An agent-based model to study the emergence of urban structure

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Introduction

- General aim: to study the interaction between transport and land use
- Research question: urban social structure ("North American" vs "European" city)
- Tool: agent-based system (NetLogo)
- Interactions between economic agents (micro-behaviour)...
- ... and emergence of a city (macro-level)
- Theoretical basis : Urban Economics standard model (Alonso, Muth, Mills)
- Why a physicist to do this ?

Outline

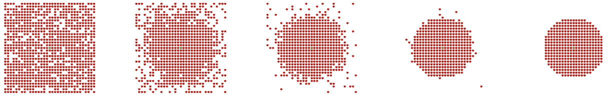
1. Analytical and agent-based models
2. Additions to the standard model
3. Perspectives

Outline

Overview of the Urban Economics model

- Monocentric model: CBD, transport cost for daily work
- Agents compete for land: landowners rent to the highest bidder
- Moves have no cost
- Utility $U(z, s)$, z composite good and s surface of housing
- Budget constraint $Y = z + tx + ps$, Y income, t transport cost (unit distance), x distance to the center, p rent
- Agents maximize their utility while respecting the budget constraint $\rightarrow$ homogeneous utility, equilibrium rent and density

Agent-based implementation

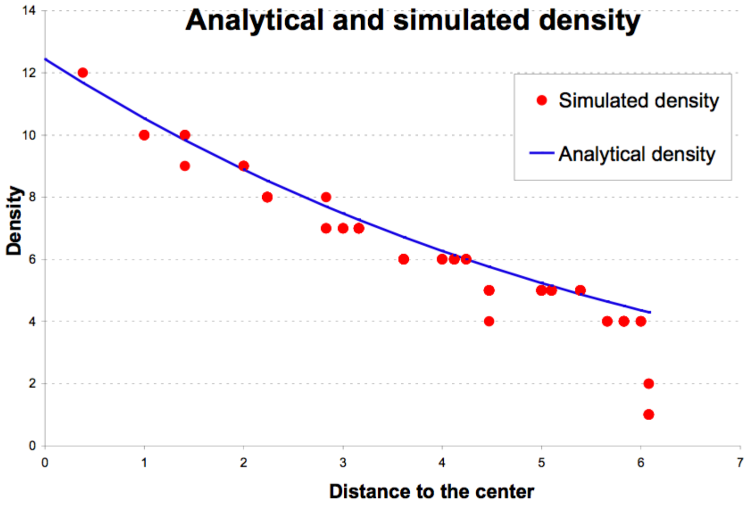


- 2D grid with cells representing residential or agricultural blocks; CBD
- Initialization: agents are placed at random
- $U = \alpha \ln z + \beta \ln s$, $\alpha + \beta = 1$
- Evolution: Agent and cell chosen at random, move if $\Delta U > 0$ with a bid $p_{n+1} = p_n(1 + \epsilon_s \frac{\Delta U}{U})$, ϵ_s bid parameter
- The price of vacant cells decreases exponentially
- If a higher bidder arrives in an already full cell, some agents go to "the hotel" with decreasing utility

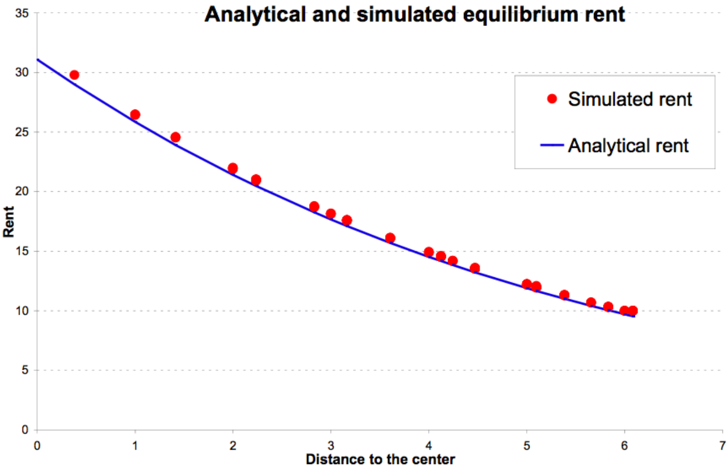
Remarks on the agent-based model

- Utility specification (while standard economics articles derive general conditions)
- Very simple interaction between agents, to obtain the analytical equilibrium
- Interaction suggested by the analytical model
- Too simple interaction: unrealistic, "no frictions" (can be improved with ABMs)

Comparison

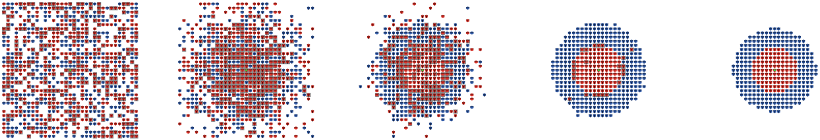

Analytical and simulated density
Simulated density
Analytical density
Density
Distance to the center
0
2
4
6
8
10
12
14
0
1
2
3
4
5
6
7

Comparison


Analytical and simulated equilibrium rent
Rent
Distance to the center
Simulated rent
Analytical rent
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
7

Evolution of the simulations

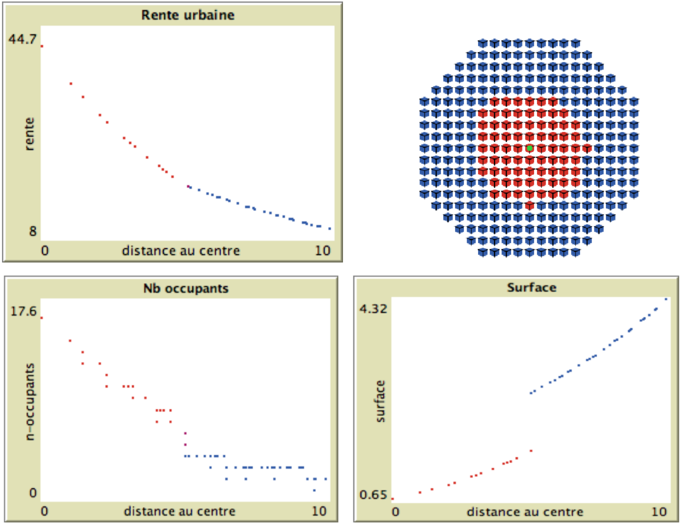
- 2 income groups: poor agents Y_p, rich agents $Y_r = Y_p \times 1,6$
- n average number of moves per agent



$n = 0$ 1 4 22 91

- Time evolution: utility U becomes homogeneous in the city
- No (obvious) link with the historical evolution of a city

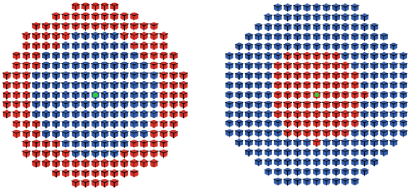
Agent-based model with two income groups



Outline

Introduction of a value of time

- $T(x) = (t + \frac{c_t}{v})x = Tx$, c_t value of time and v speed
- If $T_r/Y_r > T_p/Y_p$ (or equivalently $T_r/T_p > Y_r/Y_p$), rich agents live in the center of the city

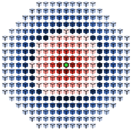


- Empirically, the value of time does not increase rapidly enough with income

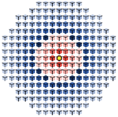
Introduction of amenities

- Environmental or historical amenities, urban facilities [Bruckner, Thisse, Zenou (1999)]
- Specification of the amenity function: $a(r) = a_0 \exp(-r/b)$, r distance to the amenity, a_0 attractiveness, b range of the amenity
- Additional term in the utility function $U = \alpha \ln z + \beta \ln s + \gamma \ln(1 + a(r))$, with γ preference for the amenity

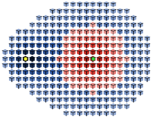
Distance from the amenity to the center



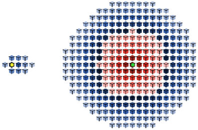
No amenity



$d = 0$



$d = 10$



$d = 18$

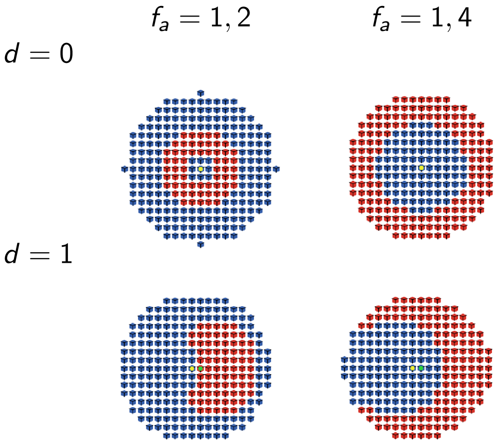
Model	$U_r - U_p$	D_{tot}	ρ_{mean}
Ref.	100	100	100
$d = 0$	98,7	74,5	132,1
3	99,1	82,6	128,2
6	99,6	95,6	117,1
10	100,1	108,2	104,1
14	100,1	113,8	95,7
18	100,0	105,5	98,3

Outcomes

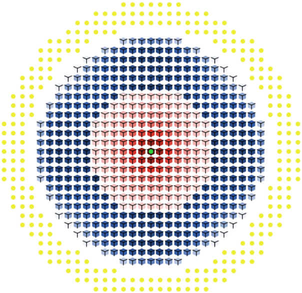
- Environmental outcome: commuting distances decrease if the amenity is close to the center, increase if it is far away
- Social outcome: if the amenity is close to the center, the utility gap between rich and poor decreases, and increases if the amenity is far from the center
- Leapfrog development: in this model an attractive amenity far away from the center can cause leapfrog development

Differentiated preferences

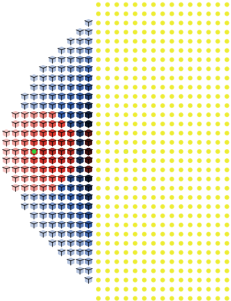
- rich agents have a higher preference for the amenity than poor agents $\gamma_r = \gamma_p \times f_a$



Extensive amenities

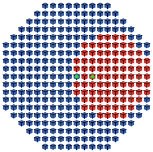


(a) Amenity around the city

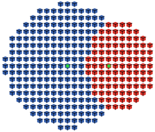


(b) Amenity on one side

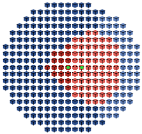
Polycentrism



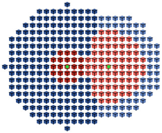
(a) d=2



(b) d=6



(c) d=2

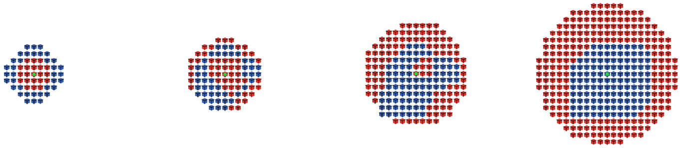


(d) d=6

Outline

Perspectives

- Calibration of the agent-based model: introduction of vertical housing
- Historical evolution of an "open" city with endogenous amenities



- In general, historical evolution of "american" and "european" cities
- Introducing more realistic mechanisms for moves, bids ("market frictions")

Conclusion

- Methodology
  - Introduction of interactions between agents in an agent-based model allows us to reproduce the standard equilibrium model
  - Features of the model that are difficult to deal with analytically can be studied
- Results
  - Value of time: no inversion of the "American" city
  - Central amenity with the same preference for both income groups: no inversion
  - Non central amenity: influence dependent on the distance to the center
  - A central amenity with differentiated preferences can inverse the city configuration