Modeling Urban Dynamics using LUTI Models: Calibration Methodology for the Tranus-Based Model of the Grenoble Urban Region

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MODELING URBAN DYNAMICS USING LUTI MODELS: CALIBRATION METHODOLOGY FOR THE TRANUS-BASED MODEL OF THE GRENOBLE URBAN REGION

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ABSTRACT

This paper describes the calibration process of a land use and transport integrated (LUTI) Tranus based model of the urban agglomeration of Grenoble (France). In particular, for several parameters related to floor-space, we applied a *semi-automatic* process for calibration. We begin with an overview of the model's structure and next we define data and calibration methodology of the land use part. Further, we describe and place in the public domain the algorithms and methodologies that we developed. We are particularly interested in demand functions for housing and "substitution" functions that capture the trade-offs that households make between housing type and price. We created tools based on non-linear optimization and curve fitting that make calibration easier, more robust, faster than typical manual approach and transferable to other study areas. Finally, we discuss the trade-off between over-fitting and minimizing error in predictions of the observed data on housing consumption.

Keywords: (LUTI, Tranus, Calibration, Housing modelling, Simulation)

1. INTRODUCTION

LUTI models represent a privileged tool to support the urban and transport planning decisional process. Nevertheless, these models are still not widely used by local authorities and urban planning actors, because of calibration and validation complexity and consequently limited confidence in LUTI results. The Tranus based model for the urban region of Grenoble (TGM) was implemented in the field of the research project CITIES[1], promoted by French National Research Agency (ANR) and in collaboration with the Grenoble Urban Agency[2] (AURG). With the aim of testing operational potentialities of LUTI, developing efficient calibration and validation methodologies, making LUTI models easier to implement and increase confidence in their results. Researchers involved in the CITIES project produced several contributions about LUTI calibration and validation, describing most common approaches and strategies (Coulombel, et al., 2015) and developing methodologies and tools for automatic and simultaneous estimation of some endogenous parameters of a Tranus based model (*shadow prices*) (de la Barra, 1989; Batty, 1976), using an optimization problem (Capelle, et al., 2017). We present an application of the optimisation algorithm exposed in (Capelle, et al., 2017) (see paragraph 3), executed in addition to classical *trial and errors* methodology and contributing to calibrate the land use part of the TGM. A *semi-automatic* process was also defined to estimate and calibrate substitution's model penalties, coupled with an optimization framework for the calibration of *shadow prices*.

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[1] CITiES (*Calibration and valIdation of Transport – land usE ModelS*) is a reseach project funded by the French Research Funding Agency (ANR). It is associated to its program "Numerical Model".
[2] Agence d'Urbanisme de la Région Grenobloise - AURG

2. STRUCTURE OF THE TRANUS BASED MODEL OF GRENOBLE URBAN REGION

The TGM base scenario refers to 2010 and to the perimeter considered by the SCOT[3] planning document of the Urban Region of Grenoble. Zoning refers to IRIS[4] size, including 127 internal zones and 14 external zones and considering seven population categories, eight economic activity sectors and two types of housing (houses and apartments). Structure of the *PTV_Visum* transport model of AURG was transferred to the TGM[5] (transport demand categories, transport network, public transport supply characteristics, population categories, etc.) to facilitate operational application and transfer to AURG professionals. In particular, the model refers to the morning peak hour (7:00 - 8:00) of a generic midweek day and includes 12 different transport modes (operators), 40 different types of link, the whole public transport supply at 2010 for the study area (PT routes, stops, frequencies, capacity, etc.) and eleven transport demand categories (trip motifs imported from the AURG transport model[6]).

2.1 Population Sectors

Five socio-professional categories (*Active*, *Partially Active*, *University Students*, *Inactive*, *Retired*[7]) and two scholar categories (*Primary* and *Secondary school Students*[8]), are considered in the TGM, each of them associated to one or more transport demand categories (trip motifs). Population was allocated to TGM zones separately for each population sector, using the variable *ipondi* (survey expansion factors) from INSEE detailed individuals database[9]. *Ac* and *PAc* sectors provide labour to employment sectors, having both endogenous and exogenous components (workers who reside in the study area work outside the study area). They also "consume" *Administration* (*Ad*), *Health and Social action* (*PAHS*) and *Commerce, Transport, and various Services* (*CTS*) sectors and residential housing floor-space. *PSt* and *SSt* are entirely exogenous and *non-transportable* sectors (see paragraph 2.4), consuming respectively *Primary* and *Secondary school employment* (teachers) (*PEm*; *SEm*). The *University Students* (*USt*) sector is entirely exogenous and non-transportable, and "consumes" *University employment* (teachers) (*UEm*), *PAHS* and *CTS* sectors and residential housing floor-space. *In* and *Re* sectors are exogenous sectors. Their members are neither employed nor dependents of another population sector, and consume *PAHS* and *CTS* sectors and residential housing floor-space.

2.2 Activity Sectors

The TGM includes three base sectors *Agriculture* (*A*), *Industry* (*I*) and *Construction* (*C*), which are entirely exogenous and consume only labour: their products are not consumed by any sector nor are the products exported. *CTS* is an induced and partially endogenous sector that consumes only labour. Some but not all of its goods and services are consumed by the study area's population sectors. *PAHS*

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[3] *Schéma de Cohérence Territoriale de la Région Grenobloise* (Territorial Coherence Scheme of the Grenoble Region – SCOT)

[4] The French Institute of Statistics and Economic Studies (INSEE) divides the territory into homogeneous meshes called IRIS ("*Ilots Regroupés pour l'Information Statistique*": grouped blocks by statistical information): an elementary mesh includes 2000 inhabitants. For municipalities of less than 10,000 inhabitants and for most municipalities between 5,000 and 10,000 inhabitants, the IRIS corresponds to the entire municipal area.

[5] TGM transport network is actually a simplified and optimized version of the *PTV_Visum* transport model network, with significant reduced number of links and nodes while maintaining unchanged the general structure.

[6] Eleven transport demand categories (trip motifs) were defined, of which four are totally exogenous (Trucks, External Public Transport, External private cars, Visit: counted trough an external OD matrix), two partially exogenous (Health, Work: induced and associated to an external OD matrix) and five completely induced by the model (Purchase, Leisure activities, Primary school, Secondary school, University).

[7] *Active*: *Ac*; *Partially Active*: *PAc*; *University Students*: *USt*; *Inactive*: *In*; *Retired*: *Re*.

[8] *Primary school Students*: *PSt*; *Secondary school Students*: *SSt*.

[9] The INSEE « *Individuals located at Township-or-Town at IRIS*» database for 2010 (*FD_INDCVIZD_2010*) was used to allocate population to TGM zones.

is an induced and entirely endogenous sector, that consume only labour. Some but not all of its goods and services are consumed by the study area's population sectors. *PEm*, *SEm* and *UEm* sectors are entirely endogenous and consumed exclusively by respectively: *PSt*, *SSt* and *USt*. Two INSEE databases were used to estimate employment data for the base scenario: CLAP[10] provides total employment by IRIS; SIRENE®[11] is a registry of French companies and economic establishments (including government entities and foreign companies), providing each establishment's principal activity, location, and number of employees[12]. More specifically, total number of employees from CLAP, were redistributed to TGM zones in function of a proportion of employees by principal activity and by zone estimated from SIRENE®.

2.3 Housing: residential floor-space sectors

The TGM considers two residential floor-space typologies (*Houses* and *Apartments*), which may be *small*, *medium*, or *large*[13]. The size classifications are the same as those used in INSEE's *SURF* variable (reported in *FD_INDCVIZD_2010* db)[14]. Data of floor-space consumption by housing type, size and zone for the base scenario comes from the MAJIC[15] database. To assure consistency between MAJIC data and population allocation in the study area (obtained from INSEE), extracted total number of houses and apartments (and consequently total available floor-space) by zone *i* were adjusted in order to match total number of households living in zone *i* (keeping unchanged final total values of residential housing units in the study area)[16]. In general, for all housing types *n*, average unit size must be greater than or equal to the adjusted minimum (observed minimum minus one square meter) and less than or equal to the observed maximum for the study area, to ensure that floor-space consumption is consistent with housing demand functions estimation (see paragraph 2.5).

2.4 Intersectoral demand relationships

A series of demand functions and intersectoral coefficients are defined in Tranus to estimate the *input* quantity that a production unit of a generic sector *n* requires from another generic sector *m*. Such demand functions allow simulating interactions between sectors and "Inter-Sectors" coefficients correspond to the technical coefficients of an *input/output* model (Leontief, 1941). Demand functions related to *transportable* sectors (whose production is demanded even outside the production area) are fixed, while for *non-transportable* sectors (whose production is consumed only in the production zone) are elastic, and describe consumption variation in function of price variation (see equation (1) for typical form of demand function in Tranus)[17].

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[10] *Connaissance Locale de l'Appareil Productif* (Local knowledge of the productive apparatus).

[11] *Système informatique pour le répertoire des entreprises et de leurs établissements* (Informatic system for the directory of enterprises and their establishments).

[12] Each establishment's number of employees is reported in the SIRENE® database with two variables: *EFETCENT* (*Salaried staff of the establishment in hundreds*) and *TEFET* (*Slice of salaried staff of the establishment*). AURG created a variant of *TEFET*, labeled *TEFET-ESTI*, which replaces INSEE's intervals (tranches) with point estimations. *TEFET-ESTI* was used to estimate employment at place of work.

[13] Three housing sectors (Large Apartments, Medium and Large Houses) were also divided in two more sectors related to urban zones (T1) and rural zones (T2) to better reproduce real estate dynamics in the study area. In total the TGM model counts nine residential floor space sectors.

[14] *Small*: less than 40 m2; *Medium*: from 40 m2 to less than 100 m2; *Large*: 100 m2 or greater.

[15] *Mise A Jour des Informations Cadastrales* (Update of Cadastral Information): Includes information on both built and not built properties. The information is declarative and comes from Property Taxes.

[16] Adjusted number of houses and apartments by zone *i* were estimated by calculating a series of weighted averages related to each housing type *n*, in function of total number of households living in zone *i*. Adjusted values of housing units by type *n* were then multiplied by MAJIC average size housing unit type *n*, to obtain available floor space surface by housing type *n* (used as entry data for the base scenario of the TGM model).

[17] In equation (1) a_i^{mn} is the amount of production of sector n demanded by a unit of sector m in zone i, $\min^{mn}$ and $\max^{mn}$ are the minimum and maximum amount of n required by a unit production of m, δ^{mn} is an elasticity parameter of m with respect to the cost of input n and U_i^n represents consumption disutility of n in i (including

$$a_i^{mn} = min^{mn} + (max^{mn} - min^{mn}) * exp(-\delta^{mn} U_i^n) \quad (1)$$

In this paper we focus on elastic demand functions estimated to describe residential housing (*non-transportable* sectors) consumption in the study area.

2.5 Demands for residential floor-space

In terms of floor-space equation (1) represents demand for housing[18], with consumption disutility measured in terms of monthly equivalent rental price (P_i^n [€/m^2]) (see paragraph 2.6).
Initial ${min_0}^n$ and ${max_0}^n$ parameters by housing type n were inferred from *DVF*[19]data on real estate transactions at 2010 in the study area[20]. Extracted data were filtered to remove houses and apartments having implausibly small size or extremely small or large prices[21]. We also verified consistency of these values with minimum and maximum observed floor-space consumption by housing type n (extracted from MAJIC db) and converted them in average consumed floor-space by persons[22].
To estimate δ^{mn}, equation (1) is transformed to yield a linear relationship between zonal average housing unit size and zonal weighted average monthly equivalent price (4).

$$ln\left(\frac{a_i^{mn}-min^{mn}}{max^{mn}-min^{mn}}\right) = \ln[\exp(-\delta^{mn}\, P_i^n)] \Rightarrow \qquad ln\left(\frac{a_i^{mn}-min^{mn}}{max^{mn}-min^{mn}}\right) = -\delta^{mn}\, P_i^n \quad (2)$$

Thus, the elasticity parameter δ^n is estimated by regressing $ln\left(\frac{a_i^{mn}-({min_0}^n-1)}{{max_0}^n-({min_0}^n-1)}\right)$on P_i^n (see Table 2), using $({min_0}^n - 1)$ as dependent variable, with P_i^ncorresponding to average monthly equivalent rental price by housing type n and zone i. Precisely the Excel function *PMT*[23] was used to estimate P_i^n as[24]:

$$P_i^n = p_i^n \cdot PMT \quad (3)$$

Two additional technical details of the regression methodology are important. First, because the transformed demand function does not have a negative or positive intercept, the regressions are conducted using the "no constant" option. Second, because the dependent variable is average housing unit size, and the variance of the sample mean is a function of sample size, the assumption of ordinary least squares of homoscedasticity would be violated[25]. The regressions are conducted using robust standard errors and because the logarithm of zero is undefined, special care must be taken conducting the regression analyses to avoid excluding the zones having $a_i^{mn} = min^{mn}$.
Nevertheless, to avoid also unrealistic values of simulated rental prices, (see paragraph 2.6)[26] ${min_0}^n$ and ${min_0}^n$ were then fixed in Tranus corresponding to floor-space surface limits used to extract MAJIC data instead of observed *DVF* data. During the calibration process these parameters have been subject to further slight adjustments to adapt average floor-space consumption to each demand category m (see Table 1). Each population category m represents different socio-professional

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monetary price)
[18] With a_i^{mn} as zonal average size of a generic housing unit in zone i [m^2]; min^{mn} and max^{mn} as minimum and maximum weighted average size (using housing unit size as the weight) of a housing unit for the study area [m^2]; P_i^n representing zonal average prices by housing type n in zone i.
[19] *Demande de Valeurs Foncières* (Demand for Real Estate Values - DVF): provides various informations related to real estate transactions in a 5-year period.
[20] Representing minimum and maximum average consumed floor space [m^2] by household category m.
[21] Size smaller than 10 m^2; Price smaller than the 1st percentile for each housing type and size classification; Price greater than the 99th percentile for each housing type and size classification.
[22] Using a factor representing average number of adult persons (age >= 18), for each housing type n (extracted from INSEE individuals database - FD_INDCVIZD_2010).
[23] Calculate the payment for a loan based on constant payments and a constant interest rate.
[24] With p_i^n corresponding to average price [€/m^2], by housing type n and zone i, extracted from *DVF* database.
[25] An average is calculated for each TRANUS zone having the requisite data in the DVF databases.
[26] In Tranus *Consumption* and *Expenditure* curves tend to infinite for values close to $min^{mn}$and $max^{mn}$of the function (1) (Modelistica, 2012).

typologies with different behaviour in floor-space consumption. Regressions furnished initial global values of elasticities δ^n by housing sectors, without a specification by demand category *n*. We used the INSEE database *IRSOCBDF11_TM103*[27], to estimate a proportion between annual expenditure for housing (including rent, energy and maintenance expenditure) by population categories ρ_m[28] and then used these proportions to estimate δ^{mn} for each housing demand category m and housing sector *n*. We used the Excel function "*solve*" to generate specific elasticities by demand category δ^{mn}[29]. The function generated a set of parameters δ^{mn}, setting as objective that average of specific elasticities δ^{mn} was equal to global elasticities δ^n and using as changing variable the expenditure proportion for *Active* persons (see Table 2).

Table 1. Initial $min_0{}^n$ and $max_0{}^n$ and Calibrated $min^{mn}$and min^{mn} for the TGM.

	Initial $min_0{}^n$and $max_0{}^n$				Calibrated $min^{mn}$and min^{mn}									
HOUSING TYPE	by households		by persons		Active		Partially Active		Students		Inactive		Retired	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*
Small Houses	10	39	*7*	*29*	7	29	7	29	7	29	7	29	7	29
Medium Houses(T1)	40	99	*21*	*51*	20	75	20	68	20	55	20	55	20	68
Medium Houses (T2)	40	99	*21*	*51*	25	72	21	58	19	58	19	58	21	65
Large Houses(T1)	100	300	*44*	*133*	44	139	44	133	42	133	44	133	44	133
Large Houses(T2)	100	300	*45*	*134*	45	144	45	134	43	134	45	134	45	134
Small Apt.	10	39	*9*	*35*	6	35	6	35	5	31	5	33	6	35
Medium Apt. (T1)	40	99	*24*	*58*	16	58	16	58	16	58	16	58	16	58
Medium Apt. (T2)	40	99	*24*	*60*	20	56	20	56	20	56	20	56	20	56
Large Apt.	100	300	48	143	50	150	50	148	19	146	42	145	60	160

Table 2. Elasticities for housing demand functions of the TGM, with global value δ^nestimated by regressions and specific values δ^{mn} related to each demand category.

HOUSING TYPE	δ^n	$\delta^{active,n}$	$\delta^{part\ ative,n}$	$\delta^{students,n}$	$\delta^{inactive,n}$	$\delta^{retired,n}$	$av.\ \delta^{mn}$
Small Apt.	0.0541	0.0399	0.0541	0.0798	0.0498	0.0469	0.0541
Medium Apt. (T1)	0.0979	0.0722	0.0979	0.1443	0.0902	0.0849	0.0979
Medium Apt. (T2)	0.0521	0.0384	0.0521	0.0768	0.0480	0.0452	0.0521
Large Apt.	0.1814	0.1337	0.1814	0.2674	0.1671	0.1573	0.1814
Small Houses	0.0383	0.0282	0.0383	0.0565	0.0353	0.0332	0.0383
Medium Houses(T1)	0.0264	0.0195	0.0264	0.0389	0.0243	0.0229	0.0264
Medium Houses (T2)	0.0347	0.0256	0.0347	0.0512	0.0320	0.0301	0.0347
Large Houses(T1)	0.1474	0.1087	0.1474	0.2173	0.1358	0.1278	0.1474
Large Houses(T2)	0.1084	0.0799	0.1084	0.1598	0.0999	0.0940	0.1084

2.6 Housing rental prices estimation

Monthly rental prices P_i^n estimated with equation (3) do not cover the whole study area[30], then two further approaches were applied:

a) Estimation using ratios between houses and apartment observed P_i^n by zone *i*;
b) Estimation transforming equation (2) to estimate P_i^n by housing type *n* and zone *i*[31]:

$$ln\left(\frac{a_i^{mn}-min^{mn}-1}{max^{mn}-min^{mn}-1}\right) \div (-\delta^{mn}) = P_i^n \qquad (4)$$

First the ratios approach was applied: ratios r_i^{nn} between P_i^n for all housing categories *n* by zone *i*

[27]The INSEE database describes *« Average annual expenditure per metropolitan household according to the socio-professional category of the reference person»*.

[28] INSEE data allowed us to generate ratios between annual expenditure for housing of *Retired* and *Inactive* persons, compared to *Active* persons.

[29] The *solve* function generated a set of parameters (elasticities), in function of proportion between annual expenditure for housing by demand category *m*. The average of estimated elasticities δ^{mn} corresponds to global elasticities δ^n coming from regressions, for each housing sector *n*.

[30] For some zones of the study area any real estate transitions were recorded by DVF at 2010.

[31] Where a_i represents observed or imputed average size of the housing units in a particular zone *i*.

(when available) and an average ratio $\bar{r}^{nn}$ by each housing sector relationship were calculated. A sequential calculation was then implemented to estimate missing rental prices. Considering small apartments (Sector 10) as example, sequential calculation consists in multiplying $\bar{r}^{10n}$ (average price ratio between Sector 10 and a generic housing sector *n*) by P_i^n, to obtain P_i^{10} in zone *i*[32].
After this calculation for few zones still without monthly rental prices, we applied *b)*, with a further constraint: avoiding estimated rental price to be more than 20% smaller than average observed *DVF* rental prices and more than 20% higher than average observed *DVF* rental prices by housing sector *n*. This constraint attenuates the effect of equation (1) that for average floor-space sizes close min^{mn} and max^{mn} gives extremely high or low (and consequently not realistic) rental prices (mathematically correct but without an economic sense). We finally obtain rental prices P_i^n by housing type *n* and zone *i* for the whole study area, respecting proportion between houses and apartments for each zone and reproducing "real" differences in attractiveness by zones of the model. Some of these prices will be slightly adjusted for certain zones and housing sectors, during the phase of calibration of the land use model.

3. ESTIMATION OF INITIAL SUBSTITUTION PENALTIES

The process of generation of induced demand (1) in Tranus allows defining substitutes, thus a group of alternative that contribute to satisfy demand of a generic demand sector. According to the Tranus Math Description (Modelistica, 2012), distribution of demand among substitutes is estimated with a discrete choice multinomial logit model (5), regulated according to the theory of random utility, that assign demand in function of maximization of utility.

$$S_i^{mn} = \frac{W_i^n exp(-\sigma^m \omega^{mn} a_i^{mn}(p_i^n + h_i^n))}{\sum_{l \in K^m} W_i^l exp(-\sigma^m \omega^{mn} a_i^{ml}(p_i^l + h_i^l))} \tag{5}$$

The set K^m represents the substitution choices sector *m* has access to, for instance, the type of housing that sector *m* consumes, e.g. $K^m = \{small, medium, large\ houses\}$. Coefficients a_i^{mn} represents the demands exposed in (1), p_i^n and h_i^n are the corresponding price and shadow prices of sector n at zone i. The quantity $a_i^{mn}\ (p_i^n + h_i^n)$ represents the household of type *m* expenditure when consuming a type *n* housing sector at zone *i*. The attractor W_i^n, represents part of the non-utility based attributes of the discrete choice model, this parameter is specified and potentially calibrated.
The logit dispersion parameter σ^m influences demand distribution among substitutes; this is one of the calibration parameters of the model. Penalties ω^{mn} allow defining an order of consumption preference by each population category, translating in "penalized expenditures" for each type of housing, increasing or decreasing the perceived cost of each floor-space housing type by each population category. Their default value is set to 1, where no preference is assumed. In the next part, we will give some details on how to semi-automatically calibrate these parameters, additional details can be found in (Capelle et al. 2017). We are particularly interested in dispersion and penalty factors because they significantly affect floor-space consumption and location choices. Calibrating these parameters cannot be done externally, because we do not have the necessary surveys with revealed preferences for housing consumption.
At this regard, we applied a *semi-automatic* methodology to estimate and calibrate the substitution model penalties by demand category and housing type and size. First, from INSEE individuals' database (*FD_INDCVIZD_2010*) we used the variables *surf* and *typl*, and then the variable *ipondi* (survey expansion factors) to expand the counts in the cross tabulation of *surf* and *typl*, to estimate the number of adult persons of each population category *m*, living in each housing type *n* (hab^{mn}). The INSEE database is not exhaustive and detailed regarding housing real estate market, but is the only one that furnishes housing consumption associated to socio-professional person category. This data

[32] In the case of small apartments we start from a similar size sectors, as Small Houses (Sector 13), multiplying $\bar{r}^{10,13}$ by P_i^{13} to obtain P_i^{10} for zone *i*. If P_i^{13} is not available then we check P_i^{14} for Sector 14 (Medium Houses) multiplying $\bar{r}^{10,14}$ by P_i^{14} to obtain P_i^{10} for zone *i* and so on.

allowed us to define an initial consumption preference for housing sector *n* by population category *m*, thus enabling an initial estimation of the substitution penalties ω_0^{mn}, which will be used as initial guess for the optimisation algorithm. The following equations is used to compute the initial guess:

$$\omega_0^{mn} = 1 + \left(1 - \frac{\mathrm{hab}^{mn}}{\mathrm{hab}^{m}}\right) \tag{6}$$

These initial values of substitution penalties ω_0^{mn} will be then adjusted by the optimisation algorithm, according to observed data for the study area related to:

a) total floor-space consumption by housing category and size: extracted from the MAJIC database;
b) total floor-space consumption by population category m and housing type *n*: obtained multiplying hab^{mn} by average consumed floor-space surface by population category s^n, estimated from initial ${min_0}^n$ and ${max_0}^n$.

4. OPTIMISATION OF THE SUBSTITUTION PENALISING FACTORS

The calibration of the land use module of Tranus consists on estimating a large number of parameters to make induced productions converge to observed productions. A good calibration, is one that has small error terms (*shadow prices*) to fit the observed productions of the base' year scenario. The error term in Tranus, is included in the computation of prices, so the value of the observed floor-space prices p_i^n, is corrected by the corresponding shadow prices h_i^n, In this work we extend the two phases technique detailed in our previous work (Capelle et al. 2017) for cases where a logistic regression is not possible to be performed on the penalising factors; for TGM, the data were not available. One would like penalising factors that reproduce as close as possible observed induced productions of floor-space. Following this premise, we define the cost function:

$$f(h, \omega) = |\, X(h, \omega) - X_0|^2 \tag{7}$$

Here, $X(h, \omega)$ represents induced productions as a function of shadow prices and penalising factors, both quantities will be optimised at the same time and X_0 are the base' year observed productions. We solve the following optimisation problem:

$$\mathrm{h}^*, \omega^* = \underset{\mathrm{h},\omega}{\operatorname{argmin}}\, c(h, \omega) \tag{8}$$

with a gradient descent algorithm, taking as initial solution the penalising factors obtained in the previous section (6) and initial shadow prices set to zero.
We have our own implementation of this part of Tranus, enabling us to compute all the partial derivatives of the cost function explicitly and using a powerful optimization solver.
Fine tuning probably would also be necessary to achieve reasonable values of the floor-space sectors' shadow prices.

5. TGM LAND USE CALIBRATION RESULTS

In this section are shown TGM calibration results related to floor-space consumption. Tranus program LCAL converges after 155 iteration, respecting a convergence factor of 0.001 for all housing sectors, and well reproducing total residential floor-space consumption in the study area (see Figure 1).

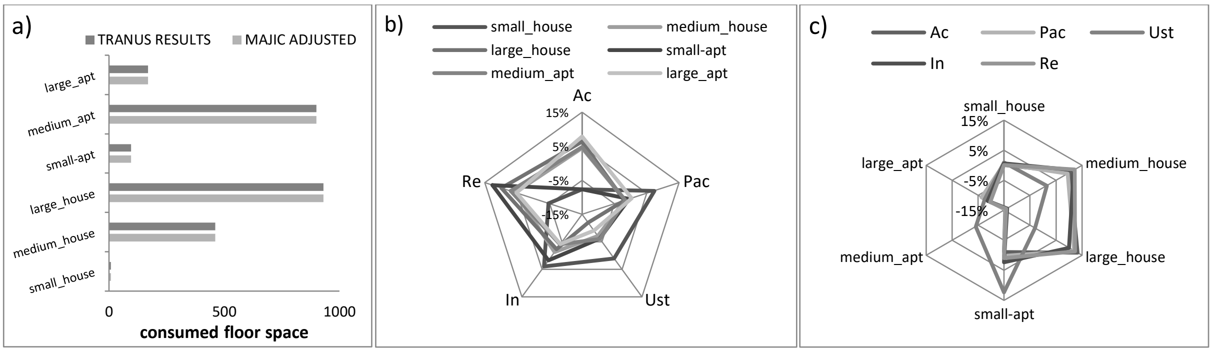

Figure 1. *a)* simulated and observed total floor-space by housing type *n*. *b)* difference between simulated and observed floor-space by housing type *n* and demand category *m*. *c)* difference between simulated and observed floor-space by demand category *m* and housing type *n*.

In particular total consumed floor-space by housing type is precisely reproduced (Figure 1 *a)*). If we analyse in detail floor-space consumption by housing type *n* and demand category *m* (Figure 1 *b)* and *c)*), we observe that differences between observed and simulated data remain between -15% and +15%. Figure 1 *c)* shows how the model slightly overestimates consumption of medium and large houses for all demand categories *m*, except for *USt* sector that has an overestimation of small apartment's floor-space consumption. This is because INSEE individuals' database (*FD_INDCVIZD_2010*), used to estimate initial values of substitution penalties ω_0^{mn}, overestimate medium and large houses total available floor-space for the study area, compared to MAJIC data, used in turn to calibrate total simulated floor-space consumption.

6. CONCLUSIONS

Using the popular Tranus modeling platform, we built an integrated land use and transport model of Grenoble. The land use component has seven population sectors, eight employment sectors, and nine residential floor-space sectors. The land use component is complex but necessarily so. The level of complexity is the minimum needed to ensure both that our model's population sectors correspond directly with the Grenoble Urban Agency's travel demand model, and that our model's employment and floor-space sectors represent the labour and real-estate markets.

Although we could have achieved our goal of building a meaningful and policy-relevant model with heuristic, trial-and-error parameter calibration, the effort we made to develop a semi-automatic process for calibrating the floor-space substitution parameters increases the transparency of our model-building process and benefits the larger community of analysts working with Tranus. (The calibration algorithm applies equally to land sectors such as high-density residential land, low-density residential land, etc.) In this work, we extended the techniques exposed in (Capelle et al. 2017) for the calibration of the substitution parameters, to models where logistic regression data is not available. For any study area, a well-calibrated floor-space (or land) substitution model is essential. The behavioral significance of the model is that it calculates the proportion of population sector m living in zone *i* that consumes sector n floor-space (see equation (5)). Obviously, for all population and floor-space sectors and for all zones, those proportions must reflect the base-scenario's floor-space market. An accurate floor-space (or land) substitution model is a prerequisite for convergence of the base-scenario land-use model and helpful predictions of how land use may evolve in response to policy implementation.

We are in the process of developing the means of disseminating the algorithm for calibrating the floor-space (land) substitution model parameters. All Tranus users will have access to a powerful tool that will help them accomplish a calibration task that otherwise would be quite daunting.

7. REFERENCES

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