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Residential demand and supply in the Alberta PECAS model

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Abstract

Random utility choice models of the selection behavior of households and developers have been specified, and the utility function parameters for these models have been estimated for application in a PECAS spatial economic model of Alberta, Canada. On the demand side, households select dwelling location, type and space quantity. In this selection households are influenced by rent, accessibility, crime rate, school quality, proportion of green space, and by preferences for dwelling type and space quantities that vary with household size, income and life cycle stage. On the supply side, developers select space type and intensity for each land parcel. In this selection developers are influenced by expected rent, costs for construction, demolition, renovation, servicing and maintenance, fees, and by preferences for greenfield sites and dwelling types. The resulting utility functions include estimated values for parameters indicating the strengths of these influences. These utility functions with their estimated parameters are set within a PECAS model, which enhances the representation of residential space markets in the model and also places it within a wider theoretical framework for more complete modelling and analysis. These utility functions and estimated parameters also provide novel empirically-based indications of the influences and tradeoffs involved. The choice behavior of households has been considered empirically at this level previously in the literature, but not with the range of factors considered here; the choice behavior of developers has not received this level of attention empirically, so the results support new insights into these aspects of behavior in residential space markets.

Keywords: household location choice; residential space demand; residential space supply; spatial economic model; PECAS; Alberta

1. Introduction

A spatial economic model of the Province of Alberta in Canada has been developed using the PECAS Framework, with the work starting in 2015. The resulting model, called the “Alberta Spatial Economic Transport” or “ASET” Model, is to be used to support work to both (a) forecast the needs for investment in transportation infrastructure and

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(b) assess the impacts of potential such investments and related planning on economic activity and quality of life in Alberta. A key component of the model is the representation of the markets for residential space, including the spatially varying demand and supply in response to (a) rents, (b) changes in accessibilities arising with additional transportation infrastructure, and (c) other potential policy options including land use plans and land services provision.

This paper presents the models of supply and demand for residential space developed for the ASET Model and it considers the implications and insights provided by these models and the estimation results obtained in developing them. Section 2, the next below, provides a brief indication of the PECAS framework for spatial economic modelling, indicating (a) its basic modules, information flows and dynamics, and (b) how in general it incorporates household behavior resulting in residential demand and developer behavior resulting in residential supply. The subsequent three sections, Sections 3 to 5 inclusive, set out the specific treatments of households and developers in the ASET Model. Section 3 outlines the definitions of the categories of households and residential space used. Section 4 covers the random utility choice models for household behavior and Section 5 covers the random utility choice models for developer behavior, with both Sections including the alternatives, attributes, utility functions and parameter estimates, along with consideration of the indications and implications of the parameter estimation results. Finally, Section 6 offers conclusions about these models, their suitability in the ASET Model and other PECAS models more generally, and the broader implications and insights arising with the estimation results obtained.

2. The PECAS Framework for Spatial Economic Modelling

PECAS stands for *P*roduction *E*xchange *C*onsumption *A*llocation *S*ystem. It is a generalized flexible theoretical system for spatial economic modelling. It provides a structure for simulating the behaviors and interactions in such systems and their resulting evolution and responses to potential policy actions, together with software for implementing specific models.

In PECAS, *activities* employ *technologies* that use *puts* (consume inputs) to make *puts* (produce outputs). Basic types of *activities* include: households, firms, governments, non-profits, importers and exporters. Basic categories of *puts* include: raw materials, commodities, goods (processed, manufactured, durable, non-durable), services (personal, business), capital (machinery and equipment, financial), buildings, floorspace, labour (by occupation), emissions, and other pollution-type externalities. Basic forms of *technologies* include: manufacturing processes, production techniques, business approaches, and household lifestyles, each expressed as a vector of the quantities of *puts* made and *puts* used per unit of *activity*.

Activities make, use, buy, sell, own and rent *inventories* of *puts* at *activity locations* (land use zones or *LUZ*). Travel and transport flows arise from the movements of *puts* among *activities* from production to exchange to consumption at different *locations*. Buildings and infrastructure at specific *locations* arise from investments in *puts* by *activities*. Market-clearing prices (or rents) for *puts* are established at *exchange locations* (again, *LUZ*) and these together with transport costs influence *activity* decisions. The evolution of the system through time is simulated using the configuration of modules and information flows shown in Figure 01 on the following page.

2.1. The AA Module

In the AA Module (see Figure 01), *activities* select *activity locations*, *technologies* and *exchange locations* for the *puts* being bought and sold. Their behavior in this selection is represented using random utility choice models with a utility function that has the general form shown in Equations 01 through 04 below. These choice models combine in a three-level nested structure with *activity locations* at the top, *technologies* in the middle and *exchange locations* at the bottom (Hunt and Abraham, 2005; Abraham and Hunt, 2007a).

$$\mathrm{U}_{a,l}^{L} = \mathrm{AU}_{a,l}^{L} + \mathrm{CU}_{a,l}^{T} \qquad (01)$$

$$\mathrm{CU}_{a,l}^{T} = (1/\lambda_a^T) \cdot \ln \left[\sum_{t \in \mathrm{T}_a} \exp(\lambda_a^T \cdot (\mathrm{AU}_{a,l,t}^{T} + \mathrm{WU}_{a,l,t}^{T})) \right] \qquad (02)$$

$$\mathrm{WU}_{a,l,t}^{T} = \sum_{p \in \mathrm{P}_t} [\, | \tau_{p,t,a} | \cdot \mathrm{CU}_{p,l}^{E} \,] \qquad (03)$$

$$\mathrm{CU}_{p,l}^{E} = \left(1/\lambda_p^E\right) \cdot \ln \left[\sum_{e \in E} \exp(\lambda_p^E \cdot \mathrm{U}_{p,l,e}^{E}) \right] \qquad (04)$$

where:

a = index for *activities*

l = index for *activity locations*, with L = the full set of all *activity locations*

t = index for *technologies*, with T_a = the full set of *technologies* available for *activity a*

p = index for *puts*, with P_t = the full set of *puts* made and used with *technology t*

e = index for *exchange locations* for buying or selling, with E = the full set of all *exchange locations*

$U^L_{a,l}$ = location utility (per unit of activity) for activity a at activity location l (utils/year)

$CU^T_{a,l}$ = composite utility for full set of technologies available for activity a at location l (utils/year)

$AU^L_{a,l}$ = additional utility (beyond $CU^T_{a,l}$) for activity a at activity location l (utils/year)

λ^T_a = dispersion parameter for technology choice for activity a

$WU^T_{a,l,t}$ = sum of *exchange* composite utilities for full set of *puts* with *technology t* for *activity a* at *location l* (utils)

$AU^T_{a,l,t}$ = additional utility (beyond $WU^T_{l,t}$) for *technology t* for *activity a* at *location l* (utils/year)

λ^E_p = dispersion parameter for *exchange* choice for put *p*

$CU^E_{p,l}$ = composite utility for full set of *exchange locations* for a unit of *put p* at *activity location l* (utils/year)

$\tau_{p,t,a}$ = technical coefficient for *put p* with *technology t* for *activity a*, including in general for *p* as both an input and an output (puts/activity)

$U^E_{p,l,e}$ = exchange utility for *exchange location e* for a unit of *put p* at *activity location l* (utils/put).

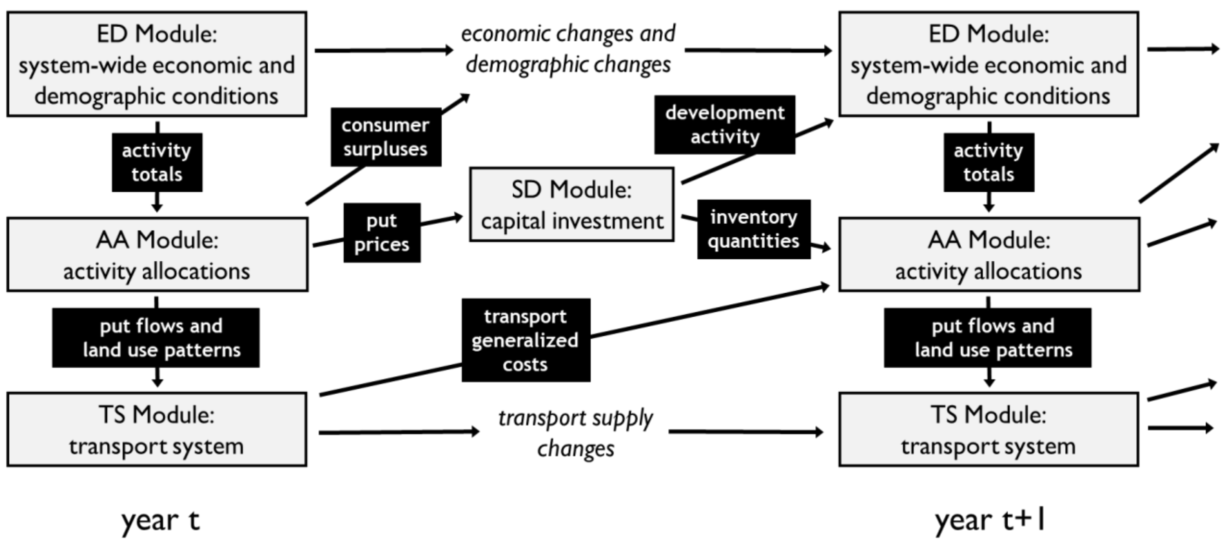

Figure 01. System of modules and information flows in PECAS: For each simulation year the *ED Module*, *AA Module* and *TS Module* are run in succession. Then the *SD Module* is run for the subsequent period to the next simulation year. This cycle iterates through all the simulation years to emulate the evolution of the full system from the first year to the last. For a given simulation year, the *ED Modul*e establishes the model-wide total for each *activity* based on forecasts of economic and demographic processes, adjusting these in response to changes in (a) the corresponding consumer surplus values established by the *AA Module* for the previous simulation year and (b) the economic stimulus determined by the *SD Module* for the previous period. The *AA Module* determines the *activity* quantities for *locations* and *technologies* and the corresponding *puts* (both in*puts* and out*puts*) quantities to *exchange locations* for the specific set of exchange prices for the *puts* that clears all the markets at the *exchange locations*. These land use patterns and flows of *puts* from *production* to *exchange* to *consumption* are used by the *TS Module* to simulate the demand for travel and transport and determine the congested times and costs and resulting *transport generalized costs* arising when this demand is loaded to the coded networks representing the transport supply. These costs are used by the *AA Module* for the next simulation year. The *SD Module* determines the quantities of capital investment in the transition period from one simulation year to the next, including investment in fixed infrastructure and buildings at locations, using the current year *put* prices together with the associated *activity* quantities determined by the *AA Module*. This establishes amounts of development activity providing economic stimulus for the *ED Module*, along with *inventory* quantities, including the changes in building space at locations, for the *AA Module* for the next simulation year.

The exchange utility $\mathrm{U}^{E}_{p,l,e}$ is the sum of three weighted components of utility in general: (a) the (dis)utility for transporting (a unit of) *put p* between *exchange location e* and *activity location l* (from *e* to *l* for buying then using, from *l* to *e* for making then selling); (b) the utility for the price for (a unit of) *put p* (negative for buying, positive for selling); and (c) the utility arising from the size (and associated heterogeneity) of *exchange location e* for *put p*.

The general form of Equation 04 for the composite utility $\mathrm{CU}^{E}_{p,l}$ – specifically, the log of a weighted sum of exponentiated values including transport cost and size for a set of locations – has been used extensively as a utility-based measure of the accessibility for *put p* at *activity location l* (Geurs and van Wee, 2004). In this case, it provides such an accessibility measure with the effects of price on utility included explicitly along with those of transport cost and size.

Changes in the prices for puts at exchange locations give rise to changes in accessibilities, exchange utilities, technologies and activity locations, all of which change the quantities demanded and supplied. The set of market-clearing prices for all puts in all exchange locations is found by an iterative search process, as the solution point where all quantities demanded match quantities supplied. Changes in other components, including those associated with specific policy actions – such as transport costs, technical coefficients, attributes of activity locations or exchange locations, and activity totals – also give rise to changes in quantities demanded and supplied. Whether the payments for puts are prices or rents depends on the nature of the put and whether continuing ownership is an issue: prices are for commodities that by definition are used up when used whereas rents are for items of capital that are not used up when used. The terms “price” and “rent” can be used interchangeably here to indicate the payment made to obtain and use puts without loss of generality.

The composite utility for all locations in the model area is given by Equation 05.

$$\mathrm{CU}^{L}_{a} = \ln\left[\, \textstyle\sum_{l\in L} \exp(\, \mathrm{U}^{L}_{a,l}\,)\,\right] \qquad (05)$$

where:

CU^{L}_{a} = composite utility (per unit of activity) for *activity a* model-wide (utils/year).

Changes in this composite utility indicate the corresponding changes in consumer surplus for the activity model-wide. They provide measures of the changes in the attractiveness of the entire model area for the activity, which can be used in both (a) evaluation of the benefits of potential policy options and (b) modelling the changes in model-wide total quantities for activities.

2.2. The SD Module

In the SD Module (see Figure 01), *activities* (as developers) make “action *vs* no action” decisions and select infrastructure (building or space) type and intensity for land parcels. Again, random utility choice models are used, with a utility function that has the general form shown in Equations 06 through 09 (Abraham and Hunt, 2005; 2007b).

$$\mathrm{U}^{D}_{p,x} = \mathrm{AU}^{D}_{p,x} + \mathrm{CU}^{D}_{p,x} \qquad (06)$$

$$\mathrm{CU}^{D}_{p,x} = (1/\lambda^{F}_{p}) \cdot \ln\left[\int_{f^{min}_{p,x}}^{f^{max}_{p,x}} [\, \lambda^{F}_{p} \cdot \mathrm{U}^{F}_{p,x}(f)\,]\, df\right] \qquad (07)$$

$$\mathrm{U}^{F}_{p,x}(f) = \alpha^{NR}_{a,p} \cdot [\, \mathrm{NR}_{p,x}(f) \,/\, L\,)\,] + \mathrm{DSF}_{p}(f) \qquad (08)$$

$$\mathrm{NR}_{p,x}(f) = \left[R_{p,x} - \mathrm{J}^{OS}_{p}(f)\right] \cdot f \cdot L + \left[R^{L}_{p,x} - \mathrm{J}^{OL}_{p}(f)\right] \cdot L - i \cdot \{\, \mathrm{J}^{IS}_{p,x}(f) \cdot f \cdot L + \mathrm{J}^{IL}_{x}\,\} \qquad (09)$$

where:

x = index for *parcels*

p = index for *puts*, with P_{t} = the full set of *puts* made and used with *technology t*

f = intensity of development of a *put* per unit land; for building space *puts* this can be a floor area ratio (FAR)

$\mathrm{U}^{D}_{p,x}$ = developer utility (per unit land) for establishing *put p* on *parcel x* (utils/year)

$\mathrm{CU}^{D}_{p,x}$ = composite utility for full set of intensities available (or permitted) for *put p* on *parcel x* (utils/year)

AU^{D}_{p} = additional utility (beyond $\mathrm{CU}^{D}_{p,x}$) for establishing *put p* on *parcel x* (utils/year)

λ^{F}_{p} = dispersion parameter for intensity choice for *put p*

$\mathrm{U}^{F}_{p,x}(f) =$ intensity utility for establishing *put p* on *parcel x* at intensity *f* (utils/year)
$L =$ quantity of land on parcel x (m^2)
$\mathrm{NR}_{p,x}(f) =$ net financial return per unit land for establishing *put p* on *parcel x* ($/year)
$\alpha^{NR}_{a,p} =$ sensitivity to net financial return for activity a establishing put p (utils/$)
$\mathrm{DSF}_{p}(f) =$ additional utility per unit land (beyond the component arising with $\mathrm{NR}_{p,x}(f)$) for establishing *put p* on *parcel x* at intensity *f* (utils/year)
$R_{p,x} =$ rent for *put p* on *parcel x* ($/$m^2$-year)
$\mathrm{J}^{OS}_{p}(f) =$ ongoing financial costs associated with using and maintaining *put p* at intensity *f* ($/$m^2$-year)
$R^{L}_{p,x} =$ rent for land on *parcel x* extra to rent for *put p* ($/$m^2$-year)
$\mathrm{J}^{OL}_{p}(f) =$ ongoing financial costs associated with using and maintaining land with *put p* at intensity *f* ($/$m^2$-year)
$i =$ annual rental cost of financial capital, typically the effective interest rate on long term bonds ($/$)
$\mathrm{J}^{IS}_{p,x}(f) =$ initial financial costs for establishing *put p* at intensity *f* on *parcel x* ($/$m^2$)
$\mathrm{J}^{IL}_{x}(f) =$ initial financial costs for land and site preparation establishing *put p* at intensity *f* on *parcel x* ($/$m^2$).

The terms in Equation 09 provide the elements of a system for representing *pro forma* investment analysis, including income from rents and costs for construction, demolition, site preparation, services development, maintenance, initial development fees and other initial or ongoing charges or levies (Hunt *et al*, 2008).

Intensity is a continuous variable, so Equation 07 is the continuous analogue to the discrete composite utility formula and the $\mathrm{DSF}_{p}(f)$ term in Equation 08 is a continuous function rather than a vector of distinct constants. This continuous function facilitates the shaping of the distribution of development intensities established by the model as part of calibration. It is given the name "density shaping function", with "DSF" used for its label as shown here.

2.3. PECAS Model design and development

The design of a specific model based on PECAS, such as the ASET Model, is the selection of the categories for *activities* and *puts* and the specification of the components of the utility functions describing their behavior and interactions. The development of a specific model includes the determination of the values for the various parameters in these utility functions.

3. Category Definitions in ASET Model

3.1. Households categories in ASET Model

Households are *activities* in PECAS. In the ASET Model, there are 15 types of household based on household size, income and life cycle stage as shown in Table 01.

The choice behavior of the households in these 15 categories when selecting location (*LUZ* in PECAS) and dwelling type and dwelling size (parts of *technology* in PECAS) in the AA Module constitutes the demand for residential space in the model. The form and parameter values for the utility functions for each of these 15 household categories were established as part of model development, and are described in Section 4 below.

Table 01. Household type definitions for ASET Model.

Household Type (a)	Household Composition	Household Income Strata within Composition	Household Annual Pre-Tax Income Range ($\$\cdot 10^3$, CAD-2011): 0–30	30–60	60–100	100–
1p_$	1 person, age < 65 years	Low	XXXXX			
1p_$$	1 person, age < 65 years	Medium		XXXXX		
1p_$$$	1 person, age < 65 years	High			XXXXXXXX	XXXXXX
2p_$	2 persons, at least one age < 65 years	Low	XXXXX			
2p_$$	2 persons, at least one age < 65 years	Medium		XXXXX		
2p_$$$	2 persons, at least one age < 65 years	High			XXXXXXXX	XXXXXX
1-2s_$	1 or 2 persons, all age ≥ 65 years	Low	XXXXX	XXXXX		
1-2s_$$	1 or 2 persons, all age ≥ 65 years	Medium			XXXXXXXX	
1-2s_$$$	1 or 2 persons, all age ≥ 65 years	High				XXXXXX
3-4p_$	3 or 4 persons	Low	XXXXX	XXXXX		
3-4p_$$	3 or 4 persons	Medium			XXXXXXXX	
3-4p_$$$	3 or 4 persons	High				XXXXXX
5+p_$	5 or more persons	Low	XXXXX	XXXXX		
5+p_$$	5 or more persons	Medium			XXXXXXXX	
5+p_$$$	5 or more persons	high				XXXXXX

3.2. Residential space categories in ASET Model

Types of residential space in dwellings are *puts* in PECAS. In the ASET Model, there are 6 types of residential space *puts* based on 4 structure types and 2 quality levels for 2 of these structure types as shown in Table 02.

These residential space categories are kept distinct throughout the ASET Model. Further sub-categories are considered in specific sub-components and then re-combined: In the SD Module, SFD*l* where the FAR is less than 0.045 is considered separately as "Country Residential", or CR, and MF*e* and MF*l* are similarly split into medium and high-density sub-categories based on FAR.

The choice behavior of developers in the provision and modification of residential space at locations – including construction, demolition, renovation, intensification and "no action" – constitutes the supply for residential space in the model. As above, the form and parameter values for the utility functions concerning this behavior were established as part of model development, and they are described in Section 5 below.

Table 02. Residential space type definitions for ASET Model.

Space Type (p)	Quality	Structure Type	Aspects of Structure Type: external entrance	External Walls	typical range of floor area ratios (FAR)	Examples
		single-family detached	separate	all separate	0-1.3	detached house
SFD*e*	economy					
SFD*l*	luxury					
SFA	all	single-family attached	separate	some shared	0-2.7	duplex, triplex, fourplex; row house terraced house; townhouse
		multi-family	shared	all shared	0.5-18.5+	apartment block; walk-up; mid-rise; high-rise; tower block
MF*e*	economy					
MF*l*	luxury					
MOB	all	mobile home			-	manufactured home, trailer, tent

4. Demand Side: Household Choice Model

The nesting structure for the household choice model is shown in Figure 02. Household choice of LUZ is the PECAS location choice component, and household choice of residential space type and space size is the dwelling use part of the PECAS technology choice component.

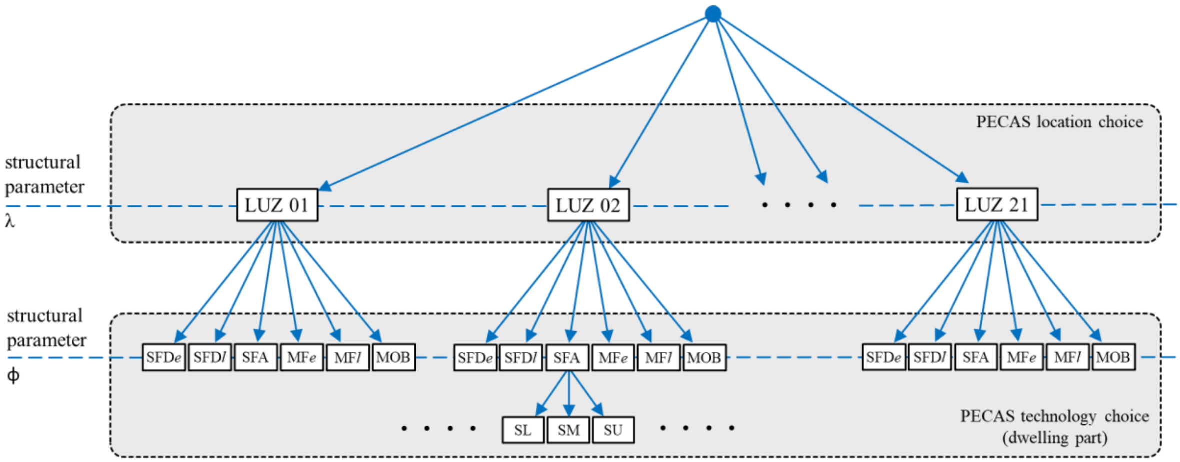

Figure 02. Nesting structure for household choice model: The location alternatives are the model LUZ. In application all LUZ are available. Residential space type alternatives are available in a given LUZ provided there is a non-zero number of dwellings and corresponding quantity of space of that structure type and quality in the LUZ. Residential space use rates arise from the range of individual dwelling sizes (m^2 areas) by space type and LUZ. The range of rates for a given space type and household type is defined using three options: SL for the lowest rate, SM for the mean rate and SU for the highest rate options. The figure shows these options for just space type SFA in LUZ 02, but these apply for all space types and all LUZ in general. They are omitted from the figure merely for clarity of presentation. Each of the two structural parameters is the coefficient factoring the composite utility (or 'log-sum') for the lower level nest of alternatives when it is added into the utility function for the corresponding upper level alternative, which in each case is the ratio of the utility scale parameter for the upper level logit model over the utility scale parameter for the corresponding lower level logit model at that point.

Just over 21,600 observations of individual household selections of dwelling location, type and size in the Edmonton Region of Alberta in 2015 were used in the estimation of the household choice model. These were developed by merging the individual household records from the Edmonton Household Travel Survey conducted in 2015 (City of Edmonton and Malatest, 2018) with the Alberta Municipal Affairs property assessment data (Alberta Municipal Affairs, 2015). Indications of household characteristics are included in the travel survey data. The size, year built and quality levels for dwellings are included in the data available from tax assessment; a quality rating is assigned as part of the annual valuation of improvements on each parcel for property taxes. Estimates of rents were developed using regression equations that included observations of actual rents along with the corresponding valuations provided in the data available from tax assessment (Wang *et al*, 2011).

Simultaneous estimation of all parameters for all nesting levels was not practical. Instead, a sequential process was used. The choice of dwelling size on the lowest level was considered first and the remaining choices of location and dwelling type on the upper levels were considered second. The location and dwelling type parameters considered second were estimated simultaneously.

4.1. First stage estimation of household choice model

The lowest level logit model (of dwelling size choice) has three alternatives, or 'options', that define the range of use rates considered, with the utility functions shown in Equations 10 through 12 below.

$$\mathrm{U}_{a,p}^{SL} = \beta_{a,p} \cdot R_p \cdot \mathrm{S}_{a,p}^{SL} + k_{a,p}^{SL} \tag{10}$$

$$\mathrm{U}_{a,p}^{SM} = \beta_{a,p} \cdot R_p \cdot \mathrm{S}_{a,p}^{SM} \tag{11}$$

$$\mathrm{U}_{a,p}^{SU} = \beta_{a,p} \cdot R_p \cdot \mathrm{S}_{a,p}^{SU} + k_{a,p}^{SU} \tag{12}$$

where:

a = index for households (PECAS *activities*)

p = index for residential space types (PECAS *puts*)

$\mathrm{U}_{a,p}^{SL}$ = utility for lowest use rate for space type p by household type a (utils/year)

$\mathrm{U}_{a,p}^{SM}$ = utility for mean use rate for space type p by household type a (utils/year)

$\mathrm{U}_{a,p}^{SU}$ = utility for highest use rate for space type p by household type a (utils/year)

$\mathrm{S}_{a,p}^{SL}$ = size for lowest use rate for space type p by household type a (m^2)

$\mathrm{S}_{a,p}^{SM}$ = size for mean use rate for space type p by household type a (m^2)

$\mathrm{S}_{a,p}^{SU}$ = size for highest use rate for space type p by household type a (m^2)

R_p = unit rent for space type p (\$/m^2-year)

$\beta_{a,p}$ = sensitivity to rent (utils/\$)

$k_{a,p}^{SL}$ = constant for lowest use rate for space type p by household type a (utils/year)

$k_{a,p}^{SU}$ = constant for highest use rate for space type p by household type a (utils/year).

The selection probabilities for these three alternatives are calculated using the standard logit form shown in Equation 13.

$$\mathrm{P}_{a,p}^{Si} = \exp\left(\mathrm{U}_{a,p}^{Si}\right) \ / \ \left[\exp\left(\mathrm{U}_{a,p}^{SL}\right) + \exp\left(\mathrm{U}_{a,p}^{SM}\right) + \exp\left(\mathrm{U}_{a,p}^{SU}\right)\right] \tag{13}$$

where:

i = index for the three alternatives, that is, $i = L, M$ and U

$\mathrm{P}_{a,p}^{Si}$ = selection probability for use rate alternative Si for space type p by household type a.

The corresponding space use rate demand curve for a given space type p by household type a is the expected value function shown in Equation 14.

$$\mathrm{S}_{a,p}^{E} = \mathrm{S}_{a,p}^{SL} \cdot \mathrm{P}_{a,p}^{SL} + \mathrm{S}_{a,p}^{SM} \cdot \mathrm{P}_{a,p}^{SM} + \mathrm{S}_{a,p}^{SU} \cdot \mathrm{P}_{a,p}^{SU} \tag{14}$$

where:

$\mathrm{S}_{a,p}^{E}$ = expected use rate for space type p by household type a (m^2).

Values for $\mathrm{S}_{a,p}^{SM}$ were calculated (as mean values) and values for $\mathrm{S}_{a,p}^{SL}$, $\mathrm{S}_{a,p}^{SU}$, $\beta_{a,p}$, $k_{a,p}^{SL}$ and $k_{a,p}^{SU}$ were estimated for for each space type p and household type a. These estimates were established by visually fitting the expected value function for each space type and household type combination to the corresponding subset of observations in the dataset of observations of household choice described above. An example of the plot of observations and the fitted function for one combination is shown in Figure 03.

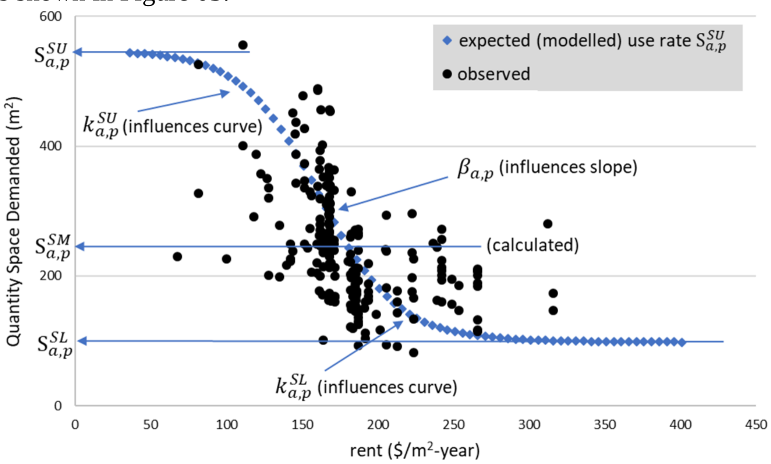

Figure 03. Example of visual fitting the expected value function providing the space use rate demand curve to the observations for a particular space type and household type combination.

In some cases, several combinations were considered together because of small sample sizes. These results are presented in Table 03. A value of -0.05 was used for $k_{a,p}^{SL}$ in all cases; using different values did not improve the fit discernably and keeping the same value seemed to establish a standardization that helped in the interpretation of the results.

Table 03. Estimated values for dwelling size choice model at lowest level of household choice model nesting structure.

Household Type (a)	Space Type (p)	$S_{a,p}^{SL}$ (m²)	$S_{a,p}^{SM}$ (m²)	$S_{a,p}^{SU}$ (m²)	$\beta_{a,p}$ (utils/$)	$k_{a,p}^{SL}$ (utils)	$k_{a,p}^{SU}$ (utils)
1p_$	SFD*e*	55	158	300	-0.000130	-0.05	6.0
	SFD*l*	80	253	300	-0.000200	-0.05	8.0
	SFA	60	134	250	-0.000300	-0.05	8.0
	MF*e*	30	100	150	-0.000250	-0.05	3.0
	MF*l*	30	76	150	-0.000250	-0.05	3.0
	MOB	100	250	550	-0.000170	-0.05	6.5
1p_$$	SFD*e*	55	159	350	-0.000130	-0.05	2.0
	SFD*l*	90	235	350	-0.000200	-0.05	9.0
	SFA	60	130	300	-0.000300	-0.05	10.0
	MF*e*	30	94	150	-0.000250	-0.05	3.0
	MF*l*	30	77	150	-0.000250	-0.05	3.0
	MOB	100	250	550	-0.000170	-0.05	6.5
1p_$$$	SFD*e*	55	169	350	-0.000125	-0.05	6.5
	SFD*l*	110	252	500	-0.000200	-0.05	13.0
	SFA	60	134	350	-0.000300	-0.05	12.0
	MF*e*	30	80	200	-0.000250	-0.05	4.0
	MF*l*	30	84	200	-0.000250	-0.05	5.0
	MOB	100	250	550	-0.000150	-0.05	7.0
2p_$	SFD*e*	60	187	400	-0.000250	-0.05	14.5
	SFD*l*	100	238	400	-0.000300	-0.05	15.0
	SFA	60	132	250	-0.000300	-0.05	8.0
	MF*e*	40	116	150	-0.000400	-0.05	4.5
	MF*l*	40	83	150	-0.000300	-0.05	4.0
	MOB	100	250	550	-0.000170	-0.05	6.5
2p_$$	SFD*e*	60	201	450	-0.000210	-0.05	14.0
	SFD*l*	100	246	450	-0.000300	-0.05	16.5
	SFA	60	148	300	-0.000250	-0.05	9.0
	MF*e*	40	85	200	-0.000370	-0.05	6.0
	MF*l*	40	91	200	-0.000250	-0.05	4.0
	MOB	100	250	550	-0.000150	-0.05	7.0
2p_$$$	SFD*e*	70	216	500	-0.000200	-0.05	14.0
	SFD*l*	120	267	550	-0.000100	-0.05	8.0
	SFA	70	160	350	-0.000250	-0.05	10.0
	MF*e*	40	130	250	-0.000320	-0.05	5.0
	MF*l*	40	101	250	-0.000250	-0.05	6.0
	MOB	100	250	550	-0.000150	-0.05	7.0
1-2s_$	SFD*e*	60	197	350	-0.000220	-0.05	11.0
	SFD*l*	100	207	350	-0.000300	-0.05	12.0
	SFA	60	131	300	-0.000280	-0.05	9.0
	MF*e*	50	169	250	-0.000400	-0.05	7.0
	MF*l*	50	90	250	-0.000240	-0.05	3.0
	MOB	100	250	550	-0.000170	-0.05	6.5
1-2s_$$	SFD*e*	60	196	400	-0.000200	-0.05	11.5
	SFD*l*	110	239	400	-0.000300	-0.05	13.5
	SFA	60	156	350	-0.000200	-0.05	8.0
	MF*e*	50	121	275	-0.000350	-0.05	7.0
	MF*l*	50	102	275	-0.000250	-0.05	5.0
	MOB	100	250	550	-0.000170	-0.05	6.5
1-2s_$$$	SFD*e*	80	226	500	-0.000100	-0.05	7.0
	SFD*l*	120	269	600	-0.000100	-0.05	8.5
	SFA	80	204	400	-0.000200	-0.05	9.0
	MF*e*	65	146	300	-0.000300	-0.05	7.0
	MF*l*	65	121	350	-0.000200	-0.05	4.0
	MOB	100	250	550	-0.000150	-0.05	7.0
3-4p_$	SFD*e*	70	185	400	-0.000150	-0.05	9.0

	SFD*l*	110	240	400	-0.000150	-0.05	7.0
	SFA	70	132	250	-0.000300	-0.05	7.5
	MF*e*	60	102	250	-0.000400	-0.05	7.5
	MF*l*	60	92	250	-0.000150	-0.05	2.0
	MOB	100	250	550	-0.000170	-0.05	6.5
3-4p_$$	SFD*e*	70	204	450	-0.000130	-0.05	8.0
	SFD*l*	120	250	450	-0.000140	-0.05	8.0
	SFA	70	137	300	-0.000220	-0.05	7.0
	MF*e*	60	131	275	-0.000400	-0.05	7.5
	MF*l*	60	94	275	-0.000150	-0.05	2.0
	MOB	100	250	550	-0.000150	-0.05	7.0
3-4p_$$$	SFD*e*	85	238	500	-0.000080	-0.05	5.5
	SFD*l*	130	278	550	-0.000090	-0.05	6.5
	SFA	85	165	350	-0.000200	-0.05	7.5
	MF*e*	85	107	300	-0.000400	-0.05	7.5
	MF*l*	85	122	350	-0.000110	-0.05	2.0
	MOB	na	na	na	na	na	na
5+p_$	SFD*e*	80	189	400	-0.000150	-0.05	8.0
	SFD*l*	140	252	400	-0.000200	-0.05	8.0
	SFA	80	129	300	-0.000180	-0.05	5.0
	MF*e*	na	na	na	na	na	na
	MF*l*	na	na	na	na	na	na
	MOB	100	250	550	-0.000170	-0.05	6.5
5+p_$$	SFD*e*	80	220	500	-0.000120	-0.05	8.0
	SFD*l*	140	273	500	-0.000180	-0.05	10.5
	SFA	80	147	350	-0.000170	-0.05	6.0
	MF*e*	na	na	na	na	na	na
	MF*l*	na	na	na	na	na	na
	MOB	100	250	550	-0.000150	-0.05	7.0
5+p_$$$	SFD*e*	100	253	550	-0.000090	-0.05	6.5
	SFD*l*	150	319	600	-0.000100	-0.05	7.5
	SFA	100	199	400	-0.000170	-0.05	6.0
	MF*e*	na	na	na	na	na	na
	MF*l*	na	na	na	na	na	na
	MOB	na	na	na	na	na	na

Note: 'na' = the household type does not select the dwelling type

The values for $\beta_{a,p}$ indicate the sensitivity to rent reduces (moves towards 0) and the values for $S^{SL}_{a,p}$, $S^{SL}_{a,p}$ and $S^{SL}_{a,p}$ indicate the size range increases and shifts higher (moves away from 0) as:

- Household income increases;
- Household size (number of persons) increases, mostly;
- Dwelling density decreases, to some extent; and
- Dwelling quality improves, to some extent.

4.2. Second stage estimation of household choice model

The utility function for the upper level choices of location and dwelling type considered in the second stage of estimation is shown in Equation 15.

$$U^{LT}_{a,p,l} = \phi \cdot CU^{S}_{a,p,l} + \gamma \cdot CU^{NS}_{a,l} + \eta_r \cdot X^r_l + \eta_j \cdot X^j_l + \eta_g \cdot X^g_l + \eta_i \cdot X^i_l + k^{TS}_p + \eta_q \cdot Q^S_{p,l} + k^{SL}_v \qquad (15)$$

where:

a = index for households (PECAS *activities*)

v = index for intra-metropolitan regions, each of which is a set of LUZ as shown in Figure 04

$U^{LT}_{a,p,l}$ = utility for space type p for household type a in LUZ l (utils/year)

$CU^{S}_{a,p,l}$ = composite utility for range of space use rates for space type p for household type a in LUZ l (utils/year)

ϕ = sensitivity to composite utility for range of space use rates (utils/util)

$CU^{NS}_{a,l}$ = composite utility for the non-space components of the *technologies* available to household type a in LUZ l

γ = sensitivity to composite utility for non-space components of *technologies* (utils/util)
X_l^r = crime rate in LUZ l (incidents/household-year)
X_l^j = school quality in LUZ l (honours/student)
X_l^g = proportion green space in LUZ l (area/area)
X_l^i = proportion low income in LUZ l (households/household)
η_r = sensitivity to crime rate (utils/incidents/household)
η_j = sensitivity to school quality (utils/honours-year/student)
η_g = sensitivity to proportion green space (utils/year)
η_l = sensitivity to low income (utils/incidents/household)
k_p^{TS} = utility constant for space type p, one for each of the six space types considered (utils/year)
$Q_{p,l}^S$ = proportion of model-wide space of type p contained in LUZ l (area/area)
η_q = sensitivity to proportion of model-wide space (utils/year)
k_v^{SL} = utility constant for locations in intra-metropolitan region v (utils/year).

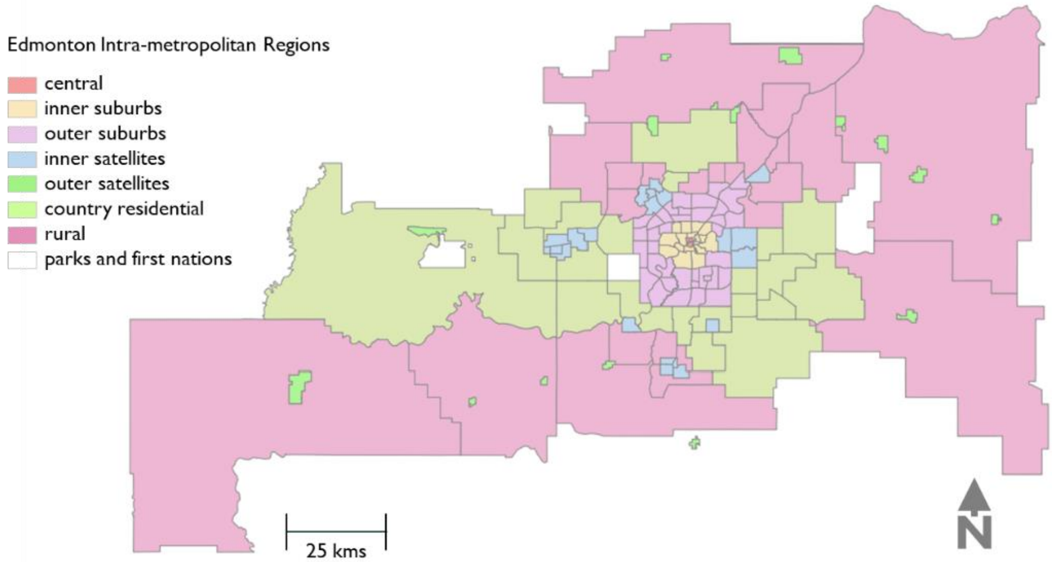

Figure 04. Map showing the definitions of the intra-metropolitan regions considered in the household choice model.

The composite utility term $CU_{a,l}^{NS}$ for the non-space components of *technologies* for households is included in Equation 15 because the $CU_{a,p,l}^{S}$ term in Equation 15 covers only the residential space *puts* in the *technologies* available to households. Both the space and the non-space components are required for consistency with the PECAS Framework, specifically, for the full representation of the $CU_{a,l}^{T}$ term in Equation 02.

Values for the parameters in Equation 15 were estimated (in a second stage, but simultaneously across the nesting levels included in this second stage) using the maximum likelihood procedure in the ALOGIT software (Daly, undated) with the full dataset of just over 21,000 observations of location and dwelling type choice described above. Observations of choice behavior were developed by combining each observed choice with a set of 20 unchosen LUZ alternatives selected randomly with uniform probability together with the full subset of space type alternatives in each of these LUZ. This draws on the property that the ALOGIT maximum likelihood estimators with the standard logit form are unbiased (McFadden, 1978). The form considered here is nested logit, not standard logit, but the full set of space type and size alternatives on the lower levels are always included so that the unbiased property should still apply.

Values for crime rate in LUZs were calculated using the numbers of reported violent crimes and the rates of these crimes per household available from municipal police force and RCMP websites (Edmonton Police Service, 2018) and from Statistics Canada (Statistics Canada, 2016). Values for multiple years between 2011 and 2014 were calculated for zones where suitable crime and household counts were available, and these values were used to determine average annual values for these zones. Some zones with very small populations appeared to be outliers because of issues with sample error and these were set to province-wide average values. Values for school quality in LUZs were calculated using the proportions of students achieving an excellence ranking in province-wide standardized achievement tests for the years 2011 to 2015 from the Alberta Department of Education website (Alberta Government, 2011). The value for a zone is the average for all the schools in the zone weighted by the official (on 30 Sept) enrolment at each school. At this point there is no ASET Model component specified for providing endogenous values for crime rate or school quality. Without such a component, values for crime rate and school quality for any future years considered with the ASET Model will have to be determined exogenously.

Values for the proportion of green space were calculated using the areas of parcels designated to be "parkland" or "greenspace" in the Municipal Affairs Assessment Data (Alberta Municipal Affairs, 2013), rather than merely vacant land or undeveloped open land, forest or scrub bush. This is included in the ASET Model parcel database and is a potential development type considered in the capital investment simulation in the SD Module, which means these values are determined by the ASET Model endogenously for future years. Values for proportion low income in LUZs were calculated using the numbers of households in the appropriate categories in the ASET Model. The value of $60,000 was respected in the definitions of the ASET household categories in order to facilitate this calculation. As a consequence, values for proportion low income are determined endogenously for future years.

The composite utility values for the space type alternatives in each LUZ were calculated using the log-sum equation for the dwelling size choice model shown in Equation 07 above, using the parameter estimates established in the first stage of the two-stage estimation process as described above.

The use of a two-stage estimation process overall means that the standard errors for these estimates obtained in the second stage are biased downwards (Ben-Akiva and Lerman, 1985), which needs to be taken into account in the interpretation of the estimation results.

The estimation results are presented in Table 04. These results were obtained after multiple estimation runs where different combinations of the parameters for different groups of households and dwelling types were included in the utility function.

In general, the overall fit of the model is acceptable, as indicated by the value of 0.1458 for $\rho^2(0)$. The results for the parameters all have signs (positive or negative) consistent with expectations. The two structural parameters are both within the required 0 to 1 range, the structural parameter being the ratio of the upper level dispersion parameter over the lower level dispersion parameter provided by ALOGIT. The value for γ is also within the 0 to 1 range. This provides empirical support for the nesting structure of the AA Module, where location utility includes the composite utility for the range of available technologies that in turn includes the weighted sums of the accessibilities for the puts. An acceptable (positive) value for the sensitivity to proportion low income, η_l, could not be obtained with acceptable values for various other estimates, so it was fixed at 0 (and thereby effectively removed from the model).

The intra-metropolitan sector constants provide some representation of the higher correlations among nearby locations in existing settlement patterns. But the value for η_q is significantly less than 1, which suggests the dwelling choices within zones are more highly correlated because of additional factors not represented explicitly in the utility functions.

Table 04. Estimation results for household location and space type choice model (second stage).

Parameter	Parameter Description	Household Categories (see Note below)		Estimated Value	| t -ratio |
η_r	sensitivity to crime rate	high		-0.0231	6.0
η_j	sensitivity to school quality	high		0.0167	9.0
η_g	sensitivity to proportion green space	high		0.0612	24.9
η_l	sensitivity to proportion low income	high	*fixed*	0	
k_p^{TS}	constant for SFD*e*	high	*fixed*	0	
k_p^{TS}	constant for SFD*l*	high		-0.4673	21.4
k_p^{TS}	constant for SFA	high		-0.9668	34.4
k_p^{TS}	constant for MF*e*	high		-3.022	64.9
k_p^{TS}	constant for MF*l*	high		-1.497	40.2
k_p^{TS}	constant for MOB	high		-2.298	27.3
k_p^{TS}	constant for SFD*e*	low	*fixed*	0	
k_p^{TS}	constant for SFD*l*	low		-1.374	21.5
k_p^{TS}	constant for SFA	low		-0.4027	9.8
k_p^{TS}	constant for MF*e*	low		-0.8524	23.0
k_p^{TS}	constant for MF*l*	low		-0.7807	17.2
k_p^{TS}	constant for MOB	low		-1.042	11.8
k_p^{TS}	constant for SFD*e*	low	*fixed*	0	
k_v^{SL}	constant for location in central region	low		7.092	14.9
k_v^{SL}	constant for location in inner suburbs region	low		4.237	22.9
k_v^{SL}	constant for location in outer suburbs region	low		2.956	16.2
k_v^{SL}	constant for location in inner satellite region	low		1.891	10.0
k_v^{SL}	constant for location in outer satellite region	low		0.739	3.1
k_v^{SL}	constant for location in country residential region	low		2.063	9.8
k_v^{SL}	constant for location in rural region	low	*fixed*	0	
γ	sensitivity to non-space technology composite utility	all		0.0327	5.2
η_q	sensitivity to proportion of model-wide space	all		0.4100	59.2
ϕ	nesting structural parameter	all		0.1624	26.9
λ	nesting structural parameter	all		0.6675	68.1

Note: 'low' = those households with annual income less than $\$60 \cdot 10^3$, CAD-2011; 'high' = all other households; 'all' = all households

fit statistic	value
Number of observation	21,626
Likelihood with 0 coefficients	-104,589.4
Likelihood with constants only	
Initial value of likelihood	-89,830.8
Final value of likelihood	-89,344.9
$\rho^2(0)$	0.1458

5. Supply Side: Residential Development Choice Model

The nesting structure for the residential development choice model is shown in Figure 05. Residential development choice is part of the PECAS development choice included in the capital investment represented in the SD Module.

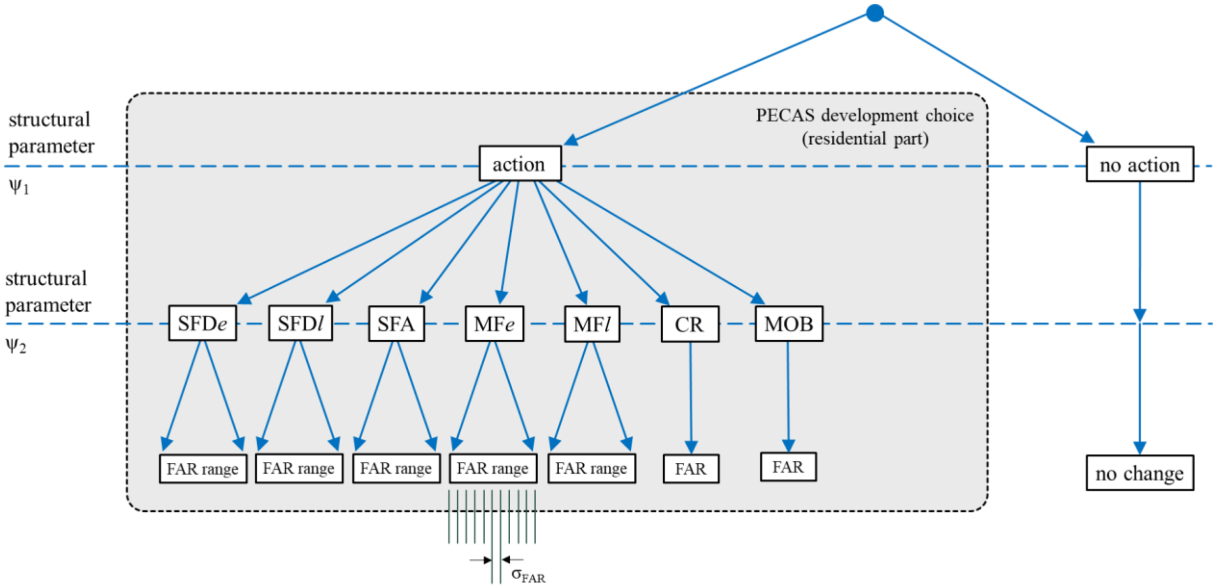

Figure 05. Nesting structure for residential developer choice model: The residential space types and ranges of intensities (FAR values) included here are only a portion of the full set of space types and their associated ranges considered by developers model-wide. But parcel-level zoning establishes the set of types and intensities permitted and thus available for a given parcel in a given year. Zoning often restricts the alternatives to either (a) just residential, or even a sub-set of residential (which is covered here) or (b) just some range of non-residential (which is not covered here). Intensity is a continuous variable in PECAS, as indicated in Equations 07 through 09 above. The estimations were done using a discrete approximation with small intervals of FAR, each with a width of δ_{FAR}. The figure shows these intervals for just space type MF*e*, but these apply for all space types with an available FAR range. They are omitted from the figure merely for clarity of presentation. The CR and MOB space types each a single FAR value available; for CR the intensity was very low by definition, and for MOB the manufactured unit came in a standard size such that the selection of an intensity was not relevant and the number of observations was too small to facilitate any expanded consideration. Each of the two structural parameters is the coefficient factoring the composite utility (or 'log-sum') for the lower level nest of alternatives when it is added into the utility function for the corresponding upper level alternative, which in each case is the ratio of the utility scale parameter for the upper level logit model over the utility scale parameter for the corresponding lower level logit model at that point.

The utility function for the residential development choice model is shown in Equations 16 and 17.

$$\mathrm{U}_{p,x}^{D}(f) = \alpha \cdot [\,\mathrm{NR}_{p,x}(f)\,/\,L\,] + \mathrm{DSF}_p(f) + M_g + M_p + M_\delta \cdot \delta_{FAR,p} \qquad (16)$$

with:

$$\mathrm{NR}_{p,x}(f) = \left[R_{p,x} - \mathrm{J}_p^{c1}(f)\right] \cdot f \cdot L - i \cdot \left\{(\mathrm{J}_{p,x}^{c2} + \mathrm{J}_{p,x}^{c3}(f)) \cdot f \cdot L + \mathrm{J}_x^{c4}\right\} \qquad (17)$$

where:

$\mathrm{U}_{p,x}^{D}(f)$ = developer utility (per unit land) for establishing *put p* on *parcel x* at intensity *f* (utils/year)
α = sensitivity to net financial return (utils/$)
$\mathrm{NR}_{p,x}(f)$ = net financial return per unit land for establishing *put p* on *parcel x* ($/year)
$\mathrm{DSF}_p(f)$ = additional utility per unit land (beyond the component arising with $\mathrm{NR}_{p,x}(f)$) for establishing *put p* on *parcel x* at intensity *f* (utils/year)
M_g = additional utility when parcel is greenfield site (utils/year)

M_p = alternative specific constants for *put p* on *parcel x* (utils/year)
$\delta_{FAR,p}$ = width of FAR interval used for set of adjacent discrete intervals used to approximate continuous range of FAR values for residential space type p (m^2/m^2)
M_δ = sensitivity to size of FAR interval used for different residential space types p (utils)
$J_p^{c1}(f)$ = maintenance costs per unit space per year for residential space type p at intensity f ($\$/m^2$-year)
$J_{p,x}^{c2}$ = initial development fees per unit space for residential space type p on parcel x ($\$/m^2$-year)
$J_{p,x}^{c3}(f)$ = construction costs per unit space for residential space type p at intensity f on parcel x ($\$/m^2$)
J_x^{c4} = site preparation costs for parcel x independent of space type and intensity ($)
i = interest rate, as the on-going cost of financial capital per year, set at 0.05 in this analysis.

The financial net return component, $\mathrm{NR}_{p,x}(f)$, is directly applicable in an investment analysis where the developer is considering rental of the resulting dwelling space to tenants. It is also applicable, at least implicitly, from the perspective of imputed rents associated with owner-occupied dwellings, and also more directly in terms of the related opportunity costs. The sensitivity parameter α provides for an empirically-established adjustment of the effect of this component across different dwelling types and developers with different tendencies *vis-à-vis* the perspectives of landlords, tenants, investors and owners. Cost rates were established for all land parcels province-wide: maintenance costs, construction cost and development fees were extracted from municipality websites and construction company websites and from information databases maintained by Alberta Transportation.

The density shaping function, $\mathrm{DSF}_p(f)$, was implemented using a piecewise linear form with three sections, the first starting at *f*=0. This form is shown in Equation 18, and an example is shown in Figure 06. The approach in estimation was to consider predefined break points and establish the estimates for the slope parameters simultaneously with the estimates for the rest of the parameters.

$$DSF_p(f) = \theta_{1,p} \cdot FARsection_{1,p} + \theta_{2,p} \cdot FARsection_{2,p} + \theta_{3,p} \cdot FARsection_{3,p} \qquad (18)$$

with

$$FARsection_{1,p} = \begin{cases} f, & for: \quad f < BP_{1-2,p} \\ BP_{1-2,p}, & for: \quad f \geq BP_{1-2,p} \end{cases}$$

$$FARsection_{2,p} = \begin{cases} 0, & for: \quad f < BP_{1-2,p} \\ f - BP_{1-2,p}, & for: \quad BP_{1-2,p} \leq f < BP_{2-3,p} \\ BP_{2-3,p} - BP_{1-2,p}, & for: \quad f \geq BP_{2-3,p} \end{cases}$$

$$FARsection_{3,p} = \begin{cases} 0, & for: \quad f < BP_{1-2,p} \\ 0, & for: \quad f < BP_{2-3,p} \\ f - BP_{2-3,p}, & for: \quad f \geq BP_{2-3,p} \end{cases}$$

where:
$BP_{1-2,p}$ = break point between the first and second sections for f for residential space type p
$BP_{2-3,p}$ = break point between the second and third sections for f for residential space type p
$\theta_{1,p}$ = slope for first section for f for residential space type p
$\theta_{2,p}$ = slope for second section for f for residential space type p
$\theta_{3,p}$ = slope for third section for f for residential space type p.

Almost 110,000 observations of individual development actions across Alberta from 2011 to 2016 were developed using the province-wide property assessment database, which included information on the year built for each structure. In order to provide observations where 'no action' is selected, a further just over 100,000 cases where no development occurred in a specific year were identified randomly with uniform probability and added to the dataset. The resulting proportion of observations where 'no action' is selected is arbitrary, which impinges on the estimated value for its alternative specific constant obtained with the dataset. An appropriate value for this constant is established as part of the aggregate calibration of the model (Weidner *et al*, 2007; Abraham, 2014).

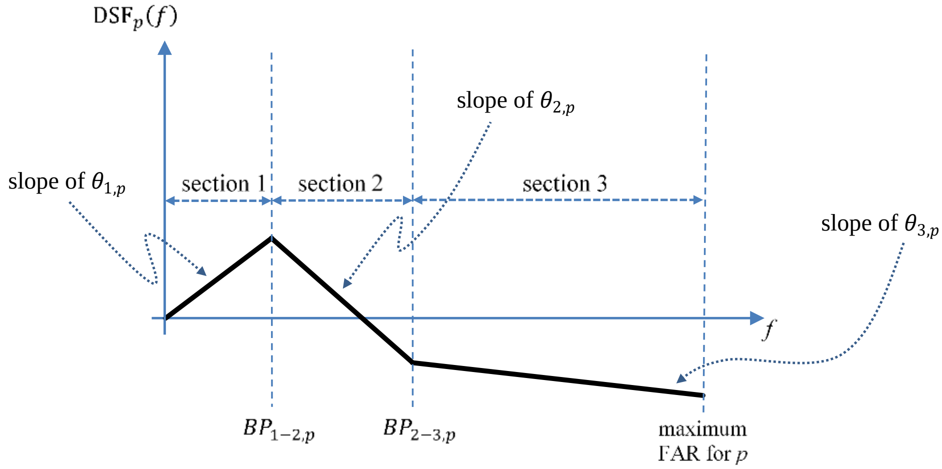

Figure 06: Example of density shaping function: It is piecewise linear with three sections. The first section begins at f=0, and the two break points between sections are at $BP_{1\text{-}2}$ and $BP_{2\text{-}3}$, the first for the break from section 1 to section 2 and the second for the break from section 2 to section 3. Each section has a linear (constant) slope, θ_1, θ_2 and θ_3 for sections 1, 2 and 3 respectively.

As an approximation to facilitate the application of available estimation software, the continuous range of possible FAR development intensities was considered as a set of adjacent discrete intervals, ranging from as few as 10 to as many as 100 such intervals in different estimation runs. The results reported here are for the case where the number is 10.

The permitted residential space types and intensities (or densities) for each parcel and their variation over time form one of the key policy inputs to the SD Module. Establishing these for the more than 350 municipalities across Alberta was one of the major tasks of model development, with further work on improvements expected to continue. Each municipality must submit its plans for future land use to the Alberta Government for review and approval, with indications of the permitted buildings and development intensities included. But no rigorous consistency is required and no central repository of this information is maintained, so various websites and wide-ranging forms of submission materials had to be consulted. The refinement of this information continues as the project progresses. The initial focus was on the permissions in place over the period 2001 to 2015 for two reasons: (a) past permissions are reported in the data directly, and (b) this information was needed to establish the sets of available alternatives in the disaggregate observations of development activity used in the estimations described here.

The parameters for the utility function were estimated using the ALOGIT software. The resulting estimated parameters and corresponding fit statistics are shown in Table 05. These results were obtained after multiple estimation runs where different combinations of the parameters for different groups of dwelling types and FAR intervals were included in the utility function.

In general the overall fit of the model is acceptable, as indicated by values of 0.3211 for $\rho^2(0)$ and 0.1191 for $\rho^2(C)$. The results for the parameters all have signs (positive or negative) consistent with expectations. Both of the two structural parameters are within the required 0 to 1 range. The value for M_δ is large and significant, indicating the need to correct for the differences in FAR intervals used for different residential space types.

The results for the slope parameters in density shaping functions indicate these functions play important roles and therefore need to be included in this context at least. As explained above, the alternative specific constant for the ‘no change’ option is considered as part of the aggregate calibration of the SD Module.

Acceptable estimates for the parameters for the manufactured home alternative (MOB) could not be established. The sample contained relatively few observations where this was selected by the developer, and the indication of the size of dwelling for this type in the assessment data was limited, often to just ‘single-unit’ or ‘double-unit’ designations (consistent with the commonly used form of tax assessment for this type). Values for the alternative specific constant for the MOB option without a specific size are established as part of the aggregate calibration of the SD Module. (Hill and Abraham, 2014; Hill, 2017).

Table 05. Estimation results for residential space developer choice model.

Parameter	Parameter Description		Estimated Value	| t -ratio |
α	sensitivity to non-space technology composite utility		0.0123	44.3
M_g	constant for greenfield site		5.9549	14.2
	constant for 'no action'	*fixed*	0	
k_p^{TS}	constant for SFD*e*		-8.7658	18.6
k_p^{TS}	constant for SFD*l*		-10.0317	21.0
k_p^{TS}	constant for SFA		-16.6516	22.7
k_p^{TS}	constant for MF*e* and for MF*l*	*estimated jointly*	-7.2838	15.8
k_p^{TS}	constant for CR		-2.298	14.2
$\theta_{1,p}$	slope for section 1 of DSF for SFD*e*		-22.4554	54.4
$\theta_{2,p}$	slope for section 2 of DSF for SFD*e*		0.27323	9.4
$\theta_{3,p}$	slope for section 3 of DSF for SFD*e*		-23.5645	61.6
$\theta_{1,p}$	slope for section 1 of DSF for SFD*l*		2.3008	5.1
$\theta_{2,p}$	slope for section 2 of DSF for SFD*l*		3.2535	78.1
$\theta_{3,p}$	slope for section 3 of DSF for SFD*l*		-16.0392	46.2
$\theta_{1,p}$	slope for section 1 of DSF for SFA		1.5144	36.8
$\theta_{2,p}$	slope for section 2 of DSF for SFA		-3.2072	41.9
$\theta_{3,p}$	slope for section 3 of DSF for SFA		-3.2278	87.4
$\theta_{1,p}$	slope for section 1 of DSF for MF*e* and for MF*l*	*estimated jointly*	5.4859	13.6
$\theta_{2,p}$	slope for section 2 of DSF for MF*e* and for MF*l*	*estimated jointly*	-1.0247	4.3
$\theta_{3,p}$	slope for section 3 of DSF for MF*e* and for MF*l*	*estimated jointly*	-3.0411	22.8
M_δ	sensitivity to size of FAR interval		24.2041	15.2
Ψ_1	nesting structural parameter		0.4979	34.3
Ψ_2	nesting structural parameter		0.8082	19.8

fit statistic	value
Number of observation	210,992
Likelihood with 0 coefficients	-313,435.0
Likelihood with constants only	-241,577.4
Initial value of likelihood	-313,342.0
Final value of likelihood	-212,807.6
$\rho^2(0)$	0.3211
$\rho^2(C)$	0.1191

The resulting DSF arising with the estimated slopes and the selected break points are shown in Figure 07.

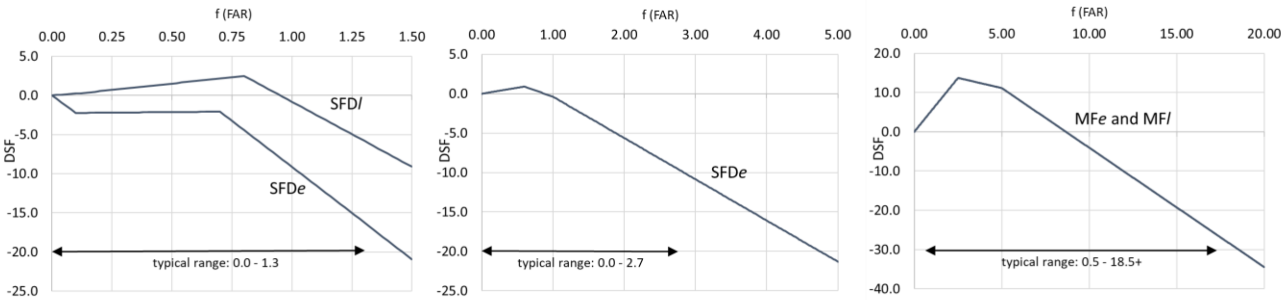

Figure 07: Density shaping functions arising from the estimated values for the slopes between the break points for the residential space types.

The DSF all exhibit the same general shape, indicating that the developer choice utility function with the net financial return term in Equation 16 and 17 on its own (without the DSF) tends to do a comparatively reasonable job of representing development utilities over the lower range of intensities but requires substantial and increasing reductions in utility over the upper range of intensities for all space types. This suggests that Equations 16 and 17 on their own, and the net financial return term in particular, struggle to represent the extent that costs and other difficulties increase with increasing intensities toward the high end of the range. The DSF for the multi-family types, MF*e* and MF*l*, is some different from the others in that it has higher values over the lower range of intensities, providing a further indication that Equations 16 and 17 also struggle to represent the attractiveness of intensities over this lower range for these space types in particular.

6. Conclusions

The choice models with estimated parameters presented here have been used to extend the representation of housing markets in the ASET Model. The PECAS Framework does not require choice models at this level of detail. Models covering larger subsets of households and including fewer factors can be used. But PECAS provides a system where more detailed models can be used and their indications interpreted and integrated within a larger simulation and analysis context. The work reported here demonstrates how such more detailed models can be developed and how they 'connect' with PECAS.

On the demand side, the model of household choice of location, dwelling type and dwelling size – including its structure and its estimated parameters – demonstrates how these three facets of demand can be considered jointly, and for a range of factors with influences represented explicitly. The behaviour of 15 different household categories regarding the trade-offs to be made among rent, dwelling size, neighbourhood quality (in terms of crime rates, school quality and proportion green space), accessibilities to non-space inputs and outputs (including labour, goods and services), dwelling type and quality and development pattern (as intra-metropolitan region) can all be explored, building on similar work reported previously in the literature.

The estimation results for the structural parameters for the model of household choice supported the nesting structure regarding activity location, technology and put exchange location used in PECAS. Others have reported estimation results supporting an alternative nesting structure, with dwelling type above and space type below (Habib and Kockelman, 2008). But this other work did not include space quantity or the development pattern regions or neighbourhood quality indices considered here. The size of the zones defining locations may also have been different. These differences could alter the structure of the utility function error terms enough to alter the appropriateness of nesting structures.

Intra-metropolitan sector constants are included in the household choice model in order to provide some representation of the higher correlations among nearby locations in existing settlement patterns. Using this representation in forecasting requires some specific assumptions about the future patterns. A useful extension would be an explicit treatment of the spatial auto-correlation present in the representation of the choice among locations based on a distance measure that will not require such specific assumptions.

On the supply side, the model of residential development choice of residential space type and intensity – including its structure and its estimated parameters – demonstrates how development behaviour can be considered for both (a) explicit financial elements (*pro forma*) and (b) other attributes and constants (and density shaping functions) with impacts beyond those associated with the explicit financial elements as represented. The behaviour of residential developers responding to rents, initial and on-going costs, space types and the associated project risks, and other aspects related to intensity can all be explored. This sort of empirical analysis of space development behaviour using choice models has received little attention in the literature. The results obtained here suggest this would be a promising direction for further work.

In the residential development choice model, a single parameter is used to represent the impacts of the specific conditions arising with greenfield sites. A large portion of residential development in Alberta occurs on large greenfield sites, and the tradeoffs among the "infill" and "edge" alternatives is one of the ongoing issues in planning (as it is in many places). It is felt that an important improvement as part of further work on the ASET Model would be to add representation of the economies of scale at larger sites that include multiple adjacent parcels and of the servicing costs as part of site preparation. This would help make the model a more relevant and useful tool in this context.

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