METROSCOPE:
THE METRO RESIDENTIAL AND NONRESIDENTIAL REAL ESTATE MODELS - GENERAL DESCRIPTION AND TECHNICAL APPENDIX

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Introduction

Metro has developed a regional econometric model (MARIO), a residential real estate model (RELM), a nonresidential real estate model and a transportation model. We have embedded the four models in a GIS based accounting and visualization tool that we call Metroscope. In regard to Metro's model development this paper discusses the reasons that Metro engages in modeling, shows how Metro is presently using the models and provides a few examples of model policy results. We also talk about the resources and time it takes to develop the land use side of an integrated transportation-land use model. Finally, in regard to the residential and nonresidential real estate models the paper includes a technical appendix showing the schematics of the models' operation and detailing the equation structure of the residential and nonresidential models.

Background of Metro's Land Use Modeling Effort

Metro's interest in integrating transportation and land use modeling began initially in 1992 and was and continues to be stimulated by a growing number of Federal, State and local information and compliance requirements. Beginning in the 1990's with Federal legislation such as ISTEA & TEA-21 along with EPA air quality conformity requirements put an increased emphasis on the land use and associated air quality effects of transportation investment. Significantly, at this time there were successful court challenges of MPO transportation plans in California and Illinois based on failure to account for the land use impacts of planned transportation improvements. This litigation further stressed the need to explicitly represent the relationship between land use and transportation within the framework of a consistent, formal simulation model.

Likewise at the State or Oregon and local level new planning requirements demanded information that ultimately must be determined by integrated transportation – land use models. Foremost among these requirements was adoption of the State Transportation Planning Rule that stipulates a 20% reduction in per capita VMT over a 20-year period. Adopted during a time period of 3 – 5 % per year increases in per capita VMT such a rule certainly challenged policy credulity and the analytical tools capable of evaluating how such a policy might be implemented within the context of a non-Stalinist system of government.

Of equal importance at the State level was the maturation of the Urban Growth Boundary (UGB) requirements particularly in the Metro Region. Throughout the 1980's the UGB amounted to a set of oversized new clothes relative to the growth needs of the region. Only in the early 1990's did the Metro Region finally began to grow into the boundary. Finally, by the mid to late 1990's Metro began to grow out of the UGB. State requirements to expand the boundary to maintain a 20 year residential land supply have now precipitated an additional set of questions regarding the interrelationships between housing prices/rents, urban densities, redevelopment and infill rates, travel distances and the share of the economic region's[1] growth we expect within the UGB. Attempting to verbally unravel such a complex fabric remains completely hopeless. However, integrated transportation – land use models properly formulated are capable of providing

[1] The UGB and the Metro jurisdiction cover approximately 1.2 million of the economic region's 1.8 million population. Metro and the UGB are surrounded by "refuge" areas that can provide housing to those willing to trade off travel time in exchange for desired housing at the appropriate price.

estimates of all the above factors for any combination of UGB expansion, zoning capacity and transportation/infrastructure investment policy that might be proposed.

A final component of need for land use models came from the development and adoption of Metro's "2040 Plan". Essentially the plan embodies much of the State transportation and UGB requirements discussed above. In addition the 2040 Plan seeks to attain a more compact urban form, build communities rather than subdivisions, increase mixed use development and increase transportation mode choices. While much of the initial 2040 planning was driven by urban design considerations, subsequent questions have arisen as to the market response to the envisioned land uses, and what regulatory tools and or financial incentives are necessary to achieve them. Not incidental to the questioning has been concern about the economic tradeoffs in terms of housing prices, economic growth and impacts on lower income households. Again these are issues that must be addressed with an integrated transportation-land use model.

Beyond the policy and legally driven needs for land use modeling, we can parenthetically note that at the technical level travel demand modelers were becoming increasingly aware that their models bereft of consistent land use feedback simply did not and indeed do not forecast very well. Independent population and employment forecasts confronted even the most econometrically sophisticated travel demand models with the conundrum of providing travel to places for which travel times suggested nothing significant should be located.

In sum Metro's interest in developing integrated transportation-land use models was driven by demands at the Federal, State and local level to better reflect how land use policies and transportation investments impact each other. While some of these demands are unique to Oregon and Metro, an increasing number of them impact many other regions of the country.

What Metro Uses the Models For

As noted previously Metro interest in integrated transportation-land us models goes back to 1992 when we developed a crude spatial interaction model to estimate how large the region would be in 50 years without an active policy of urban containment. Experience with that model pointed out the need to develop land use models explicitly dealing with real estate and solidly grounded in micro-economic theory. Work on the real estate models has progressed slowly over the years in conjunction with other work efforts and mostly on an after hours and weekend basis. Nevertheless, given enough time and persistence we have developed both residential and nonresidential real estate models that provide the land use information needs demanded of integrated transportation – land use models. At present we use 20 zone residential and nonresidential models for sketch policy level analysis and are completing a 400 zone residential model and 70 zone nonresidential model for detailed forecasting and urban design evaluation. The 20 zone models are spreadsheet based and can be iteratively solved in less than 1 hour. The more detailed models run in Visual Basic with spreadsheet based input and output. The residential model with 328 census tracts and 64 categories of household size, income and age takes from 2 to several hours to solve depending on the starting values of the location prices.[2]

[2] The longer time is when all location prices are set equal to one. In practice initial starting value are much closer to final values so computing time is closer to 2 hours or less.

At this time Metro is using or planning to use the real estate models on 4 separate work efforts. These are:

1. The first project is presently underway and involves the 20 zone models working with fixed travel times[3] to evaluate the public welfare impacts of proposed additions to the Urban Growth Boundary. Specifically, Metro is interested in knowing the areas for UGB expansion that best meet Metro 2040 planning guidelines and State land use law. We are testing 600 acre additions with various combinations of land use in several areas of the region. In these tests we compare model output to a 2015 base case forecast. Some of the model outputs of interest are:
   - Change in household allocation
   - Change in employment allocation
   - Change in housing prices/rents
   - Change in tenure percentage
   - Change in work travel distance of primary commuter
   - Household density of potential UGB expansion area
   - Employment density and SIC mix of potential UGB expansion area
   - Impacts on central city, CBD and other areas with large vintage investment in public facilities.
   - Share of regional growth occurring inside the UGB

2. The second project will be starting this summer and will use the 400/70 zone real estate models in conjunction with the regional econometric model and the transportation model. This project, the I-5 Trade Corridor Study, involves determining whether to provide additional transportation capacity across the Columbia River between the Metro Region and Clark County. The modeling work run in 5 year increments will determine land use and transportation impacts throughout the economic region. Of particular concern in this study will be the growth shares of households and employment in Clark County resulting from a particular transportation investment alternative.

3. The third project is the year 2000 forecast update beginning in June that will use the 400/70 zone real estate models in conjunction with the regional econometric model and the transportation models. This project conducted in conjunction with local government review teams will produce a detailed projection by housing type, price/rent category, etc. Modeling will occur in 5 year increments with land added to the UGB and transportation investments made according to the relevant regional transportation plan.

4. The fourth project is an urban design evaluation of the 3500 acres included inside the UGB in the last year. We will use the 400/70 zone models in conjunction with the

[3] With the 20 zone policy models we generally manually change travel times rather than iteratively running them through the travel demand model.

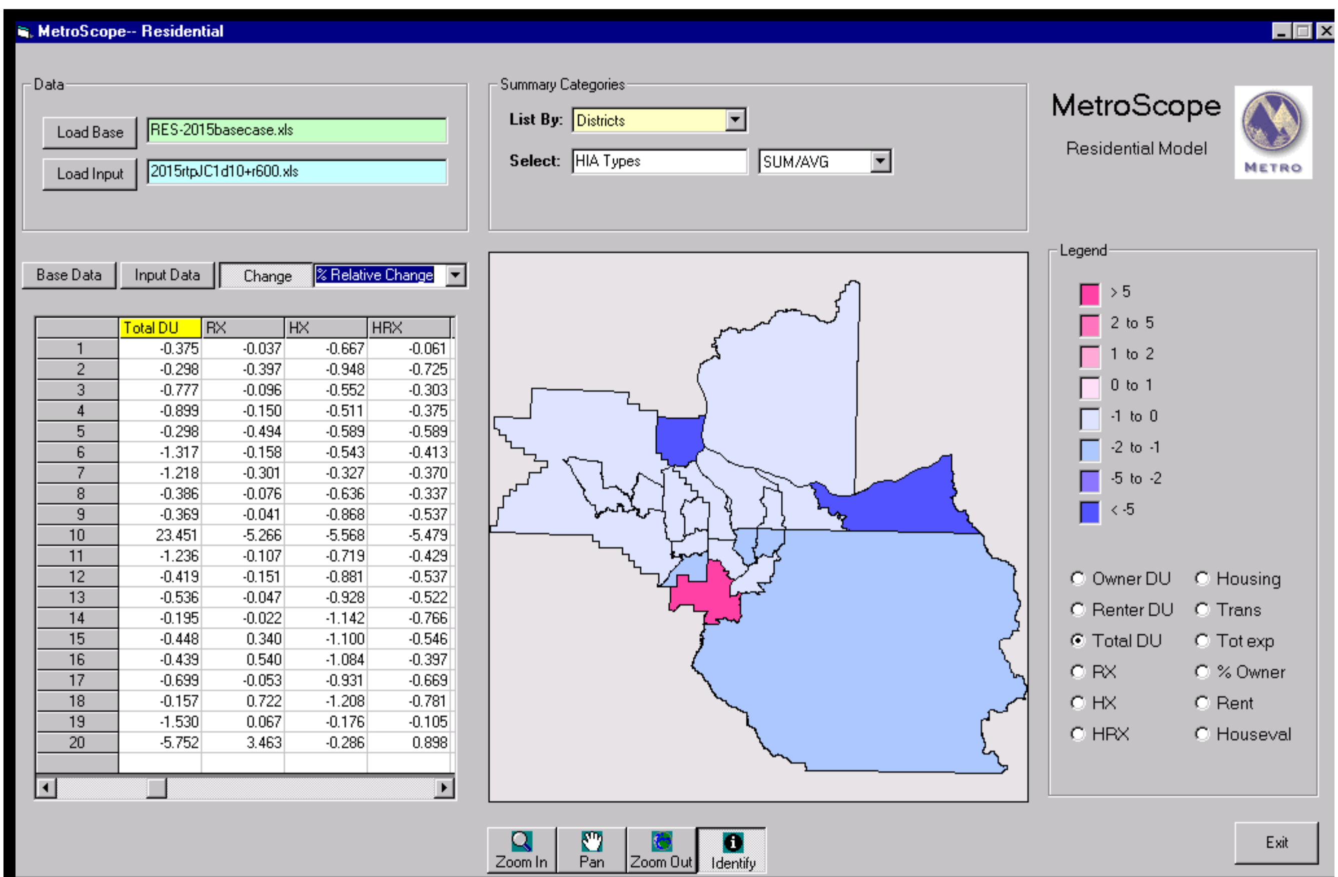
transportation model to determine design, land use mix configurations that will maximize use and minimize vehicle miles traveled.

From the above list we note that one project deals with UGB expansion policy, one project deals with a major transportation infrastructure evaluation, and another project consists of an urban design and regulation evaluation. The year 2000 forecast will be a major work effort that will involve evaluating all items of land use regulation, UGB expansion policy, urban design and transportation infrastructure investment. All of the above project outputs will be visualized and communicated through Metroscope.

Metroscope in Action

Within Oregon and Metro considerable legal and planning significance is attached to the concept of "jobs/housing balance" with the general contention that improving jobs/housing balance[4] will reduce per capita VMT. In the Metro area Zone 10 (Wilsonville) constitutes a zone of extreme jobs/housing imbalance with jobs outnumbering households by a ratio of more than 3 to 1. Accordingly, the Metro Council is considering adding additional residential land to the UGB in the Zone 10 (Wilsonville) area. The Metro Council requested we use Metroscope (20 zone version) to evaluate the impacts of adding 600 gross acres of residential land (500 owner occupied single family, 100 acres renter occupied apartments) to the UGB in the Zone 10 area. Chart 1 below shows the resultant change in total dwelling units compared to the 2015 baseline forecast.

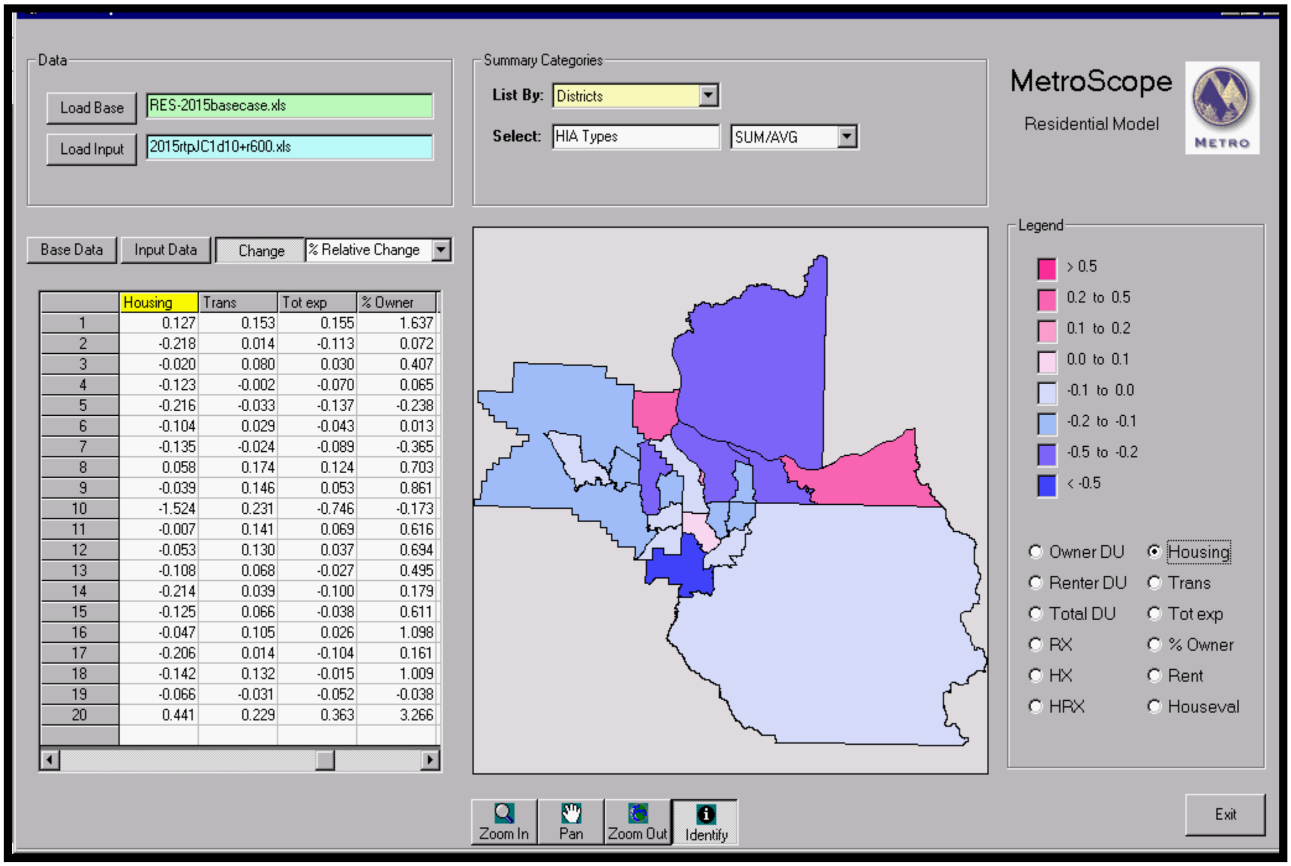
Chart 1: Residential Growth Shifts Southward



balance.

As expected Zone 10 gains about 6,000 households at the expense of surrounding zones. At this point the impact is simply to shift household growth from areas north of the region toward the southern part of the Metro region. Significantly, some growth is shifted from outside the UGB to inside the UGB. Chart 2 displays the change in annual spending for housing by zone.

Chart 2: Additional Housing Supply Reduces Housing Spending



For most zones annual housing expenditure decreases. The apparent increase in a few zones owes to the disproportionate shift of lower income households out of those zones into cheaper housing elsewhere. Not surprisingly, the largest spending reductions occur in zone 10. Overall, the impacts of adding additional supply to the Urban Growth Boundary have been to shift growth in the direction of the new supply and reduce housing prices/rents.

Chart 3 depicts the change in owner occupied housing throughout the region as a result of the supply addition in zone 10.

Chart 3: Price Reduction Increases Owner Occupied Stock

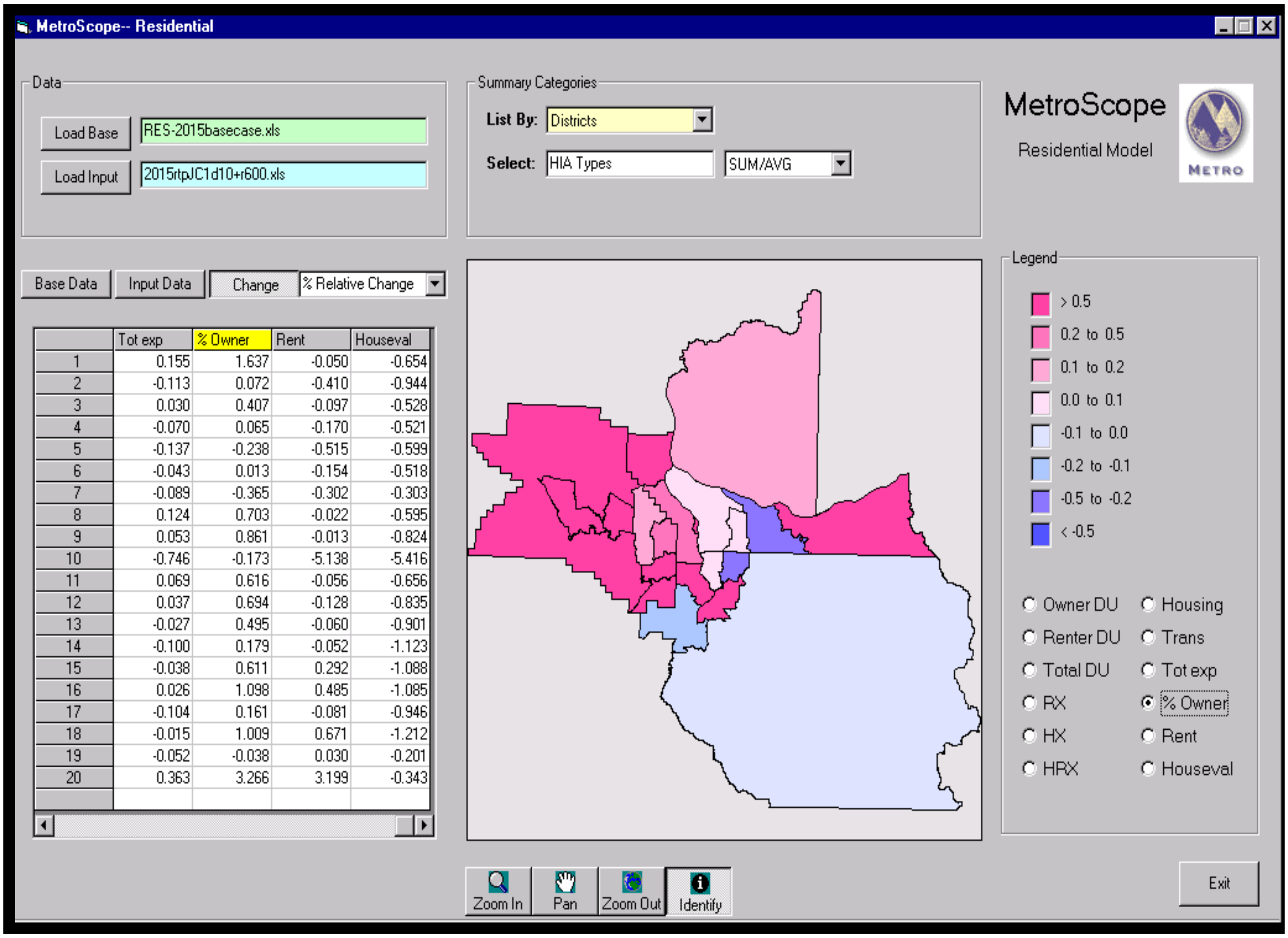
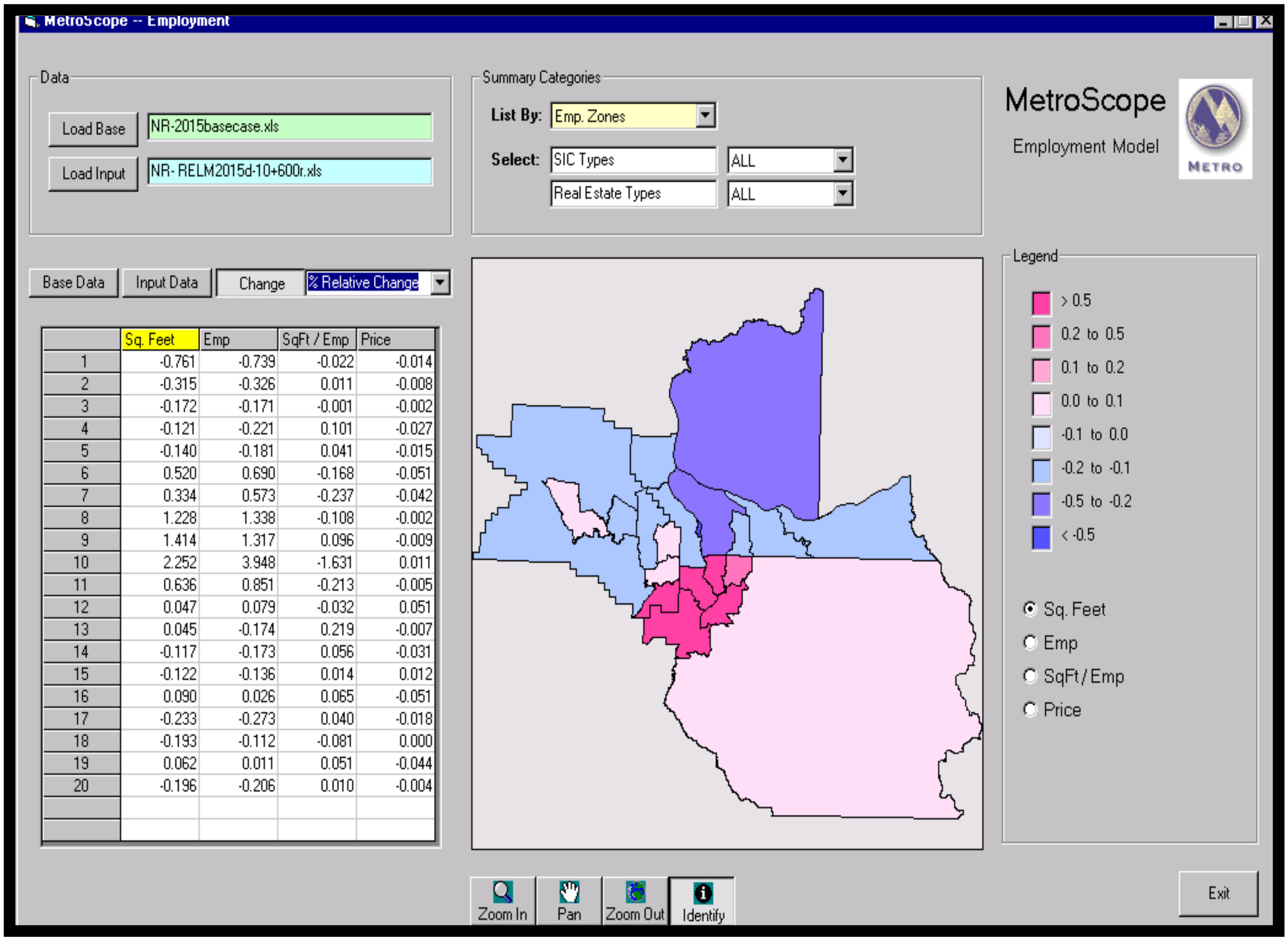


Chart 3 indicates the price reduction increases consumption of owner occupied housing stock except in zones 5, 7, 10 and 19. In zone 10 our zoning assumption of 100 acres for renter occupied apartments induced a supply shift toward renter occupied stock. In the remaining 3 zones rents declined more than home prices thereby shifting tenure slightly in favor of renting. In all other zones the reduction in housing prices and rents shifted tenure in favor of home ownership.

In Chart 4 we move to the output of the nonresidential real estate model. Though we made no changes in nonresidential land supply, the shift in households impacts the nonresidential real estate location and prices. Chart 4 below shows the change in nonresidential square footage resulting from the increase in zone 10 residential land supply.

Chart 4: Employment Follows Households Southward

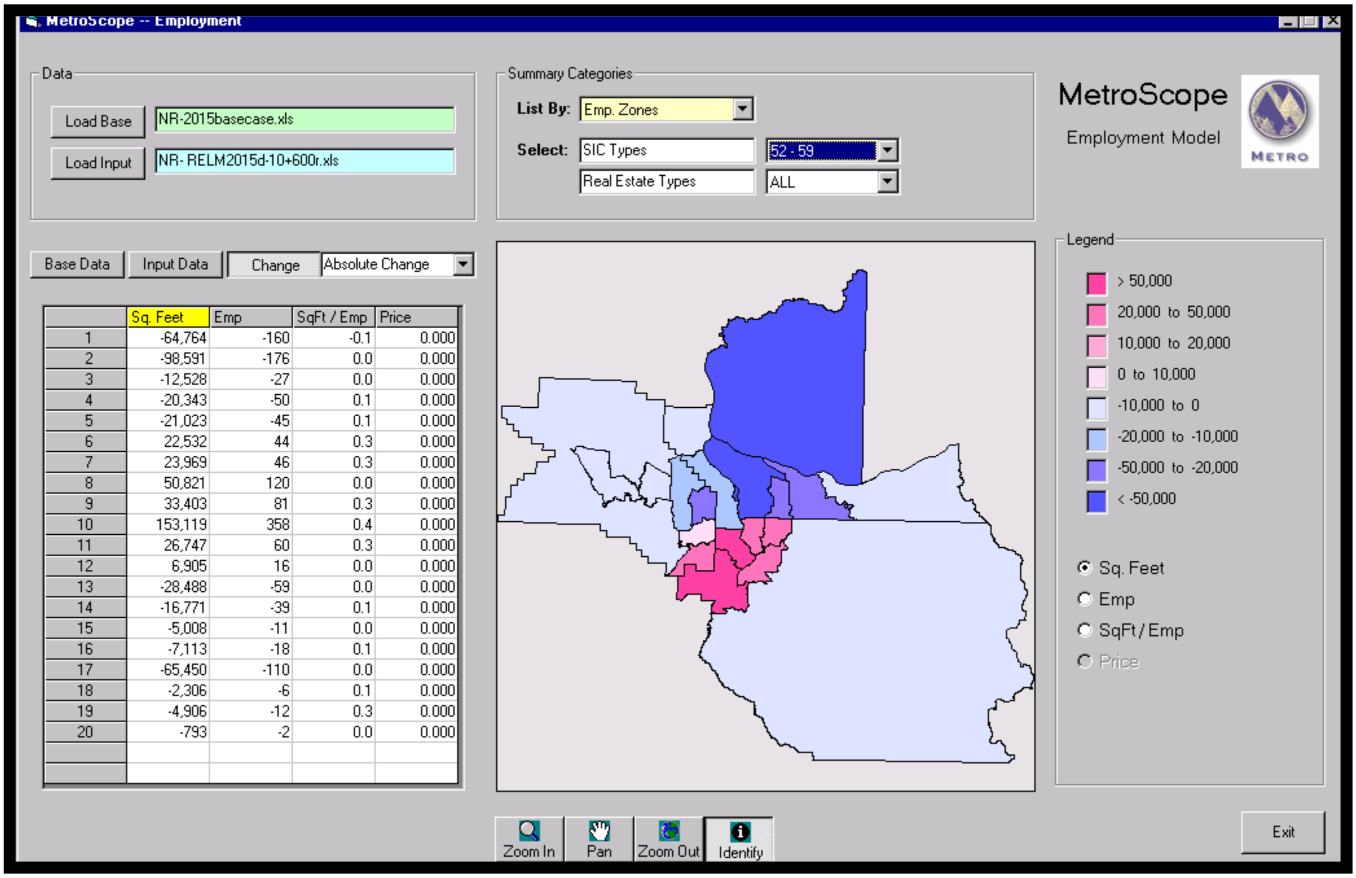


	Sq. Feet	Emp	SqFt / Emp	Price
1	-0.761	-0.739	-0.022	-0.014
2	-0.315	-0.326	0.011	-0.008
3	-0.172	-0.171	-0.001	-0.002
4	-0.121	-0.221	0.101	-0.027
5	-0.140	-0.181	0.041	-0.015
6	0.520	0.690	-0.168	-0.051
7	0.334	0.573	-0.237	-0.042
8	1.228	1.338	-0.108	-0.002
9	1.414	1.317	0.096	-0.009
10	2.252	3.948	-1.631	0.011
11	0.636	0.851	-0.213	-0.005
12	0.047	0.079	-0.032	0.051
13	0.045	-0.174	0.219	-0.007
14	-0.117	-0.173	0.056	-0.031
15	-0.122	-0.136	0.014	0.012
16	0.090	0.026	0.065	-0.051
17	-0.233	-0.273	0.040	-0.018
18	-0.193	-0.112	-0.081	0.000
19	0.062	0.011	0.051	-0.044
20	-0.196	-0.206	0.010	-0.004

Chart 4 indicates that considerable employment shifted as a result of the zone 10 residential addition. Chart 4 also shows that employment growth was more widely distributed than the residential impacts. Notable as well is that the CBD, east Portland and Clark County lost the most employment.

Chart 5 displays the change for retail trade. Again the same pattern as in Chart 5 prevails. Not unexpectedly fully 70% of the employment shift was in retail trade and services.

Chart 5: Bulk of Employment Shift is Population Serving



As shown previously the largest losses were in the central city, CBD and Clark County.

Up to now the changes that we have depicted have been much as expected. The next set of charts address the major purpose of jobs/housing balance adjustments – reducing per capita VMT. Chart 6 displays residential data by place of employment. In the case of Chart 6 we show the residential distribution of people who work in the CBD. Or more accurately, we show the change in residential distribution of CBD workers as a result of adding 600 residential acres to zone 10.

Chart 6: More Workers in Wilsonville and Hillsboro Commute Downtown

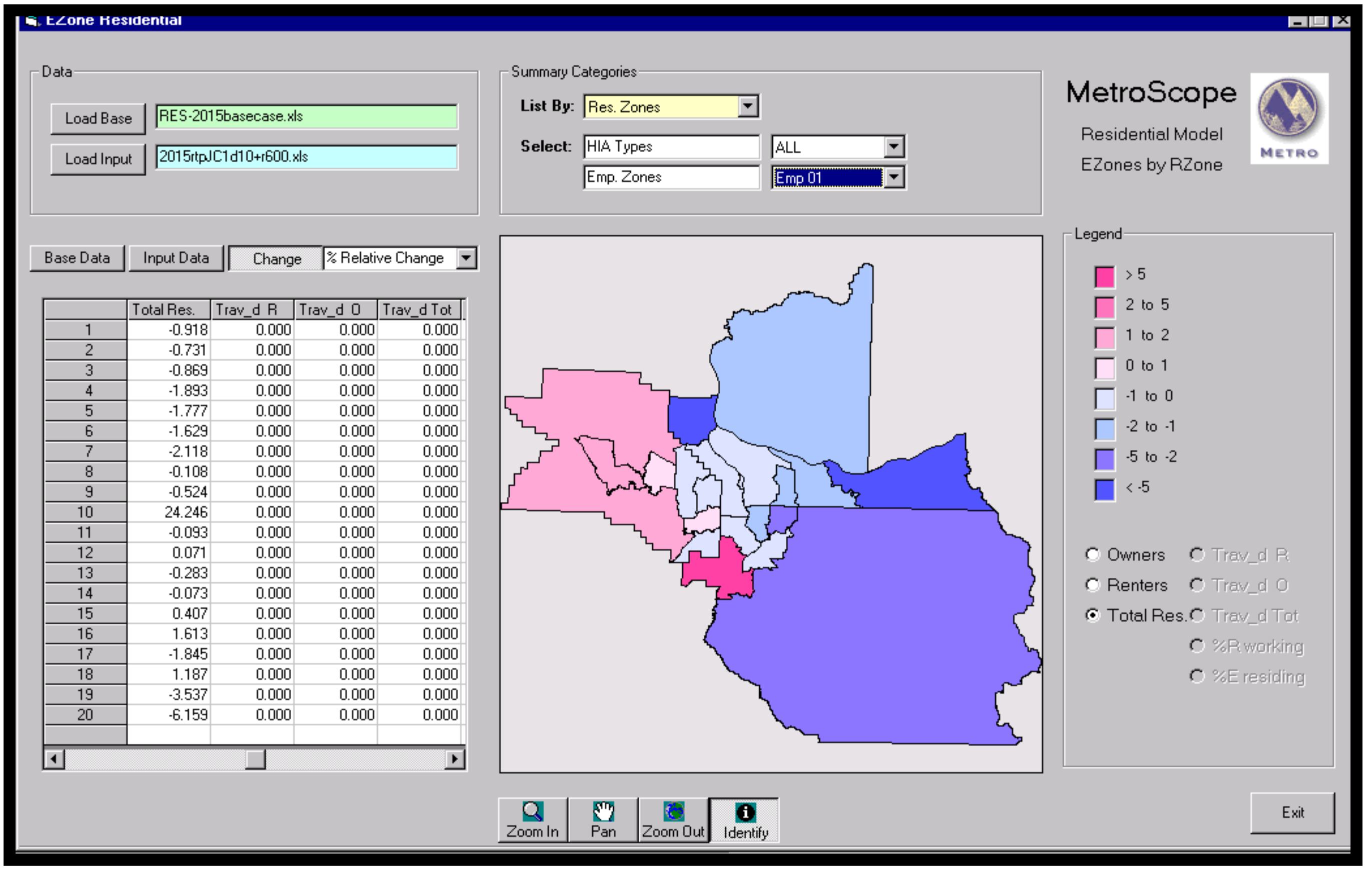


Chart 6 indicates that after the addition of land to zone 10 more workers from zone 10 commute downtown. This is also true for Tigard, Hillsboro and western Washington County. By the same token fewer workers commute downtown from Multnomah County, Clark County and eastern Clackamas County.

Chart 7 shows similar data but using zone 10 rather than the CBD as the place of employment.

Chart 7: More Workers in Wilsonville Live in Wilsonville & Washington County

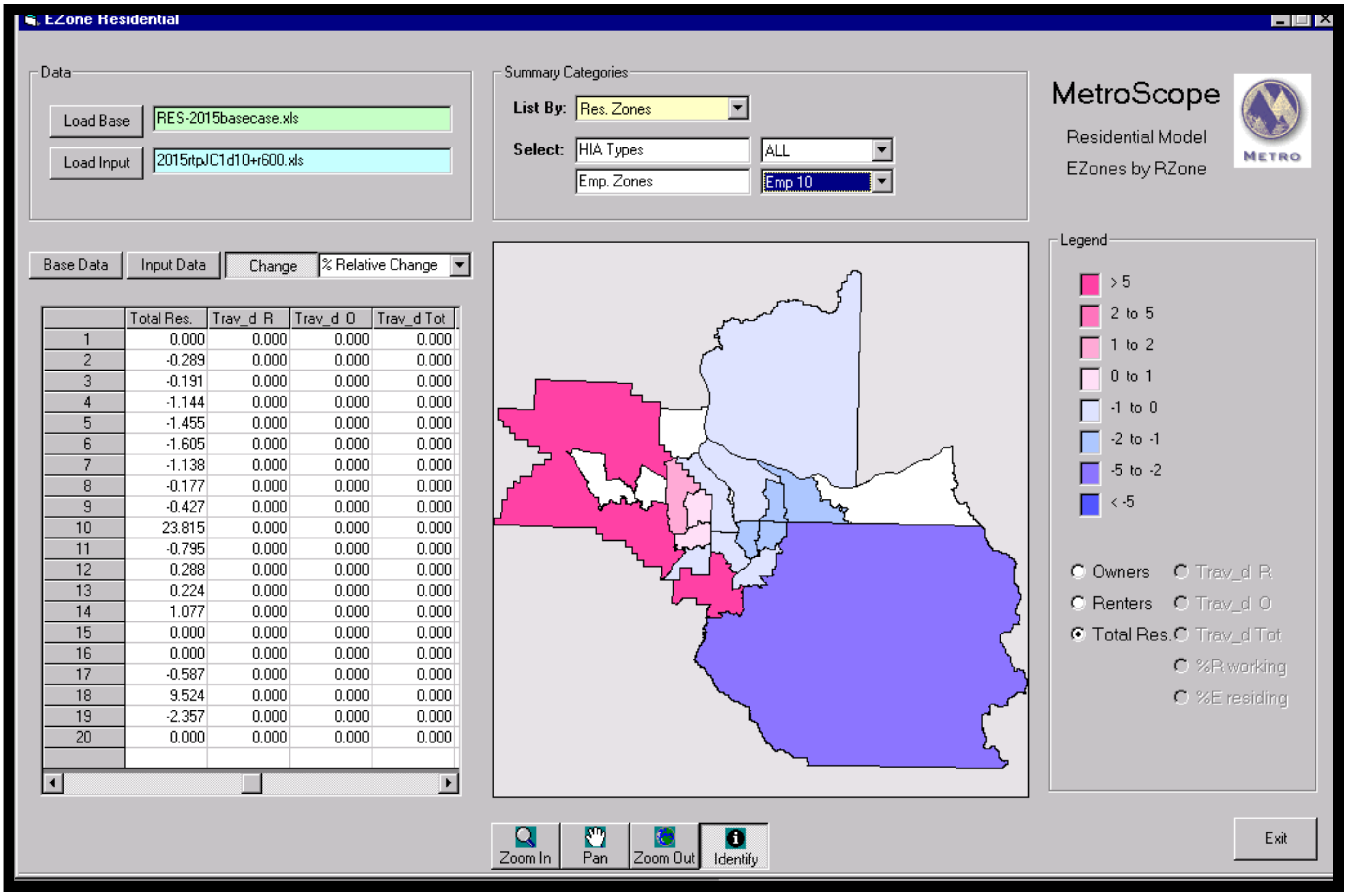
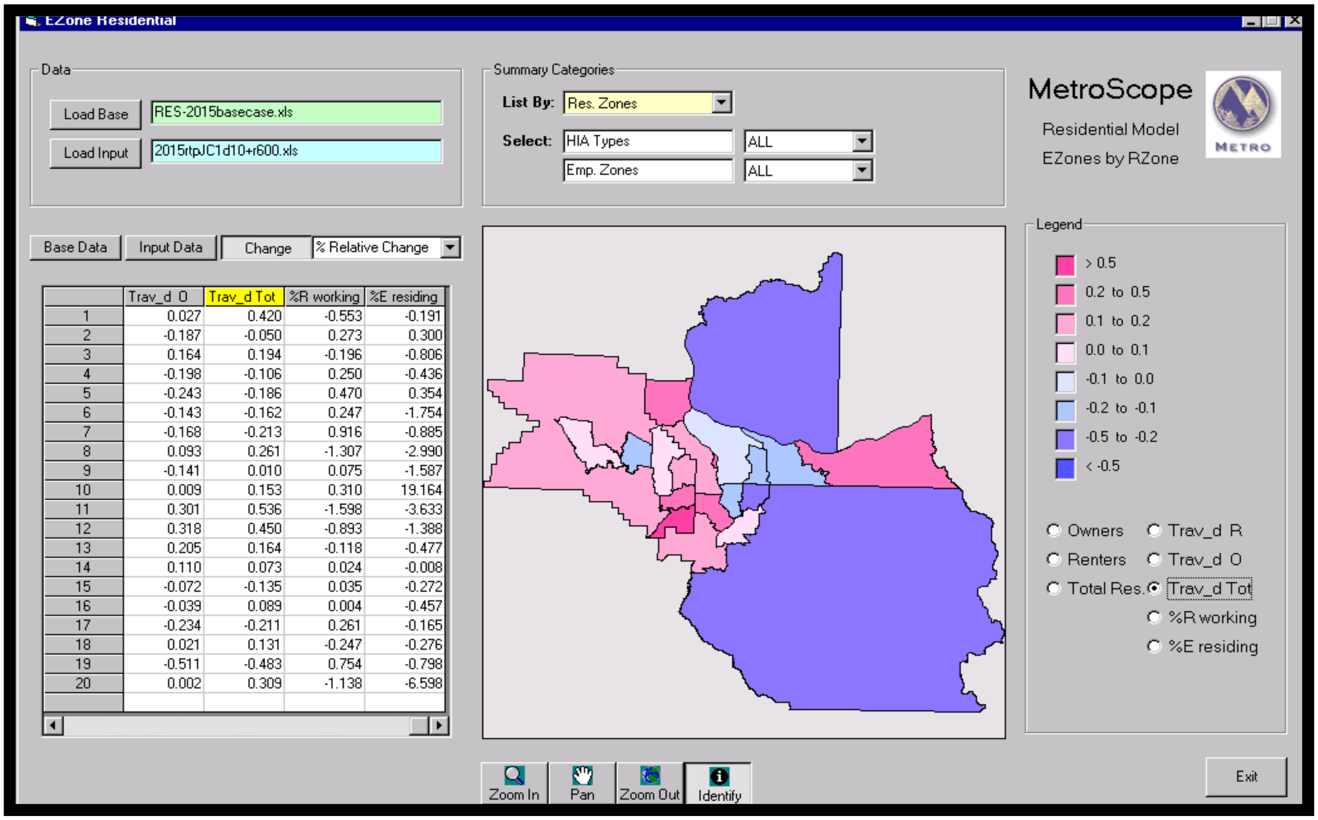


Chart 7 indicates much like the proponents of "jobs/housing balance" expect that a higher percentage of zone 10's workforce now live in that zone, thereby shortening their work trips. What they may not have anticipated is that the number of workers commuting from Washington County has increased and the number of workers commuting from nearby zones and Multnomah and Clark County has decreased. The shift in households and employment associated with the 600 acre increase in residential capacity has resulted in more households chasing relatively fewer jobs in Washington County and fewer households chasing relatively more jobs in Multnomah, Clackamas and Clark Counties.

Chart 8 depicts the change in travel distance of the primary commuter by residential zone.

Chart 8: Average Commute Lengths Shorten on the East Side and Increase on the West Side



Zones that ended up with fewer households and proportionally more jobs slightly shortened commute distances. Zones, including zone 10, that ended up with more households and proportionately fewer jobs experienced increased commute distances. Strangely enough, when we compare weighted averages for the entire region the commute distance remains exactly the same as it was in the base case. Our efforts to improve "jobs/housing balance" did not improve it at all.

The above result emphasizes an important advantage simulation modeling has over competing methods. It requires that the impact of an isolated change be consistently measured over the entire region. Almost without exception, jobs/housing balance arguments focus on a specific arbitrary area and ignore the remainder of the region. The zone 10 (Wilsonville) simulation emphasizes policies based on such an approach are not likely to achieve their stated objective.

Resources Required for an MPO Land Use Modeling Effort

As mentioned earlier in the paper, Metro began work on land use modeling in 1992. However, work on land use models at Metro has been periodic in nature with never more than 0.2 FTE devoted to land use modeling. Almost always the land use model development has been in conjunction other needs: better housing data for housing, more detailed demographics for the transportation model, more accurate employment density data for the business committee, etc. Though developed incrementally, Metro has nevertheless produced land use models that satisfy most of the requirements of market based real estate models. Most importantly, the models are being used and in the process of making important contributions to the development of regional land use and transportation policies as well as producing explicable, data rich forecasts. Put succinctly, land use model resources need not be large; rather organizational patience and persistence are much more important.

Compared to the development and model maintenance resources devoted to transportation, Metro's land use effort has been very small. On the basis of 8 years experience with land use model building we recommend the following:

- One staff member who knows enough about land use models to be capable enough to develop in-house models should it be necessary. All too often MPO's spend little on staff while relying on very expensive consulting assistance and software that result in little useable product.
- Avoid expensive, one time only data collection efforts for model parameter estimation and calibration. Instead review the data you collect on a continuing, periodic basis and develop models around those data. Use national data (such as the Survey of Consumer Expenditures) if necessary to estimate key demand and supply relationships.
- Give equal development time to model output visualization (such as Metroscope) and data accounting. Land use models are only as good as their initial conditions. It is necessary to have a good vacant land accounting system, a building permit tracking system and a method of periodically locating employment within the region. All of the above data tracking systems provide useful information without a land use model and so can be justified on their own merits.

To sum up integrated transportation-land use modeling at the MPO level has become a reality. Furthermore, land use modeling efforts result from a set of national and locally based needs that will only add to the pressures for all MPOs to adopt some level of an integrated transportation-land use model. Portland Metro's response to this need has been to develop and adapt models incrementally over time with a relatively small allocation of staff and material resources. It has been our experience that knowledgeable staff, patience and persistence are the most important in-house resources.

Technical Appendix

TECHNICAL SPECIFICATIONS
OF THE NONRESIDENTIAL AND RESIDENTAL REAL ESTATE MODELS

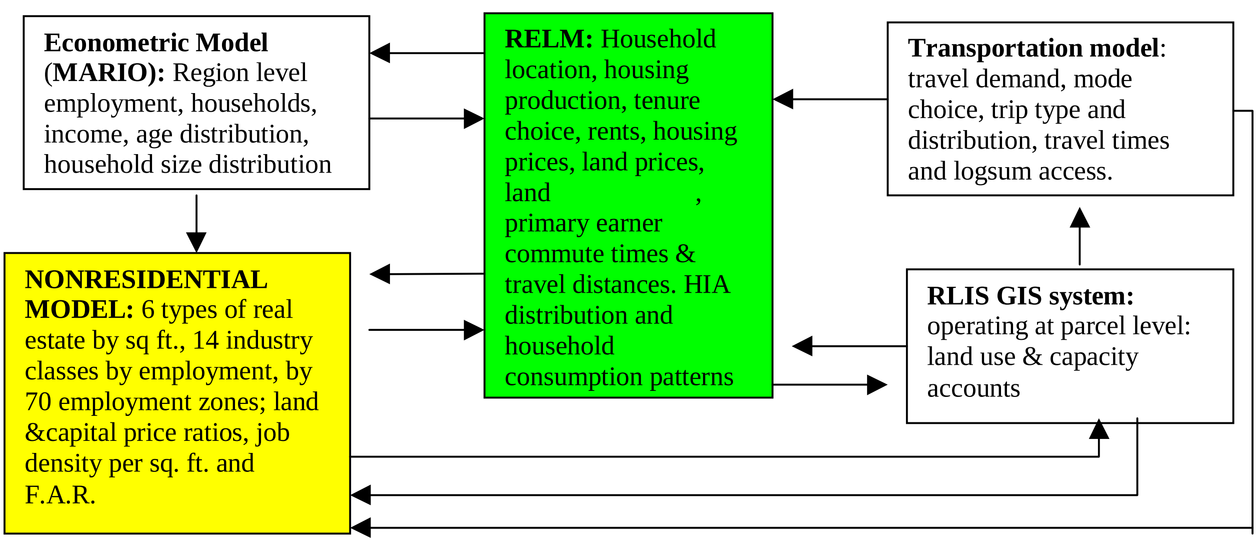
NONRESIDENTIAL REAL ESTATE MODEL – GENERAL DESCRIPTION

Introduction

This paper reports on and describes the Metro Nonresidential Real Estate Model. The paper describes its relationship to the Metro residential model (RELM), to the econometric model (MARIO), to the travel demand model and to the Metro GIS (RLIS). The paper provides a general description of how the model works and reports on its calibration and sensitivity testing to date. The report also explains its use and zonal configuration in the upcoming 6 – 8 month forecast cycle that Metro will be undertaking.

Relationship to Metro Models and GIS

The schematic below illustrates how the nonresidential real estate model fits into Metro's policy modeling and forecasting process.



In the schematic the nonresidential model receives industry specific employment control totals from the regional econometric model. From the residential model, the nonresidential model receives household totals by residential zone and income level. The RLIS GIS provides detailed land capacity and existing stock data to the nonresidential model aggregated to the employment zone level of detail. The transportation model computes prior iteration period travel times between employment zones for use in the nonresidential model. In return the nonresidential model provides employment levels by employment zone to the residential model and to the RLIS GIS system. Also provided to the RLIS GIS system are building square footages by real estate type and land consumed data by floor-to-area class by employment zone. Concurrently, the residential real estate model provides comparable real estate and land use data to RLIS GIS.

As implied in the above schematic, RLIS GIS serves a vital information processing, storage, transformation and visualization function. RLIS receives residential real estate information for up to 400 control zones and nonresidential real estate information for up to 70 zones. Using additional land capacity, land use, transportation and density data available at the parcel level, RLIS then simulates individual parcel locations by real estate type. These data are in turn passed along to the transportation activity modeling system. Equally as important RLIS provides a data visualization and storage system at a number of geographic scales for the hundreds of data choices available for location, real estate type, price, employment type, tenure, income, household size, age, employment density, floor-to-area ratio, etc. RLIS also facilitates easy comparison of policy option model runs with baseline model forecast output.

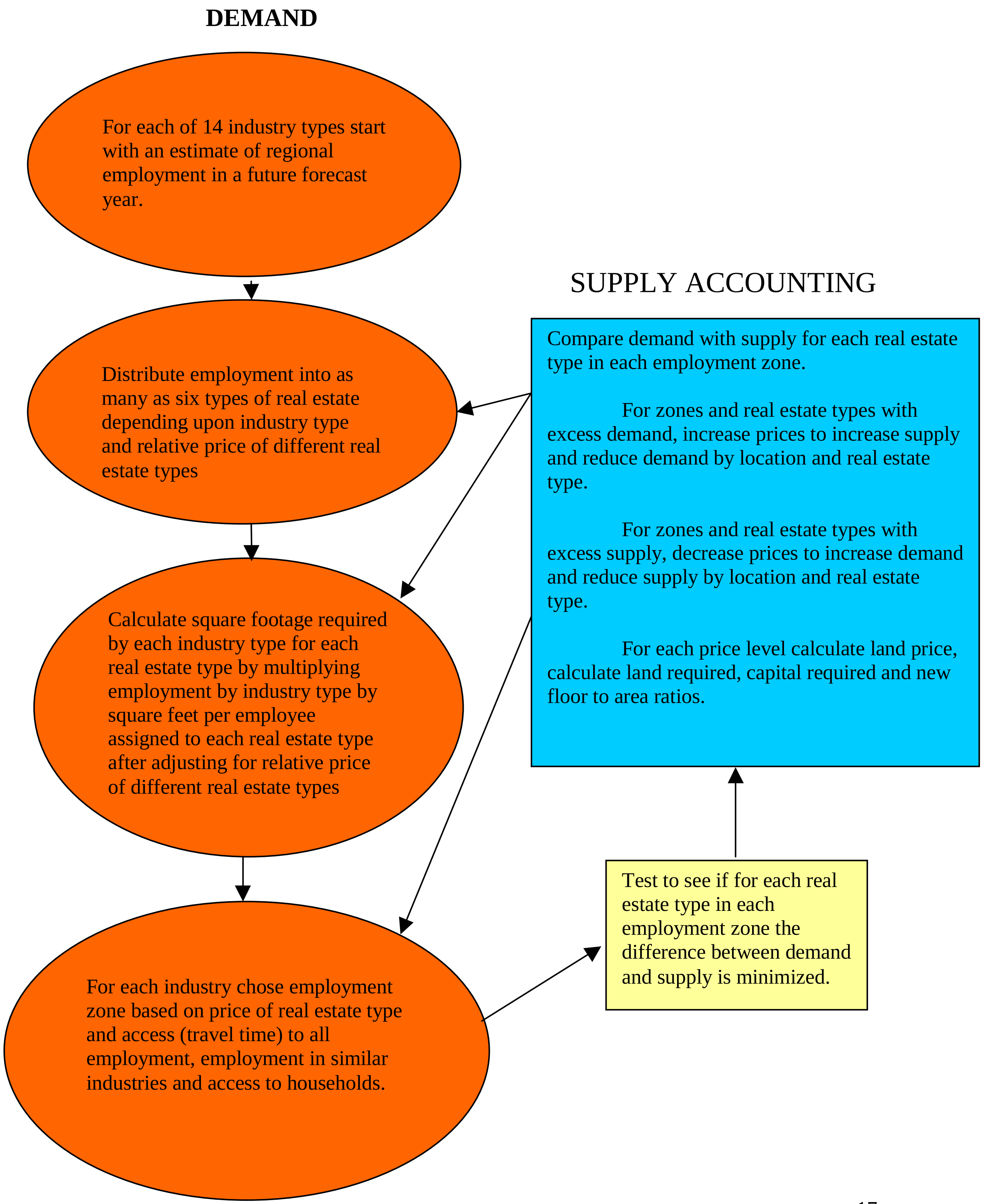
Nonresidential Model Operation

Again the operation of the nonresidential model is best explained schematically. The accompanying Chart shows the decision-making flow of the nonresidential model. To enhance clarity the decision-making process appears as a sequence where in reality a set of simultaneous equations represent the decision process.

A. Demand

The demand side of the model begins with regional totals of 14 employment categories that are estimated by the regional econometric model (MARIO). The model then distributes these employment categories into as many as 6 real estate types depending on relative price and their percentage distribution observed during the base calibration period. Next the model calculates the square footage required per employee by employment category by real estate type. This calculation involves adjusting the space per employee as a function of relative price and the space requirement per employee observed during the base calibration period. Finally the model determines the location of the real estate as a function of access to similar economic activities, access to households and access to total employment. Access is based on travel times computed in the travel demand model (TRANSIMS). The location determination model also includes relative price by real estate type for each employment location.

In the demand side of the model price ratios are employed to allow shifts between real estate types, changes in space consumption per employee, and changes in location.



B. Supply

The supply side of the model uses an estimate of land available by floor-to-area class for three types of land use – industrial, commercial and institutional. Depending on the price ratios for each location capacities change and more or less real estate space is produced as demand prices exceed or fall below the cost of production. Increasing price ratios increase densities and total real estate output. Decreasing price ratios decrease densities and real estate output.

C. Model Equilibrium

Finally the model compares demand in each location and real estate type with supply in each location and real estate type. The model adjusts price ratios for each location by real estate type so that demand matches supply as closely as possible.

In reality only the regional control totals for employment by industry remain constant in the model. All other quantities change as the model determines a price in each employment zone for each real estate type that most closely matches real estate demand and supply. Again the above schematic and explanation is a greatly simplified explanation of the model's operation. The technical specifications attached at the rear of the report provide a more detailed explanation.

NONRESIDENTIAL REAL ESTATE MODEL – TECH SPECS

Demand Equations:

$$DSqFt_{i,k,j} = [TotalEmp]_i [Percent_o]_{i,k} [SqFtEmp_o]_{i,k} [\Pr ice]_{j,ko}^{-\beta_{i,k}} \{\sum_{k \neq ko}^{5} [\Pr ice]_{j,k}^{+\beta_{i,k}}\} [\Pr ice]_{j,k}^{-\gamma_{i,k}} [\Pr ice]_{j,k}^{-\alpha_{j,k}}$$

$$\{A_{1,i}(AllEmpAcs)_i + A_{2,i}(SameEmpAcs)_i + A_{3,i}(AllHhAcs)_i\}$$

Subject to: $\beta_{1,2,i} = \beta_{2,1,i} \ldots \beta_{mn,i} = \beta_{nm,i}$; $\sum_m \beta_k \sum_n \beta_k = 0$

and: $A_{1,i} + A_{2,i} + A_{3,i} = 1$

$$AllEmpAcs_i = \frac{\sum_{j=1}^{20} (AllEmp_l / acres_l)(B_{1,i} Time_{jl} + B_{2,i} Time_{jl}^2)^{-1}}{\sum_{l=1}^{20} \sum_{j=1}^{20} (AllEmp_l / acres_l)(B_{1,i} Time_{jl} + B_{2,i} Time_{jl}^2)^{-1}}$$

$$SameEmpAcs_i = \frac{\sum_{j=1}^{20} (SameEmp_l / acres_l)(B_{1,i} Time_{jl} + B_{2,i} Time_{jl}^2)^{-1}}{\sum_{l=1}^{20} \sum_{j=1}^{20} (SameEmp_l / acres_l)(B_{1,i} Time_{jl} + B_{2,i} Time_{jl}^2)^{-1}}$$

$$AllHhAcs_i = \frac{\sum_{j=1}^{20} (AllHh_l / acres_l)(B_{1,i} Time_{jl} + B_{2,i} Time_{jl}^2)^{-1}}{\sum_{l=1}^{20} \sum_{j=1}^{20} (AllHh_l / acres_l)(B_{1,i} Time_{jl} + B_{2,i} Time_{jl}^2)^{-1}}$$

$$Emp_{i,k,j} = DSqFt_{i,k,j} \Big/ (SqFtEmp_o)(\Pr ice)_{k,j}^{-\gamma_{i,k}}$$

Supply Equations:

$$SupSqFt_{i,k,j} = \sum_{n=} (acres_{j,k,n})(F.A.R.)_{k,n}$$

Subject to: $(SqFt\Pr ice)_{j,k,n} \geq (SqFtCost)_{j,k,n}$

$$SqFt\Pr ice_{j,k,n} = (SqFt\Pr ice_o)_{j,k,n} (\Pr ice)_{j,k}$$

$$SqFtCost_{j,k,n} = (SqFtLandCost)_{j,k,n} + (SqFtCapitalCost)_{j,k,n}$$

$$SqFtLandCost_{j,k,n} = +f[(\Pr ice)_{j,k} : (SqFtLandCost_o)_{j,k,n} : \sigma_k]$$

$$SqFtLand_{j,k,n} = -f[(\Pr ice)_{j,k} : (SqFtLand_o)_{j,k,n} : \sigma_k]$$

$$F.A.R._{j,k,n} = (SqFtCapital_o)_{k,n} / SqFtLand_{j,k,n}$$

$$SqFtCapitalCost_{k,n} = +f[K_{o,k} + K_{1,k}(F.A.R.)_{k,n}]$$

Subject to: $(SqFtCapital_o)_{k,n} \Big/ SqFtLand_{j,k,n} \leq MaxF.A.R._{j,k,n}$

Equation System Solution:

Find: $\Pr ice_{j,k}$

Such that: $\sum_i \sum_j \sum_k DSqFt_{i,k,j} - \sum_i \sum_j \sum_k SupSqFt_{i,k,j} = Min.$

Definitions:

$DSqFt_{i,k,j}$: Demand in square feet for nonresidential real estate type k by industry type i in zone j.
$TotalEmp_i$: Total regional employment in industry type i.
$[Percent_o]_{i,k}$: Percentage of employment in industry type i that chooses real estate type k when the price ratio is set at one.
$[SqFtEmp_o]_{i,k}$: Square feet per employee required by industry i in real estate type k when the price ratio is set at one.
$Price_{j,k}$: The price ratio in zone j for real estate type k
$\beta_{i,k}$: The cross price elasticity of industry type i for real estate type k. Cross price elasticities allow the substitution by industry of one real estate type for another as a function of their relative price ratios. We apply the usual cross price elasticity restrictions in that they be symmetrical and sum to zero.
$\gamma_{i,k}$: The square feet per employee consumption price elasticities by industry type i for real estate type k.
$\alpha_{j,k}$: The location choice price elasticities by zone j for real estate type k
$AllEmpAcs_i$: Measure of the access of industry type i in zone j to total employment within the region.
$SameEmpAcs_i$: Measure of the access of industry type i in zone j to the same industry type employment within the region
$AllHhAcs_i$: Measure of the access of industry type i in zone j to all households within the region
$A_{1,i}, A_{2,i}, A_{3,i}$: Share each access measure contributes to the "attractiveness" of zone j to industry i.
$AllEmp_l$: Total employment in one of 20 zones j (l is arbitrary counter for 20 zones located at various travel times from zone j.)
$Acres_l$: Acres of total developed nonresidential land in each of 20 zones j (l is arbitrary counter for 20 zones located at various travel times from zone j.)
$Time_{j,l}$: Travel time in minutes from zone j (for which access is being measured) to each of 20 zones l.
$SameEmp_l$: Employment in the same industry type in one of 20 zones for which access is being measured. (l is arbitrary counter for 20 zones located at various travel times from zone j.)
$AllHh_l$: All households in one of 20 zones for which access is being measured. (l is arbitrary counter.)
$B_{1,i}, B_{2,i}$: Estimated coefficients measuring the importance of travel time to employment and households for each industry type i.
$SupSqFt_{i,k,j}$: Supply in square feet of real estate type k for industry type i in zone j
$Acres_{j,k,n}$: Acres of available nonresidential land in zone j, designated for real estate type k in floor-to-area ratio(F.A.R.) regulatory class n

$F.A.R._{k,n}$: Computed actual floor-to-area-ratio for industry type k in regulatory class n in zone j.
$SqFt\Pr ice_{j,k,n}$:Market price for real estate type k in zone j for F.A.R. regulatory class n.
$SqFtCost_{j,k,n}$: Cost to suppliers to construct real estate of type k for F.A.R. regulatory class n in zone j.
$SqFtLandCost_{j,k,n}$:Cost per sq. foot to supply "ready-to-build" land in zone j for real estate type k for F.A.R. regulatory class n.
$(SqFtLandCost_o)_{j,k,n}$:Base cost per sq. foot to supply "ready-to-build" land when all price ratios are set to 1.
σ_k : Capital – land substitution parameter for real estate type k with respect to $\Pr ice_{j,k}$
$SqFtLand_{j,k,n}$: The percent share of land required for each unit of capital produced for zone j, real estate type k and F.A.R. regulatory class n.
$(SqFtLand_o)_{j,k,n}$:The base share of land required for each unit of capital produced for zone j, real estate type k and F.A.R. regulatory class n when price ratios are set to 1.
$(SqFtCapital_o)_{k,n}$:The base share of capital for real estate type k in F.A.R. regulatory class n when the price ratios are set to 1.
$SqFtCapitalCost_{k,n}$:Cost per square foot for capital for real estate type k in F.A.R. regulatory class n
$K_{o,k}, K_{1,k}$:Constants on a function that relate capital costs per square foot to floor-to-area ratio by real estate type k.
$MaxF.A.R.$: The maximum floor-to-area ratio allowable under the regulations in zone j, for real estate type k for F.A.R. regulatory class n.

HOUSING DEMAND AND PRODUCTION MODEL: TECHNICAL APPENDIX 2 - EQUATION SYSTEM AND PARAMETER ESTIMATES

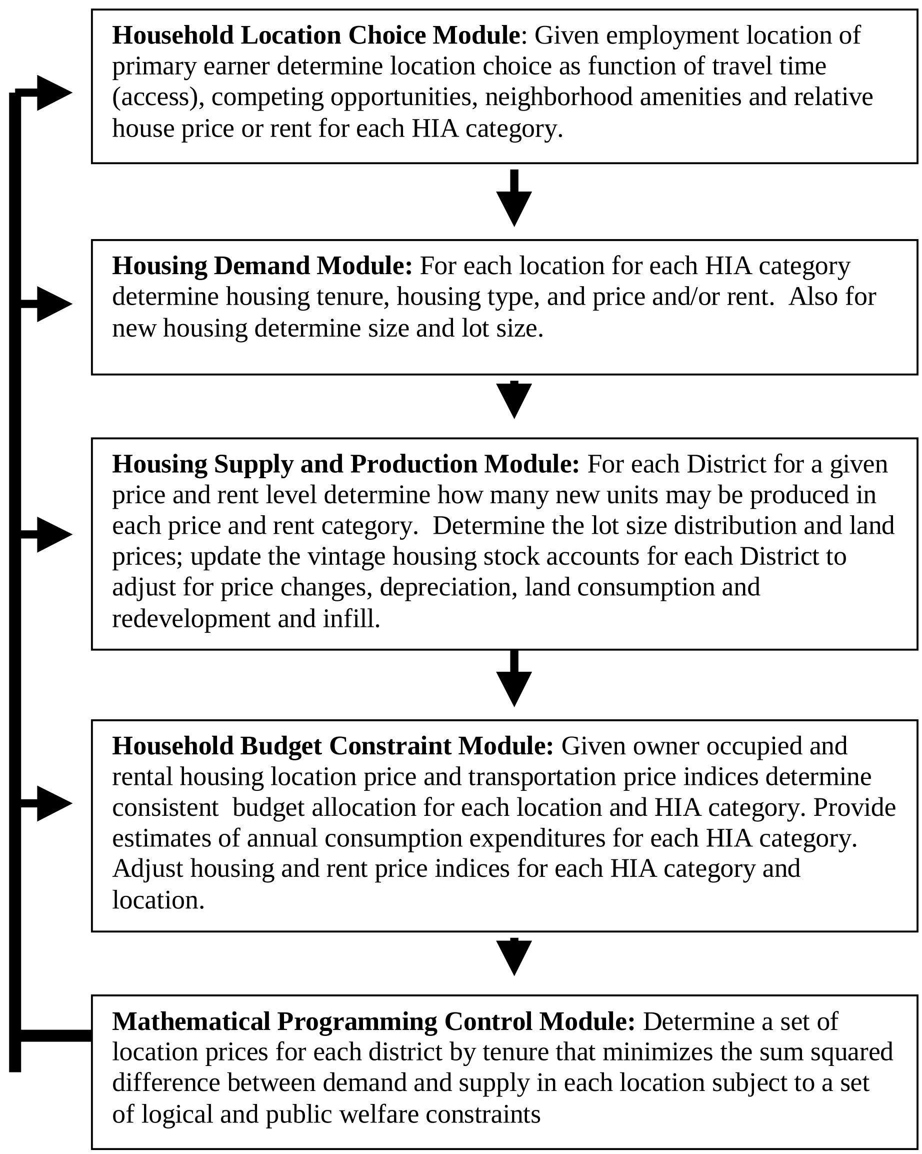
PART ONE

Introduction

Technical Appendix 2 consists of 3 parts. Part One is the Introduction including schematics showing in general RELM's external and internal working relationships. Part Two lists and defines the equations of the system. Part Three reports parameter estimates and "goodness of fit" tests where appropriate as well as results of sensitivity tests.

Schematic for RELM's Internal Operation

Below we depict how the various "computational modules" work in RELM.



To run the model we select a base year and set our location rents to one. By changing two region level parameters (asymptotic house price and rent) we calibrate to the region-wide house price and rent distribution for the base year. We then engage the mathematical programming module to solve the system for location rents for our base year and forecast years.

PART TWO

In Part Two we denote parameters estimated from data sets by the lower case Roman letters - a, b, c, etc. Parameters given as constants, published estimates, point estimates or derived from other equations, we denote with both lower and upper case Greek letters ($\alpha, \beta, \Delta, \Phi$, etc.).

Housing Demand Module

Housing demand stems from the regional change in households in each 5 year projection period. The change in households is subdivided by household size class, income class and age of head of household class. We can break each class into various groups which yields anywhere from 10 to 128 classes of household size, income and age. We refer to these household classes as "HIA's".

In this section of the model for each of the HIA classes we first compute tenure - rent or own- as a binomial choice as a function of HIA status and prices (adjusted as appropriate for location rent) of chosen, substitute and complimentary goods. We then compute for renters and owners an estimate of rent level or house price as a function of HIA status and prices of substitute and complimentary goods (again adjusted for location rent). For both owner and renter we compute for each HIA class the expected single family price and the expected monthly rent for each HIA class at each iteration of the model. We have specified the model for housing prices and rents to be a percent of an asymptotic maximum subject to an equilibrium price multiplier. This allows the housing price distribution to be updated to new initial conditions and allows it to vary robustly to changes in supply and demand growth.

For both owner and renter we estimate demand for three housing types - single family detached (traditional homes and manufactured homes), single family attached (row house, townhouse), and multifamily (condominiums, apartments). We are presently implementing the choice with multnomial choice equations for owners and renters. In the demand module we also estimate the size of owner occupied housing and the number of bedrooms of renter occupied housing as a function of HIA status and price. As an adjunct to the housing demand module we also calculate the number of earners and number of vehicles per household by HIA category.

All housing demand equations we specify in real dollar terms relative to 1995. Housing price changes relative to the 1995 baseline produce changes in tenure, house type, housing consumption (house size distribution) and lot size. We point out here that lot size changes as a result of both the house size distribution changing and producers changing the ratio of capital to land as the square foot prices of each change.

<u>Housing Demand Equations:</u>

A. Tenure computation by HIA class:

1.)
$$PRCNTOWN^{HIA} = \{EXP(-b_o - b_1(AGEHD) + b_2(AGEHDSQ) - b_3(INC) + b_4(INCSQ) + b_5(HSZE) + b_6(RX) - b_7(HX) - b_8(TX))\} / \{1 + EXP(-b_o - b_1(AGEHD) + b_2(AGEHDSQ) - b_3(INC) + b_4(INCSQ) + b_5(HSZE) + b_6(RX) - b_7(HX) - b_8(TX))\}$$

2.) $PRCNTRENT^{HIA} = [1 - PRCNTOWN^{HIA}]$

Where:

(All variables are in logarithms unless otherwise specified.)

$PRCNTRENT^{HIA}$: Percentage of each of the HIA classes that chooses to rent

HSZE: Household size class

AGEHD: Age of head of household

INC: Income level of household; measured at midpoint of class.

RX, HX, TX : Weighted rent, housing and transportation price index for area *I* at iteration *K* for a particular HIA category except for *TX* which is a constant within the region.

AGESQ: Square of age of head of household

$PRCNTOWN^{HIA}$: Percentage of each of the HIA classes that chooses to own.

B. House price and monthly rent computation by HIA class:

3.)
$$OWN : PRC_l^{HIA} = \langle\{EXP(b_o + b_1(AGEHD) - b_2(AGESQ) - b_3(INC) + b_4(INCSQ) - b_5(HSZE) + b_6(RX) + b_7(TX))\} / \{1 + EXP(b_o - b_1(AGEHD) + b_2(AGESQ) - b_3(INC) + .b_4(INCSQ) - b_5(HSZE) + b_6(RX) + b_7(TX))]\}\rangle (MAXPRC)(PRC_{IK} EQUILIBRIUMMULTIPLIER)$$

4.)
$$RENT : MRENT_l^{HIA} = \langle\{EXP(b_o - b_1(AGEHD) + b_2(AGEHSQ) - b_3(INC) + b_4(INCSQ) + b_5(HSZE) + b_6(HX) - b_7(TX))\} / \{1 + EXP(b_o - b_1(AGEHD) + b_2(AGESQ) - b_3(INC) + b_4(INCSQ) + b_5(HSZE) + b_6(HX) - b_7(TX))\}\rangle (MAXRENT)(PRC_{IK} EQUILIBRIUMMULTIPLIER)$$

Where:

$OWN{:}PRC_l^{HIA}$: For those choosing to own, the house price level that a give HIA class will pay in 1995$. This amount is given as a.) a baseline with 1995 household expenditure and consumption patterns held constant, and b.) with real prices and consumption allowed to vary. Bid prices for each HIA class are grouped into 8 price classes *l*.

$RENT{:}MRENT_l^{HIA}$: For those choosing to rent, the monthly rent level that a given HIA class will pay in 1995$. This amount is given as a.) a baseline with 1995 household expenditure and consumption patterns held constant, and b.) with real rents and consumption allowed to vary. Bid rents for each HIA class are grouped into 8 rent classes *l*.

MAXPRC: An asymptotic limit on the price for the topmost price class.

MAXRENT: An asymptotic limit on the monthly rent for the topmost rent class.

$PRC_{IK}EQUILIBRIUMMULTIPLIER$: A constant for each area and tenure determined as part of the mathematical programming routine that shifts prices and rents up or down to satisfy the behavioral equations, identities and constraints of the program solution. In the baseline run this value is set at one; otherwise it may vary from .25 to 10. This factor, variable by geography, may be loosely interpreted as “location rent”.

C. Housing type (single family detached, single family attached and multifamily) by tenure:

5.)

$$RENT:\%MFD^{HIA} = \{EXP(-a_o + b_1(HSZE) + b_2(INC) - b_3(AGESQ) - b_4(RENT:MFD) + b_5(MFD) - b_6(MFD*HSZE) - b_7(MFD*INC) + b_8(MFD*AGESQ) + b_9(RENTDIFF:MFD))\} / \sum_m (RENTUTIL)_m$$

6.)

$$RENT:\%SFA^{HIA} = \{EXP(-a_o + b_1(HSZE) + b_2(INC) - b_3(AGESQ) - b_4(RENT:SFA) + b_5(SFA) - b_6(SFA*HSZE) - b_7(SFA*INC) + b_8(SFA*AGESQ) + b_9(RENDIFF:SFA))\} / \sum_m (RENTUTIL)_m$$

7.)

$$RENT:\%SFD^{HIA} = \{EXP(-a_o + b_1(HSZE) + b_2(INC) - b_3(AGESQ) - b_4(RENT:SFD))\} / \sum_m (RENTUTIL)_m$$

8.)

$$OWN:\%SFD^{HIA} = \{EXP(a_o + b_1(HSZE) + b_2(INC) - b_3(AGESQ) - b_4(HPRC:SFD))\} / \sum_{K=1}^{3} (OWNUTIL)_K$$

9.)

$$OWN:\%SFA^{HIA} = \{EXP(a_o + b_1(HSZE) + b_2(INC) - b_3(AGESQ) - b_4(HPRC:SFA) - b_5(SFA) - b_6(SFA*HSZE) - b_7(SFA*INC) + b_8(SFA*AGESQ) + b_9(PRCDIFF:SFA))\} / \sum_{K=1}^{3}(OWNUTIL)_K$$

10.)

$$OWN:\%MFD^{HIA} = \{EXP(a_o + b_1(HSZE) + b_2(INC) - b_3(AGESQ) - b_4(HPRC:MFD) - b_5(MFD) - b_6(MFD*HSZE) - b_7(MFD*INC) + b_8(MFD*AGESQ) + b_9(PRCDIFF:MFD))\} / \sum_{K=1}^{3}(OWNUTIL)_K$$

Where:

(Variables are not in logarithms.)

$RENT:\%MFD^{HIA}$: Percent of households choosing to rent that choose multifamily dwelling units by HIA class.
$RENT:\%SFA^{HIA}$: Given rent choice and choice of single family, the percentage of renters choosing single family attached.
$RENT:\%SFD^{HIA}$: Percent of households in a particular HIA class choosing to rent single family detached dwelling units.
$OWN:\%SFD^{HIA}$: Percentage of owners choosing single family detached.
$OWN:\%SFA^{HIA}$: Percentage of owners choosing single family attached.
$OWN:\%MFD^{HIA}$: Percentage of owners choosing multi-family dwelling units.
SFD: Single family detached generic label: 1 if; 0 otherwise.
SFA: Single family attached generic label; 1 if; 0 otherwise.
$RENT:SFD, MFD, SFA$: Rent level by housing type
$RENTDIFF:SFA, MFD$: Rent difference between SFD and other housing types.
MFD: Multi family generic label; 1 if; 0 otherwise.
$HPRC:SFD, SFA, MFD$: House price by housing type.
$PRCDIFF:SFA, MFD$: House price difference between SFD and other housing types.
$RENTUTIL$: Total utility of renting – sum of SFD, MFD and SFA equations.
$OWNUTIL$: Total utility of owning – sum of SFD, MFD and SFA equations.

D. Single family house size, multi-family number of bedrooms, number of earners and number of vehicles per household equations

11.) $OWNSZE = EXP(b_o - b_1(INC) + b_2(INCSQ) + b_3(HSZE) - b_4(HX))$

12.) $RENTSZE = EXP(-b_o + b_1(INC) - b_2(INCSQ) + b_3(HSZE) - b_4(RX))$

13.)
$$NVEHLS = EXP(-b_o + b_1(AGE) - b_2(AGESQ) + b_3(INC) - b_4(INCSQ) + b_5(HSZE) + b_6(RX) - b_7(HX) - b_8(TX))$$

14.)
$$NEARNS = EXP(-b_o + b_1(AGE) - b_2(AGESQ) + b_3(INC) - b_4(INCSQ) + b_5(HSZE) - b_6(TX)$$

Where:

(Variables are in logarithms.)

OWNSZE **:** Size in sq. ft. of newly constructed owner occupied housing by HIA and location.
RENTSZE : Size in number of bedrooms of newly constructed renter occupied housing by HIA and location.
NVEHLS : Number of vehicles per household by HIA and location.
NEARNS : Number of earners per household by HIA and location.

This completes the housing demand section of the model. The quantities above are then summed by HIA to arrive at demand totals at each model iteration for a particular jurisdiction for each 5 time period. As is indicated in the demand equations owner prices and monthly rents we adjust to be consistent with the production cost, location choice and location capacity sections of the model subject to the household expenditure constraint section documented below.

Household Budget Expenditure Constraint Module

Housing consumption, expressed as a percentage of the annual household budget devoted to it, varies markedly by income level and cross sectionally by level of housing prices and rents. Low income groups devote a higher proportion to housing than do high income groups. Moreover, households identical in size, income and age of head may devote dramatically different shares to housing depending on the relative cost of housing in the regions in which they live. Literature indicates that housing is a superior composite good with a very restricted and asymmetric elasticity of cross substitution between product types. In a word people need shelter almost before everything else and while people eagerly switch from renter to owner status whenever circumstances allow it, they almost never switch from owner to renter. Literature indicates that the short term price elasticity for housing consumption is very low; in other words it is very inelastic. Given excess demand prices will rise and an increasing share of household income will be devoted to housing. However, other work shows that the long term supply compensated price elasticity is roughly one. Given enough time to work and no restrictions on supply, the market will act to bring demand prices back to an equilibrium level. However, in regions with housing supply restrictions (cost of entry in the market is very high relative to demand) and for households whose demand price falls below the threshold level for new housing production long run price adjustment may never occur or may be very slow.

In the context of achieving price equilibrium in the regional housing market all of the above greatly complicates the *ex ante* housing demand equations we specified in the prior section. Based on our literature review and data from the *American Housing Survey* and the *Annual Survey of Consumer Expenditure* we constrained housing expense as a function of a set of 5 pseudo-translog consumer cost equations. The equations relate total housing expenditures and prices to all other household expenditures and prices. Based on data from both low and high housing cost regions the equations provide a realistic depiction of how household budgets adjust to changes in housing prices. In interpreting results however, we need keep in mind that the equations estimate average budget shares; not marginal budget shares. Households actually buying homes or renegotiating rent contracts may experience dramatically different cost impacts.

Household Budget Share Equations

15.)
$$\begin{aligned} FOOD = EXP(b_o - b_1(INC) + b_2(INCSQ) + b_3(AGE) - b_4(AGESQ) + b_5(HSZE) \\ - b_6(FDX) + b_7(FDX * HRX) - b_8(FDX * TX) \\ + b_9(FDX * HLX) - b_{10}(FDX * OTX)) \end{aligned}$$

16.)
$$\begin{aligned} HOUSE = EXP(b_o - b_1(INC) + b_2(INCSQ) + b_3(AGE) - b_4(AGESQ) + b_5(HSZE) \\ - b_6(HRX) + b_7(HRX * FDX) - b_8(HRX * TX) \\ + b_9(HRX * HLX) - b_{10}(HRX * OTX)) \end{aligned}$$

17.)
$$\begin{aligned} TRANS = EXP(-b_o + b_1(INC) - b_2(INCSQ) - b_3(AGE) - b_4(AGESQ) + b_5(HSZE) \\ + b_6(TX) - b_7(TX * FDX) - b_8(TX * HRX) \\ - b_9(TX * HLX) + b_{10}(TX * OTX)) \end{aligned}$$

18.)
$$\begin{aligned} HEALTH = EXP(-b_o + b_1(INC) - b_2(INCSQ) - b_3(AGE) + b_4(GESQ) + b_5(HSZE) \\ + b_6(HLX) + b_7(HLX * FDX) + b_8(HLX * HRX) \\ - b_9(HLX * TX) + b_{10}(HLX * OTX)) \end{aligned}$$

19.)
$$\begin{aligned} OTHER = EXP(b_o - b_1(INC) + b_2(INCSQ) + b_3(AGE) - b_4(AGESQ) + b_5(HSZE) \\ - b_6(OTX) - b_7(OTX * FDX) - b_8(OTX * HRX) \\ + b_9(OTX * TX) + b_{10}(OTX * HLX)) \end{aligned}$$

20.) $RX = RENT : MRENT_l / RENT : MRENT_{BB}$

21.) $HX = OWN : PRC_l / OWN : PRC_{BB}$

22.) $HRX = (RENTDU * RX + OWNDU * HX)/(RENTDU + OWNDU)$

Where:

(Variables are in logarithms.)

FOOD : Amount spent on food by HIA category by location.
HOUSE : Amount spent on housing including utilities, taxes, upkeep, furniture, etc. by HIA category by location in 95$.
TRANS: Amount spent on transportation of all types including travel away from home by HIA category by location in 95$.
HEALTH: Amount spent on health by HIA category by location.
OTHER: Amount spent on everything else by HIA category by location in 95 $.
FDX,HLX,OTX : Price indices for food, health and other. These are set as constants in the model and not changed.
TX: Transportation cost and travel speed index which measures both transportation cost and speed of travel. Valid at regional level only. (Cannot vary by location within the region).
RX, HX, HRX: Price indices for rental, owner and combined housing price index by HIA by location.
RENTDU: Total rental dwelling units by HIA by location for a particular model interation.
OWNERDU: Total owner occupied dwelling unts by HIA by location for a particular model iteration.

The above equation system allows housing prices and rents to change consistently in an *ex post* demand, supply and price equilibration. The *ex ante* price estimates we adjust with an "equilibrium price multiplier" which adjusts the bid price distribution up or down.

Neighborhood (Region) Vintage Housing, Initial Condition Accounting and Housing Production Module

Before we can estimate the producer response to the demand signals created in the housing demand and household budget constraint sections, we need estimate the vintage housing stock, capacity, vintage housing price distribution, and land price distribution for each neighborhood (region). These equations specific to whatever units of geography the model is being run for. They are updated at the beginning of each 5 year time period based on the relevant equilibrium price, demand and supply levels determined in the prior 5 year time period. Here we list the equations for single family only. Multi-family equations where relevant have the same structure.

We account for housing stock by type, geography and price (rent) category. The stock available at the beginning of the time period is the stock available at the end of the previous time period less depreciation out of the price (rent) category plus depreciation into the price (rent) category from more expensive stock. Depreciation in a given time period is a function of overall housing price change less than intrinsic depreciation rate. The intrinsic depreciation rate we determine from the age coefficient of our hedonic price equations.

We determine the difference in land prices between areas as the residual between the estimated housing price (rent) and the "nonland" terms of our hedonic price equations. We express the relative prices as the ratio of particular areas to the region overall. The hedonic price equations we estimate from a sample of recent sales using variables to measure neighborhood, access and structure characteristics.

We recalculate capacity for each area for each time period. For a given land use (SFD or MFD) and zoning density class we calculate the DU capacity of vacant land. In addition we calculate the DU capacity from "infill" land. Infill and redevelopment rates we estimate as a function of the observed 1995 rates, housing prices and the potential return versus estimated current return on investment. These rates we multiply be the potential stock of infill and redevelopment acres in each area. The potential stock we estimate from our GIS which uses the particular attributes of each tax lot.

In the equations below we calculate vintage supply and depreciation for each housing tenure and housing type SFD, SFA and MFD though we show equations for only OWN:SFD. Depreciation is calculated for only SFD and MFD. SFA depreciation is assumed equal to SFD. Relative land price we calculate for only SFD with SFA and MFD given as a function of the SFD relative price factored for yield differences.

<u>Neighborhood Vintage Supply, Relative Land Price and Capacity:</u>

A. Vintage supply and depreciation:

23.)
$$NMBROWN:SFD_{ilt} = [(NMBROWN:SFD_{il,t-1})(1-DEPRC_{it})] + [(NMBROWN:SFD_{i,l+1,t-1})(DEPRC_{it})$$

24.) $DEPRC_{it} = (PRC_{IK} \ / \ PRC_{BB}) - \Delta_i^{DUTYPE}$
25.) $\Delta_i^{DUTYPE} = -EXP(b_i (STRUCAGE)_i^{DUTYPE}$

Where:

$NMBROWN:SFD_{ilt}$: Number of single family detached dwelling units in jurisdiction (*i*), in price category (*l*), at time (*t*).
$DEPRC_{it}$: Depreciation rate in jurisdiction (*i*) at time (*t*).
Δ_i^{DUTYPE}: Annual depreciation rate estimated from hedonic price equations by jurisdiction and dwelling unit type (single family - multifamily).
$STRUCAGE$: Age of buildings from sample of housing sales included in hedonic price analysis.

B. Relative land price:

26.)

$$PLAND_{it}^{PZ} / PLAND_{Ot}^{PZ} = SFD\!:\!HEDPRC_{it} - [b_i(STRUCSIZE) + b_{i+1}(LOTSIZE) + b_{i+2}(STRUCTYPE)...+b_{i+n}(STRUCAGE)] / \tfrac{1}{N}\sum_{i=1}\{SFD\!:\!HEDPRC_{it} - [b_i(STUCSIZE + ...+b_{i+n}(STRUCAGE)]\}_i$$

27.)

$$SFD\!:\!HEDPRC_{it} = a_o + a_1(ACSSUTIL) + a_2(INFILL?) + a_3(MIXEDLU?) + a_4(VIEW?) + a_5(PRESTIGE?) + a_i(JURISDLABEL)+\ldots a_{i+n}(NEIGHLABEL) + b_i(STRUCSIZE)\ldots + b_{i+n}(STRUCAGE)$$

Where:

$PLAND_{it}^{PZ} / PLAND_{Ot}^{PZ}$: Relative land price ratio measures the ratio of land prices in a particular jurisdiction to the average of all regional jurisdictions for land use type (*PZ*). This ratio is measured from the hedonic price equation by subtracting out structure and lot size effects from the actual selling price of housing.
$SFD\!:\!HEDPRC_{it}$: Single family sales price of housing in a particular jurisdiction at a particular time.
STRUCSIZE : Structure size in sq. ft. from house sales sample.
LOTSIZE : Lot size in sq. ft. from house sales sample.
STRUCTYPE : Structure type such as SFA, SFD, MFD.
STRUCAGE : Structure age in years from house sales sample.
ACSSUTIL: Access utility from zone *i* to all destination zones as a function of travel time and cost over all available modes.
INFILL?: Variable measuring whether neighborhood is infill area or not.
MIXEDLU?: Variable measuring whether neighborhood has mixed land uses or not.
VIEW: Measures whether a neighborhood has a view or not.
PRESTIGE?: Measures whether a neighborhood is a prestige area or not.
JURISDLABEL: Variable denoting which jurisdiction home sale is in.
NEIGHLABEL: Variable denoting which neighborhood a homes is located in.

C. Capacity calculations:

28.)

$$DUCAP_{itk}^{PZ} = (VACANTLANDSTK)_{itk}^{PZ}(DUACRE)_{itk}^{PZ} + \Phi_{it}^{PZ}(INFILLLANDSTK)_{it}^{PZ}(DUACRE)_{itk}^{PZ} + \Gamma_{it}^{PZ}(REDEVLANDSTK)_{it}^{PZ}(NETREDEVDUACRE)_{itk}^{PZ}$$

29.)

$$VACANTLANDSTK_{it}^{PZ} = (VACANTLANDSTK)_{i,t-1}^{PZ} - \sum_{l=1}^{8} (NEWCON:OWN+)_{i,l,t-1}^{PZ}$$

$$\sum_{n=1}^{7}\sum_{HIA=1}^{64} (LOTSZE)_{i,t-1}^{PZ,HIA} - \sum_{l=1}^{8} (NEWCON:RENT)_{i,l,t-1}^{PZ}(MFCONSTANTLOTSZE)$$

$$+ (SFDEMO + MFDEMO)_{i,t-1}^{PZ}(CONSTLOTSZE)$$

30.)

$$INFILLLANDSTK_{it}^{PZ} = (OVRSIZELOTINVENTORY)_{it=0}^{PZ} - \sum_{t=t-n}^{t} \Phi_{it}^{PZ}(INFILLLANDSTK)_{it}^{PZ}$$

31.) $$\Phi_{it}^{PZ} = K_{95}(PRC_{it}^{PZ} / PRC_{95}^{PZ})^{\alpha}(LANDCHAR_{it}^{PZ})^{b}(DEMOCHAR_{it})^{c}$$

32.)

$$REDEVLANDSTK_{it}^{PZ} = (REDEVLANDINVENTORY)_{i,t=0}^{PZ} - \sum_{t=t-n}^{t} \Gamma_{it}^{PZ}(REDEVLANDSTK)_{it}^{PZ}$$

33.) $$\Gamma_{it}^{PZ} = C_{95}(PRC_{it}^{PZ} / PRC_{95}^{PZ})^{a}(LANDCHAR_{it}^{PZ})^{b}(DEMOCHAR_{it})^{c}$$

Where:

(Variables are not in logarithms.)

$DUCAP_{itk}^{PZ}$: Dwelling unit capacity of area (*i*) in time (*t*) for land use *PZ* for tenure *k*.

$VACANTLANDSTK_{it}^{PZ}$: Vacant land stock in time *t* of jurisdiction *i* for land use *PZ* taken from prior iteration or from the RLIS data base in the initial time period.

$DUACRE_{it}^{PZ}$: The calculated yield per acre on land by parcel size, land use category and housing type, jurisdiction and time period subject to lot sizes not falling below the regulatory minimum size or above the regulatory maximum size.

Φ_{it}^{PZ}: The estimated rate at which the stock of infill land is consumed for each jurisdiction, time period and land use.

$INFILLLANDSTK_{it}^{PZ}$: Infill land stock for each jurisdiction, time period, etc.

Γ_{it}^{PZ}: The estimated rate at which the stock of redevelopment land is consumed for each jurisdiction, time period and land use.

$REDEVLANDSTK_{it}^{PZ}$: Redevelopment land stock for each jurisdiction, etc.

$NETREDEVDUACRE_{it}^{PZ}$: Net increase in capacity per acre of redeveloped land

$NEWCON:OWN:RENT$: New construction of owner and renter dwelling units by jurisdiction, time period and price (rent) class.

MFCONSTANTLOTSZE: Lot size assumption for multi-family

SFDEMO, MFDEMO: Number of single family and multi-family units demolished each period that are not redeveloped.
CONSTLOTSZE: Constant lot size assumption for demolished structures.
OVERSZELOTINVENTORY: Established by RLIS and expert committee in base year.
REDEVLANDINVENTORY: Established by RLIS and expert committee in base year.
LANDCHAR: A vector of land characteristics including average parcel size, site access and amount of vacant land within 500 ft.
$DEMOCHAR$: A vector of demographic characteristics such as average age, household size, etc. indicative of willingness to develop surrounding land to a higher intensity.
PRC_{it}^{pz}: The calculation from the hedonic equations of the parcel value in the maximum allowable use in a particular area in time t for a particular land use. Limited to the stock of vacant, infill and redevelopable parcels.
PRC_{95}^{PZ}: The calculation from the hedonic equations of the parcel value in terms of its current use.
K_{95}: The observed infill rate as of the 95-96 survey.
C_{95}: The observed redevelopment rate as of the 95-96 survey.

Housing Production and Supply

In this section we list the equations for determining the minimum housing price (rent) at which producers will enter the market (construction cost). We also list equations for determining the single family lot size and land price per sq. foot. Beyond equations which represent how private producers will respond to price, regulation, fee and capacity conditions in each area in each time period, we also include in this section the accounting equations for adding new construction to the vintage supply.

We also estimate the distribution of owner occupied house and lot sizes for each HIA class. We distribute each price category of owner occupied housing demand according to the observed size distribution in 1990 (or alternatively the 1995 - 96 distribution observed for new sfd construction). Similarly we assign each owner occupied house size category to a lot size frequency distribution observed in 1990 (or alternatively the 1995 - 96 distribution for new sfd construction). In each 5 year projection period the lot size distribution for each housing size category changes in response to changes in housing prices as housing price changes work back into land prices as a function of the capital-land substitution parameter in the housing production equations.

A. Calculation of Housing Construction Cost, Lot Size and Land Price per Sq. Ft.

34.) $IF:(SFLOTSZE)_{it=0}^{DUTYPE}\delta_{it} > MINLOTSZE_{it}^{DUTYPE}$

$$CONSTCOST_{itp}^{DUTYP} = K_o[K_{LND}(SFLOTSZE)_{i,t=0,p}^{DUTYPE}(LANDPRCRATIO)\delta_{it})]$$

35.) $$+(DEVELOPFEES)_{it}^{DUTYPE} + (LANDCAPCOST)_{it}$$

$$+(STRUCTCAPCOSTSQFT)_{pt}^{DUTUYPE}(MINSTRUCTSQFT)_{i}^{DUTYPE}$$

36.) $IF : (SFLOTSZE)_{it=0}^{DUTYPE} < MINLOTSZE_{it}^{DUTYPE}$

$$CONSTCOST_{itp}^{DUTYPE} = K_o[K_{LND}(MINLOTSZE)_{it}^{DUTYPE}(LANDPRCRATIO)]$$

37.) $$+(DEVELOPFEES)_{it}^{DUTYPE} + (LANDCAPCOST)_{it}$$

$$+(STRUCTCAPCOSTSQFT)_{p,t}^{DUTYPE}(MINSTRUCTSQFT)_{i}^{DUTYPE}$$

38.)

$$\delta_{it} = \left(\begin{array}{c} STRUCTSQFT_{i,t=0} \;/\; \{[(STRUCTSQFT_{i,t=0} \;/\; SFLOTSZE_{i,t=0}) \\ /\;(STRUCTCAPCOSTSQFT_{t=0} \;/\; LANDCOSTSQFT_{t=0})]^{-\Psi} \\ [(STRUCTCAPCOSTSQFT_{t=0})\;/\;(LANDCOSTSQFT_{t=0})(LANDPRCRATIO)]^{-\Psi}\} \\ /\; SFLOTSZE_{i,t=0} \end{array} \right)$$

39.) $$LANDPRCRATIO_t = [(OWN\!:\!PRC_{i,t=n} \;/\; LOTSZE_{i,t=n}K_O)^{1/\Psi+1}] \;/\; [(OWN\!:\!PRC_{i,t=0} \;/\; LOTSIZE_{i,t=0}K_O)^{1/\Psi+1}]$$

40.) $$\Psi = \left(\begin{array}{c} Ln\{\{\{[SFDPRC - (LOTSZE)(HEDLANDPRC)] / LOTSZE\} \\ -K_O\} / (HEDLANDPRC)\} \end{array} \right)$$

41.) $LOTSZE_{i,t=n} = \delta_{it}(LOTSZE_{i,t=0})$

Where:

(Variables are not in logarithms.)

Ψ : Capital-Land substitution parameter estimated assuming CES production function and land cost per sq. ft. estimated as residual from hedonic pricing model.

$LANDPRCRATIO_t$: Land price per sq. ft. at time t in area for a given lot size.

K_o, K_{LND}, K_O : Arbitrary constants necessary to initialize the values to the baseline conditions

MINSQFTLOTSZE: The minimum lot size for a particular DU type allowed under the regulations.

$DEVELOPFEES_{it}^{DUTYPE}$: Development fees charged by each jurisdiction by dwelling unit type and density if applicable.

$LANDCAPCOST_{it}^{DUTYPE}$: Developer’s direct capital costs to develop a lot of a particular dwelling unit type

$STRUCTCAPCOSTSQFT_{t}^{DUTYPE}$: Capital cost per sq. ft. to build a particular type structure.

$MINSTRUCTSQFT_t^{DUTYPE}$: The minimum structure size for a particular DU type consistent with present building patterns.
$SFLOTSZE_{i,t=0}$: Single family lot size distribution in a particular jurisdiction in the base period.
SFDPRC: Single family sales prices observed in data used to estimate hedonic sales price model.
HEDLANDPRC: Land prices estimated from structural coefficients of hedonic sales price model.

B. Housing Supply and New Construction Determination Algorithm

Using owner occupied SFD, SFA and MF as an example we compare total demand from the demand equations with vintage supply. Next we determine the excess demand the price of which exceeds the cost of construction. This excess demand equals new construction if it is less than or equal to the capacity of the zone. If new construction requirements exceed the capacity of the zone, the remaining capacity available above the cost of construction is assigned to new construction. New construction is allocated by type in proportion to each housing type's share of demand. Finally, we compare total original demand to the new supply to determine if excess demand exists in the zone. If so, the excess demand is assigned to the "subsidy required" category.

42.)

$$DMD:OWN_{i,l,t} = (OWN:SFD_{i,l,t}) + (OWN:SFA_{i,l,t}) + (OWN:MFD_{i,l,t})$$

$$SUPPLY:OWN_{i,l,t-1} = NMBROWN:SFD_{i,l,t-1} + NMBROWN:SFA_{i,l,t-1} + NMBROWN:MF_{i,l,t-1}$$

$$FOR:DMD:OWN_{i,l,t} \geq CONSTCOST_{i,t}^{OWN} \; AND > SUPPLY:OWN_{i,l,t-1} THEN:$$

43.) $$NEWCON:OWN_{i,l,t} = DMD:OWN_{i,l,t} - SUPPLY:OWN_{i,l,t-1}$$

44.)

$$IF:NEWCON:OWN_{i,l,t} < \sum_{DUTYPE}^{3} DUCAP_{i,t,k}^{DUTYPE} \; for \quad all\, l > CONSTCOST_{i,t}^{OWN}$$

$$THEN:TSUPPLY:OWN_{i,l,t} = NEWCON:OWN_{i,l,t} + SUPPLY:OWN_{i,l,t-1}$$

45.)

$$IF:NEWCON:OWN_{i,l,t} > \sum_{DUTYPE}^{3} DUCAP_{i,t,k}^{DUTYPE} \; for \quad all\, l > CONSTCOST_{i,t}^{OWN}$$

$$THEN:TSUPPLY:OWN_{i,l,t} = \sum_{DUTYPE}^{3} DUCAP_{i,t,k}^{DUTYPE} + SUPPLY:OWN_{i,l,t-1}$$

46.) $$NEWCON:SFD_{i,l,t} = [NEWCON:OWN_{i,l,t}][OWN:SFD_{i,l,t} / \sum_{K=1}(OWN_{i,l,t})_K$$

47.)

$$IF:DMD:OWN_{i,l,t} \leq CONSTCOST_{i,t}^{OWN} \; OR < SUPPLY:OWN_{i,l,t-1} THEN:$$

$$TSUPPLY:OWN_{i,l,t} = SUPPLY:OWN_{i,l,t-1}$$

48.) $$XCSDMD:OWN_{i,l,t} = DMD:OWN_{i,l,t} - TSUPPLY:OWN_{i,l,t} \; IF:> 0$$

49.) $$SUBSIDY:OWN_{i,l,t} = XCSDMD:OWN_{i,l,t}$$

Where:

(Variables are not in logarithms.)

$TSUPPLY:OWN_{i,l,t}$: Total supply at time *t* of owner occupied housing.

$SUPPLY:OWN_{i,l,t-1}$: Housing supply at time *t*-1.

$OWN:SFD_{i,l,t}, OWN:SFA_{i,l,t}, OWN:MFD_{i,l,t}$: The total demand for single family detached, single family attached and multi-family detached for a particular jurisdiction in a particular price (rent) class.

$DMD:OWN_{i,l,t}$: Total vintage plus incremental demand by dwelling unit total, price category, jurisdiction and time period.

$SUPPLY:OWN_{i,l,t}$: Total vintage plus incremental supply by dwelling unit type, price category, jurisdiction and time period.

$XCSDMD:OWN_{i,l,t}$: Excess demand remaining after demand-supply reconciliation by price (rent) category

$SUBSIDY:OWN_{i,l,t}$: Housing demand that the private market will not supply without a subsidy.

Household Location Choice Given Place of Employment of Primary Earner

At this stage in model development we take the value (E_j^{HIA}) as given. In this notation (E) represents the employment in zone (j) by HIA class. As noted in the introduction we allocate employment using the econometric model and an expert panel using data generated from GIS, RELM and the transportation model. The exogenous estimate of employment in each zone is converted into an estimate of total households by HIA category. The model then determines tenure choice for the households working at each employment center. The household location choice module then determines location choice by tenure for each employment zone. So for a given number of households of a particular HIA category working in E_j, we specify their location choice as:

50.) $HSHLDS_{jk}^{HIA} = [\sum_{j=1}^{y} HSHLDS_j^{HIA} / \sum_{j=1}^{x} E_j^{HIA}] \times E_j^{HIA} \times PRCNTRENT^{HIA}$

51.)

$$HSELOC_{ijk}^{HIA} = \left(\frac{\begin{array}{l} EXP[-b_o - b_1(INC) - b_2(INC*TRAVELMIN_{ij}) + b_3(PLAND_{i,t} / PLAND_{O,t})*(INC) \\ + b_4(NEARNS) + b_5(NEARNS*TRAVELMIN_{ij}) \\ - b_6(PRC_{IK}EQUILIBRIUMMULTIPLIER_{iK}) \\ + b_7(PLAND_{i,t} / PLAND_{O,t})*(TRAVELMIN_{ij}) - b_8(TRAVELMIN_{ij}) \\ - b_9(TRAVELMINSQ_{ij}) - b_{10}(HSEOPP_{nm,t})] \end{array}}{\begin{array}{l} \sum_{i=1}^{y} \{EXP[-b_o - b_1(INC) - b_2(INC*TRAVELMIN_{ij}) + b_3(PLAND_{i,t} / PLAND_{O,t})*(INC) \\ + b_4(NEARNS) + b_5(NEARNS*TRAVELMIN_{ij}) \\ - b_6(PRC_{IK}EQUILIBRIUMMULTIPLIER_{iK}) \\ + b_7(PLAND_{i,t} / PLAND_{O,t})*(TRAVELMIN_{ij}) - b_8(TRAVELMIN_{ij}) \\ - b_9(TRAVELMINSQ_{ij} - b_{10}(HSEOPP_{nm,t})]\}_i \end{array}} \right) \times (HSHLDS)_{jk}^{HIA}$$

Where:

(Variables are not in logarithms).

$HSEOPP_{nm,t}$: Intervening housing opportunities measure which represents the percentage of the region's housing units that can be reached in a shorter travel time than the units in the area being evaluated.

$HSHLDS_{jk}^{HIA}$: Households of tenure k and HIA category employed in employment zone j.

E: Total regional employment

E_j^{HIA}: Employment in HIA class in employment area *j*.

$HSELOC_{ijk}^{HIA}$: Number of households of HIA class , tenure class k, working in area *j* who chose housing location i.

$TRAVEMIN_{ij}$. Travel time in minutes peak am from location i to employment zone *j*.

The household location choice model we specify to work recursively with the transportation model. The location choice model provides the transportation model with updated information on HIA's and employment by traffic analysis zone. The transportation model in turn calculates traffic flows, modes splits and new estimates of travel time between each traffic analysis zone for each mode. This information in turn provides the travel time data for the location model in the next time period.

Note that we specify the location model to be scale invariant. The utility of a location we estimate from the perspective of one household making a choice. From the perspective of a particular location the probability of the calculated choice occurring is a scale invariant function including only arguments relevant to the individual household decision. Demand and supply (capacity of the location at a particular price level) adjust through the location rent term $PRC_{IK} EQUILIBRIUMMULTIPLIER$.

Mathematical Programming for *Ex Post* Equilibrium

Each iteration of the model equations outlined above yields by jurisdiction (i) and time period (t) changes in land prices and housing prices (rents) as well as changes in tenure, lot sizes and housing sizes. To adjust demand and supply using price we calculate *RX*, *HX*, and *HRX* for each area that minimizes the difference between supply and demand. To do this we use a mathematical programming technique that determines an equilibrium multiplier (location rent) for each area and tenure that most efficiently adjusts supply, demand and price/rent in each area.

A. Mathematical Programming:

Given that we have established a set of baseline conditions (1995 economic conditions with the price (rent) ratio set equal to 1, we then operate the model in a mathematical programming framework to determine an equilibrium price level for the entire region. As presently implemented we determine a price equilibrium multiplier for each area i and tenure as follows:

52.) $FIND: \quad (PRC_{IK} EQUILIBRIUMMULTIPLIER) \quad SUBJECT\ TO:$

53.) $\sum_{i=1}^{n} \sum_{l=1}^{2} (SUPPLY_{i,l} - DMD_{i,l})^2 = MIN$

54.) $SUPPLY_{i,l} \geq 0$

55.) $DMD_{i,l} \geq 0$

56.) $PRC_{IK} EQUILBRIUMMULTIPLIER > .5 < 8$

57.) $\sum_{i=1}^{n} \sum_{l=1}^{2} SUBSIDY_{i,l} = 25{,}000$

Program conditions 1.) through 5.) are sufficient to obtain *ex post* estimates consistent with the equation system outline above and implicit in condition 6.). Please note that when the constant term in condition 6.) is set at 0, then total housing demand and supply are equated; which is the classical price equilibrium condition. However, in reality we find that without substantial subsidy that condition is never met.

PART THREE

Tables of Parameter Estimates:

Equation Number	1.)		3.)		4.)		5.)		6.)	
Dependent Variable	*prcntown*		*own:prc*		*rent:mrent*		*rent:%mfd*		*rent:%sfa*	
Estimation Method	*WLS*		*WLS*		*WLS*		**WRLS**		*WRLS*	
RSQ.	*.92*		*.88*		*.85*		*.40*		*.40*	
Data Source	*Cons. Ex. S.*		*Cons. Ex. S.*		*Cons. Ex. S.*		*Pums*		*Pums*	
N	*612*		*612*		*612*		*12711*		*12711*	
Variable Names	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.
Intercept	-1.78	-.66	1.78	1.40	1.98	1.30	-9.03	-23.2	-9.03	-23.2
Agehd	-.605	-.62	4.72	7.37	-2.67	-4.77	-	-	-	-
Aghdsq	.476	3.70	-.551	-6.47	.387	5.19	-.0002	-2.88	-.0002	-2.88
Inc	-1.64	-3.79	-3.28	-11.5	-.33	-1.34	.0593	7.52	.0593	7.52
Incsq	.132	6.28	.187	13.4	.043	3.6	-	-	-	-
Hsze	.728	20.3	-.042	-1.75	.145	6.92	2.498	24.3	2.498	24.3
Rx	2.22	11.9	.704	6.61	-	-	-	-	-	-
Hx	-1.31	-9.9	-	-	.374	5.58	-	-	-	-
Tx	-.891	-6.8	1.19	21.6	-.298	-3.92	-	-	-	-
Rent:mfd							-.0055	-13.2	-	-
Mfd							12.74	31.5	-	-
Mfd*hsze							-4.5	-35.4	-	-
Mfd*inc							-.227	-11.7	-	-
Mfd*agesq							.0004	3.28	-	-
Rentdiff:mfd							.01	-	-	-
Rent:sfa									-.0055	-13.2
Sfa									.70	6.57
Sfa*hsze									-.50	-18.5
Sfa*inc									-.0745	-6.85
Sfa*agesq									.0000	.026
Rentdiff:sfa									.005	-

Tables of Parameter Estimates:

Equation Number	7.)		8.)		9.)		10.)	
Dependent Variable	*rent:%sfd*		*own:%sfd*		*own:%sfa*		*own:%mfd*	
Estimation Method	*WRLS*		*WRLS*		*WRLS*		**WRLS**	
RSQ.	*.40*		*.87*		*.87*		*.87*	
Data Source	*Pums*		*Pums*		**Pums**		*Pums*	
N	*12711*		*21569*		*21569*		*21569*	
Variable Names	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.
Intercept	-9.03	-23.2	10.92	48.51	10.92	48.51	10.92	48.51
Agehd	-	-	-	-	-	-	-	-
Aghdsq	-.0002	-2.88	-.0004	-9.76	-.0004	-9.76	-.0004	-9.76
Inc	.0593	7.52	.0265	10.66	.0265	10.66	.0265	10.66
Incsq	-	-	-	-	-	-	-	-
Hsze	2.498	24.3	.726	15.43	.726	15.43	.726	15.43
Rx	-	-	-	-	-	-	-	-
Hx	-	-	-	-	-	-	-	-
Tx	-	-	-	-	-	-	-	-
Rent:sfd	-.0055	-13.2	-	-		-		-
Hprc:sfd			-.0155	-25.8				
Hprc:mfd							-.0155	-25.8
Mfd							-3.22	-79.6
Mfd*hsze							-1.22	-18.5
Mfd*inc							-.054	-16.1
Mfd*agesq							.0007	13.22
Prcdiff:mfd							.030	-
Hprc:sfa					-.0155	-25.8		
Sfa					-2.92	-80.8		
Sfa*hsze					-1.07	-16.2		
Sfa*inc					-.03	-8.86		
Sfa*agesq					.0007	12.93		
Prcdiff:sfa					.015	-		

Tables of Parameter Estimates:

Equation Number	11.)		12.)		13.)		14.)	
Dependent Variable	*ownsze*		*rentsze*		*nvehls*		*nearns*	
Estimation Method	*WLS*		*WLS*		*WLS*		**WLS**	
RSQ.	*.59*		*.64*		*.89*		*.91*	
Data Source	*AHS*		*Pums*		**Cons. Exp. S.**		*Cons. Exp. S.*	
N	*206*		*200*		*612*		*612*	
Variable Names	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.
Intercept	14.594	8.16	-.122	-.07	-18.55	-15.5	-30.9	-18.6
Agehd	-	-	-	-	.453	1.05	9.85	16.06
Aghdsq	-	-	-	-	-.028	-.485	-1.41	-17.33
Inc	-1.79	-5.03	.055	.157	3.05	15.9	2.327	8.62
Incsq	.104	5.85	-.0031	-.169	-.13	-13.9	-.0953	-7.26
Hsze	.261	6.14	.64	18.41	.390	24.48	.494	21.52
Rx	-	-	-.191	-1.63	.968	11.7	-	-
Hx	-.096	-1.35	-	-	-.218	-3.69	-	-
Tx	-	-	-	-	-.728	-12.5	-.253	-5.62

Tables of Parameter Estimates:

Equation Number	15.)		16.)		17.)		18.)		19.)	
Dependent Variable	*food*		*house*		*trans*		*health*		*other*	
Estimation Method	*RSUR*		*RSUR*		*RSUR*		**RSUR**		*RSUR*	
RSQ.	*.94*		*.96*		*.89*		*.86*		*.97*	
Data Source	*Cons. Ex. S.*		*Cons. Ex. S.*		*Cons. Ex. S.*		*Cons. Ex. S.*		*Cons. Ex. S.*	
N	*612*		*612*		*612*		*612*		*612*	
Variable Names	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.	Coef. Est.	T Val.
Intercept	6.77	9.9	6.24	10.5	-2.88	-2.2	-6.85	-4.2	3.8	4.4
Agehd	1.02	4.51	3.30	16.8	-.155	-.36	-1.08	2.05	2.36	8.4
Aghdsq	-.12	-3.92	-.443	-16.7	-.005	-.09	.327	-4.6	-.332	-8.8
Inc	-.51	-4.4	-1.12	-11.1	1.73	7.7	2.06	7.5	-.65	-4.5
Incsq	.042	7.36	.078	15.9	-.055	-5.05	-.08	-6.02	.072	9.9
Hsze	.415	43.2	.102	12.3	.212	11.5	.22	9.8	.041	3.4
Fdx	-1.72	-1.41	-	-	-	-	-	-	-	-
Hrx	-	-	-.027	-.40	-	-	-	-	-	-
Tx	-	-	-	-	.405	6.05	-	-	-	-
Hlx	-	-	-	-	-	-	4.05	3.29	-	-
Otx	-	-	-	-	-	-	-	-	-9.39	-3.11
Fdxhrx	2.71	2.54	2.71	2.54	-	-	-	-	-	-
Fdxtx	-2.97	-2.84	-	-	-2.97	-2.84	-	-	-	-
Fdxhlx	10.2	1.63	-	-	-	-	10.2	1.63	-	-
Fdxotx	-.54	-.048	-	-	-	-	-	-	-.54	-.048
Hrxtx	-		-.147	-4.02	-.147	-4.02	-	-	-	-
Hrxhlx	-		.681	2.81	-	-	.681	2.81	-	-
Hrxotx	-		-1.95	-4.38	-	-	-	-	-1.95	-4.38
Txhlx	-		-	-	-1.32	-6.19	-1.32	-6.19	-	-
Txotx	-		-	-	2.31	5.87	-	-	2.31	5.87
Hlxotx	-		-	-	-	-	17.15	3.32	17.15	3.32

Tables of Parameter Estimates:

Equation Number	51.)		51a.)	
Dependent Variable	*hseloc:own*		*hseloc:rent*	
Estimation Method RSQ. Data Source N	*WLS* *.25* *Pums* *21882*		*WLS* *.28* *Pums* *13916*	
Variable Names	Coef. Est.	T Val.	Coef. Est.	T Val.
Intercept	-2.164	-5.48	2.407	4.95
Inc	-.032	-6.02	-.115	-11.2
Inc*travelmin	-.00012	-1.04	.00045	2.4
Neighdx*inc	.00018	7.25	.00006	4.46
Nearns	.7904	3.8	.1809	.70
Nearns*travelmin	.0272	5.29	-.0097	-1.51
Prcequilmultiplier	-.03748	-15.6	-.00984	-11.9
Neighdx*travelmin	.00019	4.41	.000053	3.06
Travelmin	-.0265	-1.47	-.085	-3.76
Travelminsq	-.00194	-13.08	-.00114	-5.92
Hseopp	-4.405	-9.21	-2.893	-4.86

PART FOUR

Bibliography

Waddell, P. ; Residential Property Values in a Multnodal Urban Area: New Evidence on the Implicit Price of Location, *Journal of Real Estate Finance and Economics; (1*993), pp 117 – 141

Waddell, P.; Vibhooti, S.; Employment Dynamics, Spatial Restructuring and the Business Cycle, *Geographical Analysis*, (1993), pp 35 – 52.

Abraham, J.;Hunt, J.; Policy Analysis Using the Sacramento Meplan Land Use Transportation Interaction Model, (1999) TRB Presentation, 21 pages.

Anas, A.; Rong, X.; Congestion, Land Use, and Jobs Dispersion: a General Equilibrium Model, *Journal of Urban Economics*, (1999), pp. 451 – 473.

McMillen D.; McDonald, J. Suburban Subcenters and Employment Density in Metropolitan Chicago, *Journal of Urban Economics*, (1998), pp 157 – 180

Wheaton, W.; The Cyclic Behavior of the National Office Market, *AREUEA Journal*, (1987), pp 281 – 299.

Wheaton, W.; Torto, R.; An Investment Model of the Demand and Supply for Industrial Real Estate, *AREUEA Journal*, (1990), pp. 530 – 547

Thompson, R.; Industrial Employment Densities, *Journal of Real Estate Research*,(1997), pp 309 – 319.

Hakfoort, J.; Lie, R.; Office Space per Worker: Evidence from Four European Markets, *Journal of Real Estate Research*, pp 183 – 196

Clapp, J.; Pollakowski, H.; Lynford, L. Intrametropolitan Location and Office Market Dynamics, *AREUEA Journal*, (1992), pp. 229 – 257.

Colwell, P.; Munneke, H.; Trefzger, J.; Chicago's Office Market: Price Indices, Location and Time; *Real Estate Economics*, (1998), pp 83- 106.

Benjamin, J.; Jud G.;Winkler, D.; A Simultaneous Model and Empirical Test of the Demand and Supply of Retail Space, *Journal of Real Estate Research*, (1998), pp 1 – 13.

Tsolacos, S.; Keogh G.; McGough, T,; Modeling use, investment, and development in the British office market, *Environment and Planning A*,(1998), pp 1409 – 1427.

Buttimer, R.; Rutherford, R.; Witten, R., Industrial Warehouse Rent Determinants in the Dallas/Fort Worth Area, *Journal of Real Estate Research*, (1997), pp 47 – 55.

Okoruwa, A.; Nourse, H.; Terza, J.; Estimating Sales for Retail Centers: An Application of the Poisson Gravity Model, *Journal of Real Estate Research*, (1994), pp. 85 – 97.

DiPasquale, D.; Wheaton,W.; Housing Market Dynamics and the Future of Housing Prices; *Journal of Urban Economics;* (1994), pp 1 - 27.

Randolph, W.; Estimation of Housing Depreciation: Short-Term Quality Change and Long -Term Vintage Effects, *Journal of Urban Economics;* (1988), pp 162 - 178.

Rubin, J.;Seneca, J.; Density Bonuses, Exactions, and the Supply of Affordable Housing; *Journal of Urban Economics;* (1991), pp 208 - 223.

Brueckner, J.; Growth Controls and Land Values in an Open City; *Land Economics;* (1990), pp 237 - 248.

Palmquist, R.; Valuing Localized Externalities, *Journal of Urban Economics;* (1992), pp 59 - 68.

Malpezzi, S.; Ozanne, L.; Thibodeau, T.; Microeconomic Estimates of Housing Depreciation; *Land Economics;* (1987); pp 372 - 385.

Harmon, O.; The Income Elasticity of Demand for Single-Family Owner-Occupied Housing: An Empirical Reconciliation; *Journal of Urban Economics;* (1988), pp 173 - 185.

Glennon, D.; Estimating the Income, Price, and Interest Elasticities of Housing Demand; *Journal of Urban Economics;* (1989), pp 219 - 229.

McGibany, J.; The Effect of Property Tax Rate Differentials on Single-Family Housing Starts in Wisconsin; *Journal of Regional Science;* 1978 - 1989; (1991), pp 347 - 359.

Singell, L.; Lillydahl, J.; An Empirical Examination of the Effect of Impact Fees on the Housing Market; *Land Economics;* (1990), pp. 82 - 92.

Herrin, W.; Kern, C.; Testing the Standard Urban Model of Residential Choice: An Implicit Markets Approach; *Journal of Urban Economics;* (1992), pp 145 - 163.

Cobb, S.; The Impact of Site Characteristics on Housing Cost Estimates; *Journal of Urban Economics;* (1984), pp 26 - 45.

Vaillancourt,F.; Monty, L.; The Effect of Agricultural Zoning on Land Prices, Quebec, 1975 - 1981; *Land Economics;* (1985), pp 36 - 42.

Dunford, R.; Marti, C.; Mittelhammer, R.; A Case Study of Rural Land Prices at the Urban Fringe Including Subjective Buyer Expectations; *Land Economics;* (1985), pp 11 - 16.

Anas, A.; Chu, C.; Discrete Choice Models and the Housing Price and Travel To Work Elasticities of Location Demand; *Journal of Urban Economics;* (1984), pp 107 - 123.

Munneke, H.; Redevelopment Decisions for Commercial and Industrial Properties; *Journal of Urban Economics;* (1996), pp 229 - 253.

Stover, M.; Specification Error in the Estimation of the Elasticity of Substitution; *Annals of Regional Science;* (1990), pp 122 - 131.

Lapointe, A.; Desrosiers, J.; Modeling Residential Choice; *Journal of Regional Science;* (1986), pp 549 - 566.

Knapp, G.; The Price Effects of Urban Growth Boundaries in Metropolitan Portland, Oregon; *Land Economics;* (1985), pp 26 - 35.

Rosenthal, S.; Helsley, R.; Redevelopment and the Urban Land Price Gradient; *Journal of Urban Economics;* (1994), pp 182 - 200.

McAndrews, J.; Voith, R.; Can Regionalization of Local Public Services Increase a Region's Wealth?; *Journal of Regional Science;* (1993), pp 279 - 301.

Stover, M.; The Role of Infrastructure in the Supply of Housing; *Journal of Regional Science;* (1987), pp 255 - 267.

McDonald, J.; Capital-Land Substitution in Urban Housing: A Survey of Empirical Estimates; *Journal of Urban Economics;* (1981), pp 190 - 211.

Jackson, J.; Johnson, R.; Kaserman, D.; The Measurement of Land Prices and the Elasticity of Substitution in Housing Production; *Journal of Urban Economics;* (1984), pp 1 - 12.

Somerville, C.; Analyzing Construction Costs: Builder Behavior and Sub-Contractor Reputation in Homebuilding; (unpublished UBC 1994), 32 pages.

Shields, M.; Time, Hedonic Migration, and Household Production, *Journal of Regional Science;* (1995), pp 117 - 134.

Cervero, R.; Wu, K.; Subcentering and Commuting: Evidence from the San Francisco Bay Area; (Working Paper no. 668, U. of California, Berkeley, 1996), 31 pages.

Burchell, R.; Listokin, D.; Land, Infrastructure, Housing Costs and Fiscal Impacts Associated with Growth: The Literature on the Impacts of Sprawl versus Managed Growth; (Lincoln Institute of Land Policy Research Papers, 1995), 25 pages.

Knapp, G.; The Determinants of Metropolitan Property Values: Implications for Regional Planning; (Metro, 1996), 51 pages.

City of Portland Auditor; Multnomah County Auditor; Housing: Clarify Priorities, Consolidate Efforts, Add Accountability; (City of Portland, Audit Services Division, 1997), 64 pages.

Metro; Housing Needs Analysis - Technical Appendix 1; (Metro Growth Management Services Department, 1997), 139 pages.