Historical Validation of an Integrated Transport – Land Use Model System

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ABSTRACT

The ILUTE (Integrated Land Use, Transportation, Environment) model system is an agent-based microsimulation model for the Greater Toronto-Hamilton Area (GTHA) in which disaggregate, process-based models of spatial socio-economic processes are used to evolve the GTHA system state from a known base case to a predicted future year end state in one-year time steps. ILUTE has reached a state of operational implementation in which historical validation runs are being undertaken. A 100% GTA population of persons, families, households and dwelling units has been synthesized for the year 1986. Twenty-year historical simulations (1986-2006) have been run, with model outputs being compared to Canadian Census data and Transportation Tomorrow Survey (TTS) data for 1991, 1996, 2001 and 2006. This paper presents recent findings from these historical validation tests, with particular emphasis on the system's modelling of demographic evolution of the population and of the region's housing market.

Keywords: integrated modelling, land use, microsimulation, validation

INTRODUCTION

The ILUTE (Integrated Land Use, Transportation, Environment) model system is an agent-based, microsimulation model that dynamically evolves urban spatial form, demographics, travel behaviour and environmental impacts over time for the Greater Toronto-Hamilton Area (GTHA). Under development for some time (*1,2,3,4,5*), ILUTE has reached the point where it is being tested within a twenty-year historical (1986-2006) time period. The primary purposes of this paper are to:

- Provide an update on the current state of ILUTE.
- Present our most recent historical test results.

The next section of the paper provides a high-level description of ILUTE, along with references to more detailed documentation of the model system. The primary focus of this paper is on two key components that are undergoing extensive testing: demographics and the housing market. These are discussed in some detail in the third and fourth sections of the paper. The final section then provides a brief summary of the paper and a discussion of on-going and future work.

OVERVIEW DESCRIPTION OF ILUTE

ILUTE is a comprehensive, integrated model system designed to project the evolution of demographics, land use and travel within an urban region over time. It is an object- and agent-based, microsimulation system. It is a time-driven simulation model in which the system state is evolved from a known base case to some future end state one time-step at a time. The system state is defined in terms of the individual persons, households, dwelling units, firms, etc. that collectively define the urban region being modeled. That is, the evolutionary engine operates upon lists of persons, households, and so on, simulating the behaviour of each of these agents over time. Figure 1 summarizes key elements of the current implementation.

The model system is initialized with a set of agents/objects which are synthesized from base year Census data. A 100% population of persons, families, households and dwelling units for each census tract in the study area has been constructed for 1986 using a modified iterative proportional fitting (IPF) procedure (*6,7*) that:

- Simultaneously generates these four objects in a fully consistent manner.
- Permits a large number of attributes to be included in the synthesis.
- Is computationally efficient.
- Makes full use of multiple multivariate tables of observed data.
- Is extendable to include additional elements.

For testing purposes, either the 100% population can be used, or a subset, randomly drawn from the full population, can be used to speed up run times, with all other model elements and processes being appropriately scaled.

The current implementation models all processes using a standard one-year time step. ILUTE, however, permits individual processes to occur at finer time steps, down to a one month resolution level, if so desired.

Resident population demographics are updated each time step. This includes in- and out-migration processes, which are very significant in the GTA, which has been growing (and is projected to continue to grow) by approximately 100,000 people per year.

The labour market component evolves the labour force over time in terms of:

- Entry and exit of persons to/from the labour market over time.
- Mobility of workers within the labour market from one job to another.
- Allocation of workers actively seeking employment to currently available jobs in the market.
- The determination of worker wages/salaries by occupation, industry and location over time.

The housing market component similarly evolves the residential location of households over time. It includes the endogenous supply of housing by type and location, as well as the endogenous determination of sales prices and rents.

Household auto ownership is dynamically evolved using the models of household vehicle transactions and vehicle type/vintage choice developed by Mohammadian and Miller (*8,9,10*)
.

Once household demographics, labour market characteristics, residential location and auto ownership levels have been determined, the activity/travel patterns for each person within each household for a typical weekday are estimated using the agent-based microsimulation model TASHA (Travel/Activity Scheduler for Household Agents) developed by the ILUTE team. For full documentation of TASHA see (*11,12,13,14,15*). TASHA is designed so that it readily interfaces with a variety of network assignment models. Currently it can be used with either EMME or MATSim (*16*). Advantages of using a microsimulation model such as MATSim relative to an aggregate model such as EMME include:

- The ability to retain an agent-based representation throughout the modeling process; i.e., the identity of individual agents and their travel behaviour is retained in MATSim, but is lost in procedures such as EMME, which aggregate individual trips into origin-destination flow tables.
- MATSim (and other dynamic assignment procedures) deal explicitly with network dynamics and provide an explicit temporal representation, in contrast to the static representation in conventional static methods such as EMME.
- For full 24-hour network modelling, we have found that MATSim is at least as computationally efficient as running 24 one-hour static assignments in EMME, while providing much higher level behavioural fidelity and enhanced representation of network performance (*16*).

Considerable work in recent years has focussed on developing an environmental modelling component within ILUTE (*17,18,19*). As illustrated in Figure 1 this involves:

- Modeling both link- and zone-based vehicle emissions. The dynamic, disaggregate nature of TASHA and MATSim permit both the running and stationary emissions of each vehicle to be dynamically computed.
- These emissions become inputs into an atmospheric dispersion model (in our case, CALPUFF) so that pollutant concentrations over time and space can be computed.

- At the same time, TASHA generates a dynamic population of where each person is over time and space.
- Putting people and concentrations together at each location in each time period results in being able to compute persons' exposures to pollutants over time.

It is the intent to implement some form of firmographic model within ILUTE, perhaps in the spirit of Maoh (*20*) or Moeckel (*21*). This has not yet been accomplished, and so for current historical model system testing purposes, observed employment levels by occupation and industry for each census track in the study area are exogenous inputs to the simulation. Similarly, a much longer-term project is to implement a microsimulation-based commercial vehicle movements (CVM) model within ILUTE (*22*). Finally, another long-term project is to endogenously evolve the "routine" components of the road and transit network (e.g., streets, bus routes) over time in response to land use development, so that changes in these important components of the network do not need to be anticipated by the modeler and pre-defined as exogenous inputs to a given simulation run.

Implicit in Figure 1 is that ILUTE is a disequilibrium model. A basic assumption is that urban areas are open, dissipative, path-dependent systems which are never in equilibrium, but rather are continuously responding to the constantly varying endogenous and exogenous forces that "drive" the evolution of the urban system state and that do not permit that system state to ever stabilize to an equilibrium. While behaviorally sound, this approach does mean that classic equilibrium-based consumer welfare measures cannot be computed. Overcoming this weakness in the approach is a matter of on-going research.

Within individual model components both rule-based and utility-maximizing models are used, depending on the process being modeled. Assumptions concerning within-component equilibrium/stabilization/optimization also vary from one process to another. In general, our preference is for "myopic" processes in which individual agents seek to maximize their utility within individual decisions (e.g., what mode of travel to take to work) but not "globally" across multiple decisions (e.g., overall optimization of daily activity patterns). Similarly, our preference is for modelling market transactions that leave both individual buyers and sellers "satisfied" with their exchange of a good or service, but which does not involve imposing strict global equilibrium constraints. Assumptions, however, do vary from one model component to another, depending on both behavioural concerns and practical considerations of available modeling methods, computational efficiency, etc.

Spatial markets play a central role in ILUTE in that it is through market demand-supply interactions that all spatial processes of interest within ILUTE occur. All markets in ILUTE involve a demand process, a supply process, and a market clearing process that mediates between demand and supply by determining the exchange of goods and services between consumers and producers and the prices at which these exchanges occur. All such market processes are modeled at the level of the individual agent (buyer, seller) and individual transactions between buyers and sellers.

No agent is continuously active in any given market. Households do not daily search for new residential locations; workers do not continuously switch jobs; etc. Rather, market participation is characterized by protracted periods of inactivity. At any point in time, however, an agent may decide to become active in a market, in response to a wide variety of "push/pull" factors. Once active in a market, the agent engages in a search process, looking for options to improve his/her current situation. The agent remains active in the market until either a satisfactory new alternative is found and successfully obtained, or until the agent decides that an improved alternative relative to the *status quo* cannot be feasibly obtained within the current market and so decides to remain in the initial state.

Supply side processes within ILUTE currently are generally modelled in a more aggregate fashion (e.g., the "development industry" produces a certain number of new dwellings by type and location each year of the simulation). The outputs from these processes, however, are a list of new individual dwellings, jobs, etc. (and their associated individual attributes) which are then matched with demanders on a one-to-one basis.

Two generic market clearing processes are currently employed in ILUTE:

- A variable-price process, in which prices are endogenously determined on a transaction-by-transaction basis within each market clearing episode, using an auction-type process (*23*).
- A fixed-price process, in which prices are fixed within each market clearing episode and then are "globally updated" between market clearing episodes in response to general demand-supply characteristics. This process also applies to in which prices do not exist but a market-like matching of agents is required (*24*).

Thus, prices are endogenous within the market in both processes; what differs is the way in which prices are determined by the market interactions.

The owner-occupied housing market is an important example of the variable-price, auction-based process. Several fixed-price market processes exist within ILUTE. Currently these consist of:

- The rental housing market, within which rents are either fixed by policy (rent control, assisted housing) or through an aggregate market adjustment process (*25*).
- The labour market, in which it is assumed that workers are in the short-run salary-takers, with salaries adjusting over time in response to aggregate market adjustments (*26*).
- The "marriage market" in which single males and females are matched to form married couples. Clearly no "price" exists in this "market", but it otherwise can be modelled in a fashion similar to other fixed-price markets (see below).

Much more extensive documentation of the ILUTE system as a whole can be found in a 10-volume series of technical reports that can be downloaded from: http://www.ecf.utoronto.ca/~miller/ILUTE.zip.

The following two sections of the paper present model validation results for two key components of the ILUTE system: demographics (including the marriage market model) and the owner-occupied housing market. The Canadian Census is used as the primary source of observed data for validating ILUTE outputs. The Census is undertaken every 5 years. All ILUTE model runs start in 1986 with an initial population synthesized from 1986 Census data (*6,7*). ILUTE outputs for 1991, 1996, 2001 and 2006 are then compared with observed Census tabulations. In addition, published Canada Mortgage and Housing Corporation (CMHC) data on annual housing starts and Toronto Real Estate Board (TREB) data on annual housing sales prices are also used. Both the CMHC and TREB data are quite aggregate in nature, limiting the spatial level of detail at which comparisons can be made. While 20-year simulation runs (1986-2006) are made, due to paper length limitations, only selected results (typically for 2001, 15 years into the simulation runs) are shown.

THE DEMOGRAPHIC MODEL & SELECTED TEST RESULTS

The demographic updating component evolves the person, family and household agents and their associated attributes over time. Families are explicitly maintained within the model system so that family relationships and interactions can be tracked over time and used to help explain family related behaviours.

A household is defined as one or more persons living within the same dwelling unit. Hence, there is a one-to-one mapping between households and occupied dwelling units. A household can consist of any of the following combinations of persons and families:

- Single person.
- Multi-person, non-family.
- Single family.
- Multi-family.
- Single family with individual (i.e. non-family) persons.
- Multi-family with individual persons.

Demographics are updated each year. A bottom-up approach is employed in which the demographic changes of a region emerge through the sequential updating of each person, family and household in the region. In-migration events introduce new persons, families and households into the study region. Out-migration is also handled as part of the demographic processes. Each demographic event uses simple transition probabilities, conditioned on a person's current state, to determine a change in a demographic attribute. Cross-tabulations, derived from empirical data, are used to compute these conditional probabilities. Monte Carlo simulation is employed to determine the outcomes of all demographic events. Further details concerning demographic updating procedures can be found in (*27,28*).

Figure 2 compares the GTHA age distributions by year as predicted with a 100,000 initial household run (hereafter referred to as a 100K run) of ILUTE, compared to Census data. Note that the 1986 distribution represents the synthesized input distribution used to initialize the ILUTE run. In general, the generated distribution tracks the Census distributions well, especially given that the predicted distribution is the net outcome of numerous processes -- births, deaths, in-migration and out-migration – in addition to the aging process *per se.*

Overall predicted and observed births, deaths and out-migrations are shown by year in Figure 4. ILUTE is doing a very good job in predicting births and deaths. In particular, it captures the declining birth rate in the region due to an aging population well. It does, however, need to improve its predictions of out-migrations. The out-migration model is currently hampered by the lack of good local data concerning out-migration rates by household/family type for the region. In-migrations are an exogenous input to the model, and so comparisons between predicted and observed values are of little value.

Of particular interest within this paper is the "marriage market", which matches prospective husbands and wives together within a utility maximization framework, both as an example of an important demographic process and as an example of a fixed-price market process. The problem can be defined as a maximum weighted bipartite matching problem. Full details of the marriage market model can be found in (*27,28*). Table 1 presents results from a 100K run. The table compares married couple age distributions in 2001 (15 years into the simulation) as observed in the Census and as predicted by ILUTE. In general, the predicted results correspond well with observed values.

Figure 4 similarly compares the 2001 Census and predicted income differences for married couples. The model tends to over-predict matches with very small income differences; this will require some adjustment of the matching algorithm utility parameters in subsequent runs. Otherwise, however, good correspondence between observed and predicted values is obtained.

THE OWNER-OCCUPIED HOUSING MARKET & SELECTED TEST RESULTS

Figure 5 elaborates the owner-occupied housing market model in ILUTE. As illustrated in this figure, at any point in time there is a list of active demanders of housing and a list of active dwelling units available to be purchased. Demanders and suppliers come together within the market and exchanges occur when a supplier agrees to sell a dwelling unit to a household at a mutually agreed-upon price. Thus, three types of agents exist within this market process: households, dwelling owners, and a *market agent* that is a "virtual agent" used within the simulation model to keep track of vacancies and prices, manage the lists of active demanders and suppliers, and manage the buying/selling market clearing process. Three key points to note about this process are:

- Prices are endogenously determined through the "bid-auction" (*29*) process of buyers and sellers interacting and coming to mutually agreeable prices for the exchange of the dwelling. These market prices can influence decisions by agents in subsequent time periods to become active in the market.
- The supply of housing comes from two very distinct processes. The first is the construction of new housing by developers/builders. The second (and quantitatively more important at any one instant in time) is the decision of owner-occupants to become active in the housing market. This decision results in the household becoming active <u>both</u> as a demander for a new dwelling unit <u>and</u> as a supplier of its old dwelling unit, which becomes active in the market on the "supply side" at the same time that the household becomes active on the "demand side"
- Until a household sells its current dwelling it has the option of exiting from the housing market and staying in its current dwelling; i.e., it need not sell if it does wish to. Similarly, owners of vacant dwellings do not need to sell in any given time period if they deem it economically unattractive to do so.

Following on from this last point, while we speak of "market clearing", there is, in fact, no behavioural need nor mechanism within ILUTE to force the market to completely clear or to "equilibrate" within any one time period. Dwellings can remain vacant from one time period to another, and households can continue to be active (or drop out without transacting) from one time period to another as they deem fit. It is expected that in times of excess supply prices will tend to fall (or at least not increase) and rates of new supply provisions will tend to fall; while in times of excess demand the converse will be true (with appropriate response lags in both cases), but there is no reason to insist that demand match supply at any point in time or that prices systematically adjust so that the market equilibrates or stabilizes in any formal sense. In particular in ILUTE it is assumed that each buyer and seller in the market is myopic in that:

- Buyers are not aware of the actions of other buyers and only have detailed information concerning dwellings that are in their choice set.
- Suppliers are not aware of the actions of other sellers, and only have detailed information concerning the buyers that are in their prospect set.
- Dwellings are auctioned one at a time, and so prices are myopically determined one sale at a time, not by some global "balancing" process.

Given these assumptions, in ILUTE dwellings are sold one at a time by randomly selecting an active dwelling, determining its sales price (while holding the prices of all other active dwellings fixed for the moment), and then randomly selecting the household from within this dwellings prospect set that will purchase the dwelling at the sales price. Once this dwelling has been sold to the selected household, the following updating steps are taken:

- The household is moved to its new location and returned to the passive state with respect to the housing market.
- The dwelling is removed from the list of active dwellings in the housing market.
- The choice sets of all households in the dwelling's prospect set are updated by deleting the sold dwelling from their choice sets. Their location choice probabilities are updated accordingly. The unsuccessful households can also decide to exit the housing market by becoming passive at their current location, providing that they have not yet sold this dwelling.

For more detailed discussions of the ILUTE owner-occupied housing market model, see (*23*).

Testing of the housing market model is still in a very preliminary stage. Figure 6 compares total predicted and observed new housing by year from an early model run. In general, ILUTE is currently under-predicting the supply of new housing, but the overall shape of the trend curve is quite good.

Figure 7 plots the distribution of GTHA 2001 asking prices, averaged over ten 10% sample runs. All prices are in 2001 Canadian dollars. We do not have observed asking prices for 2001, but we do have average transaction prices. The average Toronto Real Estate Board (TREB) transaction price for 2001 is $222,000, whereas the ILUTE average asking price is $380,000. As is discussed further below, ILUTE transaction prices are higher than observed transaction prices. Given the asking prices shown in Figure 7, it is clear that the current asking price model is initializing the market with prices that are too high, leading to transaction prices that are also too high. A next step in the model development process will be to recalibrate the asking price model so that lower, more representative, asking prices are generated.

Table 2 summarizes the means and standard deviations for 2001 predicted transaction prices, categorized by dwelling structure type, compared with average TREB values. It should be noted that the TREB values are average values per "TREB zone", where these zones are geographically large. Thus, a considerable amount of variance has been squeezed out of the TREB data. In all cases, ILUTE is over-predicting average transaction prices relative to the observed average TREB values ("DELTA" in Table 2), although the TREB averages do all fall within one standard deviation of the ILUTE averages. Further, the predicted averages for 3 of the 4 dwelling types are within $50,000 of the observed averages. Prices for detached dwellings (which constitute a significant majority of the transacted dwellings), however, are clearly significantly over-predicted. Again, the most logical source of this error is the asking price model, which clearly needs to be revisited in subsequent testing.

SUMMARY AND FUTURE WORK

This paper has summarized the current state of the ILUTE agent-based, microsimulation integrated urban model system. In addition, the paper has focussed on the demographic and housing market components of the model system, which are two of the key components which currently undergoing extensive testing. This testing consists of running 20-year historical simulations (1986-2006) so that model outputs can be compared with observed data for this time period.

Much work remains to be done. With respect to the demographic model, improvements in both the in-migration and out-migration models are possible, providing that improved historical data for the Toronto region can be obtained. The marriage market model also requires further testing and calibration.

With respect to the owner-occupied housing market model, the asking price model, particularly for detached dwellings, urgently requires improvement. The new dwelling supply model also requires further calibration. Once this model has been improved, further detailed testing of the owner-occupied housing market model is required, with respect to temporal mobility rates, transaction prices, and the spatial distribution of location choices.

Several components of ILUTE are still currently under development. Rental housing market and labour market models will be implemented within the model system shortly. More medium-term activities will include implementation of a firmographic model and improved feedback from the transportation (TASHA-MATSim) model sub-system and the location choice processes modelled.

In addition to these components, a general concern that cuts across all of the ILUTE spatial choice models is choice set modeling. As has often been observed in the literature (*30,31*), choice set modeling is all too often the weak link in integrated urban models. ILUTE is no exception in this regard. A major forthcoming research thrust by the ILUTE group will be to develop improved spatial choice models for residential and commercial location, labour and travel choice set determinations. One recent attempt in this regard is the Ph.D. thesis of Elgar (*32*), but much remains to be done to generalize and operationalize these findings.

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TABLES AND FIGURES

Table 1 – Observed and predicted 2001 age distributions for married couples

CENSUS 2001 MARRIED COUPLES		Age Male							
		18 - 24	25 - 34	35 - 44	45 - 54	55 - 64	65 – 74	75 - 84	85 & over
Age Female	18 - 24	0.28 %	1.00%	0.14%	0.03%	0.00 %	0.00 %	0.00 %	0.00%
	25 - 34	0.18 %	10.94 %	7.10%	0.39%	0.06 %	0.00 %	0.00 %	0.00%
	35 - 44	0.02 %	1.57%	19.11 %	7.84%	0.55 %	0.08 %	0.00 %	0.00%
	45 - 54	0.01 %	0.08%	1.59%	15.21 %	6.19 %	0.46 %	0.03 %	0.00%
	55 - 64	0.00 %	0.01%	0.05%	0.95%	8.58 %	4.40 %	0.24 %	0.02%
	65 - 74	0.00 %	0.00%	0.01%	0.04%	0.51 %	5.98 %	2.39 %	0.08%
	75 - 84	0.00 %	0.00%	0.00%	0.00%	0.03 %	0.43 %	2.56 %	0.51%
	85 & over	0.00 %	0.00%	0.00%	0.00%	0.00 %	0.01 %	0.11 %	0.24%

ILUTE 2001 MARRIED COUPLES		Age Male							
		18 - 24	25 - 34	35 - 44	45 - 54	55 - 64	65 – 74	75 - 84	85 & over
Age Female	18 - 24	1.21 %	0.71%	0.17%	0.00%	0.00 %	0.01 %	0.00 %	0.00%
	25 - 34	0.05 %	11.40 %	3.78%	1.00%	0.03 %	0.03 %	0.00 %	0.00%
	35 - 44	0.02 %	0.97%	18.74 %	8.73%	2.38 %	0.12 %	0.03 %	0.00%
	45 - 54	0.00 %	0.40%	4.62%	12.28 %	6.32 %	1.69 %	0.07 %	0.00%
	55 - 64	0.00 %	0.01%	0.72%	3.44%	5.96 %	3.33 %	0.61 %	0.02%
	65 - 74	0.00 %	0.01%	0.02%	0.40%	1.83 %	3.60 %	1.54 %	0.23%
	75 - 84	0.00 %	0.00%	0.00%	0.01%	0.10 %	1.02 %	1.25 %	0.47%
	85 & over	0.00 %	0.00%	0.00%	0.00%	0.01 %	0.05 %	0.28 %	0.32%

Table 2 – Predicted & observed transaction prices by dwelling structure type, 2001

	ILUTE		TREB	DELTA
Dwelling Type	**Average**	**St. Dev.**	**Average**	
Detached	480,000	200,000	307,000	173,000
Semi-Detached	280,000	130,000	230,000	50,000
Attached	260,000	110,000	212,000	48,000
Apartment	226,000	96,400	182,000	44,000
Total	392,000	180,000	222,000	170,000

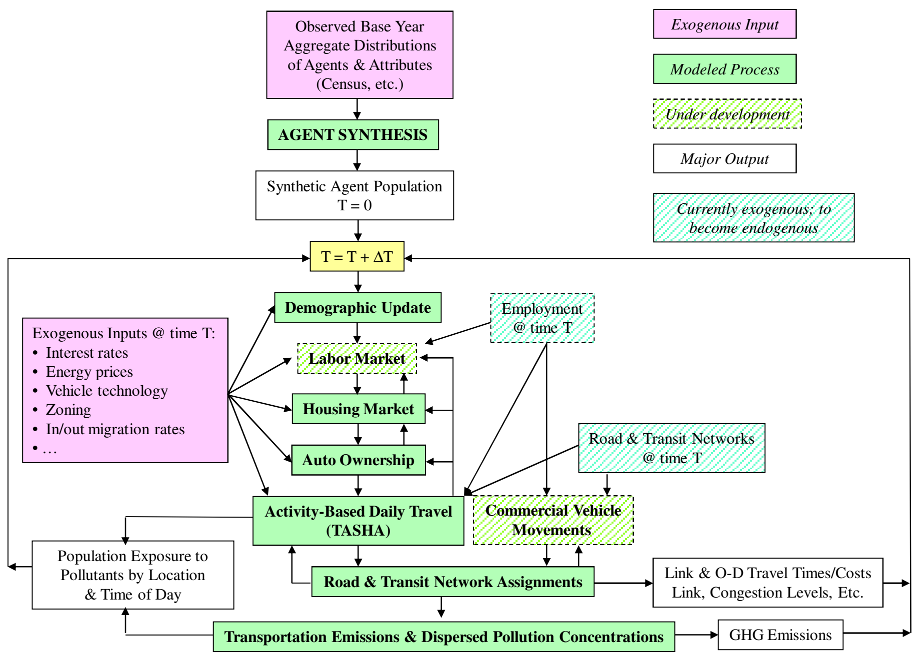

Figure 1 – High-level flowchart of ILUTE processes

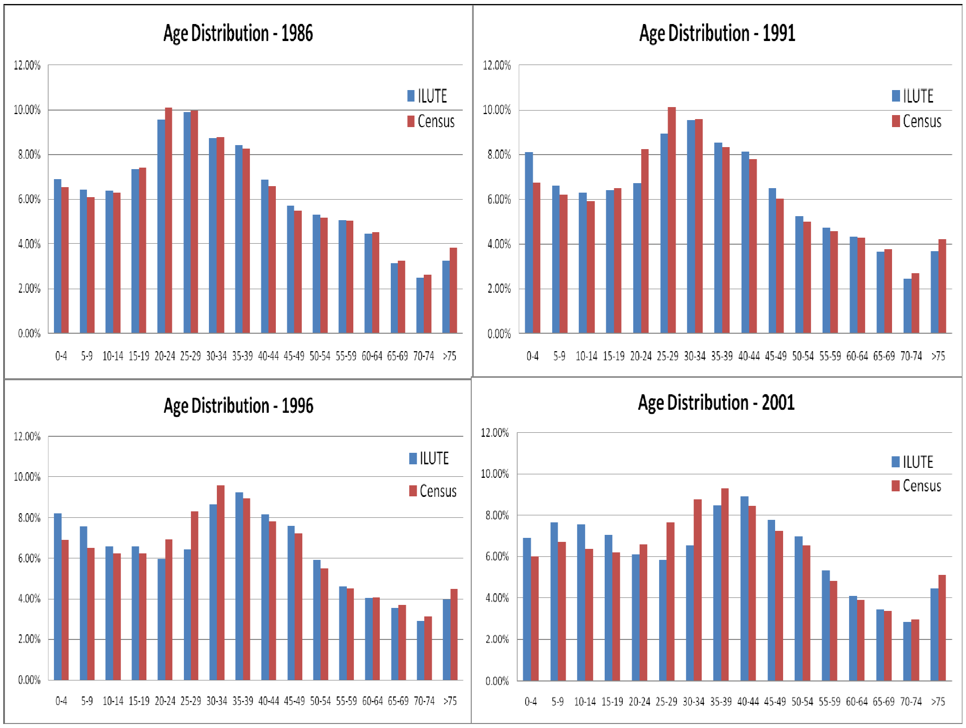

Figure 2 – Predicted & observed GTHA age distributions by year

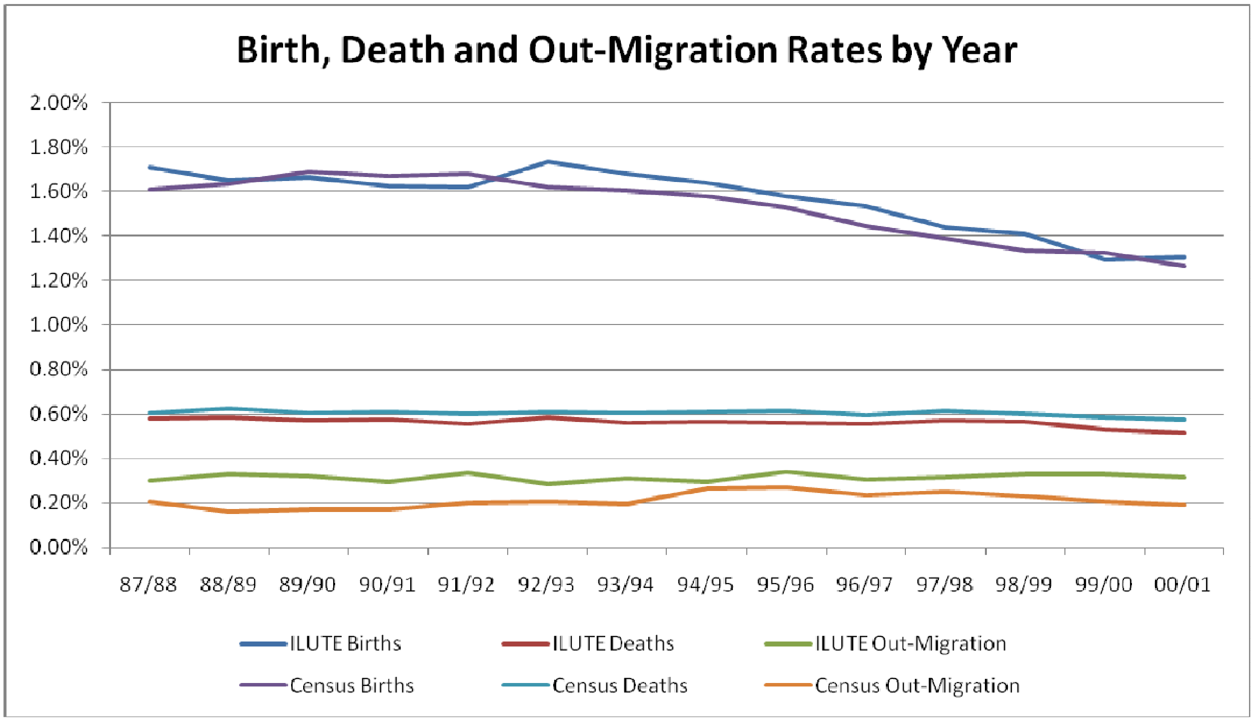

Figure 3 – Predicted & observed births, deaths & out-migrations by year

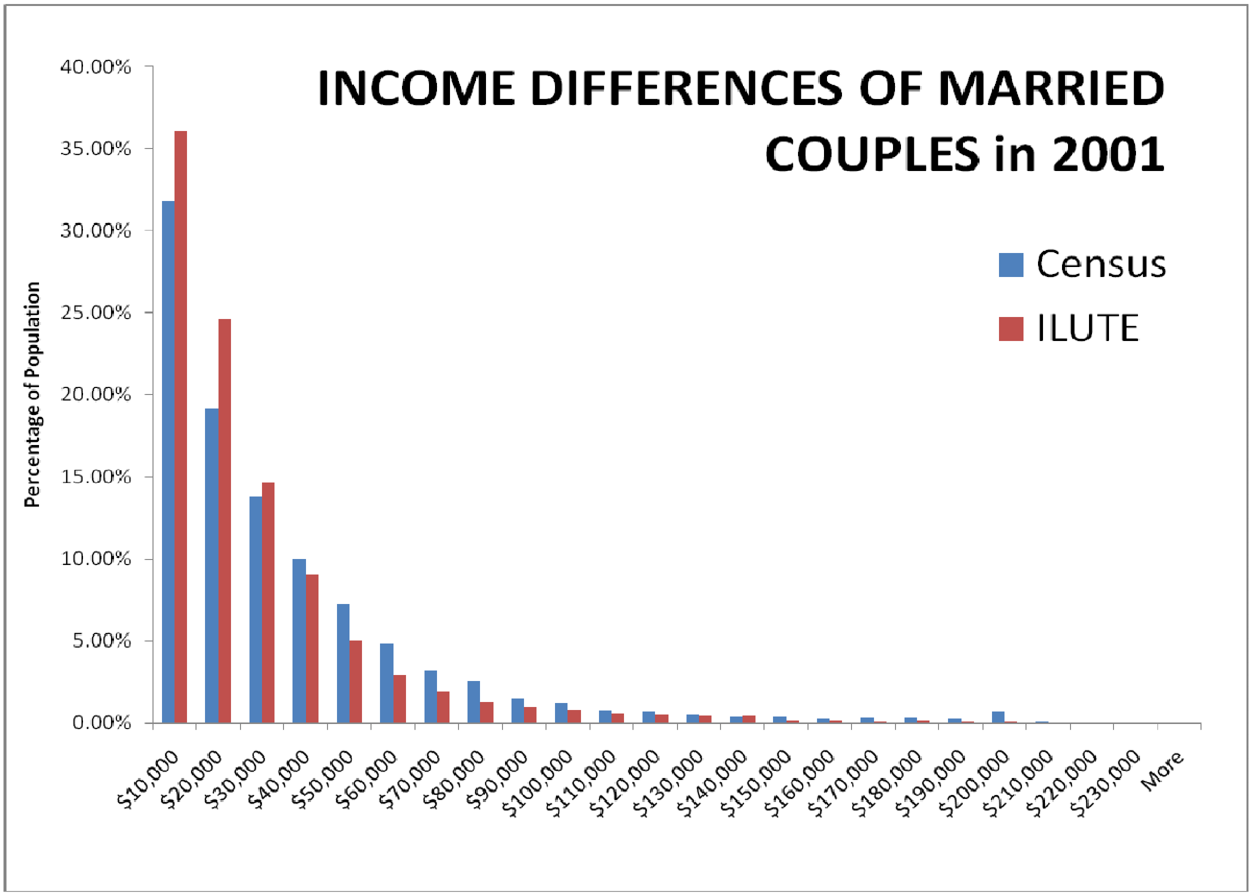

Figure 4 – Observed & predicted 2001 income differences for married couples

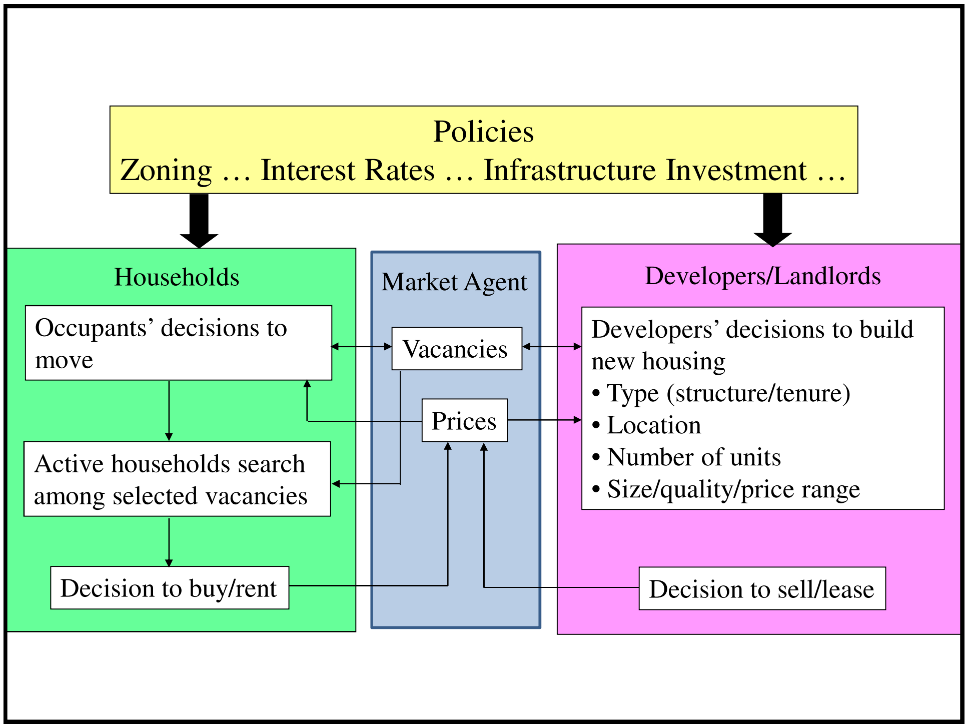

Figure 5 – Simulating owner-occupied housing demand, supply & market-clearing

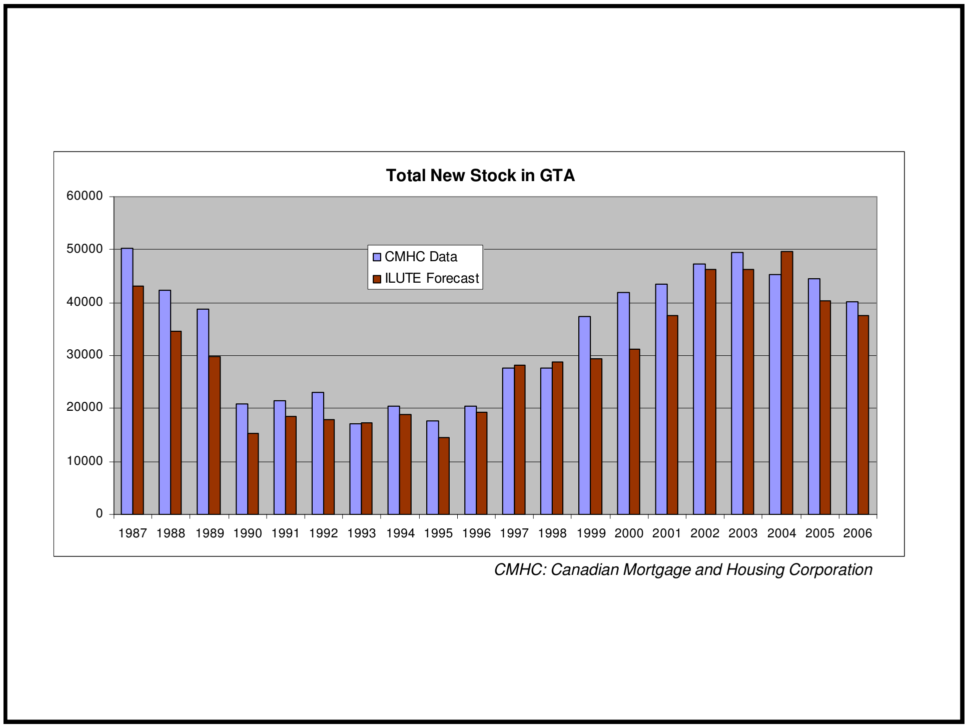

Figure 6 – Predicted & observed GTHA supply of new housing

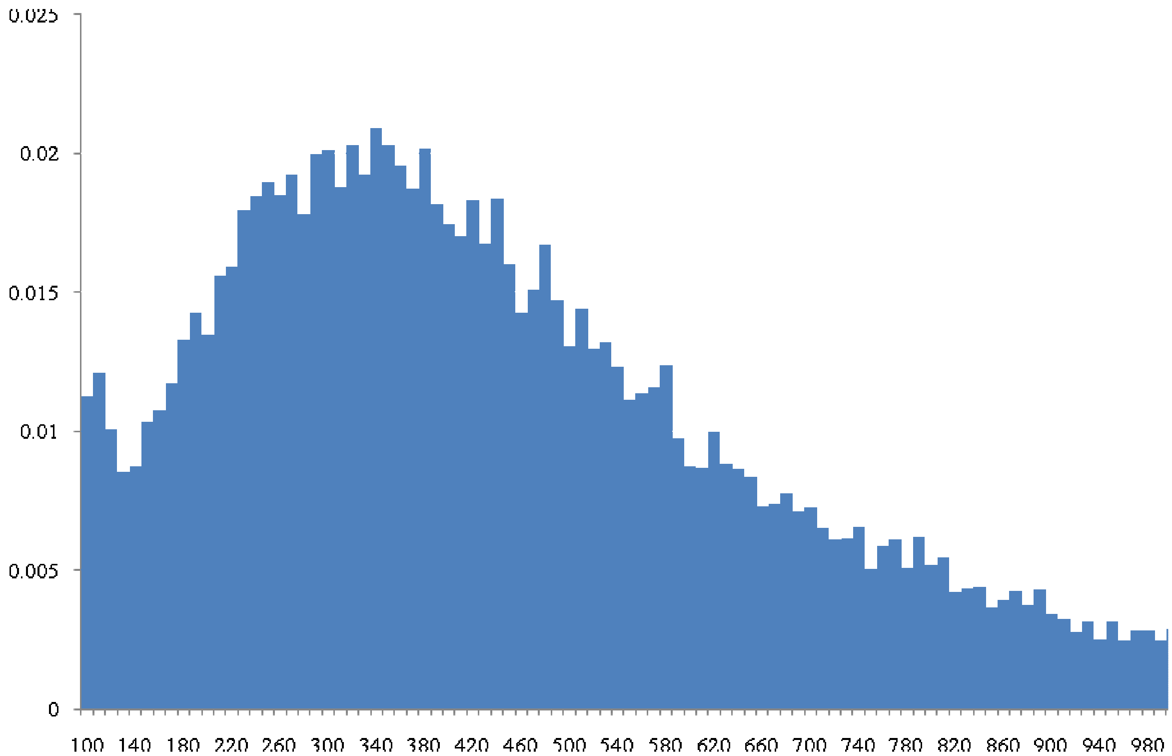

Figure 7 – 2001 predicted asking prices