



Emergence of scattered and leapfrog urban development

from analytical results to complex simulation outputs with realistic calibration

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18th ECTQG, Dourdan (Paris), September 7, 2013



Outline

Background

- Sprawl

- Literature models

- Goal

Model

- Space and agents

- Households decision

- Dynamics

- Example

Analysis

- Analysis strategy

- Analysis results

Simulations

- Calibration

- Output

- Comparative statics

Conclusion



Urban sprawl challenges/debates

- Sprawl impacts debate
 - Excessive expansion source of market failures (congestion, open land loss,...) (Brueckner 00)
 - Environmental impacts (emissions, fragmentation of ecological habitats,...)
- Today's normative responses seem unsatisfactory
 - compactness policies, land use zoning schemes or regulations
 - but commutes beyond green belts, households deviate because of local authorities competition, non-attractive/low acceptability on densification,...
- Designing more innovative policies?
 - Any better (if not optimal) morphologies than just compact?
 - **Requires deeper microeconomic understanding of the emergence of sprawl morphologies**



Sprawl morphologies: scattered / leapfrog development

- Sprawl as scattered or fragmented pattern.
 - Various measures (p/a, edginess (e.g. Irwin Bockstael 07 PNAS, Burchfield et al 06 QJE), fractals (Thomas, Frankhauser, Tannier), multidimensional (e.g. Arribas-bel 10 CEUS))
- Leapfrog development: '*discontinuous, although possibly compact, patches of urban uses*' Harvey Clark 65 LE
- Scattered vs Leapfrog Mills 81 JUE:
 - *scattered* development reveals mixed rings of developed and undeveloped land.
 - *leapfrog* development explicitly involves radial discontinuity, thus closely connected with a monocentric view of the city.



Literature: Microeconomic models for emerging scatteredness and leapfrog

- Two sources for urban discontinuities:
 - Anticipations Fujita 82, Turnbull 88 and uncertainties Capozza Helsley 90, Bar-Ilan Strange 96
 - Spatial interactions since Beckmann 76
 - Equilibrium with mixed ring from interactions Fujita Ogawa 82, Cavailhès Peeters Sekeris Thisse 04 RSUE
 - ...but all assume radial symmetry!
- **scatteredness** requires 2D models with no *ex ante* symmetry
 - '*satisfactory theory should yield all possible configurations*' Fujita Ogawa
 - Spatial explicit models with endogenous open-space externalities or repelling density effects Irwin Bockstael 02 JEG, Caruso et al 07 RSUE
- **leapfrog** is a simpler case, where 1D is acceptable

Turner 05 JUE, Caruso et al 09 EPB



Goal

A dynamic 2D model

- leading to theoretical scattered morphologies based on endogenous local open-space externalities and endogenous transportation network
- Caruso et al 11 JGS explored phase transitions from a unconstrained set of parameters and liaise to physical DBM and DLA models

This contribution

- Analytically identify conditions for existence, timing and size of leapfrog
- Simulate a reasonable theoretical city (calibrated) in order to later test policies



(Model with endogenous transport network)

Why?

- Not many CA let the network grow (DUEM, Xie and Batty)
- More realistic outputs expected (CA + roads = fractal?)
- Ribbon development creates **morphological lock-ins**
 - 'privatizing' green space view
 - hindering developments in backyards
- Leapfrog to unlock lock-ins?

Restriction of Ribbon Development Act, 1935

'It was unpleasant, undesirable, and obnoxious that the appearance of our highways and the beauty of the country which surround them should be impaired and very often entirely ruined by the disorganised, unsightly, and highly dangerous method of Ribbon Development' (Clarke, Town Planning Review 1936)



Space and agents

- 1 square grid of cells with 1 CBD at (0,0)
- 2 preexisting roads (exogenously financed) crossing at the CBD
- 3 classes of land use: Residential, Road, Agricultural (or Undeveloped, or Green)
- 4 types agents:
 - Landowners: absentee – arbitrage auctions and pocket rents
 - Households: arrive and locate sequentially
 - Farmers : passive – constant bid rent, opportunity rent R_A
 - Public authority: road provider



Space and agents

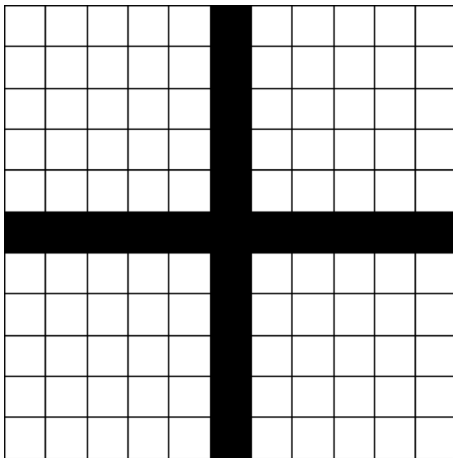


Figure: Preexisting grid and roads



Households decision

Utility:

$$U(Z, H, E, S) = \kappa Z^{1-\alpha} H^\alpha E^\gamma S^\delta$$

Budget:

$$Z + RH = Y - \theta D$$

Z : non spatial good (numéraire)

H : plot size

θ : unitary transport cost

D : commuting distance along road network

α : preference for housing ($0 < \alpha < 1$)

δ : preference for social ($\delta > 0$)

Y : income

E : local green space externalities ($E > 0$)

S : local social externalities ($S > 0$)

R : land rent

γ : preference for green ($\gamma > 0$)

$\kappa = \alpha^{-\alpha} (1 - \alpha)^{\alpha-1}$



Neighbourhood externalities

- Neighbourhood: \hat{w} (window, viewshed, 'amenity-shed')
- Local density: ρ
- Open space amenities:

$$E = e^{-\rho}$$

- Social amenities:

$$S = e^{\rho}$$

- Net amenities:

$$E^{\gamma} S^{\delta} = e^{-\gamma\rho} e^{\delta\rho} = e^{-\beta\rho}$$



Dynamics

- Households enter the city one by one. t : “time” of arrival.
- Households choose a cell, road network follows (minimized new roads at each t)
- **Long-run equilibrium** at t^* : the households obtain the utility of the rest of the world, \bar{U} , since in this case there is no incentive to migrate from/to the region: $\forall x U^{t^*}(x) = \bar{U}$.
- **Short-run equilibrium** at t : all households obtain the same utility regardless of their location x : $\forall x U^t(x) = U^t$.
Households can move at no cost from one built site to another
- Dynamic rents adaptation:

$$R^t(x) = [Y - \theta D(x)]^{1/\alpha} (U^t)^{-1/\alpha} \exp[-\beta \rho^{t-1}(x)]$$



Example of long-run equilibria

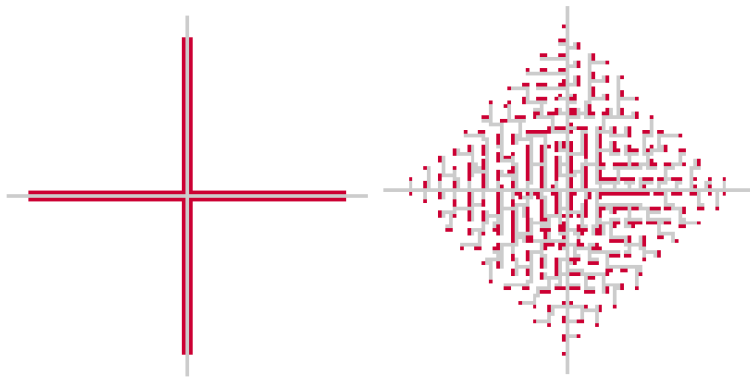


Figure: left: $\beta = 0$ (Alonso) right: $\beta > 0$.

Key: red=housing, grey=road, white=undeveloped



Analysis

- Long-run equilibrium structure in 2D is analytically difficult
- But "first jump" is essential transition from continuous development to sprawl
- Existence of a first leapfrog? When? How far?
- Strategy: find optimum location g^* of newcomer (max of indirect utility function) for each possible configuration of existing city size and neighbourhood size. Leapfrog if $g^* > 0$



Cases

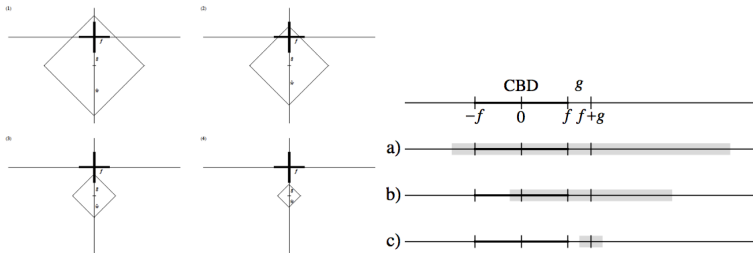


Figure: 2D: 4 cases, 1D: 3 cases



Results: Phases 1D

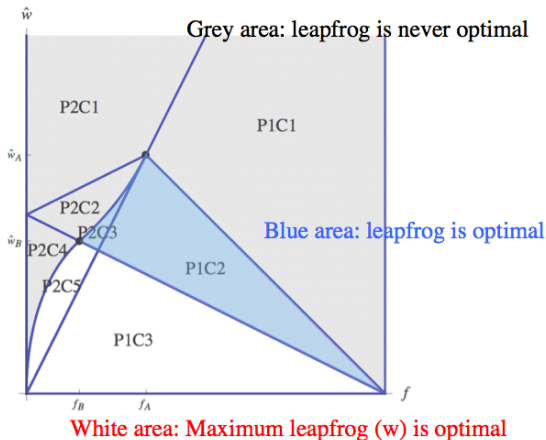


Figure: Phase transitions in the city size /neighbourhood size plane



Calibration

- observable parameters (income, commuting costs, opportunity rent,...) from France INSEE
- α and unobservable β and \bar{U} estimated from structural equations (two stages) using data from Dijon, Brest and Besançon functional urban areas (rents and greenspace)

$$RS = \alpha (Y - \theta D)$$

$$\alpha \ln R - \ln (Y - \theta D) = -\ln \bar{U} - \beta \rho$$



Calibration

$\alpha = 0.07$ (share of land only in housing good)

$\beta = 0.37, \bar{U} = 18033$ (Income being 29000 per year)

Nombre d'observations utilisées 6284
R car. ajust. 0.2811

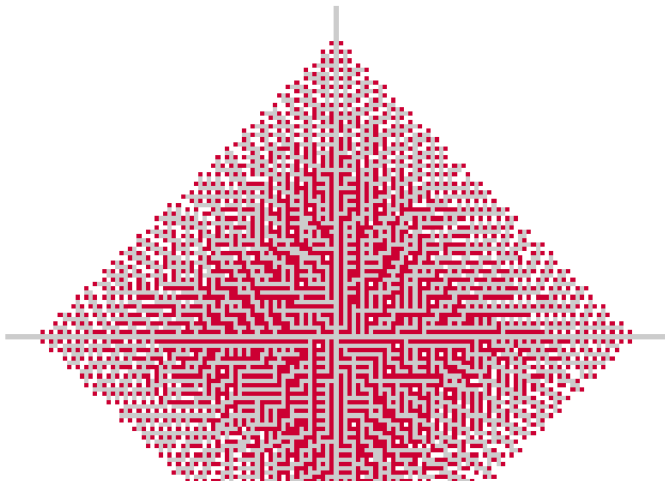
Valeurs estimées des paramètres

Variable	DDL	Valeur estimée des paramètres	Erreur type	Valeur du test t	Pr > t
Intercept	1	-9.83195	0.00407	-2415.7	<.0001
rho	1	-0.37721	0.00999	-37.77	<.0001
besancon	1	-0.08496	0.00425	-20.00	<.0001
brest	1	0.02182	0.00422	5.17	<.0001
an_00	1	-0.07061	0.00452	-15.62	<.0001
an_02	1	-0.05660	0.00468	-12.10	<.0001
an_04	1	-0.03642	0.00454	-8.03	<.0001



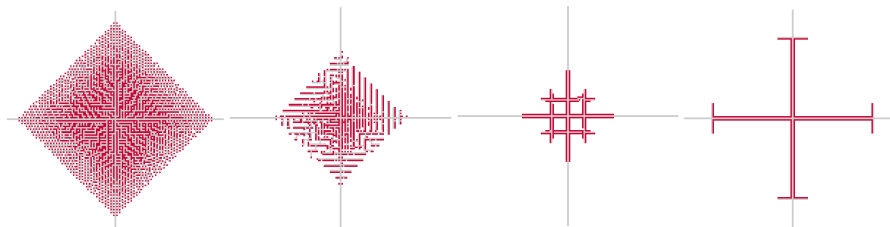
Output

Expected: leapfrog in long-run, dense core plus mixed ring,
expected long-run population





Comparative statics: example neighbourhood size \hat{w} increase





Conclusion

- Analytical demonstration that leapfrog emerges from neighbourhood open-space preference and depends on trade-off between size of 'amenity-shed' and size of city.
- Transitions between no leapfrog and leapfrog cases can be abrupt while changing city size or neighbourhood size
- Analysis reduces drastically exploration space - important to combine analysis with simulation for understanding complex 2D patterns
- After calibration, the model holds reasonable outputs, thus usable testbed for policy scenario testing
- Standard land use and transport policies to be tested after fixing population.
- Current results suggest that increasing the scale of local interaction (by design?) could well lead to more satisfactory while less fragmented cities