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A GENERAL EQUILIBRIUM MODEL OF AUSTRALIA'S PREMIER CITY

by

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Abstract

Australian cities suffer from urban sprawl — leading to long average commute distances and high energy use by urban transport. To investigate this problem, we define and construct a medium-sized general equilibrium model of Australia's second-largest city — Melbourne. Individuals are modelled as utility maximisers who face a discrete number of choices. We follow the logit approach, where the probability of an individual pursuing an option (for example, living in high-density housing in zone A while working in zone B) is proportional to the utility derived from that option — taking into account the cost of the option and the effect of this cost on the total utility obtainable with given income-producing opportunities. The spatial layout of the city, through the cost of travel from one zone to another, influences the pattern of land rents, industrial activity, and housing location and density. As in other general equilibrium models, market-clearing and accounting equations allow the whole economy of the city to be presented within an integrated framework. The result is a fairly general economic model of urban land use and travel demands. We use it to analyse the effects of population growth and policy initiatives on transport usage.

1. INTRODUCTION

Australia is one of the world's most urbanised nations — its five largest cities account for 60% of its population. For their population size, these cities are very large — per capita use of urban land is high by world standards. High levels of automobile ownership and use are both a cause and a consequence of this urban sprawl. Traffic congestion, pollution, and a high national oil bill are associated problems.

The policy focus of this paper is the connection between planning or transport policies and road transport usage, and between road transport usage and energy usage.[1] Road transport accounts for 65% of Australia's consumption of petroleum products. Commuting trips account for about 35% of private transport usage. Hence, reductions in average commuting distances can make a substantial contribution to energy conservation.

To address these issues we develop a prototype applied general equilibrium model which can cope realistically with some of the special demands of urban modeling. In particular, we concentrate on geography — an area which has received little attention by formal modellers. As befits a prototype, our model is simple and stylized — yet it still incorporates a considerable degree of empirical realism.

The model is applied to the city of Melbourne — Australia's second largest city. It is used to investigate three propositions that have gained currency in the discussion of the relation between urban form and transport energy demands:

- that if population growth is allowed to bring about an extension of the city fringe, average per capita transport demands will increase dramatically - because fringe dwellers currently tend to travel much more than inner urban residents. *The model suggested that this fear may be exaggerated.*
- that government-imposed transport cost increases could produce a smaller, denser city, with reduced per capita transport demands. *The model supported this conclusion, at the same time predicting the side effects of such a policy.*
- that a government policy of urban consolidation (i.e., denser housing) could also produce a smaller, denser city, with reduced per capita transport demands. *The model lent little support to this idea; it illustrated mechanisms that worked in the opposite direction.*

The remainder of this paper is laid out as follows. We first consider previous approaches to urban modeling, contrasting neo-classical general equilibrium models with partial equilibrium and non-economic models of city form. In Section 2 we present a formal description of our own model. The model is applied in Section 3, which describes the results of three simulations. We conclude in Section 4.

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[1] The research leading to this paper was undertaken as part of NERDD (National Energy Research Development and Demonstration) Project no. 1388. Some additional details of the material presented here may be found in Horridge (1991).

A. Other Approaches to Urban Modeling

The majority of studies of urban transport use have been narrowly focussed, and have been of a partial equilibrium nature. For instance, such a study might examine the relative importance of various determinants of public transport use. More comprehensive models also typically adopt a partial equilibrium approach. For example, a model of transport demand might take the distributions of population and employment to be fixed, with travel costs merely determining the 'trip' matrix. That is, the model determines the number of people living in area *h* who choose to commute to work location *w*, but the row and column totals of this matrix are given. Partial models of this type do not incorporate the influence of travel costs on land values, or the influence of land values on land use. They are generally ill-suited to longer-run analyses which must account for increases in city size, and for changes in the use of existing urban land.

A general equilibrium model offers the opportunity to capture these feedback effects. Unfortunately many of the general equilibrium models of land use that have been developed by theorists are poorly adapted to empirical work. They exhibit three principal drawbacks. First, because they are formulated in continuous space, they must be solved analytically. Mathematical tractability then enforces a series of very restrictive and unrealistic assumptions, for example that:

- space is uniform in all directions, except for one singular point – the city centre or CBD. The city will then display circular symmetry, so that geographical position can be represented by a single variable, the distance from the CBD.
- all employment is located in the CBD.
- the CBD consists of a point or else of a circular region.
- transport costs depend only on distances: there are roads everywhere.

Real cities have evolved in a far more untidy pattern, influenced by natural features and by the presence of existing transport routes. The continuous treatment of space also hinders the collection of data for these models. Spatial data are normally available on a discrete basis – as population by suburb, say, rather than as a population density function.

A second aspect of theoretical models is that tastes and technology tend to be uniform, or are represented by only a few representative individuals or firms. The profit-maximising assumption that land will be used for the purpose which commands the highest rent leads to the result that the city is divided into a number of annular zones, each of which is dedicated exclusively to one particular purpose. In reality, specialization in land use is normally incomplete; alternative uses coexist in most areas of the city.

Third, theoretical models often portray static or timeless equilibria which are governed only by market forces. In effect, the city is constructed afresh according to free market principles at each moment in time. Real city development, on the other hand, is constrained by the historical pattern of development and by numerous government interventions. The latter include zoning regulations and the provision of infrastructure.

These drawbacks hinder the empirical application of this type of model to real-life policy and planning problems. Instead, such models are used to explore the qualitative implications of particular mechanisms. For example, they provide an explanation for the usual negative correlation between rent levels and distance from the city centre.

In the next section, we present a model which preserves the advantages of a formal neo-classical, general equilibrium approach, but which avoids the three disadvantages mentioned above. This is achieved *via* three changes in the assumptions.

- The continuous treatment of space is replaced by the division of the urban area into a discrete number of zones. Zone boundaries may be irregular; they are chosen to correspond to existing administrative or data collection boundaries. We take no account of spatial differentiation *within* zones: fine geographical detail is achieved by increasing the number of zones. The spatial relation between zones is represented by tables showing distances and travel costs between any pair of zones.
- We explicitly take account of variety in consumer tastes, enabling us to model the city's varying mixture of land uses, instead of being forced to represent it as an arrangement of monocultures.
- We make generous allowance for historical fixities and for government intervention or regulation, both of which may be location-specific.

These innovations allow us to utilise existing data sources and to represent the city as it really is — an untidy, irregular pattern of land-use proportions. We sacrifice the possibility of a purely algebraic solution: our model must be solved numerically. Today's cheap computing means that numerical solution techniques impose few constraints either on the choice of functional forms or on the dimensionality of the model. We can construct as complex a model of the city as our data sources allow.

When used to forecast transport energy demands, a general equilibrium model has two particular advantages.

- We can simulate the effects of a very wide range of policy and other exogenous changes, whether or not these are directly transport related — such as emission controls — or have only an indirect effect — such as changes in residential density.
- Whatever change is simulated, we capture not only the direct impact of the change, but also the full system-wide pattern of indirect effects. Not only is our projection of energy demand more accurate; we can explore implications in various other dimensions, such as the effects on employment distribution, income distribution and social equity, the net effect on environmental pollution from all sources including non-transport sources, and so on.

2. FORMAL DESCRIPTION OF THE MODEL

2A. Model Categories

The urban region is divided into Z zones. Within each zone, the model distinguishes between land used for:

- residential purposes,
- business or industrial purposes, and
- 'other' purposes: land within the urban area which does not command a rent comparable with that payable on land used for business or residential purposes. This includes swamps, flood-prone land, parks, cemeteries, army facilities and agricultural land: all areas where physical unsuitability or current public policy preclude business or residential use.

Residential land in each zone is further distinguished by housing density — measured as the area occupied by a single worker/household. We assume that residential land is divided into R types, and that all plots of a given type in the same zone are of the same size.

We assume that each household contains one worker, i.e., there are no non-working or two-income households. The population is divided into S income groups. In the model these income differences arise from differential access to non-labour income, i.e., land rents. In reality, access to accumulated wealth — in particular the owner-occupied home — is one of the main characteristics of residents of the more expensive zones. There is only one type of labour, although the wage does vary between zones.

There are two types of produced goods: transport services and 'other' goods. There are two primary factors: land and labour. Land is also consumed directly by the household sector.

2B. Equations of the Model

Table 1 lists the equations of the model. Table 2 contains a typical choice of endogenous variables, while Table 3 contains the corresponding choice of exogenous variables.

In Tables 1 to 3 the subscripts w, h and z run from 1 to Z. w refers to zone of work or of production; h refers to zone of residence, and z refers to zones in general. Subscript r runs from 1 to R and indicates housing density, while subscript s runs from 1 to S, and refers to income group[2].

Individual Consumption and Location Decision

Each worker faces three separate choices: where to work, where to live, and what size of plot to occupy: RZ^2 options in all. The decision is modelled using a multinomial choice or logit model derived from Domencich and McFadden (1975) and Anas (1982). Under this approach, each individual is assumed to choose the option which yields him or her the most utility. However, each individual has a unique utility function of the form:

$$U_{ij} = V_i + \varepsilon_{ij}$$

[2] The convention in using subscripts w, h, z, r, and s is only an aid to memory.

Table 1: Equations of the Model

Individual Consumption and Location Decision		**No.**
(1)	$W_{whrs} = A_{wh}(O_{whrs}\text{-}O')^{\alpha}(L_{hr}\text{-}L')^{1\text{-}\alpha}$	Z^2SR
(2)	$\ln(N_{whrs}) = \lambda_s + \sigma.\ln(W_{whrs})$	Z^2SR
(3)	$\sum_{w,h,r} N_{whrs} = Q_s$	S
(4)	$O_{whrs}P_o + R_{hr}L_{hr} = I_{whsr}$	Z^2SR
Disposable Income		
(5)	$I_{whrs} = W_w + S_s - D_{wh}P_t(1\text{+}V) + \delta_{whrs}$	Z^2SR
(6)	$\delta_{whrs} = \Omega/(O_{whrs}\text{-}O')$	Z^2SR
Market Clearing Equations		
(7)	$\sum_{w,h,r,s} N_{whrs}O_{whrs} = \sum_{w} O_w$	1
(8)	$\sum_{w,h,r,s} N_{whrs}D_{wh} = \sum_{w} T_w$	1
(9)	$\sum_{w,s} N_{whrs}L_{hr} = B_{hr}$	ZR
(10)	$C_z + M_z + \sum_{r} B_{zr} = F_z$	Z
(11)	$\sum_{h,r,s} N_{whrs} = E_w$	Z
Industry Technology		
(12)	$Z_w = J_wE_w^{\beta}C_w^{1\text{-}\beta}$	Z
(13)	$\beta C_wH_w = (1\text{-}\beta)E_wW_w$	Z
(14)	$T_w + \theta O_w = Z_w$	Z
(15)	$P_o = P_t\theta$	1
(16)	$O_w = T_w\phi$	Z
(17)	$O_wP_o + T_wP_t = E_wW_w + C_wH_w$	Z
Miscellaneous Equations		
(18)	$G_{zr} = R_{zr}/H_z$	ZR
(19)	$S_s = \mu\tau_s$	S
Total Equations		$5Z^2RS + 2ZR + 7Z + 2S + 3$

Table 2: Typical Endogenous Variables

		No.
δ_{whrs}	Technical income supplement	Z^2RS
E_w	Employment in zone *w*	Z
I_{whrs}	Disposable income (after transfers and transport)	Z^2RS
λ_s	Slack variable for income group *s*	S
μ	Slack variable for income distribution	1
ϕ	City-wide ratio of other/transport goods	1
N_{whrs}	No. working in *w*,living in *h*, on plot type *r*, of income group *s*	Z^2RS
O_w	Output of other goods, zone *w*	Z
O_{whrs}	Per capita consumption of other goods by *w,h,r,s*	Z^2RS
P_t	Price of travel services (per kilometre, ex tax)	1
R_{hr}	Rent per hectare, zone *h*, residential purpose *r*	ZR
S_s	Per capita allocation of rents and tax revenue	S
T_w	Output of transport services, zone *w*	Z
W_w	Wage in zone *w*	Z
W_{whrs}	Utility of sub-population *w,h,r,s*	Z^2RS
Z_w	Industrial output level, zone *w*	Z
For each zone, TWO of:		
C_w	Area used for industrial purpose, zone *w*	Z
H_w	Rent per hectare, zone *w*, industrial purpose	Z
M_z	Area devoted to non-market use, zone *z*	
For each zone and residential density, ONE of:		
B_{hr}	Area devoted to residential density *r*, zone *h*	ZR
G_{zr}	Ratio, (residential rent *r*)/(business rent)	
Total Endogenous Variables		$5Z^2RS + 2ZR + 7Z + 2S + 3$

where U_{ij} is the utility derived by individual *j* from option *i*. V_i is the 'systematic' utility of option *i*, while ε_{ij} is an individual or idiosyncratic component of utility with the Weibull or extreme value stochastic distribution:

$$\Pr(\varepsilon_{ij} < \varepsilon) = e^{-e^{-\varepsilon}}$$

It can be shown[3] that the proportion of individuals choosing option *i* is given by:

$$e^{V_i} / \sum_j e^{V_j} \qquad \text{(A)}$$

For the utility function V we chose a modified Stone-Geary form with two arguments: consumption of residential land and of 'other' goods. The 'other' goods, it should be noted, include the services derived from housing itself as opposed to the land on which it stands. Commuter transport services are also consumed, but these yield no direct satisfaction; instead the cost of commuting is deducted from income to give the household budget. In the logit framework, monotonic transformations of the V function affect the distribution of the options chosen. Our form of the Stone-Geary utility function is:

$$V_i = \sigma.\ln(W_i) \qquad \text{(B)}$$

where W_i represents the conventional Stone-Geary form:

$$W_i = A_i(O_i\text{-}O')^{\alpha}(L_i\text{-}L')^{1-\alpha}$$

Here, O_i and L_i are the quantities of other goods and land respectively, consumed by an individual choosing option *i*. O' and L' are 'subsistence' or minimum levels of consumption. A_i is an option-specific taste parameter.

[3] See Maddala, 1983, sections 2.12 and 3.1. The Weibull distribution is chosen for reasons of mathematical tractability; it is responsible for the simplicity of (A). It resembles the logistic or cumulative normal distribution and gives similar empirical results. If the logistic distribution had been used, (A) would have been a non-analytic expression containing an improper integral.

Table 3: Typical Exogenous Variables and Model Parameters

		No.
A_{wh}	Work-and-home-specific taste variables	Z^2
D_{wh}	Distance from zone *w* to zone *h*	Z^2
J_w	Production efficiency, zone *w*	Z
L_{hr}	Plot size of residence type *r* in zone *h*	ZR
P_o	Price of other goods (numeraire)	1
Q_s	No. of workers of income class *s*	S
τ_s	Income distribution variable	S
V	Rate of transport tax	1
For each zone, ONE of:		
C_w	Area used for industrial purpose, zone *w*	Z
H_w	Rent per hectare, zone *w*, industrial purpose	
M_z	Area devoted to non-market use, zone *z*	
For each zone and residential density, ONE of:		
B_{hr}	Area devoted to residential density *r*, zone *h*	
G_{zr}	Ratio, (residential rent *r*)/(business rent)	ZR
Total Exogenous Variables		$2Z^2 + 2ZR + 2Z + 2S + 2$
Model Parameters:		
α	Parameter of utility function	
β,θ	Parameters of production function	
F_z	Total area of zone *z*	
L',O'	Subsistence quantities of land and other goods	
σ	Elasticity of substitution between options	
Ω	Technical income supplement parameter	

We can deduce from (A) and (B) that, in each zone, the number of individuals choosing option *i*, N_i, is given by

$$\ln(N_i) = \lambda + \sigma.\ln(W_i) \qquad \text{(C)}$$

where the value of λ is given by the condition that the sum (over *i*) of the N_i is equal to the given population. The percentage change in the ratio of the numbers of individuals choosing options *i* and *j* is given by:

$$n_i - n_j = \sigma(w_i - w_j)$$

Here n_i and n_j are the percentage changes in the numbers of individuals choosing options *i* and *j*; similarly w_i and w_j are the percentage changes in the W. The σ parameter thus resembles an *elasticity of substitution* between options.[4]

The numbers of individuals in each income class S are given exogenously; whether to be rich or poor is not on the menu of choices offered to individuals. Hence equation (C) must be applied separately to each income class. Adopting a more explicit enumeration of the RZ^2 options mentioned above, we get the first two equations of Table 1:

$$W_{whrs} = A_{wh}(O_{whrs}-O')^{\alpha}(L_{hr}-L')^{1-\alpha}$$

$$\ln(N_{whrs}) = \lambda_s + \sigma.\ln(W_{whrs})$$

Here, the subscripts *w* and *h* refer to the zones of employment and residence respectively. The subscript *s* refers to income class and while r refers to housing density type. A_{wh} is an option-specific taste parameter reflecting the possibility that particular home-work combinations may

[4] The analogy to the elasticity of substitution underlies our choice of the σ symbol. Note that σ also controls the weight of the stochastic term in total utility. In fact, σ is inversely proportional to the share of the variance of U in total U. A very large value for σ implies non-stochastic utility, with complete specialization in consumer demand.

display some special attraction or repulsion, not explicable by the consumption levels which they offer.The λ terms are defined by the adding-up requirement (3) that:

$$\sum_{w,h,r} N_{whrs} = Q_s$$

where Q_s is the exogenous number of individual s in each class.

When aggregated over all individuals, the choice of home and work location implies two core mechanisms of the model:

- a series of 'bid rent' schedules showing how much residential land in each zone would be demanded at given land rentals.
- a series of labour supply schedules, showing how many people would opt to work in each location at given wage levels and commuter transport costs.

Demand for Other Goods

Individuals consume transport services and other goods, although they derive utility only from the latter and from land. Further, their spending on residential land and on transport is fully determined by their choice of work, home, and plot size. Two consequences follow. First, the expenditure shares of land and other goods are not the shares which would be optimal if individuals could choose plot size: they are the outcome of a constrained choice. Second, since all income is consumed, spending on other goods can be determined as a residual through the budget constraint (4).

Disposable Income

Equation (5) states that disposable income, I_{whrs}, is the sum of wages, W_w, and non-wage income, S_s, *less* the cost of commuting, $D_{wh}P_t(1+V)$, *plus* an income-supplement term, δ_{whsr}, defined by equation (6). The income-supplement term is required to ensure that consumption of the other good, O_{whrs}, always exceeds O' — otherwise equation (1) would be undefined. By assigning Ω a sufficiently small value, we can ensure that for all *w*,*h*,*r*, and *s*, either δ_{whrs} or N_{whrs} is tiny: thus no meaningful model results are affected by this artifice.

Market Clearing Equations

Equation (7) states that the sum of all individual demands for other goods is equal to the total production of other goods. Similarly, equation (8) equates demand and supply for transport services. An implication of these equations is that consumers treat goods from different sources as perfect substitutes. Also, transport of goods from source to user is assumed to be costless. We return to these assumptions later.

Equation (9) equates the sum of individual demands for residential land to the supply of each density type in each zone. Next, equation (10) states that in each zone the sum of the land used for industrial, other, and residential purposes is equal to the total area of the zone, F_z.

Finally, equation (11) equates the supply and demand for labour within each zone.

Industry Technology

In each zone, industry produces a composite measure of output, Z_w, by combining two primary factors, land and labour, according to the Cobb-Douglas production function (12). The cost minimizing factor proportions are given by (13). The capacity measure Z_w may be converted into either transport services or other goods, as in (14). The transformation frontier between the two is flat; in each zone it has the same slope, θ, so that (15) determines the relative prices of the two goods. Each zone produces the same output mix, given by (16). Finally, the zero-pure profits condition (17) provides that costs equal revenue for industry in each zone.

Miscellaneous Equations

Equation (18) defines a potential target of planning policy, G_{zr} — the ratios of residential land rents relative to the rents on business land.

The variable τ_s in equation (19) allows for variation in the distribution of non-wage income. The slack variable μ is needed to ensure that equation (20) is not violated.

Supplementary Budget Identity

By Walras' Law, the following equation is redundant; we use it for checking purposes only. It states that the sum of all the transfers S_s is equal to the total non-wage income.

$$\sum_{h,r} B_{hr} R_{hr} + \sum_{z} C_z H_z + TP_t V = \sum_{s} Q_s S_s + \sum_{w,h,r,s} N_{whrs} \delta_{whrs}$$

2C. Model Closure

The complete system contains $5ZR^2S + 2ZR + 7Z + 2S + 3$ equations. Hence, the same number of variables must be left endogenous, leaving $2ZR^2S + 3ZR + 2S + 2$ variables to be set exogenously. A possible choice of exogenous variables is listed in Table 3.

The variables A_{wh}, D_{wh}, and J_w may be viewed as physically and psychologically determined. Variables L_{hr}, τ_s and Q_s are determined partly by policy and partly by history. Once house plots have been laid out, it is costly to change plot sizes. The income distribution variables τ_s and Q_s reflect not only government redistributive policy but also the life-cycle structure of the population — older families are more asset-rich.

The variables H_w, M_z, C_w, B_{hr}, and G_{zr} may be thought of either as instruments or as targets of planning policy. For example, a planning authority which resisted market forces might control the land areas used for each purpose by setting values for C_w and B_{hr}. Since the area of each zone is fixed, the area of land used for 'other' purposes would also be under direct planning control.

Alternative choices of exogenous variables allow land allocation to be more responsive to market forces. In the simulations described below, the central and inner zones of the urban area are treated differently to those zones around its perimeter. The former are assumed to be land constrained — the free land area of each, M_z, is set exogenously. The implies that the average rental level of the remaining land area adjusts to balance supply with demand. The allocation of this area between different usages, however, is price-determined. Planners issue change-of-use permits in such a way as to hold the rental ratios G_{zr} constant.[5]

In the zones at the city's edge we assume that planners are still more accommodating: land may be used for any purposes that the market demands at the prevailing rental levels. Here, H_w and G_{zr} are held exogenous. M_z is endogenous so that all land types are in elastic supply.

Even in the latter case, planners still wield considerable power, for there is no requirement that rental levels H_w and R_{wr} be *equal* as they would be in a free market. Rather planners reflect community preference in insisting that land used for business purposes command a higher rent than residential land, and that high-density residential land command a higher rent than low-density residential land.

As for the final two exogenous variables, the transport tax rate V is purely a policy variable. The price of other goods, P_o, is the numeraire. Behaviour in the model is influenced only by relative prices — the value of P_o sets the overall price level without, however, affecting the values of any real variables.

2D. Aggregation Level

To simplify both computing and the analysis of model results we kept the dimensions of the model (i.e., the numbers Z, R and S) as small as was consistent with maintaining empirical relevance.

For our initial implementation of the model we divided the Melbourne Statistical Division into 9 (Z=9) zones. This seemed to be the smallest number that allowed full scope for the model's spatial mechanisms. Each zone included a number of the 56 Melbourne Local Government Areas (LGAs) — the level at which most data are available. The boundaries of the zones were chosen to point up the distinction between zones in which free land is available, and zones which are more or less built up. The 9 zones are shown in Figure 1. The boundary between the five inner zones and the four outer zones roughly corresponds to the edge of the built-out parts of Melbourne. Importantly, the outer zones contain ample space to allow for foreseeable expansion in the city's area — if planning authorities were prepared to allow this.

[5] Another option would be to exogenize the M_z, C_w, and the ratios of the R_{hr} to each other. This would imply that total areas of business and residential land were fixed, while allowing residential density to vary.

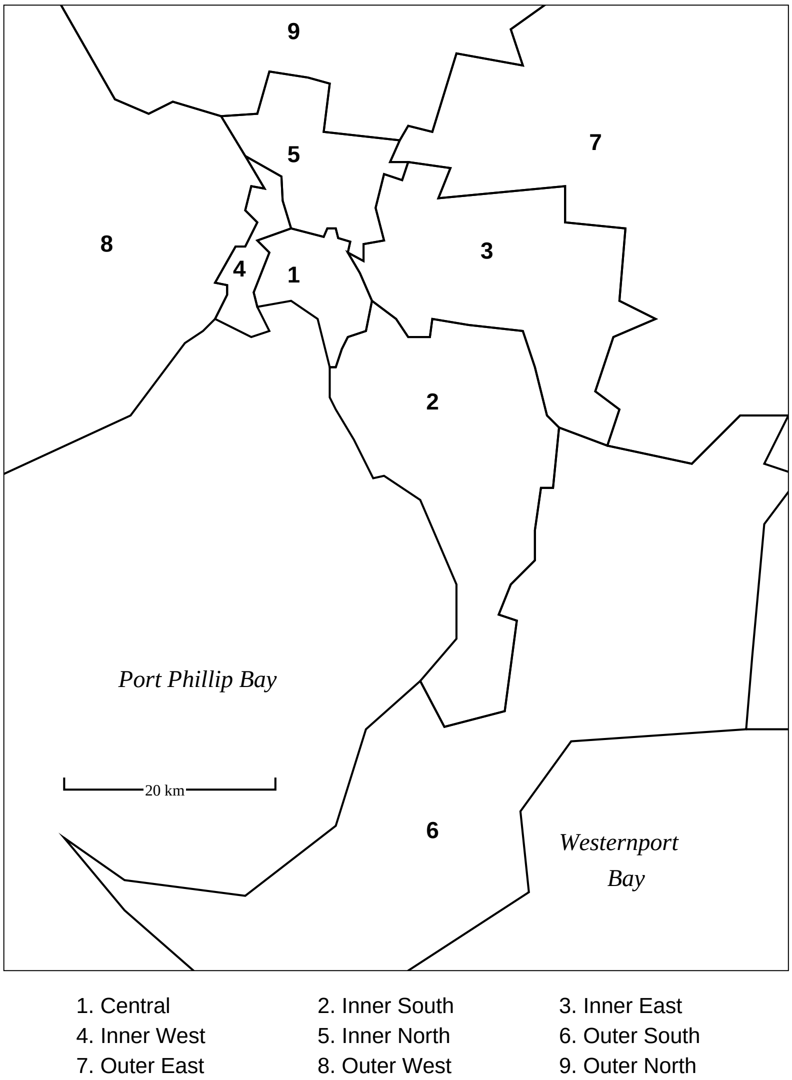

Figure 1. Zones of the Melbourne Region

Residential land is divided into two types (i.e., R=2):

- 'flats', that is, higher density housing
- 'houses', that is, lower density housing

It is assumed that the area occupied by a 'flat' is half that used by a 'house'. In fact, this is used as the definition of these two terms: if we ranked all dwellings according to their land area we could divide the spectrum into two parts in such a way that the average area of the larger dwellings was double that of the smaller.

Two income groups are defined: the 'rich' and the 'poor' (i.e., S=2). The 'rich' group is defined as that half of the population which receives greater than the median income; the rest are 'poor'.

With these values for Z, R and S the equation system of Table 1 contains 1726 equations and 1948 variables. Definitions of useful subtotals and ratios of the core variables added an additional 200 variables and equations.

2E. Model Solution Procedure

The model is solved using a non-linear equation-solving package developed by the author to solve a macro forecasting model. The package accepts an arbitrary system of equations in algebraic format and solves them using the Newton-Raphson procedure. Numerical differentiation and sparse matrix methods are used. The package allows any partition of variables between exogenous and endogenous groups which satisfies rank constraints.

A typical solution (finding all variable values to around 10 significant figures) involves 5 or 6 Newton-Raphson iterations and takes about 5 minutes on an IBM AT.

2F. Calibration of the Model

Calibration is the process of constructing a base solution of the model: the unshocked scenario. We infer unknown or unobservable parameter and variable values from those values that are known. We used the standard model solution procedure to perform this task — treating as exogenous variables all observable data and as endogenous variables most behavioural parameters and unobservable data. The dimensionality of the taste and technological shift variables therefore reflects that of the available data. Our exogenous settings included both genuine data and judgemental priors. The genuine data included:

- the F_z, drawn from ABS (Australian Bureau of Statistics) geographical data.
- the N_{wh} ($=\sum_{r,s} N_{whrs}$), found by aggregating a 56 × 56 cross-tabulation of workers by LGAs of work and residence, drawn from 1986 Census data.
- The D_{wh} (interzone distances), computed from data supplied by the city transport authority, showing the length of the quickest road route between any two zones.
- the ratios of 'housedwellers' to 'flatdwellers in each zone (that is, the $\sum_{w,s} N_{wh1s} / \sum_{w,s} N_{wh2s}$), drawn from 1986 Census data.

Other assumptions included the following:

- we constrained the average value of the A_{wh} to be one.
- the value of σ was determined *via* a primitive form of estimation. We chose that value of σ which implied (when the entire model was solved) a minimum variance for the A_{wh}, weighted by the N_{wh}. The chosen value was 20.
- we set $Q_1 = Q_2$ as a matter of definition.

Some necessary data were unobtainable. We replaced these data by judgements, influenced in some instances by partial or indirectly relevant data sources. For instance:

- we assigned per hectare rental rates for land used for 'houses', influenced by housing price data — the latter cannot be used directly as they also include the value of structures.
- we set values for the average plot size of 'houses' in each zone on an impressionistic basis. Houses in the central zone occupied only half the area, on average, of those in the outermost zone.
- in the inner zones, we set the proportions of all land not used for commercial or residential purposes — this includes roads, parks, schools and so on. In the outer zones market demand determined how much land was used.

Table 4 summarizes the main aggregates of the model database. The first three rows (which add to 1) show the proportions of all residential and commercial land devoted to high and low-density housing and to business use. The fourth row shows the proportion of all land which is not devoted to any of these purposes. Row 5 shows the proportion of residents who live in 'flats'; highest in the central zone and very low in the outer zones. Row 6 shows the proportion of all residents of each zone who also work in that zone: it is the 'outward measure of self-containment' (see Sams and Beed, 1984). Row 7 shows the proportion of all residents of each zone who work in the Central zone: these are the commuters most likely to use public transport. Row 8 shows the average commute distance in kilometres for residents of each zone: it increases with distance from the city centre. Rows 9 and 10 are deduced by the model: they indicate that, apart from the economic factors incorporated in the model, taste and technology differences between zones are needed to explain the data incorporated in the base scenario. Row 9 shows the averages over w of the A_{wh}; these may be interpreted as measures of the attractiveness of each zone to potential residents. They suggest that the Central and Inner South zones are particularly attractive, while the Outer zones are the reverse. Row 10 is an index of the technological efficiency of industry in each zone — the model variable J_w. The values suggest that industry located in the inner zones enjoys a special advantage which is sufficient to outweigh the penalty of higher rents. Row 11 shows the plot sizes in hectares of the 'houses' in each zone: it serves as a measure of net residential density. Rows 12 and 13 show respectively the proportions of the upper and lower income residents who live in 'flats'. They indicate that 'flats' are mainly occupied by the poorer residents.

Table 4: Selected Data: Base Scenario

	1 Central	2 Inner South	3 Inner East	4 Inner West	5 Inner North	6 Outer South	7 Outer East	8 Outer West	9 Outer North
1 land ratio, high density housing	0.337	0.102	0.058	0.123	0.104	0.042	0.023	0.037	0.018
2 land ratio, low density housing	0.202	0.721	0.857	0.664	0.735	0.842	0.887	0.846	0.860
3 land ratio, industrial purposes	0.461	0.177	0.085	0.213	0.162	0.116	0.090	0.117	0.122
4 land used for other purposes / total land	0.200	0.450	0.300	0.200	0.250	0.933	0.903	0.876	0.939
5 proportion of residents who live in high density housing	0.770	0.220	0.120	0.270	0.220	0.090	0.050	0.080	0.040
6 proportion of residents who live & work in same zone	0.747	0.565	0.417	0.294	0.427	0.404	0.285	0.392	0.255
7 proportion of residents who work in Central zone	0.747	0.317	0.359	0.403	0.370	0.112	0.238	0.334	0.284
8 average commute distance (km)	8.9	15.6	15.4	11.2	12.0	21.5	21.8	16.5	19.7
9 residential preference factor	1.129	1.169	1.086	0.951	1.026	0.962	0.892	0.911	0.874
10 industrial efficiency factor	199	188	191	187	189	182	182	182	182
11 area of house plot (ha.)	0.060	0.070	0.100	0.080	0.080	0.120	0.120	0.120	0.120
12 proportion of 'poor' who live in high density housing	0.939	0.375	0.261	0.325	0.300	0.107	0.057	0.090	0.042
13 proportion of 'rich' who live in high density housing	0.331	0.107	0.080	0.104	0.094	0.059	0.041	0.052	0.036
14 ratio of jobs to residents	4.365	0.829	0.637	0.993	0.867	0.559	0.430	0.570	0.611

The chief data source was the 1986 Census. For confidentiality reasons, the ABS released this not in unit record form, but in the form of cross-tabulated data. Limits on the size of each cross-tabulation meant that only the subtotals of some matrices (e.g., the N_{whrs}) were available. As mentioned previously, we compensated for these deficiencies by restricting the dimensionality of option-specific taste parameters.

The most important omissions in the non-Census data were the areas in each zone devoted to particular purposes. This information is publicly available only in the form of maps. Our resources did not allow for the manual measurement of map areas. However, the widespread adoption of computerised geographical information services promises more ready access to cartographic data.

3. MODEL SIMULATIONS

In this section we construct three scenarios for the future development of Melbourne over the next 20 years, showing the effects of:

- a 30% growth in population and employment.
- a tax on travel which increases the per-kilometre price of travelling by 20%. Although not explicit in the model, this could be brought about by increasing fuel taxes. Alternatively, a similar result could be brought about through road tolls.
- urban consolidation: a change in planning rules which favours the construction of medium density housing ('flats') relative to low-density housing ('houses'), or facilitates the conversion of land used for houses into that used for flats. Such policies have been advocated as an indirect means of bring about reductions in transport use — and hence fuel savings.

The length of the timescale — 20 years — does not enter explicitly into the model equations. It signifies only that the choice of exogenous variables, and the size of the exogenous shocks and resulting endogenous changes, presuppose a fairly long adjustment period. For example, our simulations allow for limited conversion of land use between different purposes. We assume that natural obsolescence of the building stock allows this conversion to take place without large adjustment costs. Too short a timescale would undermine the plausibility of this assumption: it might imply that new factories, say, were torn down to make way for housing. For shorter timescales, a different closure would be appropriate, which placed the burden of adjustment on prices rather than quantities.

The results are presented in percentage change form, i.e., they show, for selected variables, the percentage difference between two solutions. For the first simulation we report percentage differences between the initial scenario which depicts *contemporary* Melbourne, and a *future* scenario which takes into account the population increase[6]. For the remaining simulations the reported percentage changes compare two different *future* scenarios. For example, the second simulation compares Melbourne with the population increase *and* a transport tax to Melbourne with the population increase alone. That is, it shows the effects of the transport tax in isolation. This presentation eases the explanation of policy effects, but requires careful interpretation. One effect of the transport tax is that the city shrinks, as remote residential locations become less attractive. On its own, such a result seems unrealistic; it would mean that houses on the city's edge were demolished to make way for fields and bushland. In reality, the adjustment to the transport tax would take place simultaneously with the effects of population growth. The transport tax does not make the city shrink; it simply causes it to expand less rapidly. In order to interpret the second and third simulations as forecasts, we need to combine their results with the results from the first simulation.

The Closure

The same choice of exogenous variables was used for each simulation. It follows the pattern set out in Table 3. Regardless of zone, exogenous variable settings controlled:

- consumer preferences for particular work and home locations.
- industry technology.
- geographic data such as the areas of, and distances between zones.
- the total numbers of 'rich' and 'poor', and their relative incomes.
- the rate of tax on transport
- the *relativities* G_{zr}, or ratios between the rental rates of land used for 'houses', 'flats', and for business purposes.
- the L_{hr} or residential plot sizes in each zone.

For the remaining exogenous variables we differentiated between the Central and the four Inner zones which are effectively 'built-out', and the Outer zones where land is still available.

- In the inner zones, we held constant the M_z or the amount of land used for 'other' purposes. This also holds constant the total amount of land used for housing and business purposes, thus determining the overall level of rents.
- In the outer zones, we held constant the H_w or business rents per hectare. This also holds constant the rents on each type of housing land. Land for each use was assumed to be in elastic supply, while the area of 'other' land accommodated.

3A. An Increase in Population

In this simulation the working population, the total number of residents, and the total numbers of 'rich' and 'poor' were all made to increase by 30%. Some results are shown in Table 5. Note that the results show percentage changes from the initial or calibrated solution of the model.

To understand the results, imagine first that residential densities in the inner zones are unchanged, so that the entire increase in population must live in the four outer zones. raising their population by about 100% (row 1). Industry in each zone in the model faces 36 individual labour supply curves — corresponding to labour from each of the 9 zones, 2 housing densities, and 2 income groups. Because of the smaller travel costs, labour living locally or nearby is prepared to work for less than is remote labour. The increase in the population of the outer zones means that for industry in these zones a greater proportion of the potential workforce now lives locally. Hence the aggregate labour supply schedule shifts down. Because industry's non-wage costs — rents — are fixed in these zones, and because industry output has to be sold at a city-wide price, output must increase and labour demand schedules must move outward sufficiently to restore the old wage level. Hence output and employment also increase by about 100% in each of these outer zones (row 2).

The expansion of employment opportunities in the outer zones relative to employment city-wide means that a greater proportion of their residents are able to, and choose to, work locally

[6] The future scenario does not incorporate the technological progress which is likely over the next 20 years.

(row 3). Because of this, the average commute distance of the outer residents falls by between 3% and 5% (row 4).

Residents of the inner zones now find that the greatly increased population of the adjacent outer zones is competing with them both in the housing and labour market. This causes a rise in housing costs and a fall in wages in the inner zones (rows 5 and 6). We assume that the relativities between the rents of land used for 'houses', 'flats', and business remain unchanged. The land market clears *via* a rise in all three. The increased rents:

Table 5: Percentage Change Effects of a 30% Population Increase

	1 Central	2 Inner South	3 Inner East	4 Inner West	5 Inner North	6 Outer South	7 Outer East	8 Outer West	9 Outer North
1 Residents	2.94	1.60	0.10	-0.14	0.50	108.5	103.7	106.7	102.7
2 Employment	17.73	12.48	13.40	36.40	23.63	108.3	105.0	105.7	90.29
3 Proportion of residents who live & work in same zone	0.00	-4.25	-5.04	-5.44	-2.81	14.36	17.54	15.82	17.65
4 Average commute distance	0.46	2.25	1.63	1.96	1.76	-4.74	-4.30	-3.81	-3.20
5 Rent of land for housing	13.33	10.89	10.16	13.87	11.30	0.00	0.00	0.00	0.00
6 Wage level	-0.92	-0.76	-0.72	-0.96	-0.80	0.00	0.00	0.00	0.00
7 Proportion who live in high density housing	8.44	13.64	5.00	31.48	20.00	2.22	0.00	1.25	0.00
8 Proportion of residents in higher income bracket	2.16	16.96	12.07	26.61	26.42	-8.96	-7.04	-6.98	-6.23
9 Amount of residential land	-2.49	-0.14	-0.20	-5.05	-1.97	108.4	103.6	106.7	102.7
10 Amount of industrial land	2.91	0.66	2.17	18.67	10.17	108.3	105.1	105.7	90.32
11 Amount of residential plus industrial land	0.00	0.00	0.00	0.00	0.00	108.4	103.7	106.5	101.2

- put downward pressure on wages and output.
- incline residents to choose high-density housing rather than low,thus saving land (rows 7 and 9).
- increase the proportion of higher income residents (row 8).
- induce business to substitute labour for land (rows 2 and 10).

Whether the share of land used for business rises or falls, or whether the resident population rises or falls, depends upon the interplay of these factors. In the Inner West, for example, the resident population actually falls slightly, in spite of a pronounced increase in residential density. This is also the zone in which rents rise the most.

Falling wages in the inner zones (relative to those on the edge) induce some inner zone residents to cease working locally and instead commute to outer suburbs. Thus the average commuting distance of inner zone residents increases (row 4).

Some concerned analysts have argued that increased population would dramatically increase *per capita* travel demand, because the bulk of the population increase would occur in the suburban fringe where currently travel use is the highest. Hence, they argue, policy should strongly encourage more and denser residential settlement in the inner suburbs. The point is dramatically illustrated by Figure 2, which is drawn from the 56-zone version of our model database. It shows how average commute distance is far higher in the outer suburbs.

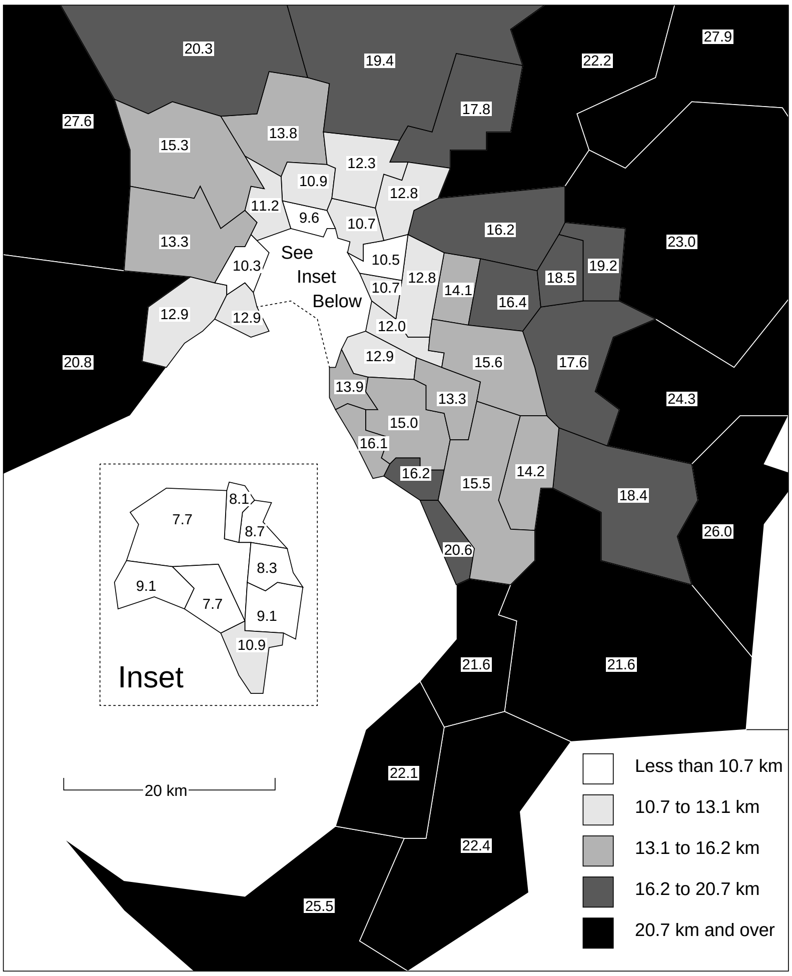

Figure 2. Average Commute Distance by LGA of Residence

The model results suggest that countervailing factors must also be taken into account. The expansion of population and employment in the outer suburbs means that average travel distance there is reduced for both existing and new residents. At the same time, falling wages in the inner suburbs may paradoxically cause inner residents to travel further than before.

The result, in the simulation reported here, is that *per capita* travel usage increases by much less than Figure 2 may suggest — by just over 4%. Leaving aside the effects of fuel-saving technological change, we could expect that commuter transport energy usage would increase by a similar percentage.

3B. A Tax on Transport

In this simulation a tax is used to increase the per-kilometre price of all commuting travel by 20%. Some results are shown in Table 6. Note that these results are percentage changes relative to the population-growth scenario.

The effect of the transport cost increases is to skew the relative attraction of the various possible work locations available to residents of each zone. The farther work locations become much less attractive than the nearer ones. Thus we see that the average commute distance for residents of each zone decreases, while the proportion who work and live in the same zone increases (rows 3 and 4). The total amount of transport used is 9.6% less than it would have been without the transport tax.

Table 6: Percentage Change Effects of a 20% Transport Cost Rise

	1 Central	2 Inner South	3 Inner East	4 Inner West	5 Inner North	6 Outer South	7 Outer East	8 Outer West	9 Outer North
1 Residents	14.35	0.36	-0.04	2.53	1.19	-6.70	-7.31	4.22	-6.04
2 Employment	-11.83	1.04	0.16	1.82	-0.31	10.32	18.80	20.61	2.09
3 Proportion of residents who live & work in same zone	8.97	13.49	11.87	21.22	15.18	24.68	37.31	25.55	32.00
4 Average commute distance	-9.44	-7.54	-4.23	-7.16	-5.59	-12.79	-11.82	-10.30	-10.08
5 Rent of land for housing	3.00	1.40	1.94	2.87	2.15	0.00	0.00	0.00	0.00
6 Wage level	-0.24	-0.12	-0.16	-0.24	-0.16	0.00	0.00	0.00	0.00
7 Proportion who live in high density housing	1.44	2.00	-3.17	9.58	4.17	3.26	2.00	1.23	0.00
8 Proportion of residents in higher income bracket	-4.93	1.63	3.09	1.91	6.35	-9.54	-7.07	-4.58	-0.60
9 Amount of residential land	13.18	0.10	0.18	0.43	0.56	-6.89	-7.33	4.15	-6.04
10 Amount of industrial land	-14.59	-0.47	-1.85	-1.26	-2.56	10.30	18.79	20.60	2.08
11 Amount of residential plus industrial land	0.00	0.00	0.00	0.00	0.00	-4.89	-4.96	6.07	-5.10

The overall effect of the increased desire to live and work in the same zone means that:

- those zones that initially had *more* jobs than residents tend to gain residents and lose jobs. In our control scenario, the land occupied by each person at work is much less than is occupied by each resident of that zone. So the exchange of workers for residents increases the demand for land. Again in our control scenario, the zones with more jobs than residents tend to be the inner zones where land is limited. Here, then, rents are forced up (Table 6, row 5). As a secondary effect, the higher rents induce business to substitute labour for land (thus mitigating or even outweighing the tendency for jobs to go) and also encourages residents to choose flats rather than houses (row 7). Notice that the only inner zone whose population did *not* increase is the Inner East, and of the inner zones this is the zone with fewest jobs per resident.
- those zones that initially had *fewer* jobs than residents tend to lose residents and gain jobs. In our control scenario, these zones tend to be the outer zones. Since a worker uses less land than a resident, the total amount of land used for housing or business decreases (row 11). Since rents in these zones are fixed, little urban consolidation (movement from houses to flats) follows from the transport cost increase (row 7).

The exception among the outer zones is the Outer West, where population and land use actually increase. To understand this, refer to Figure 1. Our choice of zone boundaries means that only a narrow strip (i.e., Zone 4 or Inner West) separates Zone 8 (Outer West) from the Central zone. The 'Outer' West is far closer to the CBD on average than is any of the other Outer zones. As transport costs increase, this advantage becomes more salient. Melbourne's development pattern is lopsided: it has expanded most towards the east and south. Much as surface tension draws a water droplet into a rounded form, so greater transport costs increase the tendency for cities to assume a circular shape. The neglected Outer West gains from this process.

3C. Urban Consolidation

In this simulation, policy measures are used to increase the relative attraction of high-density housing relative to low-density housing. Examples of such policies might include free permission to build higher density housing in residential locations, or permission to subdivide existing housing plots. Such policies increase the supply of higher density housing, thus lowering its price. Some results are shown in Table 7. Again note that these results are percentage changes relative to the population growth scenario.

The effect of the policy measures is to reduce the cost of 'flats' relative to 'houses', inducing more residents to choose the former. Reference has already been made to the power of planners to control the areas of land used for business and for high- and low-density housing. Associated with this power are the ratios of the per-hectare rents for land used for 'houses' to that used for 'flats'. Deviations from unity in these ratios are a measure of the 'distortion' associated with these planning controls. The ratios were endogenously determined in the calibration exercise reported in the previous section. Their values were: 1.1 in the Central zone (indicating a prejudice in favour of flats); an average of 0.8 in the remaining Inner zones (indicating a prejudice against flats); and an average of 0.6 in the Outer zones (again indicating a prejudice against flats). These values, inferred from the model, confirm casual observation. Developers find it more profitable to use vacant land in any Inner zone for flats rather than houses, if they can get permission. The planning permission increases the value of land. The price differential indicates the market disequilibrium. Councils for their part frequently oppose applications for high-density housing on the grounds that flats are disliked by other residents. Indeed, the erection of flats reduces the value of adjacent houses[7]. Planning controls on flats are thus similar to pollution quotas for factories - a response to a negative externality. A second reason for the land-rent difference between houses and flats in the Inner zones is the durability of a housing stock or subdivision pattern which dates from a time when land in these zones was much cheaper than it is now. The lower rents to land/house packages in these zones may be interpreted as a low return to an outmoded investment. Finally, the perverse result for the Central zone is due to a concentration of high-density welfare housing. If the real value of the land occupied by these flats was reflected in their rents, or if their tenants had the option of occupying a house and land farther from the city centre but of similar real value, we would observe fewer high-density residences in the Central zone. Most inner-city lower-income home-owners have already traded in their homes for a more comfortable suburban replacement - an option unavailable to the public tenant.

Table 7: Percentage Change Effects of Urban Consolidation Policy

	1 Central	2 Inner South	3 Inner East	4 Inner West	5 Inner North	6 Outer South	7 Outer East	8 Outer West	9 Outer North
1 Residents	-14.78	15.06	31.62	2.14	13.88	-24.07	-17.92	-21.93	-16.47
2 Employment	6.88	6.41	16.99	-9.27	-2.94	-22.50	-18.04	-24.54	-15.31
3 Proportion of residents who live & work in same zone	-0.80	0.55	8.33	-2.16	-6.02	-6.93	-11.64	-10.57	-11.67
4 Average commute distance	1.24	-0.69	-2.94	0.61	0.82	4.35	6.32	3.71	4.25
5 Rent of land for low density housing	-3.86	1.15	4.75	-4.64	-0.42	0.00	0.00	0.00	0.00
6 Rent of land for high density housing	-3.86	-24.14	-33.31	-14.34	-24.23	-30.35	-42.46	-33.85	-46.24
7 Wage level	0.28	-0.08	-0.36	0.36	0.04	0.00	0.00	0.00	0.00
8 Proportion who live in high density housing	-7.19	98.40	369.05	2.82	76.89	97.83	254.00	132.10	362.50
9 Proportion of residents in higher income bracket	34.86	-13.02	-29.10	16.88	-5.53	28.62	23.23	34.17	25.38
10 Amount of residential land	-10.40	-1.11	-1.08	1.52	0.54	-27.67	-23.25	-26.29	-22.66
11 Amount of industrial land	11.51	5.12	11.31	-4.58	-2.46	-22.50	-18.07	-24.54	-15.33
12 Amount of residential plus industrial land	0.00	0.00	0.00	0.00	0.00	-27.07	-22.78	-26.08	-21.81

[7] A very small part of the reduction in the values of adjacent houses may be attributed to a purely pecuniary externality: the flats increase the supply of local housing, driving down its price. The greater part of the reduction arises from the flats' perceived effect on local amenity: loss of view, parking scarcity, noise, litter and so on.

The shocks in this simulation consist of an exogenous change to the G_{z2} (see equation 18) so that the per-hectare rents for land used for 'flats' are equal to that used for 'houses' except in the Central zone, where the existing ratio remains. That is to say, we simulate removal of all planning prejudice against flats, and the retention of the Central zone prejudice in favour of flats. Alternatively, some of the changes in the rental ratios may be interpreted as a endogenous return to market equilibrium as the attrition of outmoded land-intensive structures allows, over time, a settlement pattern more appropriate to modern market conditions.

The policy changes have the direct effect of reducing land rents for high-density housing in all zones except the Central zone. The reductions are greatest in the Outer zones where 'flat' rents fall by 30-40%. In the Inner zones, rents fall by less, between 15% and 35%. The effect spills over to the Central zone, where 'flat' rents fall by about 4%.

The relative cheapness of flats causes the proportion of residents who occupy flats to increase in all zones but the Central (row 8). The most dramatic differences are seen in the Inner East and the Outer North; in both cases the ratio increases by over 350% (in the latter case, from a very low base).

The overall effect of the move to flats is that 14% less land is needed for housing, and that the Inner zones can accommodate a larger population and more industry (rows 1 and 2). Population, employment and the occupied area (row 12) of the Outer zones shrink by about 20%, resulting in a smaller, denser city. Population in the Inner zones increases. For flatdwellers, the Central zone becomes relatively less attractive, since flat rents have decreased elsewhere. Thus in the Central zone net residential density decreases, and residential land is converted to industrial use (rows 10 and 11). The shift by industry to a Central location offsets the migration of Outer industry to the Inner zones, leading to a varying employment result in the Inner zones.

For reasons covered in our discussion of the effects of population growth, it might be supposed that a shift of population to the Inner and Central zones would dramatically lower average transport use. In fact it declines by only 0.3%. Two factors enter into the explanation.

The first factor stems from simple geometry. If we were to photographically reduce the entire city together with its existing commuting patterns so that its *area* shrunk by 20%, the total *distance* travelled would fall by only 10%. Transport usage will fall at only half the rate that land per person falls.

The second factor is an income effect. Reductions in the cost of cheaper housing and associated substitution towards that housing leave consumers with more money for other goods. In the model and in reality, commuter transport, although not a good in itself, is prized because of the access it gives to a wide choice of employment and residential location. Consumers trade off this derived utility from transport against its cost. Increased household budgets (after housing is paid for) allow consumers to purchase more valuable transport opportunities. So in spite of the shrinking of the city (which moves people from high-transport-using zones to low-transport-using zones) the average per capita use of transport in 7 of the 9 individual zones increases (row 4).

The changes in housing patterns implied by this simulation are dramatic: the number of high-density housing occupiers increases by over 100%. Yet only a tiny reduction in commuter transport is achieved. According to the model, then, a desire to reduce transport energy use is a poor motivation for an urban consolidation policy.

However, if we interpret current planning restrictions as a market distortion which induces consumers to use more residential land than they would in a free-market situation, the planning reform that was simulated does leave the population better off. That is one reason that more transport was purchased. But to advocate an urban consolidation on these grounds may be premature, since the simulation takes no account of the negative externalities associated with an increase in high-density housing.

4. CONCLUSION

Previous work has included several large and detailed models of land and transport usage within cities. Most were constructed during the sixties and seventies and were neither general equilibrium nor neo-classical in flavour. They presented only a partial view of economic activity within the city, and behavioural specifications were sometimes *ad hoc.* Such large models also demand a larger research budget, and greater access to official data than was possible for this research.

Our model adheres more closely to the ideal specifications of a neo-classical general equilibrium model. Our starting point is a logit model of discrete choice; this forms the core of a complete model of urban growth and development which includes descriptions of:

- attributes of different regions within the city (e.g., employment opportunities and land availability);
- attributes of households (e.g., income levels, housing and lifestyle preferences);
- commuter transport costs, and
- location decisions of households and industries, taking account of regional and household attributes and transport costs.

Because the model was still in the prototypical stage, we deemed it advisable to compute results at a 9-zone level of disaggregation. The smaller number of zones greatly eases the task of computing and especially understanding model results. The 9-zone database was aggregated from an initial 56-zone database, and was then used to calibrate the computer model.

We have presented 3 applications to show how government policies or other exogenous changes could affect the form of urban development and urban transport usage over the next 20 years. The three simulations show the effects of:

- a 30% growth in population and employment.
- a tax which increases the cost of travel by 20%.
- urban consolidation: a change in planning rules which favours denser housing.

The simulations illustrated two particular advantages of the general equilibrium approach. First, we can simulate the effects of a wide range of exogenous changes, whether or not these are directly transport related. Second, we capture not only the direct impact of the change, but also the full pattern of indirect effects.

Other advantages of our approach include the following.

- It allows for asymmetry and multicentrism: there is no presumption of any particular shape for the city, nor has any particular location a special importance (as does the CBD in some models). The model could thus be applied to urban regions with multiple concentrations of population and employment.
- A uniform road system is not assumed; the model can cater, for example, for a city where transport facilities to and from the centre are better developed than are facilities for tangential travel.
- Uniform tastes are not assumed: the model allows for random variation in consumer taste as well as for systematic preferences for particular zones. Consequently, the model does not force zones to specialize completely in single activities. This adds to model realism.
- Although the model assumes that industry and consumers act in their own interests, it makes generous provision for various types of government intervention. Planning policy is active and diverse

We could suggest many extensions to the model. Some of the most useful might be:

- incorporation of time costs into transport.
- allowance for road congestion, and for road provision to be an instrument of Government policy, and for road construction costs to vary by area.
- incorporation of various externalities, such as the effect of traffic on the amenity of the area through which it passes.
- inclusion of non-commuting private transport, and of freight transport.
- modeling of alternative, non-urban productive uses of land: i.e., agriculture or leisure.

In addition, a finer disaggregation of model categories would be a straightforward improvement. We could distinguish more, smaller, zones, more dwelling densities, and more income classes.

The general equilibrium approach has its own disadvantages — especially its voracious appetite for data. For very detailed studies of particular problems, the partial equilibrium approach may dominate. For example, it allows us to use finely disaggregated data which may be available only for some of the zones distinguished in the general equilibrium model. The two approaches, however, are not necessarily incompatible. Results from a general equilibrium model could be used to decide what should be held constant in partial equilibrium, or what values variables exogenous to a partial model should assume. General equilibrium models supplement — rather than replace — the existing toolkit of the urban economist.

REFERENCES

Anas (1982), *Residential Location Markets and Urban Transportation*, North-Holland, Amsterdam.

Domencich and McFadden (1975), *Urban Travel Demand: A Behavioural Analysis*, North-Holland, Amsterdam.

Horridge (1991), "A General Equilibrium Model of Australia's Premier City", Discussion Paper No. 149, Centre of Policy Studies, Monash University.

Maddala, G.S. (1983), *Limited-Dependent and Qualitative Variables in Econometrics*, Cambridge University Press, 401 pp.

Sams, D., and C. Beed (1984), 'Changes in Self-Containment Within Melbourne, 1966-1981', *Urban Policy and Research*, Vol.2, No.3, September