steps and five zones. The model is designed to match US census data sources.

The estimation of the model's parameters occurs piecemeal, with certain coefficients fixed at the beginning, then specially tailored statistical procedures are used to find the other coefficients in sequence. Anas states that "the sequential and highly selective calibration procedures ... cannot be claimed to result in any unique coefficient set, nor is it possible to claim that the estimated coefficients are such that the entire model's predictions are maximum likelihood."

MEPLAN models developers in the incremental model not the equilibrium model, so it can not simulate a horizontal supply curve, although with adequately small time steps it would be possible to approximate one. Minimal standards of housing would be difficult to implement since land owners are not directly included in MEPLAN as an economic actor, but it may be possible to use MEPLAN's constraint process in a clever design. Otherwise, minimal standards would need to be represented in the incremental model, where landowners could improve, demolish or remove from the market any properties that do not meet minimum standards. The impact of travel time on leisure time in MEPLAN is done in a linear way, which is not as appealing as the time constraint in the Urban Institute Model. The racial and wealth externalities could perhaps be modelled as non-transportable economic factors in MEPLAN, although this would be a fairly non-intuitive artificial construction. The behaviour of land owners as expected discount profit maximisers can not be done in MEPLAN as variables in previous time periods can not be made dependent on variables in future time periods.

Coefficient estimation in MEPLAN is typically done using methods similar to those in the Urban Institute Model: certain parameters are given fixed values, then other parameters are investigated and changed to find good matches to available data. So MEPLAN model calibration is, like and Urban Institute Model's calibration, quite dependent on the priorities and skills of the model builder.

Anas's criticism of this method seems harsh however, for two reasons:

- For many of the other models in his monograph Anas does not even mention any calibration, leading to the suspicion that such models are calibrated only to the model builder's expectations.
- Using prior knowledge of parameter values or parameter relationships is well accepted in parameter estimation theory (Bard, 1974).

Both MEPLAN and the Urban Institute Model are practical to apply to real world problems - the theory has been made to fit with the data and resources available in real-world settings.

2.4.2 NBER

The National Bureau of Economic Research model (NBER) aims at being a model of the housing market with appropriate demand and supply side representations. This is a very large scale, highly disaggregated model, modelling market disequilibrium over a sequence of years. There are sub models for employment (basic and population serving) and for demographic change. Households have models of job change, the decision to move, the formation of new households and the choice of tenure (own or rent). The supply side has models for land use, the formulation of expectations, new construction and structure conversion. The NBER model has a large number of sub classifications of employment, structure, neighbourhood, housing quality, household types, life cycle, income brackets and education.

All the different types of households are allocated to dwelling sub markets by considering each household and market in turn. This lends itself to microsimulation, and indeed the 1976 model of Pittsburgh uses microsimulation. The microsimulation technique could allow the consideration of details about individual houses, such as age, number of rooms or size, but instead these have been rolled into the alternative specific constant for the dwelling sub market. An inconsistency that would make the model's results difficult to evaluate is that the choice of dwelling sub market is done using logit techniques, but the assignment to individual dwellings is done using a total cost minimisation mathematical programming technique. Each of the sub-markets do not clear in equilibrium, but the shadow rents from the cost minimisation are used to update the rents in the next time year, so presumably over time the markets would tend to equilibrium.

Some may consider the disequilibrium in housing markets to be realistic, but without a strong economic theory about how urban markets clear in disequilibrium it is difficult to interpret and understand the NBER model. The general complexity of the model only makes matters worse. It would seem that in a model this complex it is even more important to conform to well understood theories, just to allow a greater understanding of the behaviour of the model. Anas does not discuss how the model is calibrated, but hints that individual relationships are calibrated to available data, and there is no final step calibrating the entire model.

MEPLAN has coarser disaggregations than the NBER model; only a handful of different household types and structure types are normally considered.

MEPLAN assumes that prices adjust in any one time period so that the market for housing does clear, with households in aggregate consuming more or less housing as they respond to price. The choice of housing sub market can be included in the variable consumption functions in MEPLAN, and the costs of the different housing markets all influence the cost of locating in each zone, making the location assignment and sub market assignment consistent in MEPLAN (although not entirely consistent with random utility theory, since MEPLAN uses weighted averages rather than log-sum averages in it's cost calculations. See section 2.2.4).

MEPLAN deals with aggregate quantities of goods, relying on the law of large numbers (where shares at the aggregate level are equal to the probabilities at the disaggregate level) to allow its use logit models. Extensive disaggregation at the level of the NBER model (or down to a microsimulation level) would overwhelm the current MEPLAN framework.

MEPLAN is calibrated in a similar way to the NBER model's calibration, where certain individual relationships are first calibrated or certain parameters are fixed and then the whole model is run. In MEPLAN, however, there is usually a final comparison of model outputs to known quantities, and parameters are further adjusted to achieve a reasonable goodness of fit for the entire model. During this calibration process it sometimes happens that various problems of goodness of fit lead to changes in "fixed" model parameters or even in model structures. This is desirable in that a typical MEPLAN model is designed around the characteristics of a region, allowing it to represent the necessary relationships for the policies that are to be analysed within the constraints of the data that is available. Most other models, including the NBER model, are much more fixed in their representations. The disadvantages of using this flexibility include a long and labour intensive implementation.

The flexibility available in the design could in theory allow a comparison of a wide range of model designs, each of which reflect the characteristics of unique cities, unique policies, unique data and unique analysts. In practice, however, time and budget considerations usually only allow for one design evolving over time as described above.

2.4.3 CATLAS - The Chicago Area Transportation-Land Use Analysis System

The Chicago Area Transportation-Land Use Analysis System (CATLAS) was developed by Alex Anas, so there is a certain bias towards it in his book. It was designed to evaluate the impacts of transportation changes on housing values, vacancies, construction and demolition. The model runs in one year periods. A nested logit model of home and commuter mode choice is used to allocate households to zones from their employment location, where the amount of employment in each zone is exogenously specified. CATLAS has a fairly detailed model of the housing industry, with logit sub models describing whether a dwelling will be kept vacant, whether a dwelling will be demolished and whether a new dwelling will be constructed. These sub models use expected rents into the future, with expected rents being simple time discounts of the current rents. In one time period, the demand for housing in a zone is a function of rent and the amount of vacant housing in the zone is also a function of rent, so supply and demand are matched in a market clearing model by finding the equilibrium price.

Anas (1987) does not specify how the travel disutilities in CATLAS are determined. They are probably exogenously specified, meaning that CATLAS can not directly model how congestion in the transportation system interacts with land use decisions.

MEPLAN is similar to CATLAS in many ways. Logit models of home location and mode choice are used. (Although MEPLAN's use of trade weighted averages instead of log-sums for connecting these two models means that the joint choice of home location and mode choice is *not* a nested logit model.) The construction, demolition and vacancy sub models in CATLAS could be duplicated in MEPLAN's incremental model, but in most MEPLAN implementations the housing industry is not modelled in quite so much detail. MEPLAN typically varies the density of occupancy with price to clear the overall market for space, rather than explicitly modelling vacancy.

Implementations of MEPLAN typically include greater detail in terms of different industries, different economic relationships, different types of buildings and different trip types than CATLAS. In CATLAS workplaces are exogenously given, while in MEPLAN secondary employment is allocated simultaneously with residences, and the incremental model can allocate primary (basic) employment according to model outputs from the previous time period.

CATLAS has more temporal detail than a typical MEPLAN implementation, since CATLAS is run in 1 year time steps and MEPLAN usually uses 5 year time steps.

2.4.4 Models of regulated European housing markets

The price regulations of European housing markets have been explored somewhat, with Anas and Cho (1986) creating a model similar to the CATLAS model. This requires sub models of illegal subleasing, and of rationing of over demanded supply by landlords or public agencies. The rationing process includes modelling of waiting lists.

MEPLAN does not have the facility to directly model such non-market behaviour as appears to occur in European housing markets. European implementations of MEPLAN have had different sectors for public and private housing (Hunt, 1994), and constraints on price and quantity could generate monetary measures that correspond to queuing.

2.4.5 HOPSIM - A supply side simulation model

Arnott (1985) has developed a model of the competitive housing market in a state of dynamic "perfect foresight" equilibrium, where "perfect foresight" means that actors in one time period have knowledge about prices and conditions in future time periods. Housing stock is described as the floor area available at various quality levels and structural densities. Households are divided into various socio-economic groups, and households choose whether to rent or own, how much space to consume and (for owners) how much to spend on maintenance.

MEPLAN implementations typically do not contain a lot of detail on own vs. rent decisions and on structure maintenance decisions. A perfect foresight model is not practical with MEPLAN since the market equilibrium in each time period is based only on inputs from the previous time period.

2.5 Regional and Inter regional Models

2.5.1 Regional and interregional input-output models

At the regional level, Anas (1987) describes a number of models based on Leontieff (1951) input-output modelling. Input-output modelling is valuable at this level because of the importance of inter-industry shipping costs in firms higher level location decisions. Anas points out some important theoretical problems with the fixed technical coefficients in standard models, especially when industries are disaggregated according to regions.

MEPLAN uses the general input-output framework, but the use of logit models to disaggregate spatially and the variation of technical coefficients, especially for households when the utility maximising formulation is used, appear to address all of Anas's concerns.

2.5.2 Regional econometric models

Here Anas describes macro-economic models. These are typically carefully calibrated to observed data, and are designed to be consistent with data on national accounts. These models do not consider actual land use or spatial structure. Their foundation in macro rather then micro economics, the lack of detailed transportation data and the lack of spatial and land use data make them quite different from MEPLAN.

2.5.3 Regional intra-metropolitan models

In 1972, Engle *et al* proposed a model of the Boston region consisting of three sub models: a macro-economic model of regional output, employment and income distribution, a model of long term adjustments of population and capital stocks, and a model of land use allocation. An interesting feature is the inclusion of local government decisions within the model.

MEPLAN has been used in many intra-metropolitan contexts, and the use of the input-output model gives it enough industrial detail to consider the trade flows at this level. The incremental model in MEPLAN is similar to the model of long term adjustments of population and capital stocks in the Engle *et al* model. MEPLAN has nothing approaching a macro-economic model of regional totals, but these inputs to MEPLAN often come from macro-economic models of the region.

2.5.4 Models of less developed nations

Less developed nations have many unique characteristics. They often have high migration to urban areas where wages are higher but unemployment is also high. They often have extensive restrictions or tariffs on imports and exports, making certain industries largely exporting and others almost strictly internal. Both labour and capital are often less mobile because of social pressures and a lack of open capital markets.

A comprehensive model was developed by Kelley and Williamson (1983) with parameters and functional forms drawn from a vast literature from the field of development economics. Once the model was developed, it was compared to actual aggregate data with apparently reasonable results.

MEPLAN has been applied to less developed nations, but it's emphasis on markets and on short run equilibrium makes it difficult to directly represent legislative or social constraints on mobility of capital or labour. Similarly, the modelling of unemployment rates requires an understanding of the disequilibrium that occurs due to incomplete information and future expectations, neither of which is specifically available in MEPLAN. These would have to be represented in an indirect manner in the incremental model.

3 Conclusions

3.1 Overall strengths of MEPLAN

MEPLAN is a flexible, general framework based on a number of well established economic theories. Its use of behavioural logit models are theoretically and practically appealing, making interpretation of results and selection of parameters easier. The use of utility maximising formulations of household consumption make it consistent with the monocentric literature, while the use of input-output modelling makes it easy to apply to regional problems. The inclusion of many different industrial factors allows a more comprehensive model of the economy than models that only emphasise the housing industry.

The incremental model in MEPLAN allows for a wide variety of formulations describing how development and redevelopment occur through time, which seems to be a central component of many urban economic models.

MEPLAN contains a fairly sophisticated transport model, allowing it to examine detailed transportation infrastructure plans and to produce results describing the conditions of transportation networks.

3.2 Weaknesses of MEPLAN

The segregation of MEPLAN into an equilibrium model and an incremental model make it difficult to model certain processes. In particular, it is difficult to represent the types of disequilibrium and market failure that occur in labour or housing markets when vacancies are high, when unemployment is high or when markets are highly regulated. The equilibrium of these markets is core to MEPLAN, and although this is appealing to many economists there is some evidence that it does not reflect the reality of household behaviour (Richardson, 1971).

The complexity of the equilibrium model means that it cannot be solved together with variables from the incremental model, with the consequence that the incremental model can only use variables from the previous time period. This eliminates any modelling of "foresight" where actors in one time period make decisions based on variables in future time periods. The fact that the incremental model can not even simultaneously solve for variables in the current time period raises questions of stability that need to be addressed by choosing appropriately sized time increments.

A new approach for integrating behavioural logit models with input-output models should be explored, where the log-sum measure of the logit model is used in the input-output model. This would eliminate certain fundamental inconsistencies in MEPLAN, and allow it to represent economically the basic benefit of increased variety that follows from increased mobility. This is already implemented to a certain degree for households, but to include it consistently for firms and households without compromising the input-output structure may be difficult.

3.3 Further research

This review compared the MEPLAN modelling framework with a fairly comprehensive book on urban modelling from a single author in 1987 (Anas, 1987). Other sources were used for this review, notably Fujita (1987) and Knox (1987), but much has happened since 1987. A worthwhile exercise would be to search out more recent material from a wider variety of authors to see how MEPLAN fits in with other's opinions and more recent works.

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