UTTRI Research Report

Advancing Integrated Urban Modelling for Housing Policy Analysis

Vol. 2: Phase I Final Report

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September, 2018

ADVANCING INTEGRATED URBAN MODELLING FOR HOUSING POLICY ANALYSIS

Volume 2: Phase I Final Report

A project report to the Canada Mortgage and Housing Corporation (CMHC)

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1. INTRODUCTION

Integrated urban models, also known as integrated land use and transportation models, model the evolution of land use and the built environment over time in an urban region. They are predicated on the understanding that the transportation system (which provides accessibility to land and enables the movement of people, goods and services) and the land use system (which determines the distribution of people, firms and activities over space) are fundamentally intertwined. They can provide essential analytic support for a wide range of urban and transportation policy analyses, notably housing market analysis. Modelling the demand, supply and market interactions (including endogenous price formation) within the housing market are core functions within any advanced integrated urban model.

A key component of the housing market which is either ignored completely (the typical case) or (at best) very poorly addressed in all current land use models is the actual financing of housing and its ramifications for ownership and sales. A selling price is typically included in such models and influences in one way or another the allocation of households to dwelling units in such models. But the explicit modelling of how households actually finance housing purchases (down payments, mortgages, impacts of interest rates, etc.) and of the equity which they hold in their homes (and how this equity changes over time and influences subsequent housing mobility decisions) is rarely, if ever, modelled. Given the critical importance that such financial considerations play in housing mobility and purchase decisions, this lack of sensitivity in current models to such considerations clearly represents a major weakness in such models, and considerably limits their usefulness as a policy analysis tool for many housing-related policies of interest to CMHC and other housing market decision-makers and stake-holders.

One partial exception to the statements above is a very early prototype model (which was never fully operationalized) developed by the Principal Investigator thirty years ago, in which an attempt was made to include within a microsimulation model equity calculations in the determination of households' residential housing bids (Miller, et al., 1987). Miller (2005, 2012) also presents a theoretical discussion about this issue, which has yet to be implemented in an operational setting.

CMHC has indicated a strong interest in developing operational integrated urban simulation models for Canadian housing market policy analysis, in particular in the application of agent-based microsimulation models, given their potential for improved policy analysis capabilities relative to more conventional, aggregate methods. Such models, however, would be greatly enhanced in terms of both their behavioural fidelity and policy sensitivity if they explicitly incorporated housing financing considerations. Given the lack of experience in the field to date with the operational modelling of these financial considerations, this study has two objectives:

1. A detailed literature review of both the academic and professional literature to identify the current state of the art/practice in modelling household home financing and equity decision-making and its role in household residential mobility and purchase behaviour.
2. Based on this literature review, a detailed work plan for CMHC to consider for possible future efforts in this area, where this work plan describes the tasks, data and methods needed to develop

an operational model of home financing and equity for possible inclusion in operational land use models of Canadian housing markets.

The findings of the Task 1 literature review are documented in the first report of this project's report series. Section 2 of this report very briefly summarizes the key findings of this review, which defines the point of departure for the proposed model development work, which is the primary focus of this report. It is proposed that this modelling work be undertaken within the ILUTE (Integrated Land Use, Transportation, Environment) agent-based microsimulation integrated urban model system that has been underdevelopment at the University of Toronto for a number of years. Section 3 provides a succinct overview of the ILUTE framework and its current state of development.

Key to the feasibility of undertaking this project within the Canadian context is the availability of the Statistics Canada 2016 Survey of Financial Security (SFS), which provides much of the data needed to build such a model. Section 4 presents a brief overview of the SFS data and their strengths and weaknesses for supporting the proposed modelling activity. It also briefly discusses other major datasets that will be used in the project,

Building upon both the current ILUTE framework and the existing literature, as well as the availability of the SFS data, Section 5 presents a detailed discussion of the proposed extended model framework for explicitly modelling housing financing within an agent-based microsimulation (ABM) approach. Section 6 then presents the work plan, schedule, major deliverables and study team for the proposed Phase 2 study. In this study, the Greater Toronto-Hamilton Area (GTHA) is taken as the case study area, given the study team's familiarity with the region, as well as the desire to demonstrate the model system's capability in modelling Canada's largest urban region. The model system design, however, will also maximize as much as possible its potential eventual transferability to other Canadian urban regions. Finally, Section 7 presents the proposed study team and budget.

2. LITERATURE REVIEW SUMMARY

This project's Volume 1 report provides a detailed review of existing studies in both the integrated urban modeling literature and macroeconomic housing market literature. This section presents a brief summary of this report.

Most of the integrated urban models consider the housing market at some level. Some models do not differentiate between housing and other land purposes such as firms. Housing market modules in integrated urban models usually consist of four main components: the supply of home locations, the demand for housing, prices and rents, and the assignment of population to residential locations. The majority of integrated urban models include a market for housing in different forms of spatial units such as zone, floorspace, or dwelling unit. Typically in each time period within the simulation, new population is generated and new housing supply is built to accommodate growth in the city. The models usually consider the decision to move or rent and the location choice as the main parts of modeling housing market. Prices are usually modelled endogenously. Most of the models consider market clearing assuming static equilibrium in each time interval, while a few treat the market as being in disequilibrium with delayed price adjustments. The matching process and assignment of households to houses is usually based on some type of willingness to pay or bid-auction method. None of the current integrated urban models take into account the actual financing and purchase procedure within the housing market.

In the macroeconomic literature, housing market models traditionally have many simplified assumptions which can lead to models that are significantly different from reality and thus produce inaccurate predictions. The many factors influencing the housing market justify the use of a detailed disaggregate framework such as agent-based microsimulation (ABM) modelling that can explicitly represent different actors within the housing market. The majority of the housing market ABMs in the economics literature aim to better understand and model housing prices and the market's bust and boom cycles. These models typically consider heterogeneous agents as buyers and sellers as well as agents for banks and mortgages. Several of the models consider a type of supply model to account for developers who add supply to the housing market. In addition, some models include the rental market in the modelling. Overall, in studies using ABM to model housing market, housing prices are generated endogenously, and some type of market clearing mechanism, such as bid auction, is used to determine the prices. Most of the studies have a "bank agent" which generates and sets the criteria for loans and mortgages required for buying a house on the market. While these models are more advanced with various finance components such as mortgages and interest rates, they lack neighbourhood attributes and/or a spatial structure.

As it is evident from the literature review, current integrated urban models do not consider the actual financing of housing in their housing market components. On the other hand, the increasing number of macroeconomic studies using ABM while accounting for financing considerations, are not as advanced as integrated urban models in terms of spatial structure, consideration of accessibility and transportation impacts, and modelling demographics and jobs. Adding a housing finance module to the current integrated urban models such as ILUTE will result in a more accurate representation of the actual complex interactions of housing market. Such a model would also allow better identification the role of different contributing factors in housing market evolution, such as mortgage rules or transportation infrastructure.

3. ILUTE

The ILUTE (Integrated Land Use, Transportation, Environment) integrated urban model system provides a fully agent-based microsimulation (ABM) of the urban spatial-temporal socio-economic processes which evolve an urban region over time in response to a wide range of exogenous factors and policy scenarios. Figure 2.1 presents a high-level flow chart of processes modelled within ILUTE, which include:

- Synthesis of a complete base year population of persons, households, buildings, firms, jobs and cars.
- Demographic evolution of the population over time, including evolution of households.
- Firmographic evolution of firms and jobs over time.
- Changes in household auto ownership over time.
- Changes in worker labour market participation (job occupation and industry, location and wages/salaries).
- Evolution of the built space (housing and commercial) over time.

- Daily activity/travel participation by all persons within the urban region.
- **The residential housing market.**

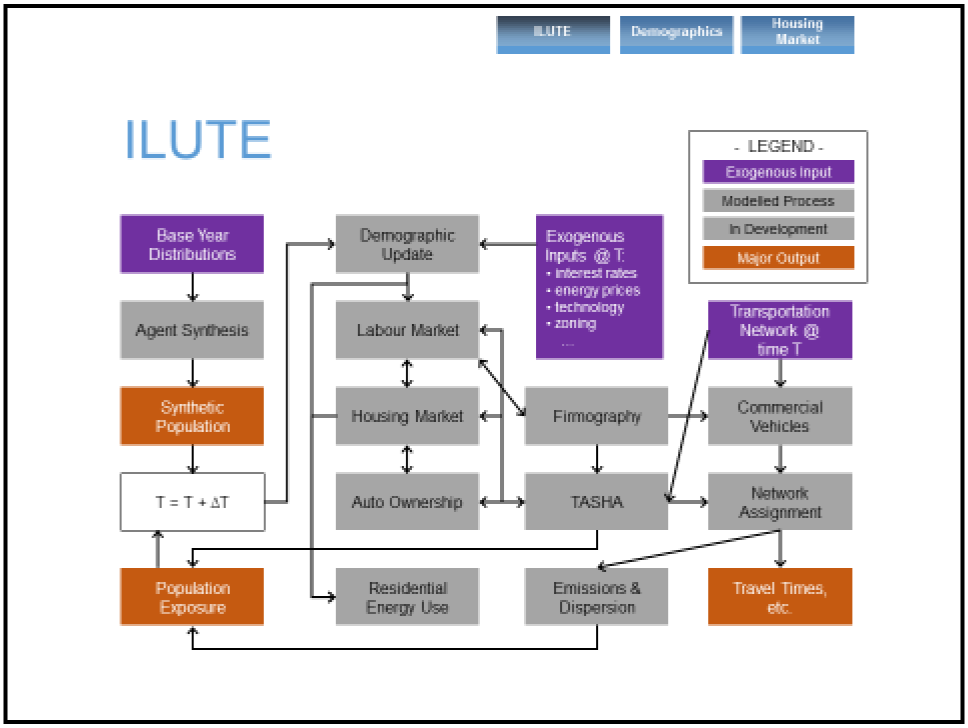

Figure 2.1: The Overall ILUTE Model System

The demand-supply interactions within the residential housing market are modelled within ILUTE at the micro level of individual households and dwelling units. As illustrated in Figure 2.2, in each time step each household decides whether to become active in the housing market or not. If it decides to enter the market, it can enter either the rental or owner-occupied housing markets, where it competes with other active households in the chosen sub-market for vacant dwellings. Vacant dwellings in the owner-occupied market are auctioned off to the highest bidder for the unit among the households competing for the given unit. Thus, sales prices for each unit transacted are endogenously determined within the model. Households who are unsuccessful over a period of time in the market may leave the market at any time, returning to a "passive" state at their original residential location.

Given ILUTE's very disaggregate, agent-based approach to modelling housing sales, it provides an ideal framework for incorporating explicit consideration of housing financing within this process. Its dynamic framework, in which household decisions and experiences over time are explicitly tracked, also provides an excellent framework for modelling the evolution of household housing equity (and, more generally, wealth) over time, and for incorporating equity considerations into housing market mobility decision-making (i.e., when to become active in the market, and for what reasons).

For further details concerning ILUTE see the selected reports and papers listed in this report's References section.

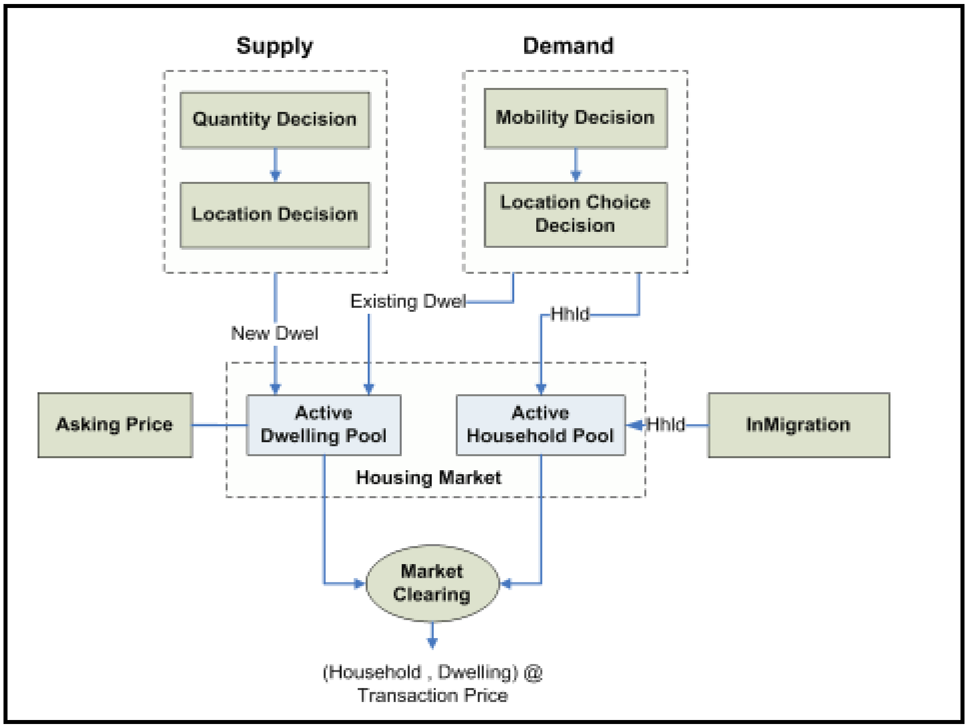

Figure 2.2: The ILUTE Housing Market Model

4. DATA

4.1 2016 Survey of Financial Security (SFS)

The latest Survey of Financial Security (SFS) was undertaken across Canada in 2016 by Statistics Canada. The purpose of the survey is to collect information from a sample of Canadian households on their assets, debts, employment, income and education. The SFS provides a comprehensive picture of the net worth of Canadians. Information is collected on the value of all major financial and non-financial assets and on the money owing on mortgages, vehicles, credit cards, student loans and other debts. The survey has been done four times during the past 20 years in 1999, 2005, 2012, and 2016.

The SFS survey is carried out nationally. Every province is categorized into rural and urban areas. A different design is used for each type of area. In rural areas, a multi-stage sample frame is used based on the Labour Force Survey area frame. In urban areas, a stratified sample was selected from the Address Register. Information from the T1 Family File (T1FF) is used for stratification which improves the efficiency of the urban part of the sample. All families residing in the selected dwellings were included in the sample. The SFS sample consists of 21,112 dwellings, 13,328 dwellings selected from urban areas and 7,784 dwellings from rural areas.

The SFS include two primary datasets: person file and economic family file. Both files are linked to the census geographic units including census tracts. The person file consists of all the basic personal information such age, gender and other sociodemographic attributes. In addition, a detailed data is collected about the respondents' employment, income, tax, pension, and retirement plans such as Registered Retirement Savings Plan (RRSP).

The household file has the information on basic household characteristics such as number of people in the household. Further, it has a comprehensive data on household financial situation including current value, type and number of properties and vehicles and the investments and loans. It has detailed information on household financing situation such as mortgage type, interest rate, the amount owed and paid, the amount and source of down-payment, timing of mortgage and equity. In addition, all the loans and credit information are collected. Other financial variables exist in dataset such as debt and liabilities of the business, and the type of banking accounts and the amount of money in each account.

Clearly, the SFS provides an exceptional database for developing a model of housing financing suitable for incorporation within a housing market ABM such as ILUTE.

4.2 Other Data

Numerous other datasets will be employed in constructing the proposed model system. These are all "in-house" within UTTRI. They include (but are not necessarily limited to:

- Teranet land transaction data for all parcels within the Greater Golden Horseshoe (GGH).
- A large, time-series, GIS-based database concerning land use, transportation accessibility and regional socio-economics that has been compiled by UTTRI researchers from a variety of sources, including the census for the Greater Toronto-Hamilton Area (GTHA).
- Other census data and other GIS-based Place of Interest (POI) datasets not yet included in the time-series database, but available through the University of Toronto Data & Map Library.
- Large-sample, time-series survey data of travel behaviour in the GGH (Transportation Tomorrow Survey).
- Travel demand models (GTAModel) and network simulation models (Emme) for the GTHA.
- A wide variety of datasets used in the development of the original ILUTE model system. Although most are rather dated, they may still prove valuable for a number of purposes.

5. PROPOSED MODEL SYSTEM FRAMEWORK

5.1 ILUTE as the Base for Modelling Housing Finance Processes

The ILUTE housing market model sketched in Figure 2.2 provides the starting point for the modelling work proposed in this project. It already has most of the key features required for microsimulating a housing market, as well as providing a sound theoretical and computational framework for its extension to include housing financing considerations. These include:[1]

- In each time step, each household considers whether it wishes to become active in the housing market at this point in time, as either a renter or an owner-occupant.
- Each household that is active in the housing market as a potential buyer and/or seller[2] is making decisions based on sound microeconomic considerations of utility versus cost trade-offs. The

[1] In addition to these features of the ILUTE housing market model, note that ILUTE also has models of the other key processes affecting housing market mobility and location choices (as sketched in Figure 2.1): personal and household demographics; labour market process; auto ownership process; and out-of-home activity/travel processes. Thus, it provides a comprehensive "evolutionary engine" within which to model housing market dynamics.

[2] All households that are current home owners will be both a buyer (of a new dwelling unit) and a seller (of their currently owned unit). Households entering the owner-occupied market for the first time, either as former renters or as new immigrants to the region will only be buyers. Households leaving the owner-occupied market (either to

result is that buyers' bids for dwelling units are based on their utility-derived willingness-to-pay, while sellers' acceptance of bids are based on their utility/profit-derived willingness-to-accept.
- Sales (transaction) prices are the outcome of the interactive "game" between buyers and sellers, in which buyers are trying to maximize the consumer surplus associated with their purchase, while sellers are trying to maximize their "producer surplus" (in the case of owner-occupant households) or profit (in the case of non-occupant sellers).
- Asking prices are endogenously and dynamically generated in each time step based on recent sales prices.
- New housing supply is endogenously generated in each time period as a function of lagged sales prices, market activity and vacancy levels, macroeconomic trends, etc.

The primary task of this project is to extend the current ILUTE housing market framework to explicitly incorporate housing financing considerations and processes. This work will draw upon existing housing finance models as reviewed in Report 1, which provide a sound starting point for this work. Key elements of the extended framework include:
- Extension of the ILUTE set of agents to incorporate finance-related actors and processes.
- Explicitly modelling and tracking household wealth, which consists of three primary components:
    - Equity in their current home.
    - Equity (and income) from any investment properties which they also own.
    - Other savings/capital investments (stocks, etc.).
- Modelling non-resident investors in the local housing market.
- Explicit modelling of the housing mortgage market.
- Extension of the current ILUTE bid formation and acceptance processes to account explicitly for equity and mortgage financing considerations.

These extensions are discussed in the following sections.

5.2 ILUTE Agents

The key agents in the extended ILUTE housing market model are:

Persons: Every person in the urban region being modelled is individually simulated. Every person must belong to exactly one household.[3] They participate in the housing market as a member of this household. Persons engage in many other activities within ILUTE (work, education, other daily activities, travel, demographic evolution, etc.), which are not discussed further here.

Households: A household consists of one or more persons living together in the same dwelling unit. Every household in the urban region being modelled is individually simulated. The number of households must be identical to the number of occupied dwelling units; i.e., each household

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become renters within the region or as out-migrants from the region) will only be sellers. "Developers" and other non-occupant dwelling unit owners will only be sellers.

[3] It is possible for a person to belong to more than one household. A child under joint custody of divorced parents may, for example, alternate between the two parents' homes on a regular basis. A post-secondary student may have a school-based residence during the school year, but still consider the family residence as "home". ILUTE does not currently allow for such use cases in its formulation (although extended family relationships among divorced parents and their children are explicitly represented).

must live in exactly one dwelling unit.[4,5] All housing-related decisions are made within ILUTE at the household level (although person-level attributes and considerations with respect to household members may enter into these decisions). Households also have other behaviours that are not discussed further here (e.g., auto ownership decisions and joint household member activity/travel interactions). All households are classified at each point in time as being either renters or owner-occupants, depending on whether they are renting or they own their current place of residence. In addition, a household might also be an income property owner, if it owns one or more dwelling units for investment/income purposes.[6]

Non-household dwelling unit owners: Developers, local corporate (as opposed to household) investors and non-local investors (corporate or individual) who purchase one or more dwelling units within the study area's housing market for investment/income generation will be included in the model system. These agents buy, sell and rent study area dwelling units for profit (either "short-run" income and/or "long-run" capital gains). It is likely that it will only be feasible to represent these agents as a single "macro agent", since the "population" of all such potential agents is essentially impossible to synthesize/represent.

Mortgage lenders: Banks, credit unions, etc. decide which households will receive mortgages and which will not, depending on central bank policies and their own profit-maximizing goals. It is likely that a single "macro mortgage market" agent will be employed.

Central (national) bank: As in other models, the central bank agent sets national prime rates and other national housing policies affecting mortgage lending rates and policies. Note that other than this central bank agent, ILUTE does not explicitly include any other "government agents" (at any level of government), nor does it endogenously model other government policy formation (immigration policies; taxation policies; etc.). All such policies are exogenously supplied to ILUTE as scenario inputs.

Developers: "Developers" construct new housing supply in each time period. They are profit maximizers who attempt to respond to housing market demand and supply signals (recent selling prices, vacancy rates, macro-economic factors, etc.). ILUTE assumes one "macro" developer agent. I.e., it models new housing supply at the industry level rather then level of individual firms.

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[4] This assumption means that there are no homeless people/households in ILUTE. The model could be extended to explicitly consider homelessness as a feasible state for persons and households (and transitions to/from this state), but it is not suggested to do this within the proposed project.

[5] While active in the housing market, it is possible for a household to be temporarily "homeless". Two use cases exist. First, new immigrants to the region are "homeless" until they are allocated a dwelling unit. Second, an owner-occupant who is active in the market might sell its current residence before it has bought a new one. In both cases, the household will remain active in the market until it successfully finds a home. During the interval when it is "homeless" the model essentially treats the household as being in "limbo".

[6] What to do about "second homes" / "cottages" will need to be determined. These are likely to be outside the urban study area boundary, so maybe they can be treated as "other investments" somehow. Certainly, we are not interested in explicitly modelling all real estate investment anywhere in the world.

Housing market manager ("realtor agent"): ILUTE employs a housing market manager to manage the interactions between active buyers and sellers within the owner-occupied housing market, auction properties update asking prices for the next time step, etc.

Rental market manager: The rental market manager plays a similar role in the rental market, by allocating household seeking rental accommodation with vacant rental units and updating rents over time.

5.3 Household Financial Accounting Model[7]

The major contribution of the proposed next phase of the research is to develop a detailed household financial accounting model that can support explicit financing components and calculations within an ABM housing market model such as ILUTE. This section delineates the accounting equations that will form the basis for the development of this model. Given the emphasis within the project on housing, combined with a strong interest in integrating the model with transportation-related effects, the equations deal with housing and transportation operating and capital transactions in greater detail than other components, which are represented in a more aggregated fashion. Additional detail, of course, can always be added to the formulation sketched herein, if need and data availability warrant.

The crux of the approach is the recognition that each household (h)[8] in each time period (t)[9] must satisfy both operating cash flow and capital (savings, debt, equity) accounting equations. These are presented in detail below.

5.3.1 Capital Goods, Equity & Wealth

A *capital good* is defined in this framework as a high-value durable good which: (a) may either appreciate or depreciate in value over time; and (b) can, in principle, be sold at any point in time for its current market value. In this framework the durable goods of explicit interest are:[10]

- Owned place of residence (N_R = [0,1]).
- Additional real estate holdings (N_I = [0,…].
- Other investments and savings (stocks, etc.) (N_S = [0,…]).[11]
- Owned household automobiles (N_V = [0,…]).[12]

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[7] It is assumed throughout this discussion that the model works consistently in constant dollars, so no inflation effects exist.

[8] This household subscript is suppressed in the following notation and equations wherever it is obvious that they refer to a given individual household.

[9] It is assumed that ILUTE will step through time in one-month time-steps, unless stated otherwise.

[10] A household may also own other durable goods that contain equity (i.e., that have a market value that could be recovered through being sold). Furniture, appliances, works of art, other collectables, etc. Many of these are of minor value and generally would only be sold under conditions of dire stress. High-value items (that might also appreciate over time, such as art) are assumed to be included within the general "other investment" category.

[11] Although the set of investments and savings is shown here as being unbounded (as it is in reality – a household may have many different individual investments, savings accounts, etc.), in practical implementation it is likely that all investments will be aggregated together into a single category.

[12] Leased vehicles are essentially rented and so do not contribute to the household's wealth. At the moment, ILUTE does not differentiate between owning and leasing vehicles; this distinction will need to be added to the model system.

A household h may purchase a capital good g at time t_g with a purchase price PP_g.[13] This purchase may involve transaction costs paid by the purchaser, such as lawyer and bank fees (TCP_g), as well as possibly taxes associated with the transaction that are paid by the purchaser (TTP_g). The household may either purchase the good with "cash", which will generally require selling other capital goods (e.g., "cashing in" an investment),[14] taking out a loan, or some combination of both:

$$PP_g + TCP_g(t_g) + TTP_g(t_g) = CASH_g + D_g(t_g) \qquad [1]$$

$CASH_g$= Amount of cash used in purchasing good g
$D_g(t_g)$ = Amount of new debt (mortgage, car loan, etc.) taken on in purchasing good g

This purchase, of course, can only occur if, indeed, the household is able to assemble the needed combination of cash and debt to meet the purchase price plus any ancillary costs. The cash component will depend on the current amount of the household's wealth, and how much it is willing to allocate to this purchase, how much new debt the household is willing/able to take on, and a lending institution's willingness to extend this level of credit to this household.

$E_g(t)$ is the *equity* which the household has in good g at time t. It is the difference between the market value of the good at time t, $MV_g(t)$ and the amount of debt that the household has associated with this good, $D_g(t)$. I.e., it is the amount of money that the household could realize from the sale of good g at time t, assuming that it is able to sell the good at its current market value:

$$E_g(t) = MV_g(t) - D_g(t) \qquad [2]$$

At the time of purchase ($t = t_g$) the initial equity that the household has in this good is:

$$E_g(t_g) = MV_g(t_g) - D_g(t_g) \qquad [3]$$

Note that $MV_g(t_g)$ need not equal PP_g in all cases, although this will be a reasonable assumption in many cases.[15]

[13] Real estate purchases, either for the household's place of residence or as an investment property, will require participation in the housing market, as briefly sketched in Section 3. We need not worry about the details of this process at this point, which is only concerned with the case of a successful outcome of this market process in which the household end sup purchasing a dwelling unit at a market-determined sales price, PP_g.
[14] It is assumed that the purchase price of these capital goods generally exceeds what could be paid out of current salary income. Even if the purchase is made from income rather than equity funds, in the model we will assume that the money from the income is first "paid into" savings, and then immediately "cashed out" to purchase the good. The one exception to this is incremental contributions to savings from excess monthly income, which is discussed further below.
[15] For example, a newly purchased car depreciates in value "as soon as it is driven off the lot". A more important case for present purposes is that a dwelling unit's purchase prices is the outcome of a dynamic, micro-auction bidding process, in which the sales price for a given transaction may be either above or below the current expected market value of the dwelling unit.

In addition to debt incurred to purchase capital goods, households may also incur debt for a variety of other reasons, including short-run coverage of unexpected, large operating expenses (credit card debt, line-of-credit, etc.), "home improvement loans", financing vacations, etc. Define $D_o(t)$ be the household's total "non-capital" debt at time t.

A household's *wealth* at any point in time, W(t), is simply the sum of it's equity at time t, less it's non-capital debt, or, equivalently, the market value of all its capital goods, less its total debt:

$$W(t) = \Sigma_g E_g(t) – D_o(t) \quad [4.1]$$

$$= \Sigma_g MV_g(t) - \Sigma_g D_g(t) – D_o(t) \quad [4.2]$$

Note that a household may well have negative wealth, if its total debt exceeds the total market value of its assets.

The fundamental financial decisions facing households in the extended ILUTE are how much money to invest in an owned place of residence, in owning cars and in equity/income generating investments, where the last is further divided into investing in real estate versus all other investment opportunities. For places of residence and cars, the option to rent (lease) rather than own always exists.[16] Place of residence and car ownership decisions are explicitly modelled in ILUTE as market processes in which households are trying to maximize their overall utility (consumer surplus). The trade-offs between residential and mobility utility versus the "deferred utility" of savings/investments will need to be incorporated into the model system's decision-making processes.

5.3.2 Debt, Savings & Equity Dynamics

$MV_g(t)$ may go up or down over time in response to market dynamics for the given good. For real estate, the general expectation by households is that real estate values appreciate over time (although this need not be the case, especially in the short run and/or in certain sub-markets). ILUTE endogenously models these market value dynamics. This allows households to know at all times the market value of both their personal home as well as any other real estate investments which they own. The same holds true for non-household investors in the real estate market.

Personal vehicles depreciate fairly systematically over time.[17] A simple model of vehicle depreciation will be added to the ILUTE vehicle ownership decision-making model. Investments/savings may either appreciate or depreciated over time due to market dynamics, inflation effects, etc. A simple model of investment market values will also need to be developed that is consistent with the overall aggregate treatment of investments in the model system. Note

[16] And in the case of cars, the option of not owning any always also exists, at least in principle. All households must, however, must have a place of residence, unless they are homeless. ILUTE currently does not include homelessness as a feasible state for households.

[17] The one exception to this is the occasional vehicle which is kept long enough (and kept in sufficiently good condition) for it to become a "vintage" car which then appreciates in value. This rare case will not be considered in the model being developed.

that if $MV_g(t)$ drops below the amount of current debt associated with this good, $D_g(t)$, then it is possible for the household to be in a negative equity position with respect to the good (i.e., it owes more money than good is currently worth).

Each debt commitment, $D_g(t)$ or $D_o(t)$, has associated with it *repayment terms* that define a schedule of monthly[18] payments. These terms will vary depending on the nature of the loan (e.g., mortgage terms are different form car loans, etc.). The details of these need not be considered at this point, but will need to be specified in the model system implementation. These monthly payments, however, share the same general nature in that they consist of two parts: an interest payment (representing the amount of interest generated by the balance (or principal) that is still owed) and a contribution to paying down the principal. Thus, with each payment, the amount of principal owed declines somewhat. This also means that with each payment the contribution towards the principal increases slightly since there is slightly less interest to be paid. The terms of the loan are such that by the end of the *amortization period*, the entire original debt has been repaid and no debt remains. I.e.:[19]

$$M_g(t) = MB_g(t) + MD_g(t) \quad [5]$$

$$D_g(t) = D_g(t\text{-}1) - MB_g(t) \quad [6]$$

$M_g(t)$ = Total monthly payment for the debt (loan) associated with good g
$MB_g(t)$ = Portion of the monthly payment that contributes to balance repayment
$MD_g(t)$ = Monthly interest payment

Thus, in addition to any increases in a good's market value, the household's equity embedded in this good goes up over time as it gradually retires the debt associated with this good. On the other hand, repayment of non-capital debt reduces the household's overall debt (and increases its net wealth by the same amount) but does not otherwise increase the household's equity/wealth.

The "affordability" of any capital good ultimately depends on this monthly debt payment, since this represents a "hard cash" payment that must be made each month from the household's operating budget (discussed further below). Failure to make this monthly payment can lead to defaulting on the loan and loss of the good (foreclosure on the house, repossession of the car, etc.) – a generally catastrophic event for the household.

If a household sells a good g at time t, the *revenue* that it receives will be the difference between the good's sales price ($SP_g(t)$) and the current debt that is attached to this good, which it is assumed must be retired (paid off) in order for the sale to proceed:[20]

$$REV_g(t) = SP_g(t) – D_g(t) - TCS_g(t) - TTS_g(t) \quad [7]$$

[18] Other payment intervals are possible, but in the proposed model, all financial processes and payments are assumed to occur in one-month time steps.
[19] These equations apply to non-capital debt ($D_o(t)$) payments as well.
[20] The one exception to this is for the sale of stocks or other investment instruments, in which case it is assumed that debt used to originally purchase these instruments need not be repaid at the time of purchase. This effectively assumes that the collateral backing such debt is not the stock itself.

where TCS_g and TTS_g are any transaction costs and taxes, respectively, that are paid by the seller. Note that, as with purchase prices, the sales price may or may not equal the expected market value, depending on the case.

A simple model of non-real estate investments/savings is:

$$SV(t) = SV(t-1)*(1+i_t) + S(t) - SW(t) + \Sigma_{g\neq s} REV_g(t) - \Sigma_{g\neq s} CASH_g(t) + \Delta SVS(t) + \Delta SVP(t) \quad [8]$$

$SV(t)$ = Total current balance of non-real estate investments/savings at time t. This is the sum of actual cash reserves/savings and the current market value of stocks, etc.
i_t = Rate of return in period t
$S(t)$ = New contribution to savings from earned income at time t
$SW(t)$ = Withdrawals from savings to spend on household operating expenditures in time t
$\Delta SVS(t)$= Net change in savings due to selling stocks, etc. in time t
$\Delta SPB(t)$= Net change in savings due to purchasing stocks, etc. in time t

$$\Delta SVS(t) = RS(t) - MVS(t-1) - TCS_s(t) - TTS_s(t) \quad [9]$$

$$\Delta SVP(t) = \Delta D_s(t) - TCP_s(t) - TTP_s(t) \quad [10]$$

$$D_s(t) = D_s(t-1) - MB_g(t) + \Delta D_s(t) \quad [11]$$

$RS(t)$ = Net revenues received from the sale of the stocks
$MVS(t-1)$= The market value at time (t-1) of the stocks sold at time t
$\Delta D_s(t)$ = Net new debt undertaken to purchase stocks, etc. at time t

Points to note with respect to Equations [8-11] include:

- It assumes a simple aggregate rate of return for all savings in time period t-1 that is received at time t.
- This rate of return need not be positive. E.g., stocks may decline in value, adjusting for inflation may result in fixed investments depreciating in value, etc.
- It is assumed that proceeds from sales of capital goods and "cashing out" of savings can occur within the time period, i.e., without significant lags.
- Any contribution from monthly income to the purchase of a capital good is included in S(t) and, thence, in $CASH_g(t)$.
- It is assumed that the cash purchase of new stocks is balance neutral, since it requires replacing savings with an equivalent value in new holdings, less any transaction costs. If debt, however, is used to purchase the new stocks, this represents a net addition to savings equal to the amount of this new debt. Since the total debt has gone up, of course, the net equity in savings is unchanged. But the new savings will (usually) generated investment income in subsequent time periods.

Note that, as with all other capital goods, the net equity associated with these savings, $E_s(t)$, is the difference between the total savings and current debt that has been associated with the purchase of these savings:

$E_s(t) = SV(t) - D_s(t)$ [12]

5.3.3 Operating Budget

Expenditures (cash outflow) in time period t for household operating expenses must equal revenue (cash inflow). This includes all debt servicing payments. Given the emphasis on housing and transportation decision-making, expenditures for these two categories are represented in greater detail than for other operating costs in the proposed model.

Payments to savings from current income and the spending of savings and/or newly incurred debt on operating expenses are included in this calculation.

Note that under "normal" circumstances, Equation [1] should balance in each time period (month), since, on the one hand, any excess income can be allocated to savings (S_t), while any shortfall in revenue is assumed to be balanced by some combination of savings withdrawals, selling of capital goods and/or taking on new debt. Clearly, there will be cases in which these options will not exist for a household (no savings, nothing to sell, can't get a loan). The model will need to deal with these cases in an appropriate way ("foreclosing" on the household's dwelling unit, etc.).

$$HC(t) + HT(t) + VC(t) + VT(t) + C(t) + \sum_g M_g(t) + M_o(t) + IT(t) + S(t) = Y(t) + TP(t) + SW(t) + \Delta D_o(t) \quad [13]$$

Expenditures in time period t:
HC(t) = Housing operating costs (utilities, maintenance, etc.)
HT(t) = Housing property taxes
VC(t) = Car ownership and operating costs, except for car loan debt servicing[21]
VT(t) = Vehicle related taxes and fees
C(t) = All other (non-housing/transportation/debt servicing) operating expenditures
IT(t) = Income taxes[22]

Revenue in time period t:
Y(t) = Household employment income (wages/salaries)
TP(t) = Non-employment transfer payments (employment insurance, etc.)
$\Delta D_o(t)$ = New non-capital debt incurred in this time period

$D_o(t) = D_o(t-1) - MB_o(t) + \Delta D_o(t)$ [14]

5.4 Modelling Non-Resident Real Estate Investors

While the actual extent of the problem is a matter of some debate, significant concern exists within many Canadian cities concerning the impacts which foreign (or at least non-resident)

[21] This might be usefully split into fixed costs (insurance, etc.) and variable costs (fuel, parking, etc.).
[22] For current purposes, it is assumed that sales taxes (e.g., HST) and any other usage-based fees or taxes are included in the expenditure payments. Similarly, it is assumed that fuel and other vehicle-related taxes/fees are including in VC(t).

investors/speculators have on the price and supply of housing. Given this, the model framework will include a non-resident real estate investment component.

Modelling non-resident real estate investment is far from a trivial task, since the population of potential investors is global in nature, as is the "choice set" for these investors to choose from (e.g., why invest in Toronto or Vancouver relative to London, New York, Shanghai, etc.?). Data on these investors and investments is also not likely to be readily available. Thus, any model developed at this point will be quite simplistic and aggregate in nature. Nevertheless, it is felt that it is important that this process be included in the model, even if it is largely a crude "place-holder" for what might eventually be a more realistic model.

5.5 Modelling the Housing Mortgage Market

An explicit representation of the housing mortgage market will be introduced within the extended ILUTE model. This model will build closely on existing models, as reviewed in the literature review presented in Report 1. In particular, it will take a form similar to the Baptista, et al. model (Figure 5.1), which has defined the general approach to this problem in the field. As in the Baptista, et al. model, a Central Bank agent will set the "rules" for mortgage lending, while a "mortgage market agent" (representing the mortgage lending industry) will interact with agents seeking financing to accept/reject their requests for financing and to set the terms (rate, term, amortization period, etc.) for these mortgages.

Many mortgage options exist in practice: fixed vs. variable rates, various monthly payment options, different terms and amortization periods. As in the current literature, it will not be feasible to model choice among all of these options in detail. Rather, a simpler "average" or "representative" mortgage instrument will likely be defined. Various options for doing this exist in the current literature. A fair amount of experimentation will likely be required to develop a "mortgage model" that is feasible to implement, captures "average behaviour" and is sensitive to market dynamics in an appropriate way (e.g., rates increase/decrease over time in a reasonable way).

5.6 Extending ILUTE Decision Processes

To incorporate the housing finance extensions envisioned in this report, current ILUTE decision processes will need to be extended in the following five ways:

- Household housing market decision-making will need to be modified/extended to account for both capital (purchase) cost and on-going operating (including debt-servicing) costs. This will include modifications/extensions to residential mobility decision-making (the decision to become active in the market), the choice set formation / search process for active households, buyers' bid formation process and sellers' bid acceptance process.
- Household decisions concerning real estate investments for income/wealth generation purposes will need to be added.
- Household decisions concerning other (non-real estate) savings/investments will need to be added.
- One or more modules for non-household real-estate investment by developers, other local corporations and non-local investors will need to be added.
- Processes for the new Central Bank and Mortgage Market Agent will need to be added. The extent to which the Central Bank will act as an endogenous agent (i.e., dynamically responding to simulated market events) versus as an exogenous "scenario input" will need to be determined.

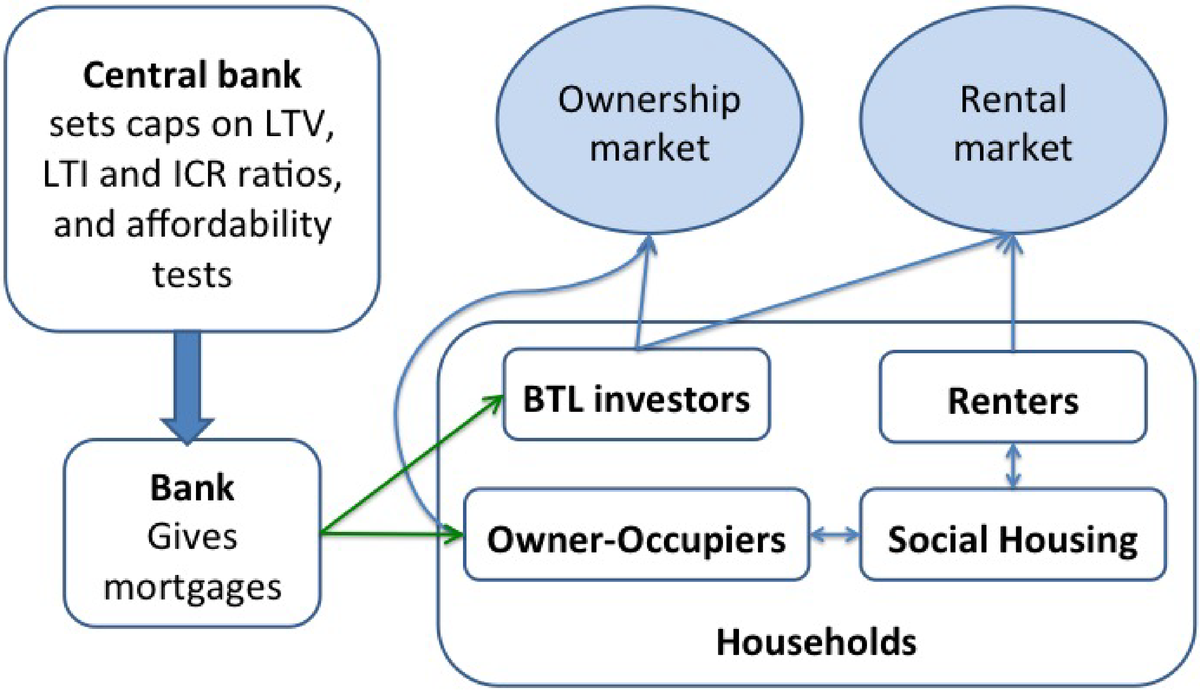

Figure 5.1: A Schematic of the Baptista, et al. (2016) Model

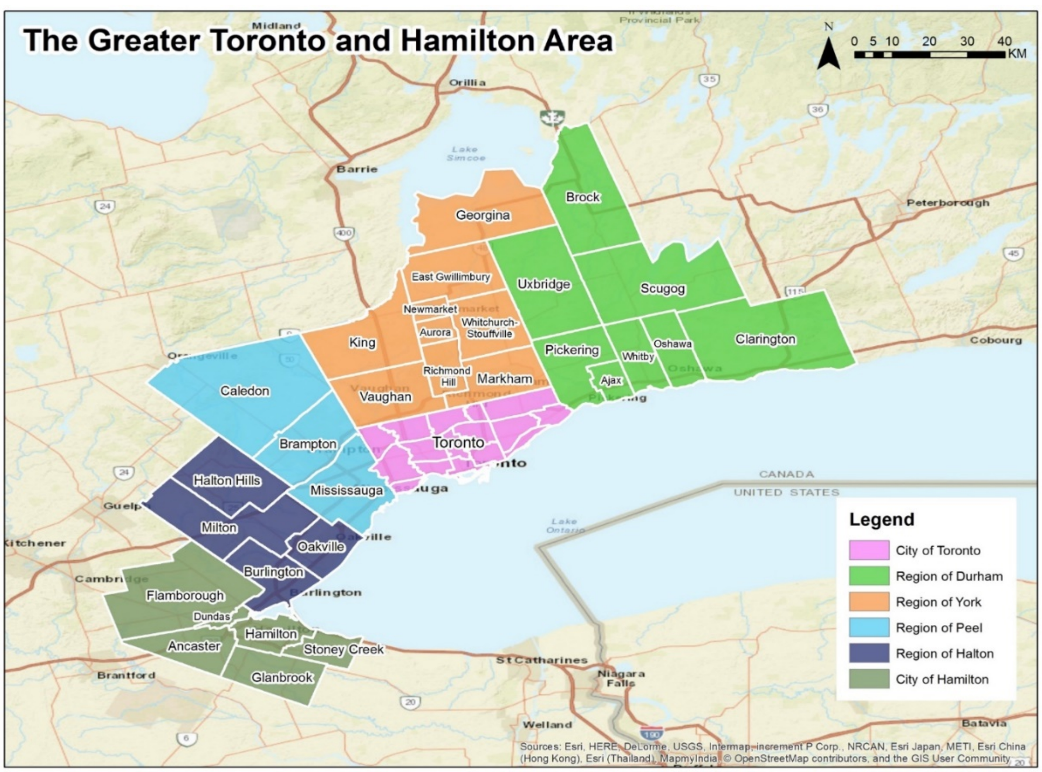

Figure 6.1: The Greater Toronto-Hamilton Area

6. WORK PLAN, SCHEDULE, DELIVERABLES & STUDY TEAM

6.1 Study Area

ILUTE has been developed to model the Greater Toronto-Hamilton Area (GTHA), Canada's largest urban region containing North America's fourth-largest City (the City of Toronto). The GTHA will also be the study area for the proposed project. See Figure 6.1.

6.2 Work Plan & Schedule

Two parallel streams of work will be undertaken in the proposed project:

1. Updating/upgrading the ILUTE housing market model software and models to be able to incorporate housing financing and equity factors.
2. Developing models of housing financing decision-making and equity/wealth accumulation.

The work plan required to accomplish these two major outcomes consists of 10 major tasks, as shown in Figure 6.2.

As also shown in Figure 6.2, the project is expected to take 9 months to complete. The work divides roughly into three unequal stages:

1. The first two months will involve building upon the framework presented in this report to develop a detailed models system design and the detailed work plan required to develop and implement this design. All datasets required for the model development and testing phase will be also be assembled (Tasks 1-4).
2. The next six months will involve detailed software and model system development and testing. In the final portion of this stage a small number of policy analysis use cases will be tested, both to assist in the validation of the developed model and to demonstrate its policy analysis capabilities (Tasks 5-9).
3. Starting in month 8, the final report will be developed that documents all work, findings and recommendations generated by the project. The draft of this report will be submitted to CMHC for review by the middle of the 9th month, leading to finalization incorporating CMHC comments by the end of the month (Task 10).

Assuming a January 2, 2019 start, this means that the project final report would be submitted to CMHC by September 15, 2019.

	MONTH:								
TASK	1	2	3	4	5	6	7	8	9
1. Detailed model system design									
2. Detailed model development work plan									
3. Data assembly and preliminary analysis									
4. Interim Report 1: Model System Design & Work Plan		*							
5. ILUTE software updates & extensions									
6. Financial accounting & decision-making models									
7. Interim Report 2: Modelling Household Financing					*				
8. Incorporating housing finances into ILUTE									
9. Example policy analysis use cases									
10. Final Project Report									*

Figure 6.2: Proposed Project Tasks & Schedule

Table 6.1 lists the primary deliverables and expected delivery dates to be generated by this project.

Table 6.1: Project Deliverables

Deliverable	Due Date
Interim Report 1: Model System Design & Work Plan	February 28, 2019
Interim Report 2: Modelling Household Financing	May 31, 2019
Final Project Report	September 15, 2019
Working, documented copy of all models & software developed[1]	September 30, 2019
Notes	
1. All IP developed during the proejct will remain the property of the study team and the University of Toronto. A royalty-free licence for any software developed will be granted to the CMHC.	

6.3 Study Team

The Principal Investigator for this project will be Dr. Eric J. Miller, Professor of Civil & Mineral Engineering, University of Toronto and Director of the University of Toronto Transportation Research Institute (UTTRI). Prof. Miller has over 40 years experience in integrated urban modelling and is the developer of ILUTE.

Dr. Ahmadreza Faghih Imani, a NSERC Post-Doctoral Fellow working under Prof. Miller's supervision will have primary responsibility for all data analysis and model building and testing within the project. He will be assisted by Khalil Martin, a Civil & Mineral Engineering MASc student. James Vaughan, UTTRI's Senior Software Architect, will be the lead software designer for the project. He will be assisted by Brendan Reilly, a UTTRI software programmer.

Curriculum vitae for the project team are available upon request.

7. Proposed Budget

Table 7.1 presents the proposed budget for the study. This totals $98,280, including University overhead, but excluding any applicable HST.

Table 7.1: Proposed Project Budget

Expense Item	Amount	Notes
Salaries & Stipends		
Ahmadreza Faghih Imani	$25,000.00	8 months @ $3125/month
James Vaughan	$11,200.00	32 days @ $350/day
Brendan Reilly	$8,000.00	32 days @ $2500/day
Khalil Martin	$10,000.00	8 months @ $1250/month
PI Stipend	$16,000.00	16 days @ $1000/day
Sub-total, Salaries & Stipends	$70,200.00	Excludes any applicable HST
Other Direct Expenses	$0.00	
Total Direct Expenses	$70,200.00	
University overhead @40%	$28,080.00	
TOTAL PROJECT BUDGET	$98,280.00	Exclude any applicable HST

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