# Urban modeling vs. actual cities: towards an operational assessment of mismatches

**Elisabetta GENOVESE, France; Vincent VIGUIÉ, France; Stéphane HALLEGATTE, France; Paolo AVNER, France**

**Key words**: urban modeling, spatial planning.

## SUMMARY

Urban growth models and methods to forecast urban land-use change are currently the subject of intense research activities, as shown by the number of financed research projects on the topic. However, the diversity and heterogeneity of the tools used, raise the issue of the adequacy of each model to deal with specific aspects of urban development.
One of the challenges is to assess to what extent models reproduce reality. Indeed, each of them is a highly simplified version of the actual world, but at the same time conveys useful information. Some aspects of the city may be simulated in a schematic way, while some others may be represented with an in-depth analysis. For a given model and its projections, this leads to a great robustness along some dimensions, and to unreliable results along others. In order to compare the different models it is necessary to measure these strengths and weaknesses and gain information from a simultaneous use of several of them.
Our work aims to create a framework to deal with this issue by developing indicators to assess the validity of urban change models. NEDUM2 is a dynamic economic land-use/transportation interaction model developed in CIRED: using it as a case study, we define a set of indicators and determine their relevance. Indicators are defined in terms of physical spatial mismatch (urbanized area, floor-area ratio), socio-economic data (population density, rents, commuting distance) and urban growth dynamics (urban sprawl, density changes).
We show an illustration of this method by comparing simulations of the NEDUM2 model on the Paris agglomeration to statistics collected by French governmental and urbanism institutes. We finally show how such indicators can help refine our model calibration, and define a roadmap of how to improve the model in the future.

## FRENCH VERSION

Les modèles urbains et les méthodes prospectives d'étude de la modification d'usage des sols en ville font actuellement l'objet d'intenses activités de recherche. Cependant, la diversité et l'hétérogénéité des outils soulèvent la question de l'adéquation de chaque modèle pour traiter des aspects spécifiques du développement urbain. Un des défis est d'évaluer dans quelle mesure les modèles reproduisent la réalité. En effet, chaque modèle est une version fortement simplifiée du monde réel, mais donne en même temps des informations utiles. Quelques aspects de la ville peuvent être simulés de manière schématique, alors que d'autres doivent être représentés avec un niveau d'analyse plus détaillé. Ceci mène à une grande robustesse sur certains aspects, et à des résultats incertains sur les autres. Afin de comparer les différents

modèles, il est nécessaire de mesurer ces forces et faiblesses et d'obtenir de l'information à partir de l'utilisation simultanée de plusieurs d'entre eux. Notre travail vise à créer un cadre pour traiter cette question en développant des indicateurs pour évaluer la validité des modèles de transformation urbaine. NEDUM2 est un modèle économique dynamique d'interaction entre l'usage des sols et le transport : en l'utilisant comme cas d'étude, il est possible de définir un ensemble d'indicateurs et d'évaluer leur pertinence. Les indicateurs sont définis en termes de disparité spatiale physique (secteur, densité de bâti), données socio-économiques (densité de population, loyers, distance de permutation) et dynamique urbaine de croissance (expansion urbaine, changements de densité).
Une illustration de cette méthode sera proposée en comparant des simulations du modèle NEDUM2 sur l'agglomération de Paris aux statistiques recueillies par l'Institut National des Statistiques français et par les instituts d'urbanisme. Il sera possible de montrer comment de tels indicateurs peuvent aider à raffiner le calibrage du modèle, et à définir une feuille de route sur la manière d'améliorer le modèle à l'avenir.

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## INTRODUCTION

The development and application of models that improve our ability to predict trends in land use changes is nowadays the subject of intense research activities. These models are useful to provide access to information, outlines and alternative scenarios and they strongly contribute to planning processes (Montano and Souza, 2007, Pontius and Schneider, 2001).

However, the variety and heterogeneity of the tools used raise the issue of the adequacy of each model to deal with specific aspects of urban development. One of the challenges involves comparing model outputs with real-world observations and assessing to what extent models reproduce reality or the product of another model assumed to adequately characterize the real-world (Parker et al. 2002).

The majority of the large number of existing land use models is an extremely schematic version of the actual world but, at the same time transmits helpful information for spatial planning activities. Some aspects of the studied area may be simulated in a simplified way, while several others may be represented with an in-depth and exhaustive analysis. For a given model and its projections, this leads to a great robustness along some dimensions, and to unreliable results along others. Moreover, while trying to compare different models, it is necessary to measure these strengths and weaknesses and gain information from a simultaneous use of several of them.

The majority of the large number of existing land use models lack a proper validation, often because of data problems (Kok and Veldkamp, 2001). Scientists need a better and larger set of tools to validate land-use change models, because it is essential to know a model's prediction accuracy (Pontius and Schneider, 2001). The most common problem with environmental models is failure to state what the validation criteria are. In 1996, Rykiel affirmed that the only way to resolve disagreements over the meaning of validation could be the establishing of a convention. Criteria must be explicitly settled because there are no common standards for selecting what test procedures or criteria need to be used for validation. Therefore an analysis based on comparison of simulated versus observed data is usually included.

The present study aims to create a framework to deal with this issue by developing indicators to assess the validity of urban change models. The method described in this study is applied on the dynamic economic land-use/transportation interaction model NEDUM2, which predict predicting scenarios for urban growth in the Paris area (Viguié & Hallegatte, 2011).

Using NEDUM2 as a case study, we show a model calibration methodology and we define a set of indicators and determine their relevance in the validation process. Indicators are defined in terms of physical spatial mismatch (urbanized area, floor-area ratio), socio-economic data (population density, rents, commuting distance) and urban growth dynamics (urban sprawl, density changes).

Finally, we give an illustration of this method by comparing different simulations of the NEDUM2 model on the Paris agglomeration to statistics collected by French governmental and urbanism institutes. We applied two methodologies to further improve the validation of NEDUM2 described in Pontius and Schneider (2001) and Pontius et al. (2004).The indicators we defined can help refine our model calibration, and determine a roadmap of how to improve the model in the future.

## 1. ASSESSING THE PERFORMANCE OF LAND-USE MODELS

### 1.1 Model calibration versus model validation

Both calibration and validation are part of the model evaluation process. It is crucial to distinguish between the procedures of calibration and validation. Separation between data used for calibration and data used for validation must be maintained (Parker, 2006; Pontius et al. 2004).

In literature, we found several definitions of calibration. According to Verburg et al. (2006), calibration is “the process of creating a model such that it is consistent with the data used to create the model”. For Parker et al. (2002), the calibration is the “Derivation of best-fit model parameters from real world data”.

Similarly Rykiel (1996) defines calibration as ‘‘the estimation and adjustment of model parameters and constants to improve the agreement between model output and a data set, as a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model”.

Otherwise, model validation is the process of measuring the agreement between the model prediction and independent data. If there is a “good” match, then the method used to make the prediction is said to be valid (Verburg et al., 2006). Validation concerns how well model outcomes represent real system behavior. Therefore it compares model outputs with real-world observations or the product of another model or theory that is assumed to adequately characterize reality (Parker et al., 2002).

Validation is just one component of the larger task of model evaluation and describes a test or a testing process on which to base an opinion of how well a model performs so that a user can decide whether the model is acceptable for its intended purpose (Rykiel, 1996). Manson raises a question about goals of validation (Verburg et al, 2006; Manson, 2003): “How well does a model characterize the target system?” “It is not particularly useful to try to define a model as valid or as invalid based on the validation results. It is more useful to state carefully the degree to which a model is valid. Validation should measure the performance of a model in a manner that enables the scientist to know the level of trust that one should put in the model. Useful validation should also give the modeler information necessary to improve the model".

More generally, numerical models are able to provide insights regarding some questions, but not all. As a consequence, a validation process cannot be designed independently of the questions the model is supposed to tackle.

According to Rykiel, validation tests if a model is acceptable for its intended use because it meets specified performance requirements and the purpose of the model. A common problem with models is failure to establish what the validation criteria are. Criteria must be explicitly stated because there are no universal standards for selecting the test procedures that has to be used for validation. Because the objective and subjective components of validation are not reciprocally exclusive, divergence over the meaning of validation can only be resolved by establishing a convention.

## 2. NEDUM

The Non Equilibrium Dynamic Urban Model (NEDUM), developed at CIRED, is conceived to address the stylized evolutions of urban systems through time and space (Gusdorf and Hallegatte, 2007a,b; Gusdorf et al., 2008).

NEDUM is based on standard urban economics approached, in particular the classic Von Thuenen model (1826), adapted to cities by Alonso (1964), Mills (1967) and Muth (1969). Dynamic analysis of cities based on the Von Thuenen framework have already been proposed before, but they only consisted in a sequence of stationary equilibriums, see e.g. Anas (1978) or Capozza and Helsley (1990), and a review in Brueckner (2000).

Its approach is innovative in that it allows to represent non-stationary states, taking into account inertia in households' relocation, in apartments' sizes, housing service production, and stickiness in housing rents. Even if stylized, the model provides useful insights to the comprehension of the interactions between city agents and help in determine future development scenarios.

Whereas NEDUM represented transport costs in a schematic way as a function of the distance to the city center, the two-dimensional version of this model, i.e. NEDUM2, introduces realistic transport infrastructure and thus reflects spatial heterogeneity in the agglomeration (Viguié & Hallegatte, 2011). The map in Figure 1 represents the urbanized area predicted by NEDUM2 (in green) against real data (Corine Land Cover) in 2006.

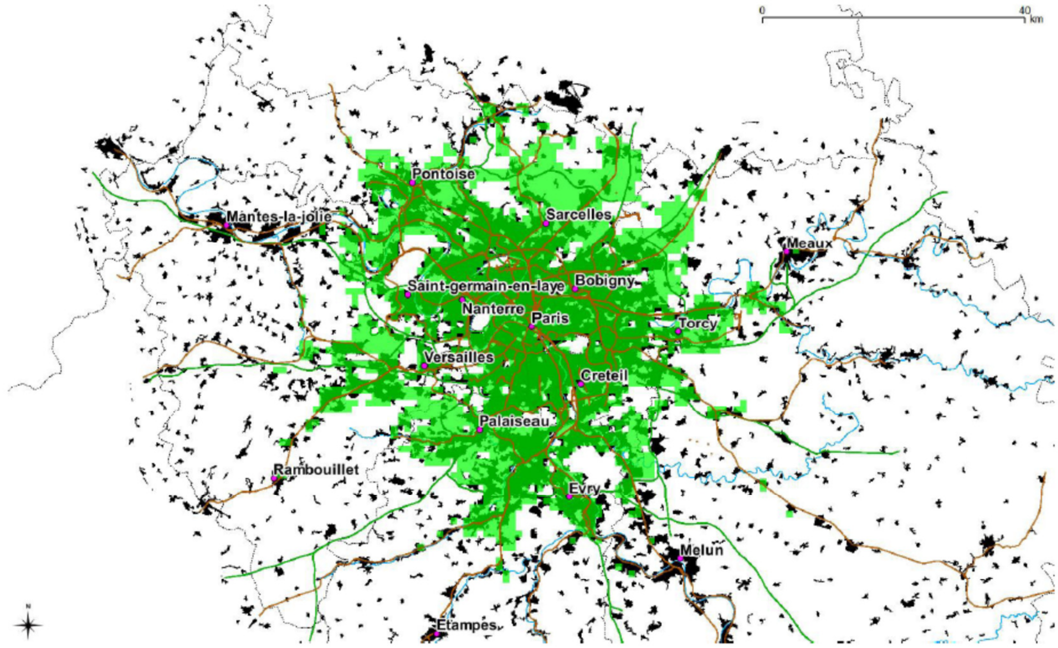


Figure 1: Simulated urban area in transparent green (NEDUM2) against real urbanization data in black (Corine Land Cover) in 2006 for the Paris agglomeration.

## 2.1 Model hypotheses

The model relies on several simplifying assumptions. Firstly, there is a unique city center, and worker daily commuting is approximated by one daily round-way trip to the center. This is a strong assumption but – as we will see - simulations show that this assumption is still acceptable in Paris, probably because of the star-like structure of the transportation network. Indeed, rents and population density reach a peak in the centre of Paris and decrease on a regular basis when we move away to other directions.

A second assumption is the tradeoff between transportation costs (including travel time costs) and accommodation size as the major factor explaining housing prices. Several other parameters (historical attraction of the place, socio-economic background of the neighborhood population) actually concur to the formation of these prices. NEDUM2 averages these characteristics across all neighbourhoods. As a result, the model fails to represent or explain differences in housing prices between locations that have the same access to the city center (comparable transport infrastructure). It is however successful on average at describing housing prices differential between locations where transport costs differ. When examining urban structure on a long term horizon and at the scale of an agglomeration, it is reasonable, at least as a first step, to suppose that real estate prices are fundamentally driven by transportation costs as will be shown in the following sections.

A third supposition is that the city structure is freely driven by market forces. In practice planning constraints exist which prevent Paris metropolitan area structure to correspond to the theoretical resulting balance of supply and demand. Some constraints have been introduced in the model, such as a limited building height in Paris. Otherwise the model shows that real estate developers would have built much higher buildings than what is observed because of the high rent level in Paris. Moreover, since the access to social housing is very constrained in practice, we have assumed that the existence of social housing does not influence private market.

Finally, all households are supposed to have the same income. Average people's income is a function of the distance to the centre of Paris and it varies less than 15 % in the first 40 km. This simplification seems reasonable, at least to the first order approximation (Viguié et Hallegatte, 2011).

## 3. Calibration

### 3.1 Model calibration methodology

This study conducted the model calibration in order to obtain a stable equilibrium which is as close as possible to the current profile of Paris metropolitan area. However not all data are used for calibration, and this over-determination makes possible the validation of the model to some extent.

Table 1 presents a summary of (i) the data that are used as a direct input to the model or as a model parameter; (ii) the unobservable parameters that need to be calibrated; (iii) the data that are used to validate the model. Some of the latter are known with a high degree of uncertainty, therefore we qualify them as "indication" in the table.

| Data used as model input | Calibration data | Validation data |
|---|---|---|
| Urban area population | Travel time cost as a function travel duration | Population density |
| Households average size | Rent determining city border | Rents and real estate prices across the city |
| Households average income | Households utility function parameters | Accommodation size (only at 3 points across the city) |
| Transport prices | The 2 coefficients determining construction costs | *Indications over construction costs* |
| Transport times | | *Indications over travel time cost* |

Table 1: Data (in Viguié V. and Hallegatte S., 2011).

We calibrated one function and four variables (second column of Table 3), and we considered three data groups for validation concerning the size of housing, as well as two data functions that describe the geographical structure of two variables (i.e. containing the equivalent of an infinite number of data points). Given the number of parameters to calibrate and validate the remaining information, a satisfactory correspondence between model results and this information suggests that the model is able to represent the main determinants of urban structure.

We proceeded as follows. First, the coefficients of the household utility function were calibrated using the part of the income of Parisian households which is dedicated to their housing expenditure (given by the level of rents at the center of Paris multiplied by dwelling size and divided by households' income).

The rent fixing the limit of the city is determined according to rent data. On the curve giving the evolution of the average rent as a function of the distance to the Paris center), rents decrease first when moving away from Paris, and then stabilize around of 12 € / square meter. This value was used as the threshold for the urban area boundary below which it is no longer profitable to build. It corresponds both to the value of land for other purposes such as agriculture and to transaction costs involved in the building and renting process (building authorisations, tenant seeking).

The function describing the evolution of the time cost (as a function of trip duration) was calibrated according to the time of travel based on our data on rents. The distribution of people density across the urban area was used to calibrate the two coefficients of the construction costs function.

## 4. Model validation

Model validation could be performed first by comparing actual rents and population density distribution curves to curves obtained from the model, and data on actual housing sizes to modeled housing sizes. In a second phase, some model outputs were compared to indications that we had on their value (indications on construction costs and indications on travel time costs).

The results show a satisfying correspondence between model results and data points, suggesting that the model is able to represent the main determinants of the urban structure. A more complete validation would be possible through the modeling of many cities.

### 4.1 Validation results

As shown in Figure 2, the model describes the evolution of rents across the city quite satisfactorily. There`s just a modest bent to underestimate the rents.

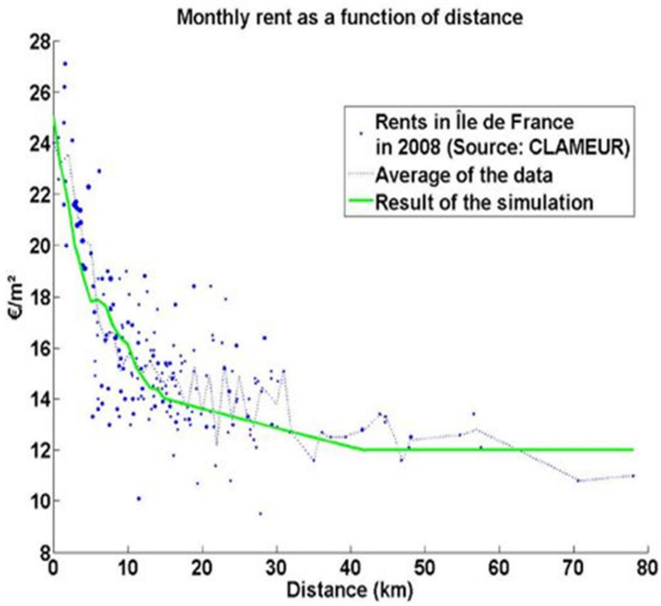


Figure 2: Actual rents (2008) and rents computed by the model.

Figure 3 shows that, in terms of population density, the model gives a growing density when getting close to the city centre. This is probably one of the limits of the monocentric model. However, the agreement between the model and the data seems satisfying.

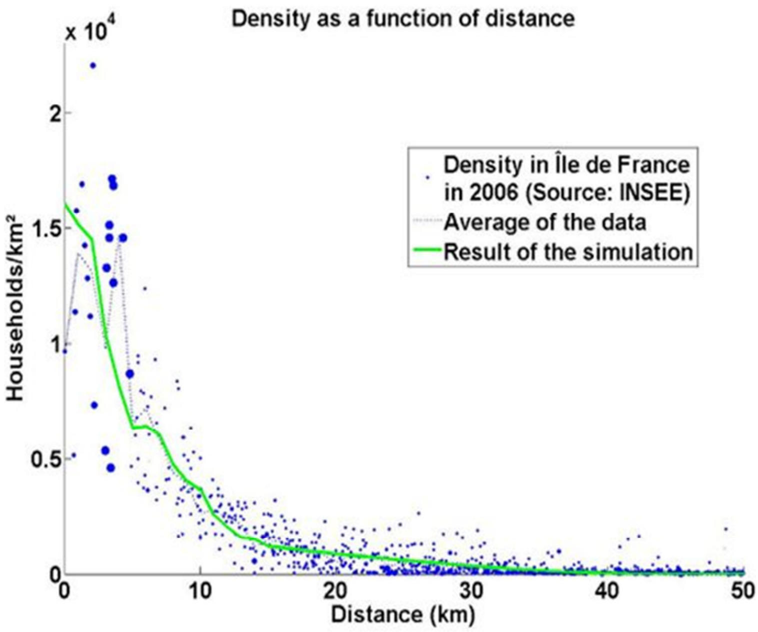


Figure 3: Actual population density (2006) and density computed by the model

Figure 4 compares the ratio between inhabited surface and ground surface dedicated to housing as calculated by NEDUM2 and as computed from our data on population density and on accommodation sizes.

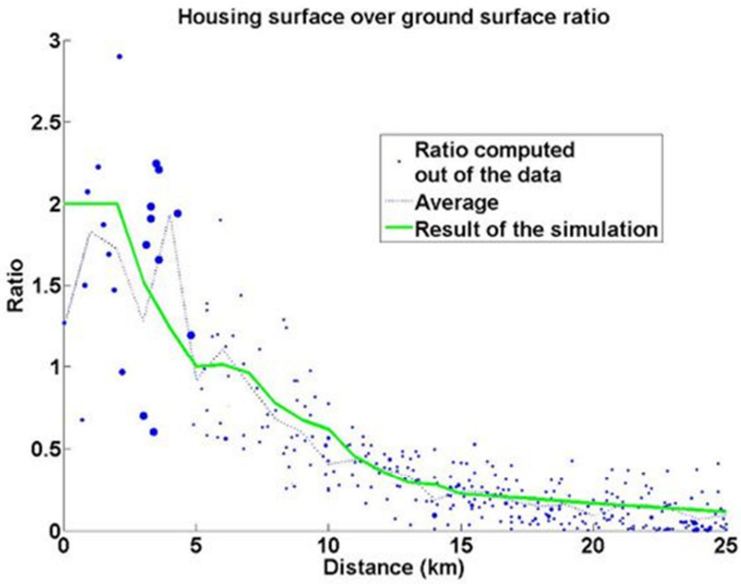


Figure 4: Actual dwelling density and computed by the model.

The curve representing model results grows when moving towards the centre of Paris, and stops when reaching the value 2, since this is how the land use constraints present within the Paris downtown. This value may seem low as most buildings in Paris have approximately 6 floors, which would induce a ratio of about 6 at the centre of Paris. However, our ratio is only taking into account housing surface, and not the total built surface, and the discrepancy is simply caused by built surface intended for purposes other than housing, and which actually concerns many buildings in Paris (offices, shops, museums, train stations, office buildings, schools, universities, etc.).

As we had little data on accommodation sizes, the data points should be considered more as orders of magnitude than as a specific value. Therefore, the agreement between the model and data seems here very satisfactory.

## 5. Validation tools and indicators

In a first step the graphical validation figures presented above sufficed to convince of the pertinence of the NEDUM model to reproduce Paris agglomeration urban structure correctly.
We are now looking into ways to further improve the model. This work can no longer be carried out solely using best fit methods. We have to look into more scientifically founded and fertile indicators. In this first stage of research on indicators applied to NEDUM2 capacity of predicting future urban development in Paris, we have used two methodologies proposed in Pontius and Schneider (2001) and Pontius et al. (2004).

## 5.1 ROC methodology

Pontius affirmed in several studies that scientists need a better and larger set of tools to validate land-use change models and proposed different statistical methods to validate land use models in order to know a model's prediction accuracy.

In 2001, Pontius and Schneider presented a method of validation that uses a quantitative measurement called the Relative Operating Characteristic (ROC). ROC gives a measurement of the distance to perfect prediction. ROC is a summary statistic derived from several two-by-two contingency tables, where each contingency table corresponds to a different simulated scenario of future land-cover change, defined by a continuous variable. The ROC can compare a map of actual change to maps of modeled suitability for land-cover change. It is usually applied in Engineering, Medicine, Meteorology, and other scientific disciplines. Pontius applied ROC to land-use change models, and we show that it is a suitable method to evaluate the performance of land use transport interaction model such as NEDUM2.

In our case, actual change map was given in terms of "urbanized" or "non-urbanized" land. In terms of data, we used land use data provided by the Corine Land-cover database. Since our model does not provide a binary answer (urbanized vs. non-urbanized) but simulates the floor-area ratio (i.e. the number of housing square meters on each land square meter), we need to set the ratio threshold beyond which an area is considered urbanized.

NEDUM2 results (red line) in Figure 5 show what happens when we change this threshold. When the threshold is very low, most of the model area is considered urbanized and the model produces many false positives (i.e. it predicts that an area is urbanized while it is not). When the threshold is very high, most of the model area is considered non-urbanized and the model produces few positives (i.e. it predicts that an area is non-urbanized while it is urbanized). Figure 5 shows that, for some selected value of the threshold, the model produces a reasonably good prediction (about 90% of true positives, with less than 10% of false positives).

The value of the floor area ratio that sets the limit of the city plays an important role in the accuracy of the model. To test the influence of this limit on our results, we compared the last two simulations by using a ROC method. The simulation NEDUM2 gets a better result than the "special" simulation (blue line): this means that it is possible to improve the model and make our simulation more efficient than the "special" simulation by changing this marker.

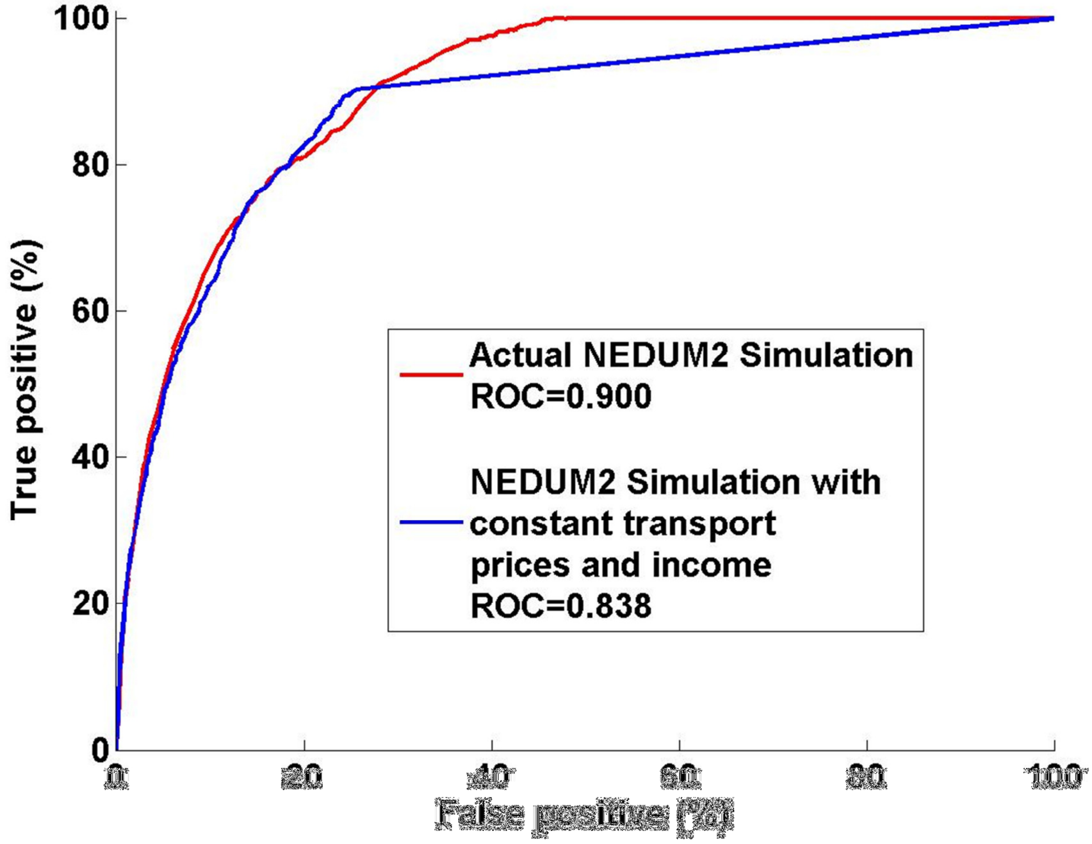


Figure 5: ROC curves to validate model: NEDUM 2 results versus the "special" model results (where transport prices and income are considered constant).

## 5.2 Pontius et al. (2004) methodology

Another methodology we tested is based on the validation method described in Pontius et al. in 2004. This technique: (a) budget sources of agreement and disagreement between the prediction map and the reference map, (b) compares the predictive model to a Null model that predicts pure persistence, (c) compares the predictive model to a Random model that predicts change evenly across the landscape, and (d) evaluates the goodness-of-fit at multiple-resolutions to see how scale influences the assessment. The study introduces a new criterion called the Null Resolution, which is the spatial resolution at which the predictive model is as accurate as the Null model (Pontius et al., 2004).

We tried to define sources of agreement and disagreement between the prediction map and the reference map, even if we need to improve this application in future and more detailed analysis.

As shown in Figure 6, we compared our simulation to simpler scenarios which could be made without using a model (a scenario where the city growths proportionally to its population), a Null model (no evolution between 1960 and 2006), and to a scenario where we used the model but did not include as an explanatory factor the change in income, transport prices and technologies. The percentage of agreement between simulation and reality is indicated on the x axis; the y axis specifies the resolution in square kilometers, in order to evaluate how the scale influences the assessment. The diagram shows that NEDUM2 (red line) performs better than the two other scenarios.

The methodology proposed by Pontius suggests the same comparison with different resolutions (i.e. by averaging over several pixels). As can be seen on Figure 6, when the resolution decreases (i.e., when the size of the pixels increase), the gap between NEDUM2 simulation and the two other scenarios tends to increase. The agreement between simulation and reality (x axis) is based on the CORINE land cover data for 2006 and the MOS data for 1960. It happens to see models that work pretty well on the large scale but are less effective on the small one. In our case, NEDUM works well both on the small and large scale, even with an increasing performance for the smaller scale.

Nedum allows to do long term simulations of urban growth. We present here a simulation of the Paris agglomeration between 1960 and 2006. We analyze the validity of such a simulation by using the approach outlined by Pontius et al. (2004). The result is useful to refine the model calibration of NEDUM2.

We compare the NEDUM2 simulation, done with the usual approach, to a "Null" model in which the city does not change. The NEDUM2 simulation obtains a much better result (which is quite normal given the expansion of the Paris area between these two dates).

Similarly, the model simulation is better than a simple expansion of the city proportionally to its population. By applying this technique, it is interesting to test the action of different parameters responsible for the city's evolution. We also compare a model simulation with a "special" model simulation (blue line) in which we assumed that the price of transportation is constant and so is household income.

In this case, the ROC analysis based on variable resolution, recommended by Pontius and Schneider in 2001, completely makes sense: for a resolution of less than 4km², we actually find that it is the "special" simulation that provides the best result. The model's ability to take into account the impact of changes in income and in the cost of transport is too limited when applied to a grid of 1km². Some changes in the model are required to improve this result.

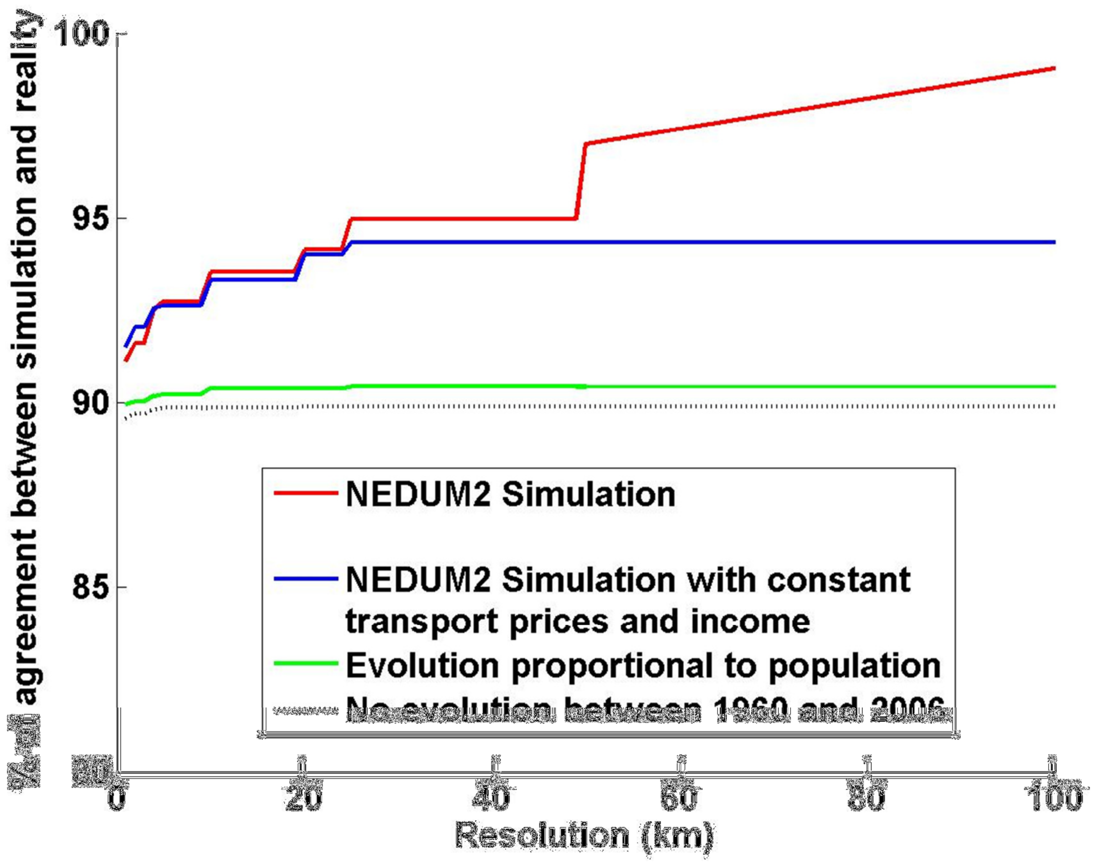


Figure 6: Comparison of the results of various simulations: NEDUM2 with constant transport prices and income, NEDUM2 with evolution of these values, city evolution proportional to population growth and the Null model (no city evolution).

## CONCLUSION

We applied classical tools of urban economics and calibrating the urban economy model NEDUM2 on the Paris urban area, using a broad range of detailed socio-economic data. This prior calibration and validation process yielded fairly satisfactory results. We found that the model reproduces fairly faithfully the available data on the Paris area and it is satisfactory in answering to specific questions, in particular describing housing prices differential between locations where transport costs differ.

Therefore, when examining urban structure on a long term horizon and at the scale of an agglomeration, it is realistic to suppose that real estate prices are fundamentally driven by transportation costs.

In sections 5 we applied two methodologies described in Pontius and Schneider (2001) and Pontius et al. (2004) to further improve the validation of NEDUM2, but much more detailed analysis is required. We have equally initiated reflections on a set of other indicators aiming to address the following issues. This work has just begun and draws on prior research on this topic.

## REFERENCES


Alonso W. (1964). *Location and land use: toward a general theory of land rent*, Cambridge, MA: Harvard University Press.

Anas A. (1978). Dynamics of urban residential growth. Journal of Urban Economics 5, 66–87.

Brueckner J.K. (1981). A dynamic model of housing production. *Journal of Urban Economics*, 10(1), 1-14.

Capozza, D. R., Helsley, R. W. (1990). The stochastic city. Journal of Urban Economics 28, 295–306.

Gusdorf F. and Hallegatte S. (2007a). Behaviors and housing inertia are key factors in determining the consequences of a shock in transportation costs. *Energy Policy*, 35(6), 3483-3495.

Gusdorf F. and Hallegatte S. (2007b). Compact or spread-out cities: Urban planning, taxation, and the vulnerability to transportation shocks. *Energy Policy*, 35(10), 4826–4838.

Gusdorf F., Hallegatte S. & Lahellec A. (2008). Time and space matter: How urban transitions create inequality. *Global Environmental Change*, 18(4), 708-719.

Kok K. and Veldkamp A. (2001). Evaluating impact of spatial scales on land use pattern analysis in Central America. Agr. Ecosyst. Environ. 85, 205–221.

Manson S. M. (2002). Validation and verification of multiagent systems. In Janssen M.,Complexity And Ecosystem Management The Theory and Practice of Multi-Agent Systems, School of Human Evolution and Social Change, Arizona State University, US, 2002

Mills E.S. (1967). An Aggregative Model of Resource Allocation in a Metropolitan Area. *The American Economic Review*, 57(2), 197-210.

Montano M. and Souza, M. P. (2007). Land use and cover change (LUCC) model and environmental Policy tools applied to regional planning. In: 10th International Conference on computers in urban planning and urban management, 2007, Iguassu Falls. Environmental and Planning Policies. Foz de Iguaçu, 2007.

Muth R.F. (1969). Cities and Housing; the Spatial Pattern of Urban Residential Land Use, Chicago: University of Chicago Press.

Parker D. (2006). Land-use modeling techniques and applications, Lecture 3, George Mason University

Parker D., Steven M. Manson, Marco A. Janssen, Matthew J. Hoffmann, and Peter Deadman (2002). Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. August 15, 2002 Forthcoming, Annals of the Association of American Geographers.

Rykiel Jr. E.J. (1996). Testing ecological models: the meaning of validation, Ecological Modelling 90 (1996): 229-244.

Pontius Jr R. G., Huffaker D. and Denman K. (2004). Useful techniques of validation for spatially explicit land-change models. Ecological Modelling 179(4) p.445-461.

Pontius Jr R G and Schneider L. (2001). Land-cover change model validation by a ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environment 85(1-3) p.239-248.

Viguié V. and Hallegatte S. (2011). The impact of a carbon tax on Paris metropolitan area and its population, submitted to Environmental and Resource Economics.

Verburg P. H.; Kok, K.; Pontius, R. G.; Veldkam, A.; Lâmbin, E. F.; Geist, H. J. (2006). Modelling land use and land cover change. Land-use and land-cover change. Local processes and global impacts, Springer, Berlin.

## BIOGRAPHICAL NOTES

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**Vincent Viguié** is a research Fellow at CIRED and Ponts Paristech, and executive top civil servant, at the French Ministry of Ecology, Energy and Sustainable Development. He is currently working on urban dynamics modelling, and conflict and synergies between adaptation and mitigation policies at a city-wide scale. He is leading the development of NEDUM 2D model.

**Stéphane Hallegatte** is a researcher in environmental economics and climate sciences for Météo-France and CIRED. He is lead author of the IPCC Special Report on managing the risk of extreme events to advance adaptation and contributing author of the working groups I and II of the IPCC fourth assessment report. He participates in the French inter-ministerial working group on the assessment of climate change impacts, and has been consultant for the

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**Paolo Avner** is a CIRED Phd student. His research aims at the modelling of urban development with a special focus on the economics of households' and industries' localisation decisions. This work builds on the theoretical frameworks of urban economics and new geographic economics. In the past, he had worked for two years in the LEPII (Grenoble) where he acquired some modelling experience on the topic of urban transportation in the context of climate change on the POLES model.

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