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PAPER SUBMITTED FOR 88th TRB MEETING, 2009, AND FOR PUBLICATION IN TRB JOURNAL

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an integrated transport and land-use model for the Paris area

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Paper Information:

Word Count: 6200 words, 4 figures, 1 table

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Submission Date: 2008-08-01

ABSTRACT

The PIRANDELLO model, currently under development by Cofiroute, is among the first significant French attempts to develop an operational land-use transport interaction (LUTI) model. It provides an easily understandable but theoretically sturdy framework to analyze and communicate on transportation and land-use policies.

Based on the linkage of a transportation with an urban model, the project benefits from Cofiroute's experience as regards the transportation model, to focus on the development of an efficient and innovative urban model.

PIRANDELLO aims at improving the representation of the housing market, and providing easily communicable results. The former point involves a detailed representation of the structure of households' residential choices. The latter is achieved thanks to a simple but efficient decomposition of the utility function into housing comfort and accessibility of the location.

The goal of the paper is twofold:

- From a theoretical point of view, to improve the representation of the housing market and thereby address the skepticism of many French decision-makers relating to the ability of LUTI models to represent its specificities.
- Secondly, to underline the relevance of this project relatively to the current situation of the Paris metropolitan area, which calls for major land-use and transportation policies in front of the structural lack of housing supply and transportation issues. We notably present the potentialities of PIRANDELLO through a first calibration for this region, and application to the case of an urban toll.

Keywords: land-use planning, land-use transport interaction, forecast, urban model, Paris metropolitan area

INTRODUCTION

In recent years, several factors have contributed to gather the attention in France on the linkages between transportation and land-use: the rise of energy prices, the associated issue of the links between energy consumption and urban form, and increasing congestion in the transportation network. In the Région Île-de-France (also known as the Paris metropolitan area) the tightness of the housing market, underlined by high housing prices, a structural lack of housing supply and subsequently a very low vacancy rate, has raised specific concerns about (see *1*):

- The well-being of households and their solvability in front of the combined burden of housing and transportation expenditures.
- The performance of the housing market considering the lack of supply and the significant hurdles to residential mobility

To address these concerns, several development projects of land-use/transport interaction (LUTI) models are currently carried on, including PIRANDELLO, which we are going to present.

As a matter of fact, LUTI models are currently underdeveloped in France relatively to other countries including the U.S. or the UK (*2*). Three elements have contributed to this deficiency:

1. Land-use planning is driven by regulation rather than by the market in France. Thus planners currently stick with classic transportation models, such as ANTONIN (*3*) which perfectly illustrates our point. While including sophisticated features such as activity-based trips and disaggregated modeling, it considers land-use hypotheses as exogenous. Yet, even if regulation drives the evolution of housing supply, taking exogenous land-use hypotheses prevents from tackling several critical issues (e.g. the evolution of housing prices or the spatial distribution of income classes).
2. French actors remain skeptical about the ability of LUTI models to represent correctly the land-use system. Notably the market-oriented nature of these models does not match their perception of the housing market.
3. The main point is likely the significant gap in experience relatively to the application of housing databases to demand-supply modeling. The unsuccessful attempt to apply the TRANUS model to the agglomeration of Lyon (*4*) exemplifies this assertion.

To remedy this gap, two projects using the activity-based model UrbanSim were recently launched: SIMAURIF in the Île-de-France (*5*), SIMBAD for Lyon (*6*). Yet, these ambitious projects are time and data consuming, notably because of the transition-oriented nature of UrbanSim. As a matter of fact activity-based models, being centered on the processes of changes, require a significant amount of housing data and corresponding expertise for their use. If furthermore one wants to consider several household classes and housing market segments, data requirements prove prohibitive in most cases. Considering these facts, PIRANDELLO, which is a static land-use transport interaction model, is being developed so as to remedy data limitations and the relative opaqueness of several LUTI models.

The objective of our paper is twofold. The first one is theoretical: we wish to address the skepticism of French stakeholders (see point 2. above) thanks to a detailed representation of the location system, including several sub-systems in interaction. Subsystems comprise the private rental housing market, the home-ownership market, the social housing market and finally the

business real estate market. Interactions involve supply and demand considerations. Relatively to supply, the different segments compete for land and/or floorspace, with obvious impacts on land-use. On the demand side and as regards housing, households are faced with two couples of options: tenancy/ownership and private/social sector (which leads in fact to three options since the social housing sector is rental only). The relative economic characteristics (mainly prices and supply) of the three segments influence transitions between them, hence interaction. While not all these elements are present yet in PIRANDELLO, we expose current achievements and projects of further development. Besides, still from a theoretical standing, we will discuss the advantages and drawbacks of PIRANDELLO relatively to quasi-dynamics models (models with successive periods of time as opposed to static models, see *2*), which are widely in use.

The second objective is to validate and test the potentialities of the model, by adducing the calibration for the Paris metropolitan area, and an experimental application of the model to the case of a urban toll around Paris. Because the Île-de-France region calls for significant land-use policies in order to struggle against urban sprawl, job decentralization, and the lack of housing supply, PIRANDELLO will constitute a significant asset to translate regional global needs into localized objectives (e.g. where to build new housing stocks). This issue is indeed paramount, as underlined by (*1*). In these applications, both private (i.e. car) and public modes are considered, yet with a focus on the private mode.

To meet these two objectives, we first proceed to a brief description of the Île-de-France, being our study area. The section is purported to present the main features of its location system. After offering an overview of PIRANDELLO in the following section, we detail in separate sections the location model (supply and demand). The two next sections are focused on the first results of calibration and the experimental application of the model. Lastly we discuss in the conclusion the advances of PIRANDELLO and its relevancy relatively to quasi-dynamic models.

ON LAND-USE IN THE PARIS METROPOLITAN AREA

Overview of the metropolitan area

The Région Île-de-France (French name for Paris metropolitan area), is the regional political district including Paris and its neighboring *départements*. The analysis of human activity density (defined as the ratio population + employment divided by built floorspace) thanks to a prism map displays a significant tropism towards a monocentric structure, which is however counterbalanced by the presence of secondary centers, with notably the “Villes Nouvelles”:

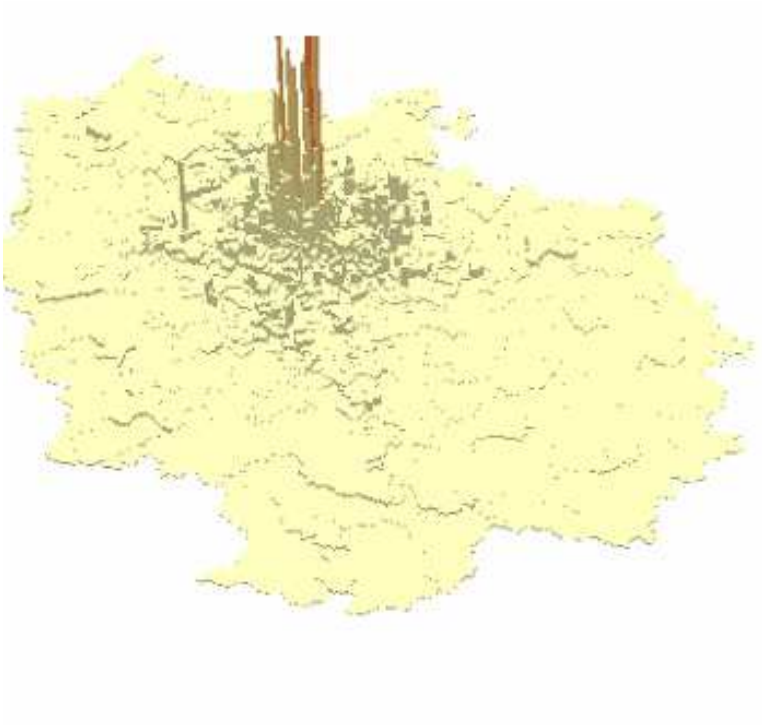

FIGURE 1 Human Activity Density in 1999 (Source: Census 99).

Its population is expected to grow from 11.5 millions today to 13 millions in 2030, thus inducing huge needs in term of housing supply in the short run.

Presentation of the housing market

Let's turn to the housing market. When analyzing the French housing market, three axis of segmentation are frequently used for data analysis purposes: ownership/tenancy, private/social sector, and individual/collective. The first criterion separates tenants from homeowners, who can be further split between homebuyers (still in the process of paying back their housing loan) and outright owners. In the case of tenancy, a second key characteristic lies in the distinction private sector/social sector. Tenants of the social sector (also known as the HLM sector) benefit from cheaper rents, especially in tight local housing markets such as Paris (*7*). Furthermore, they are known to display lower residential mobility due to the advantages of such dwellings, and the difficulty to move within the social sector (*8*). Lastly, the individual or collective nature of the dwelling is often considered, but this characteristic will not be used in the present paper.

Table 1 presents the repartition of households living in the Paris metropolitan area according to the dwelling status and to the location within the region.

TABLE 1 Distribution of Households according to Dwelling Status and Location

	Location	Dwelling Status					All
		Home Buyers	**Tenants Private Sector**	**Tenants Social Sector**	**Outright Owners**	**Others**	
% in row	**Paris**	5	**40**	16	**33**	6	25
% in col.		10	**41**	18	**23**	26	
	Inner Suburbs	9	**26**	**28**	**31**	6	27
		19	29	**35**	**24**	29	
	Outer Suburbs	15	18	**23**	**39**	5	22
		26	17	**23**	**25**	22	
	Fringes of the agglomeration	**23**	13	16	**44**	4	7
		13	4	5	9	5	
	"Villes Nouvelles"	24	13	**30**	**26**	8	6
		12	3	8	4	9	
	Accessible Secondary Aggl.	22	14	**26**	**34**	4	7
		12	4	8	6	5	
	Isolated Secondary Aggl.	14	14	19	**49**	4	2
		3	1	2	3	2	
	Rural	**26**	7	2	**59**	5	3
		7	1	0	5	3	
	All	13	24	22	35	6	100

Several important features of the Paris metropolitan area are pointed out:

- The three first zones account for 75% of the total population (which gets along with Figure 1).
- Households are evenly distributed between homeowners (48%) and tenants (46%). Among tenants, the private sector and the social sector have similar weights.
- The distribution of dwelling status varies greatly with location: whereas the most remote areas mainly welcome homeowners, central parts are more likely to host tenants.

This last element underlines the importance of distinguishing the different market segments in a spatial model.

Trends in the location system and land-use

The *Etats Généraux du Logement en Île-de-France* (*1*) and the current *Schéma Directeur de la Région Île-de-France* (or SDRIF, being the main planning document of the Paris metropolitan area) have both established a gloomy picture of the location system:

- Relatively to the housing supply, stocks are scarce, being the result of a prolonged insufficient level of construction. Affordable land supply has become more and more rare, both elements contributing to high prices for potential homebuyers.
- On the other hand the decrease in the number of persons per household has strongly supported housing demand.
- Because of the scarcity of housing supply, vacancy rates have achieved extremely low levels, and urban renewal is held back; these phenomena contribute respectively to a significant hurdle to residential mobility and a declining quality of the dwellings.
- Lastly decentralization of jobs spurs urban sprawl and longer commuting trips, and favors car use.

On the transportation and land-use linkages and the planning needs

Considering this diagnostic, there is currently a general political agreement as regards land-use planning in the Greater Paris Area, which is epitomized by the current SDRIF. The main measures advocated are:

- Developing housing and business floorspace supply;
- Densification in the centre of the agglomeration;
- Supporting polycentrism and autonomous secondary centers;
- Favoring non-polluting modes for proximity transit, motorized modes and especially rapid transit to travel between the poles of the agglomeration.

To sum it up, planning needs comprise at the same time a significant development of the housing and business floorspace stocks, and the reinforcement of transportation capacities, which notably implies structuring the public transit network. Thus the use of a LUTI model for planning these developments seems more than profitable, which is where PIRANDELLO intervenes.

OVERVIEW OF PIRANDELLO

The PIRANDELLO model, currently in development by Cofiroute (a major actor in the road building industry), is among the first significant French attempts to develop an operational land-use/transport interaction model. It aims at giving an easily understandable but theoretically sturdy framework to analyze and communicate on transportation and real estate development projects.

Model objectives and issues for application

Relatively to classic transportation models, PIRANDELLO accounts for four significant economic mechanisms:

- Modal choice, and the relation with the car ownership decision.
- Selection of trip destinations, according to transport times and costs: a global decrease in speed reduces the average length of trips, but not their number.
- Households' residential mobility, being influenced at the local level by housing prices, accessibility or income. Macroeconomic factors such as interest rates are not considered for they are assumed not to have locally differentiated impacts
- Formation of real estate prices and real estate supply, that are both intertwined with the level of demand

Thanks to the representation of these mechanisms, the model aims at tackling issues such as:

- Analysis of the short and long term effects of housing and transportation policies.
- The impact of a new infrastructure on housing prices, residential choices, segregation.
- Elaborating sustainable cities, designing policies in favor of densification, considering the issue of real estate supply (dwellings, office floor space) as well as the accessibility required for the population and jobs that will come to selected locations…

Model scope and main principles

The central objective of PIRANDELLO is to represent and analyze the interactions between the location and the transportation systems. Therefore, the following elements fall within its scope:

"Location demand": microeconomic agents (households or firms) simultaneously choose a location, a floorspace area, and the quality/type of their building (which we synthesize with the notion of "location demand"). To do so, households trade-off between the accessibility procured by the location and the comfort of the dwelling. Firms choose the location that maximizes their profit relatively to the price of the location and its market potential.

"Location supply": the corresponding "location supply" is described at the local level and for each market segment in terms of total floorspace supply and price per m².

Balancing location supply and demand: economic agents willing to locate in a given zone compete for floorspace if total demand exceeds the available supply.

Transportation supply: it includes the road network and a simplified version of the public transit network.

Transportation demand: the demand model estimates the number of trips between the different zones by mode and by purpose of activity. It is influenced by the location system.

Equating transportation supply and demand: this is done classically with the use of congestion functions.

Model structure

Similarly to several LUTI models, PIRANDELLO is based on a dual structure linking the location model to the transportation model. The transportation model feeds the location model with accessibility measures, while the location model determines the land-use patterns that are used in the transportation model.

The transportation model

The transportation model is a multimodal 4-step model. The key features of this model are as follows:

- The transportation model is a static model that considers four time periods: morning and evening peak hours, daytime off-peak hours and nighttime hours.
- It mainly aims at analyzing road transport demand. Public transit is also considered but in a more simple fashion.
- Spatial distribution of trips is based on discrete choice modeling with a multimodal variable of accessibility.
- The modal choice model is coupled with a car ownership model.
- The road assignment model accounts for congestion, generalized cost of travel and distributed values of time in order to efficiently analyze transportation projects involving tolls.
- The assignment to public transit modes is modeled in a simplified way, with detailed representation of rail services only and use of travel impedance OD matrix for bus transport.

The transportation model was first developed in 1991. Thus, contrary to the recent urban model, it has undergone numerous tests and improvements, and is known to be accurate and efficient.

The urban (or location) model

As mentioned in introduction, one key criterion in designing PIRANDELLO was to attain within a reasonable amount of time an operational model that could be calibrated with a sensible amount of data. Thus several simplifying modeling choices were made in order to ensure closure of the project and reaching fixed objectives:

- PIRANDELLO is a static model;
- Modeling of housing supply and prices formation is simplistic, focus being put on households and firms location choices.

While there is currently wide support for quasi-dynamic models, the choice of a static model may seem odd. Yet this decision was made based on three elements:

- Time development of the project: quasi-dynamic models are time consuming
- Data requirements: in the Île-de-France, several housing surveys are available, but none of them tackles specifically residential mobility.
- To the best of our knowledge, it has no been proved that quasi-dynamic models fare better than static models, and if so under which circumstances…

THE LOCATION SUPPLY IN PIRANDELLO

Let us now turn our attention to the location model, by presenting first the location supply model.

Representation of location supply

Representation of location supply in PIRANDELLO is based on an exogenous initial condition (the reference scenario), and an incremental model: floorspace stocks in alternate scenarios are derived from the reference scenario.

Description of the housing and business floorspace supply

Housing supply is characterized by the stock of residential square meters available by zone. In the initial version, no distinction is being made between different types of residential buildings. Furthermore, housing stock is perfectly flexible: total floorspace in a zone is fixed, but not the number of dwellings, which is determined by demand.

The same goes for business floorspace: stocks are measured in square meters available by zone, with currently solely one type of business floorspace.

Initialization and evolution of the location stock

During calibration (the reference scenario), location stocks are exogenously fixed. By default, housing supply in alternate scenarios is given by a state equation:

$$\frac{S(i)}{S_0(i)} = \left(\frac{p_i}{p_{0,i}} \right)^{a-b.\log(density)}$$

where 0 represents the reference scenario, p_i total population in zone i and $S(i)$ total available residential floorspace in zone i. This equation, based on empirical considerations, allows determining the evolution of residential floorspace for each zone at equilibrium.

Evolution of business floorspace per zone is fixed by the user at the moment. In order to account for significant residential projects that are already planned, the same may be done in place of the state equation for the stock of residential floorspace of any zone.

Demand competition and local equilibrium of the residential system

Because demand for residential floorspace in a zone (see section below for more detail on demand) can exceed the available supply, competition for floorspace may arise between the households. In such a case, PIRANDELLO determines a competitive local equilibrium.

Since households are price-takers, households willing to locate in a given zone only bid for surface area. The basic mechanism leading to the local equilibrium is fairly simple. Suppose that there is a large excess of demand in zone *i*. The model sorts it out in the following manner:

- Households share available floor space according to a certain rule of competition (see below);
- This leads to smaller surfaces than the ones households would opt for in the unbounded case;
- Excess demand leads to higher prices (except in calibration where prices are exogenously set);
- Higher prices, combined to smaller surfaces, ultimately generate a utility loss that spurs some households to relocate in less congested areas.

Here is the rule when demand is superior to supply: households share total zonal floor space $S_0(i)$ so as to equate the marginal utilities of all the households, which is equivalent to substituting the market price by a shadow price that integrates the scarcity of surface.

Formation of prices in the housing sector

Besides the floorspace sharing rule, a second equilibrium mechanism is the formation of housing prices within each zone. While prices are exogenously fixed in the reference scenario, they are modified in alternate scenarios according to the variation of demand:

$$\frac{\pi(i)}{\pi_0(i)} = \left(\frac{p_i}{p_{0,i}} \right)^{\varsigma}$$

$\frac{\pi(i)}{\pi_0(i)}$ standing for the relative change in prices, $\frac{p_i}{p_{0,i}}$ in population, and ς referring to elasticity of price with respect to demand.

Discussion

Location supply in PIRANDELLO is currently designed in a simple fashion. There is no explicit description of microeconomic agents as regards the supply side, which is based on the description, measurement and evolution of stocks according to preset rules. As a matter of fact, covering precisely such a topic would require at least months of work, since supply mechanisms are still badly known compared to demand mechanisms, as it appears in most LUTI models.

However, future versions of PIRANDELLO will include a more detailed description of the location supply, with notably segmentations of the housing stock according to the quality and the status of the dwelling (social/private sector and tenancy/ownership).

THE LOCATION DEMAND IN PIRANDELLO

Let us now focus our attention on the location demand. We first present location demand for households, then for firms, and lastly discuss the current model and the developments to come.

The location demand of households

First we consider how households' residential choices are modeled. As will be seen, PIRANDELLO was influenced by both entropic models and urban economics: thus it shares common features with Lowry's model (*9*) and the monocentric model (*10*). Yet, it is micro–economically founded, contrary to entropic models.

Modeling the household's residential choice

In the model households, when choosing their housing, trade-off between the comfort offered by the dwelling and the accessibility to populations that the location provides. It is indeed a trade-off: while the search for accessibility tends to gather populations and raise housing prices, the yearn for surface exerts the opposite effect. This formulation seems similar to the classic monocentric model (*10*). However the description of the housing choice is more refined, as regards the consideration of accessibility as well as the housing comfort issue.

To account for the great variability of households' choices, households, stratified by income, maximize a random utility function depending on zone *i* and housing size *s*:

$$U_Y(i,s) = S_Y^h(i,s) + S_Y^a(i) - \pi(i)s - \varphi(i,Y)s + \varepsilon_{i,Y} + \eta_1$$

where *Y* stands for the household's income (assumed to be discrete). The global utility function of the household comprises:

- A utility term assessing "domestic comfort": $S_Y^h(i,s) = A.\left(\frac{s}{s_0}\right)^{\alpha}\left(\frac{Y}{Y_0}\right)^{\beta}(1+\gamma.Ind_i)$. It is a Cobb–Douglas function of surface area and income, with respective elasticities α and β. Besides a constant term *A*, a linear term $1+\gamma Ind_i$, where Ind_i designates the share of individual housing in zone *i*, represents the households' preference for individual housing.
- An accessibility term $S_Y^a(i) = \frac{\theta Y^{\alpha}}{\lambda}\log\left(\sum_{j,Y'}\mu_{Y,Y'}p_{j,Y'}\exp\left(-\frac{\lambda}{\theta Y^{\alpha}}(\theta Y^{\alpha}t_{ij}+c_{ij})\right)\right)$, which is the usual log–sum formula used to compute accessibility to a set of populations ($p_{j,Y'}$), based on travel–time t_{ij} and travel cost c_{ij} between zone *i* and *j*. θ is the factor relating the value of time to the hourly wage.
- A residential cost including the housing price $\pi(i)s$ and local housing tax $\varphi(i,Y)s$.
- An idiosyncratic fixed effect $\varepsilon_{i,Y}$, proper to income class *Y* and zone *i*. It might be interpreted as a form of valuation of urban amenities present in zone *i* by class *Y*.
- A random term η_1, which follows Gumbel's law.

The location choice

Since random term η_1 follows Gumbel's law, the household maximization program leads to a multinomial logit formulation. Therefore, household's probability of settling in zone *i* is:

$$P_Y(i) = \frac{S_0(i)\exp\left\{\omega \overline{U}_Y(i, s(i,Y))\right\}}{\sum_j S_0(j)\exp\left\{\omega \overline{U}_Y(j, s(j,Y))\right\}}$$

where $S_0(j)$ represents total floorspace in zone *j* and $\overline{U}_Y(i,s)$ the household deterministic utility, i.e. $U_Y(i,s)$ deprived of random term η_1.

Modeling the location choices of firms

The second module of the location model is focused on the location choices of firms. It aims at representing the following phenomena:

- The spatial distribution of jobs, jobs being localized in the most efficient locations considering their specificity.
- The paramount role of accessibility for certain types of jobs, such as proximity jobs (e.g. bakeries, banking services, hair dressers…) and more generally services jobs.

This second point is particularly important since most of the activity in the Greater Paris Area belongs to the tertiary sector, that is to say services. In 2006, the service industry accounted for 85% of the total gross value added in this region, against 77% for France. Consequently we make the assumption that all jobs pertain to the service industry within the study area. Secondly, PIRANDELLO locates jobs on a single basis, rather than firms, which would prove much more complex (one would have to account for the different sizes of firms, their location strategies relatively to suppliers or retailers…). Thus we use the term "unit firm", one unit firm being equivalent to one job.

The production and profit functions of the service industry

Considering the phenomena that the module wishes to address, the average production function per job of the service industry is given by a Cobb-Douglas function of wage and accessibility:

$$Q(i,w) = kw^a A(i,w)^b$$

where *w* is the wage, with elasticity *a*, $A(i,w)$ the accessibility of zone *i* for wage *w*, with elasticity *b*, and *k* a constant term. Thus increasing the accessibility of a given zone *i* increases the average production $Q(i,w)$ of a job with wage *w*. Wages are exogenous in the model.

Given this production function, the profit per unit firm is obtained by subtracting wage and floorspace price to the average production of the firm, and adding a fixed effect and a random term that account for local and job-based heterogeneities. This brings about the following formulation:

$$\Pi(i,w) = Q(i,w) - w - (\pi(i) + \phi(i))s(i) + \varepsilon_{i,w} + \eta_2$$

with the following notations:

- $\pi(i)$: price per square meter of office floorspace
- $\phi(i)$: local taxes in zone i per square meter of floorspace
- $s(i)$: office floorspace per unit firm
- $\varepsilon_{i,w}$: idiosyncratic fixed effect similar to the one present in the housing model
- η_2: random term following Gumbel's law

Location program of firms

Each unit firm maximizes its profit subject to the following constraints:

$$\max \Pi(i,w) \;\; s.t.$$

$$\begin{cases} \sum_w L(i,w)s(i) \le S_0(i) \\ \sum_w L(i,w) = L_0(i) \\ \sum_{i,w} \left(kw^a A(i,w)^b - \pi(i)s(i)\right)L(i,w) = GRP \end{cases}$$

where $L(i,w)$ is the number of jobs with wage w in zone i. The three constraints represent respectively:

- The total available floorspace $S_0(i)$ constraint that allows to determine the office floorspace per job $s(i)$;
- The employment constraint: aggregation of jobs over wages gives the total number of jobs $L_0(i)$ in a given zone i;
- The production constraint: aggregation of production over jobs gives the gross regional product GRP.

The three elements $S_0(i)$, $L_0(i)$ and GRP are exogenous variables that set the level of each constraint.

Since η_2 follows Gumbel's law, the profit maximization program brings about the following probability for a job to locate in zone i:

$$P(i) = \frac{\exp\left\{-\tau\left(kw^a A(i,w)^b - w - (\pi(i) + \phi(i))s(i) + \varepsilon_{i,w}\right)\right\}}{\sum_i \exp\left\{-\tau\left(kw^a A(i,w)^b - w - (\pi(i) + \phi(i))s(i) + \varepsilon_{i,w}\right)\right\}} L_0(i)$$

$$s.t. \sum_{i,w} \left(kw^a A(i,w)^b - \pi(i)s(i)\right)L(i,w) = GRP$$

Discussion

Concerning housing demand

First, it is important to note that PIRANDELLO is micro–economically founded, with neoclassical considerations such as utility maximization, and a proper description of housing demand (consisting in both location and floorspace area). Contrary to mechanistic models such as Lowry's model or its derivatives, this allows for interpretation of the model's outputs and even more importantly for welfare analysis.

Secondly, formulation of the household program implies that the individual housing demand is characterized by the following features:

- For a given income class, residential location choice is influenced positively by available floor space in zone *i*, accessibility to populations, housing surface, the share of individual housing in zone *i*, and by a fixed effect $\varepsilon_{i,Y}$. It is affected negatively by local tax level and average housing price in zone *i*
- Choice of housing size is influenced positively by income and the proportion of individual housing in zone *i*, and negatively by average housing price and tax level operating in a given zone

This tends to validate our formulation since the roles of most variables in determining location or surface area correspond to intuition or known results.

Thirdly, PIRANDELLO takes into account urban amenities in two ways: through the estimation of the fixed effect $\varepsilon_{i,Y}$, and through the accessibility–to–populations term $S_Y^a(i)$. Income segregation can therefore be modeled, since this last term allows accounting for any type of preference for a given income class. Calibration of PIRANDELLO thereby exhibits a preference of income groups for their own class. On the other hand, several urban amenities, e.g. presence of schools, malls, …, are not explicitly considered. However, because their presence is strongly linked with density, and consequently with accessibility, they are most probably either captured by the accessibility term or the fixed effect term.

Current developments

Standard of the dwelling To improve the representation of the housing market, one current development lies in integrating the variations of standing between dwellings. Indeed, housing goods differ substantially between affordable houses and luxurious residencies, in the utility they procure as well as in their price. Besides, each income class usually turns to the most appropriate segment according to its financial capacity.

To account for these phenomena, the utility term assessing residential comfort is amended by switching $(Y/Y_0)^{\beta}$ with $(Y/Y_0)^{\beta+\chi}$ where χ accounts for the standing of the dwelling:

- For luxurious dwellings $\chi > 0$
- For more humble residences $\chi < 0$

This formulation proves particularly relevant: while all income classes exhibit preference towards greater quality (since χ increases with quality), the greater the income, the greater the

valuation of this characteristic. Therefore richer households will be willing to pay more for quality than other households, which is quite intuitive.

First implementations seem promising and do affect richer households to the highest quality dwellings, while low-income households turn to more affordable housing. This mechanism will allow for a better representation of income segregation, by considering the influence of the supply side (development choices in term of the quality of the housing projects).

Structuring the choices of households Another significant development aims at structuring the residential choices of households at two levels of decision. At the upper level, two couples of options are considered: ownership/tenancy and in case of tenancy social/private sector. Because these three segments exhibit significant differences in prices, available supply, characteristics of the housing stock, and residential mobility, this distinction is of paramount importance.

This would be first achieved by distinguishing the three corresponding types of housing stocks. The second step would consist in modifying the assignment mechanism of each sector. For the social sector for instance, in first approximation households living in HLM could be located exogenously to account for the lower residential mobility of this segment. In the longer term, the aim is to account for the transitions between the different segments, notably based on the price differentials.

At the lower level, the zonal options could be organized in option subsets, to account for instance for transport characteristics and the situation of the zone: zones close to a pole could be separated from zones in the suburbs, which would in turn be divided between the zones with good access to public transit against isolated zones implying an intensive use of car. Following this idea, the zoning system provided by the IAURIF provides a good starting point to classify the different zones:

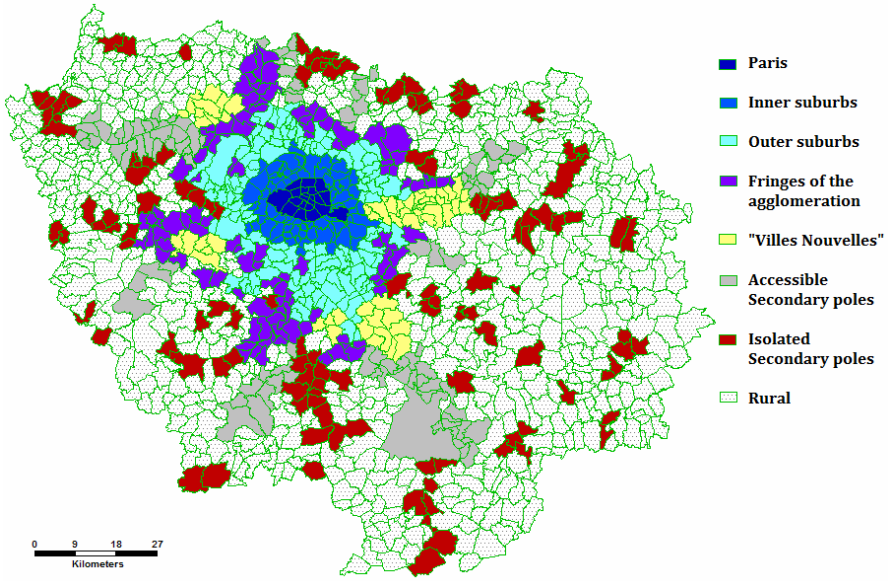

FIGURE 1 The IAURIF Zoning System.

This zoning system accounts particularly well for the transport characteristics of a zone, and its situation in the region according to its centre or the secondary centers.

APPLICATION SETTING AND CALIBRATION FOR THE PARIS METROPOLITAN AREA

The aim of this section is to validate our location model and point out the potentialities of PIRANDELLO by exposing the first significant results obtained during the calibration process.

Application setting

Zoning system The area of study is divided into 415 zones that are used for both the urban and transportation model. This mutual zoning system accounts for the main spatial features such as the structure of human activity or of the transportation network; notably when density rises, the size of the zone decreases.

Transportation model While a detailed representation of the network is used for the private mode (car), public transit services are implemented in a more simple fashion with a detailed representation of rail services and the use of a travel impedance OD matrix for bus transport. Transit fares are not considered.

Location supply and demand segments Eight household income classes are considered with average income ranging from 4000€ to 69000€ a year. Size or socio-economic characteristics of the household are not considered for the time being. Similarly services firms are split into two wage classes, with respective average wages of 23000€ and 38000€ a year.

As regards the supply side, the model is currently set with one type of housing and one type of business floorspace.

Calibration of the residential model

The residential model is calibrated with the *Enquête Globale de Transport 2001-2002*, a detailed household mobility survey regularly carried out for the Paris metropolitan area. Because it covers the socio-economic features of the household, as well as the characteristics of its dwelling, this database can be used for the calibration of both the transportation and urban model, giving coherency to the estimations. The notaries' BIEN database provides the average housing prices per zone.

The first and most significant result of calibration lies in the following property: **the utility of each income class is quasi-constant for all zones** (or equal to zero when no household of the given income class is present in the zone), and **this constant rises with income**. More precisely, intra-class variations of utility are negligible compared to inter-class variations of utility.

First, this result implies that households substitute perfectly accessibility and comfort. Secondly, it bears similarity with the monocentric model, in which households of a given income class all attain the same utility level at the land-use equilibrium, level which increases with the income of the class. Yet PIRANDELLO accounts for social mixing within a zone, while the monocentric model completely segregates the different income classes. Lastly, Figure 5 underlines the role of the distance to the centre of the agglomeration in this trade-off, phenomenon once again similar to the monocentric model.

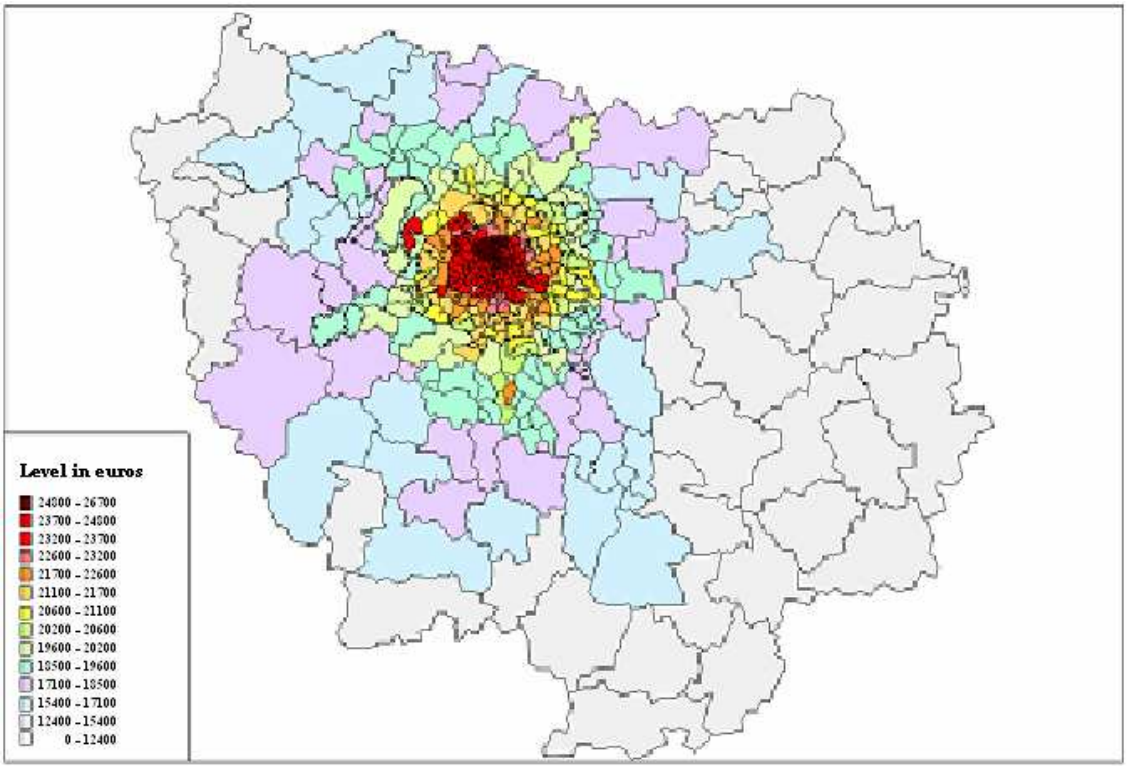

FIGURE 2a Accessibility-based utility for income class 7.

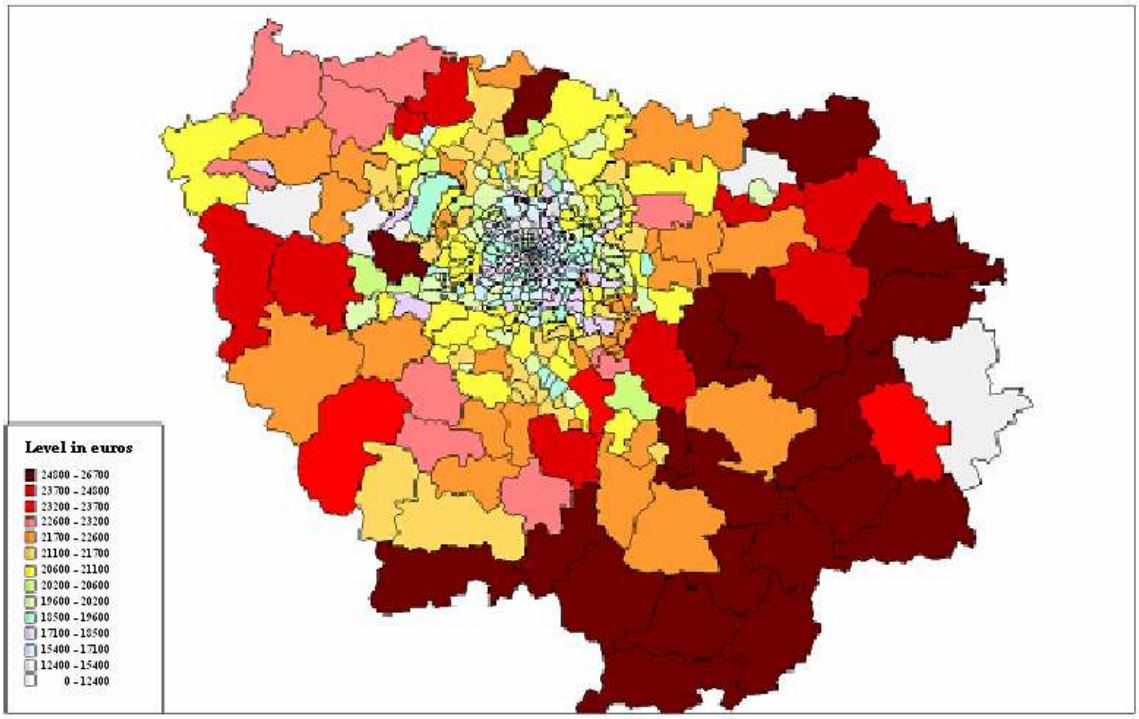

FIGURE 2b Domestic comfort based utility for income class 7.

While households pertaining to the 7th income class (well-off households) retrieve the major part of their utility from accessibility in the center of the agglomeration, they opt for greater domestic comfort when settling farther from the CBD.

It can also be shown that the local equilibrium model provides consistent estimates of:

- Average surface area by income: as observed the average surface area per person rises with income
- Average housing budget share by income: it decreases gradually from 30% for the lowest income class to 11.4% for the highest. While the model slightly underestimates housing budget shares (see *7*), it accounts well for the influence of income.

Calibration of the firm location module

Calibration of the firm location module is carried out thanks to the survey DADS (standing for Yearly Declaration of Social Data) provided by the INSEE, the main French institute of economical statistics. Due to the constrained form of the program (see the location demand section), we proceed to an estimation using the constrained maximum likelihood method.

To validate our model, Figure 3 confronts for each zone the estimated number of jobs to the observed one.

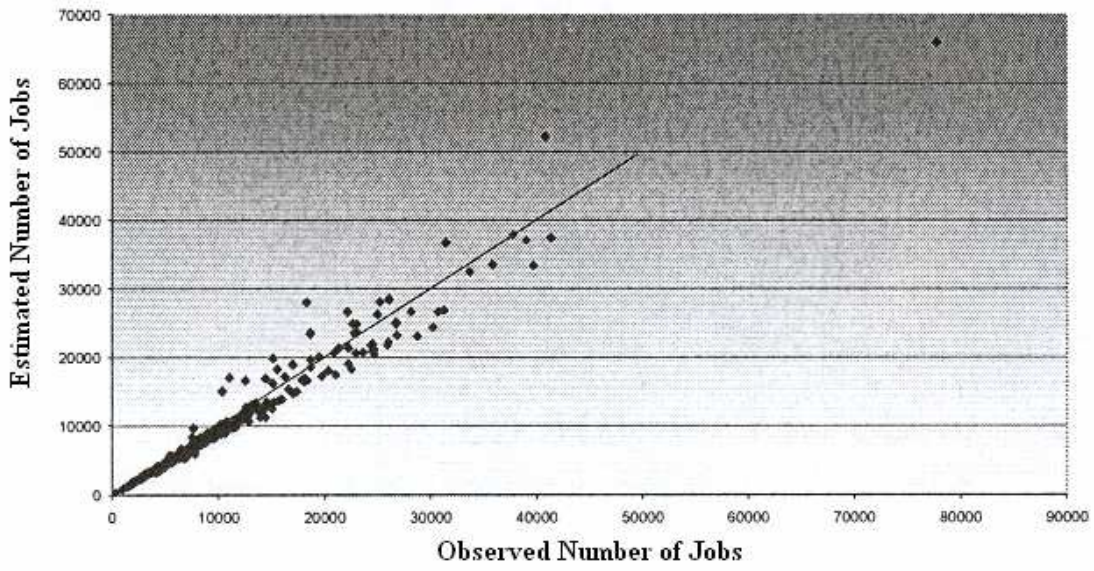

FIGURE 3 Simulated vs. observed number of jobs.

This strong fit to the observed data underlines the potential of the firm location model.

APPLICATION: THE CASE OF AN URBAN TOLL

In this section we present succinctly the analysis of a study case: an urban toll around Paris. Each car trip going inside or outside of Paris is fared 10€. The goal of this application is twofold:

- To underline the sensitivity of the location model
- To test and validate the model

Let us first consider the variations of population triggered by the policy. The urban toll favors suburbanization as is shown on Figure 7. In order to avoid the costly toll, people move out from the central zone and relocate in the outer rings of the agglomeration.

Yet, restricting this analysis to the 7^{th} income class (high-income class) mitigates this result. Richer households, being less sensitive to transport costs, take advantage of the reduced competition for floorspace within Paris induced by the toll. This leads to population increases for this class within several zones of the capital.

On the other hand, if we now consider the variations of accessibility for the 2^{nd} income class (low-income households), figure 7 underlines that their accessibility is dwindled within the central zone, resulting from the combination of higher transport costs and the migration of lower income classes towards the most peripheral areas of the agglomeration.

To sum up, this quick analysis has provided pronounced and intuitive results. While this would tend to corroborate the achievement of the two objectives set at the beginning of the section, further study cases must be tested, this with greater care, to confirm this point.

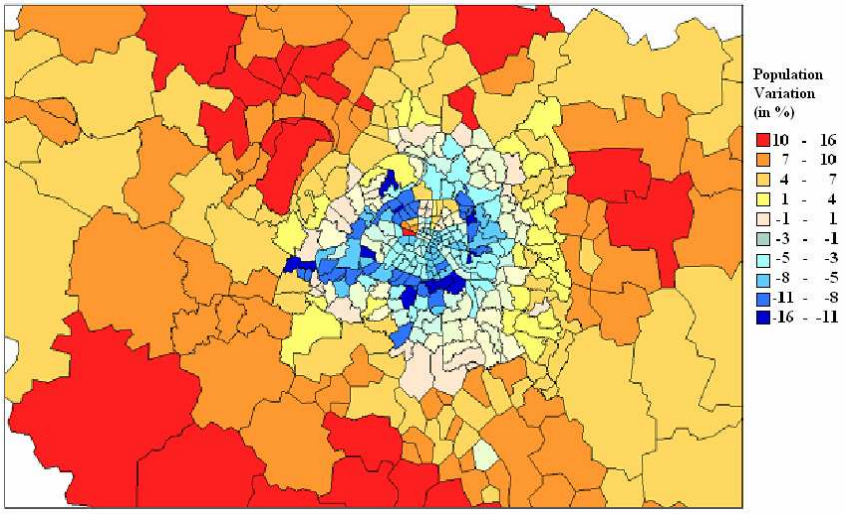

FIGURE 4a Variation of population in the case of an urban toll.

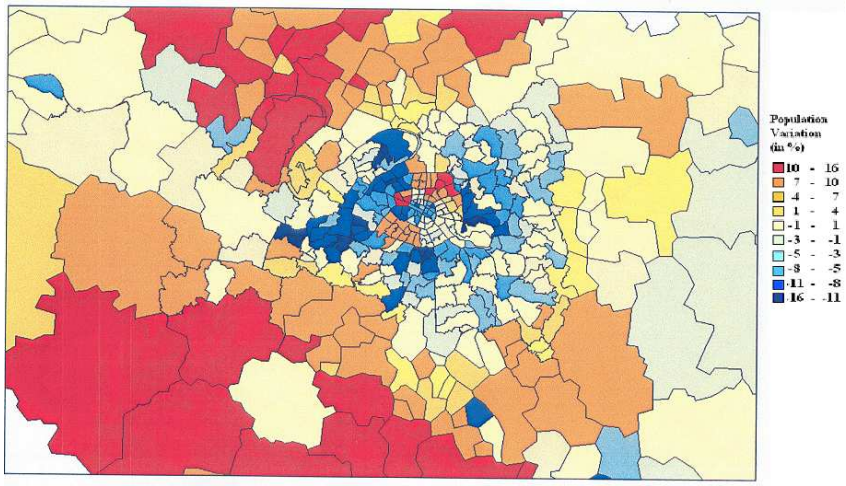

FIGURE 4b Variation of population for income class 7.

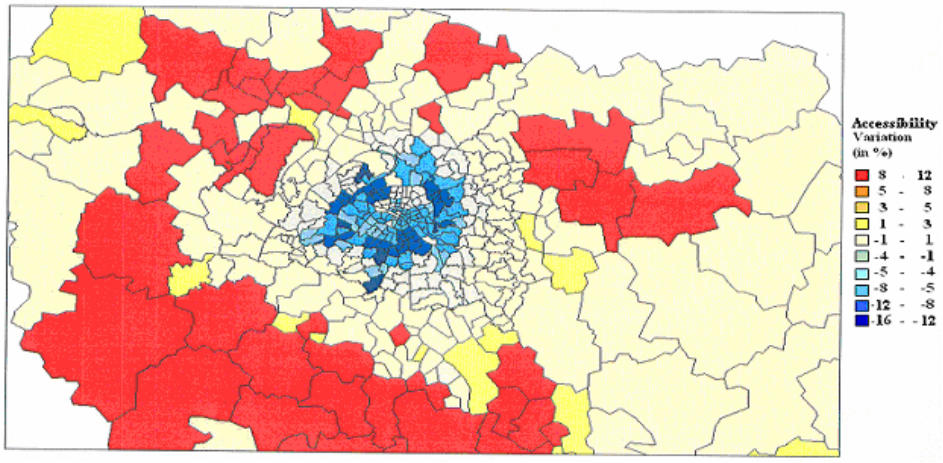

FIGURE 4c Variation of accessibility for income class 2.

CONCLUSION

PIRANDELLO displays three major qualities that make it a promising tool for analyzing transportation and land-use policies:

- It requires a reasonable amount of data for calibration. As regards the residential model census databases would in most cases prove sufficient.
- The most significant mechanisms relative to the location choice of economic agents are accounted for.
- Its intuitive notions (accessibility, residential comfort) are easily understandable by decision makers.

First results of calibration support our point, as PIRANDELLO fits well the observed situation of the Paris metropolitan area, and provides intuitive welfare indicators. Application to the case of an urban toll confirms the sensitivity of PIRANDELLO and tends to validate the model by exhibiting results conform to intuition.

The choice of a static urban model may be discussed depending on the policies one wants to analyze. Because PIRANDELLO considers long term equilibriums, it cannot account for the different temporalities of urban change, nor can it be useful for determining the optimal timing for a set of given projects. Yet, when considering the analysis of a project where the timing factor is not of the utmost importance, the superiority of quasi-dynamics models to a static model has yet to be thoroughly exposed. Comparative tests such as were carried out during the ISGLUTI project (*11*) could prove enlightening relatively to this issue.

PIRANDELLO is an ongoing project: further developments include above all a more detailed representation of the structure of households' residential choices according to higher level (ownership/tenancy, social/private sector) and lower level (lifestyle) sets of options. In the longer term, PIRANDELLO aims at a better representation of both the formation of housing supply and housing prices.

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