Modeling the emergence of metropolitan transport autorithy in a polycentric urban region – the model LUTECIA

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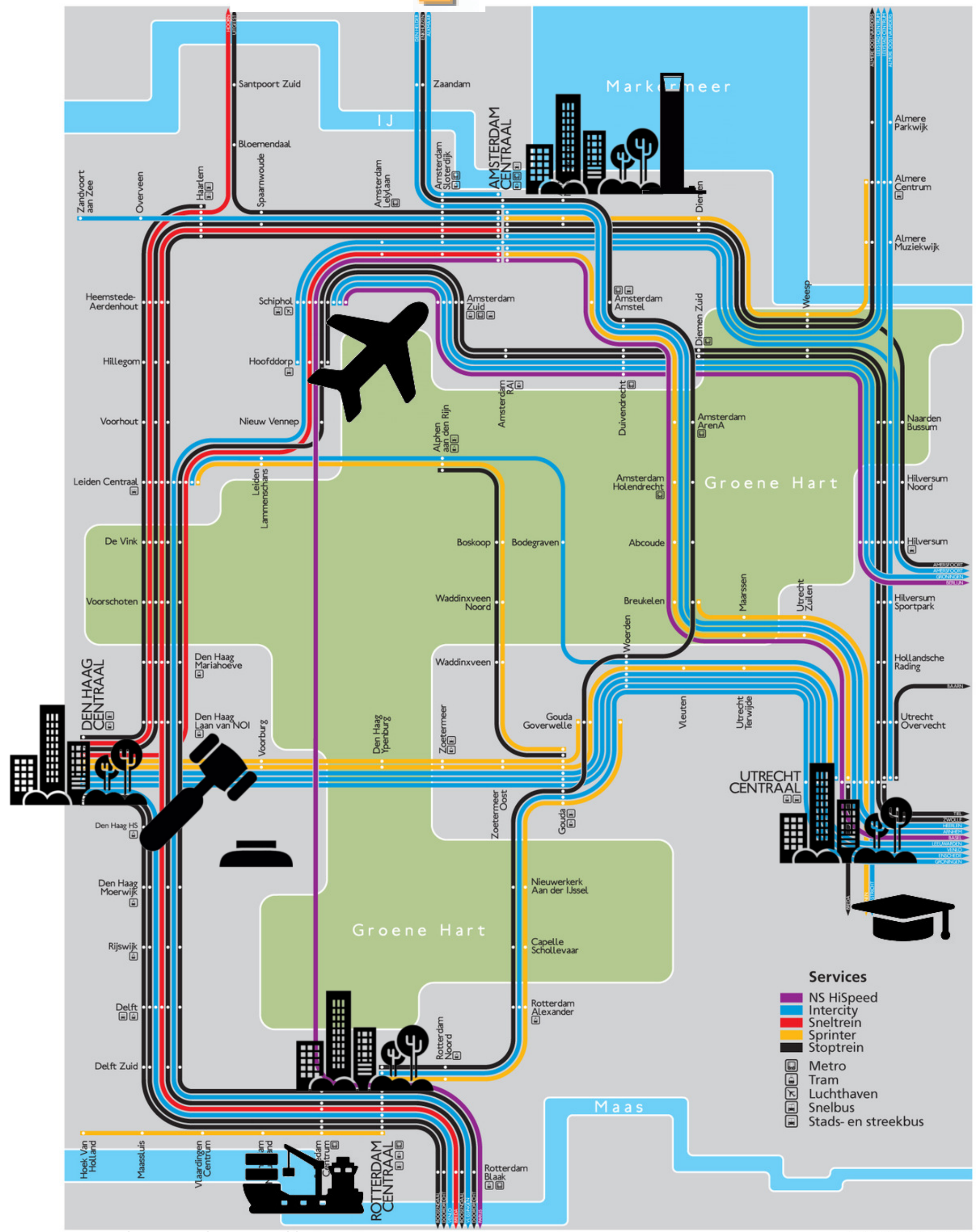
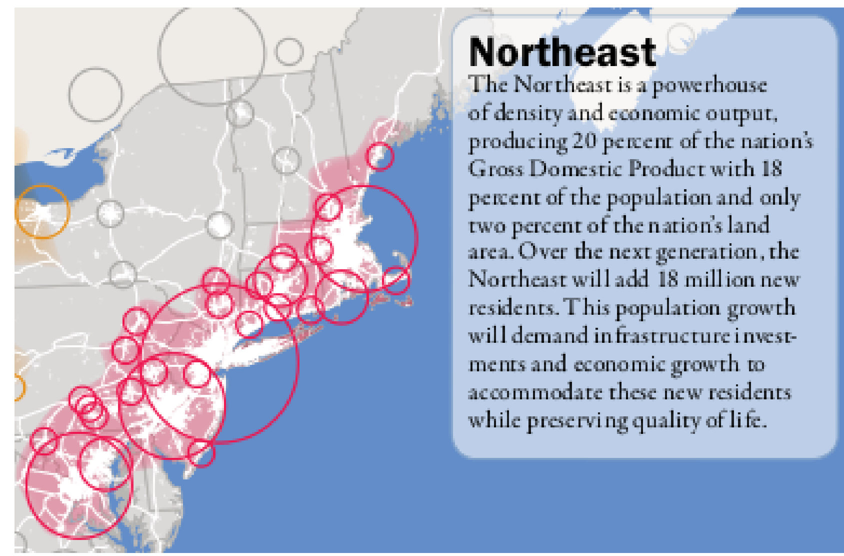


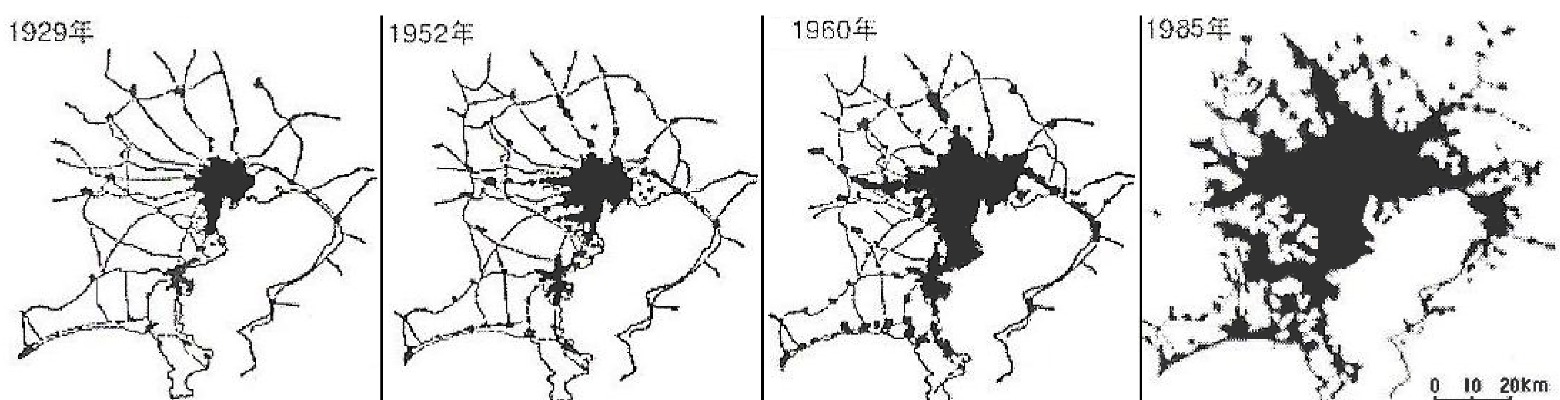
Source : http://transitmaps.tumblr.com
modifications by authors

Context

- From 50's emergence of Mega City Regions (Gottmann, 1957 ; Hall & Pain, 2006).
- New problems to be faced at larger spatial scales
- Towards new form of governance ?

Source : America 2050 report





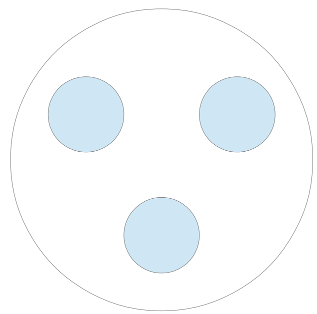
Source : IAURIF, 2005

Outline

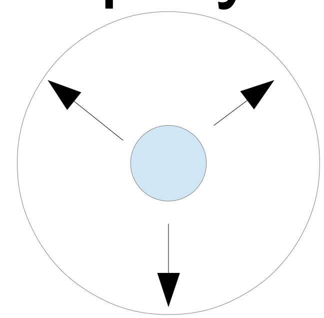
- Emergence of Mega City Regions
- Caracteristics of a Mega City Region
- Modelling framework
- LUTECIA model
- Discussion

Emergence of Mega City Regions

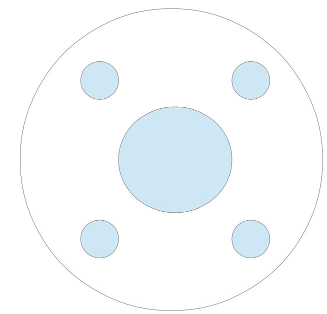
- Champion : emergence of polycentric urban area
  - Fusion
  - Diffusion
  - Absorbtion



e.g. Ruhr area



e.g. Atlanta area (Edge Cities)

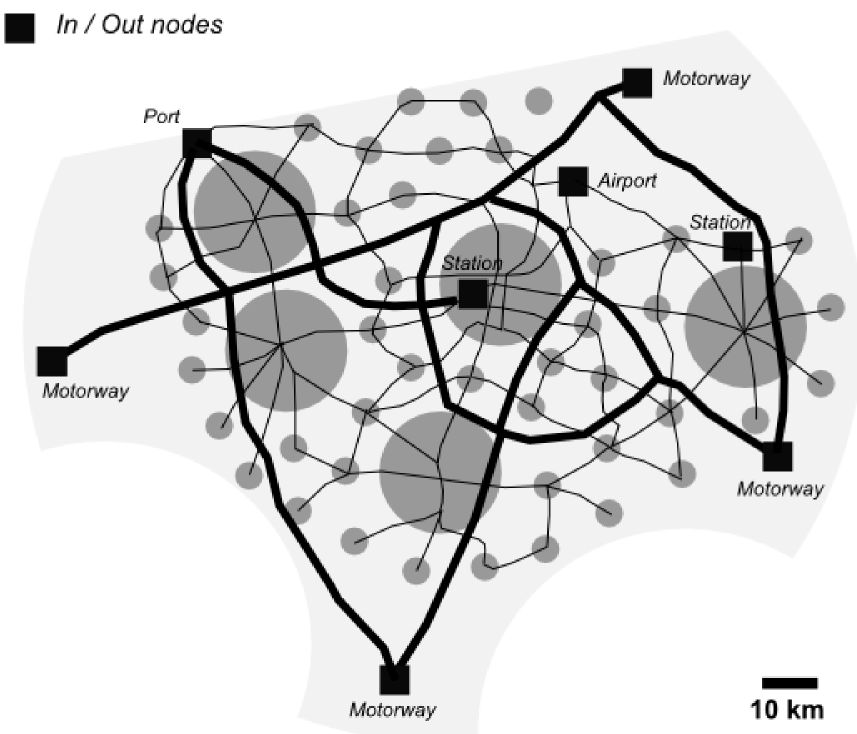


e.g. Paris area

- Paasi : formation of centralized governance
  - Identity (e.g. culture)
  - Name (formalization)
  - Institution (public or not)
  - Capacity to sustain

> ‘most metropolitan regions in the past were focused mainly on one or perhaps two clearly defined central cities, the city-regions of today are becoming increasingly polycentric or multiclustered agglomerations’ (Scott et al., 2001, p. 18; emphasis added by Hoyler & Kloosterman).

Caracteristics of MCR



Examples : Randstad Holland (8 M inh.), Flemish Diamond (5 M), BowWash (50 M), Pearl River Delta (60 M)...

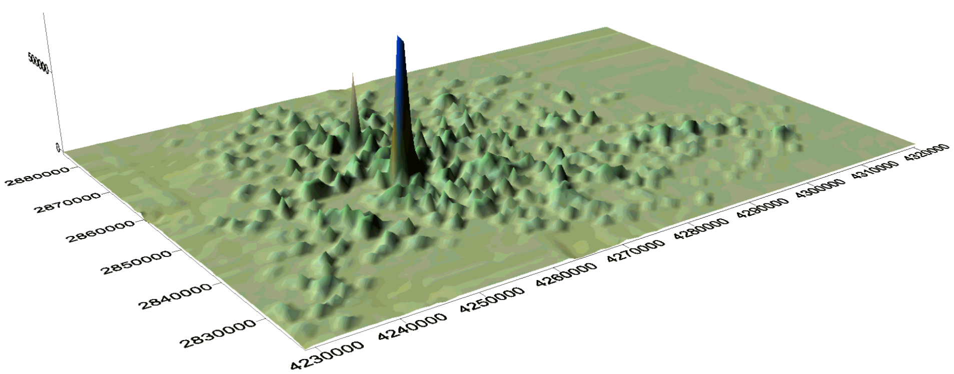
- Made of several urban regions
- With economic and social integration
- Typically served by few major international transport nodes > <u>importance of accessibility at continental level</u>
- Has a few major metropolitan facilities (e.g. CBD, university...) <u>> importance of accessibility at the MCR level</u>
- Transport networks play great role in provision of accessibility at MCR
- No harmonized definition (Polynet network in Europe, America 2050 in US, and others...)
- Flows are typically used to define « self-sufficient » urban region envelops

Gouvernance in Mega City Regions

"Stuttgart metropolitan region"
Regionalverband Stuttgart tackled
- increase in traffic
- consumption of open space
- increasing ecological problems
- social segregation

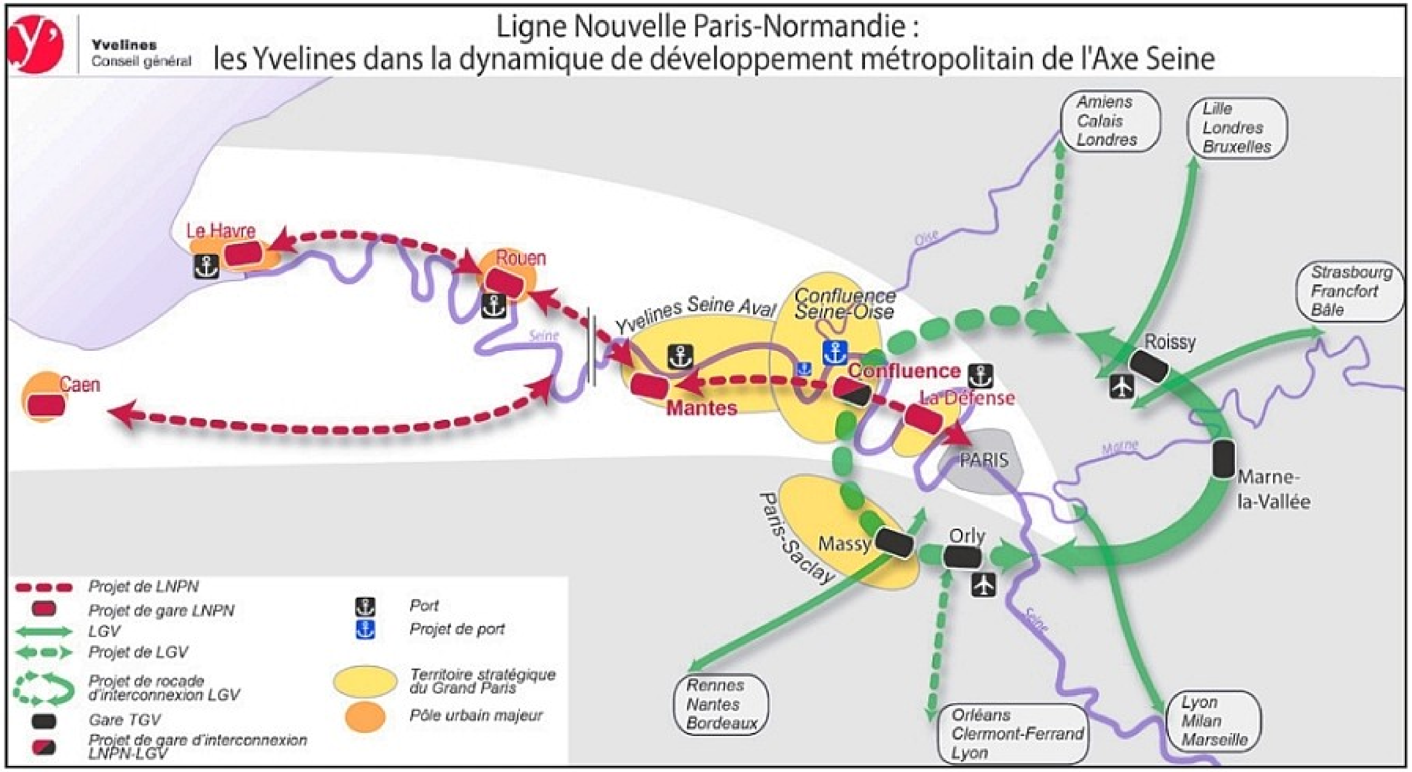
"Globalisation has increased the significance of regions - as autonomous actors and not only as objects of analysis" ("Region Stuttgart Aktuell")

Stuttgart area urban form

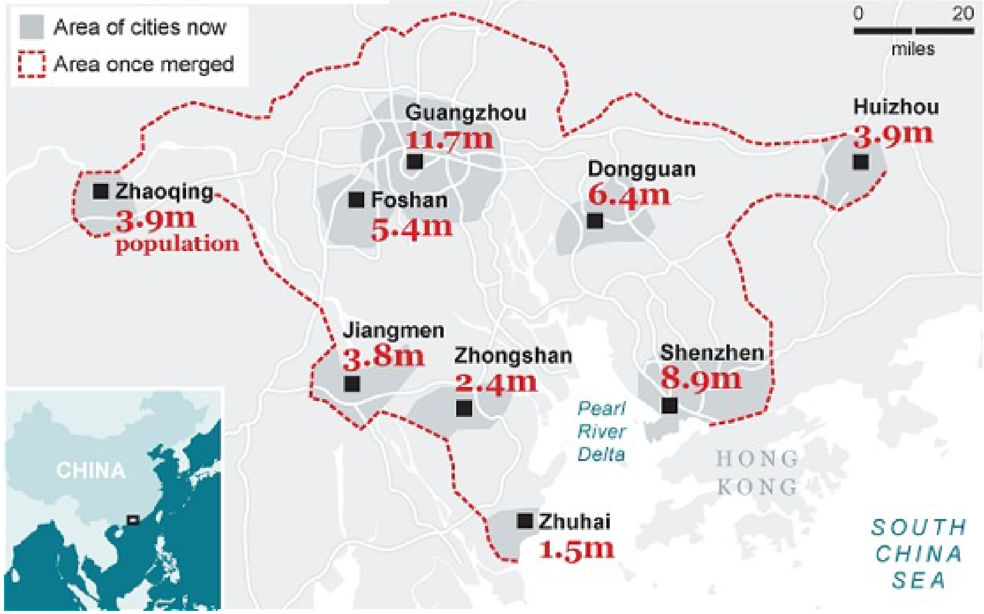


Centralisation forces	Non-centralisation forces
•Mutualisation of ressources (Meijers & Romein, 2003) •Reach a critical mass (Stuttgart) •changed perception of problems (Haag, 2003) •Fostering spillover between agglomeration economies (Sassen, 2007) •Response to intensitified economic competition (Muller, 1994 ; Heeg, 2003)	• • Lack of financial competencies of the new entity • Continued role of central state • Negative impact on environment (Manchester) • Continued localism (Davoudi, 2007) • Lack of economic / cultural integration • Distance between main cities •Costs of cooperation

Paris area : possible better linkeage between Normandy and Roissy airport



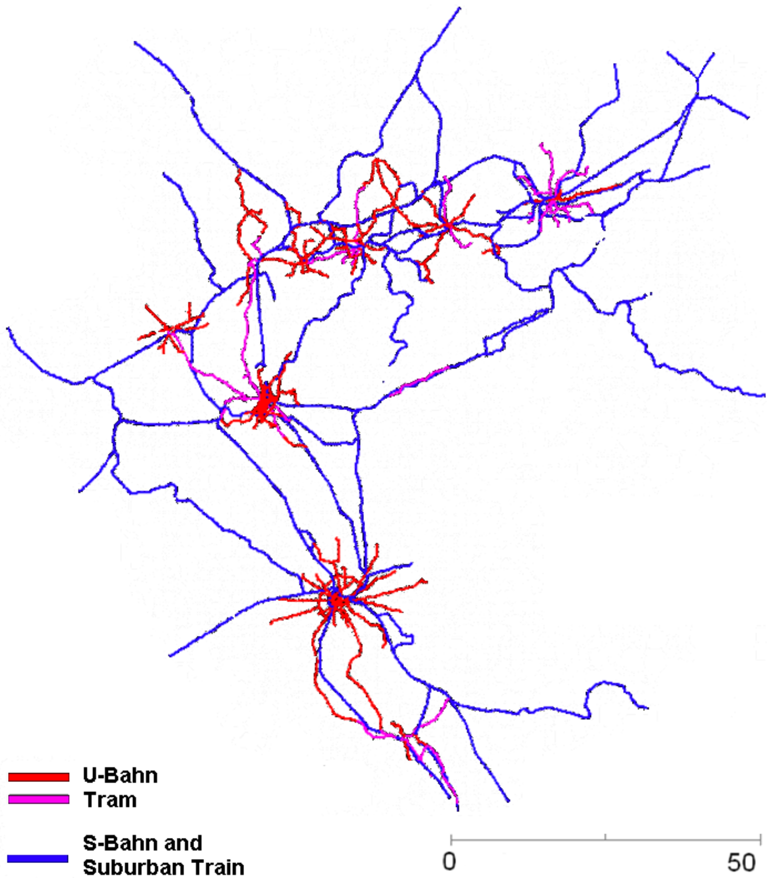
Some exemples of planning transport at MCR scale



Pearl river delta : planned High Speed
Rail system linking Guangzhou to Shenzhen

Thematical questions

- What factors explain the emergence of centralized decision within a set of towns ?
- What consequences does it have on urban dynamic ?

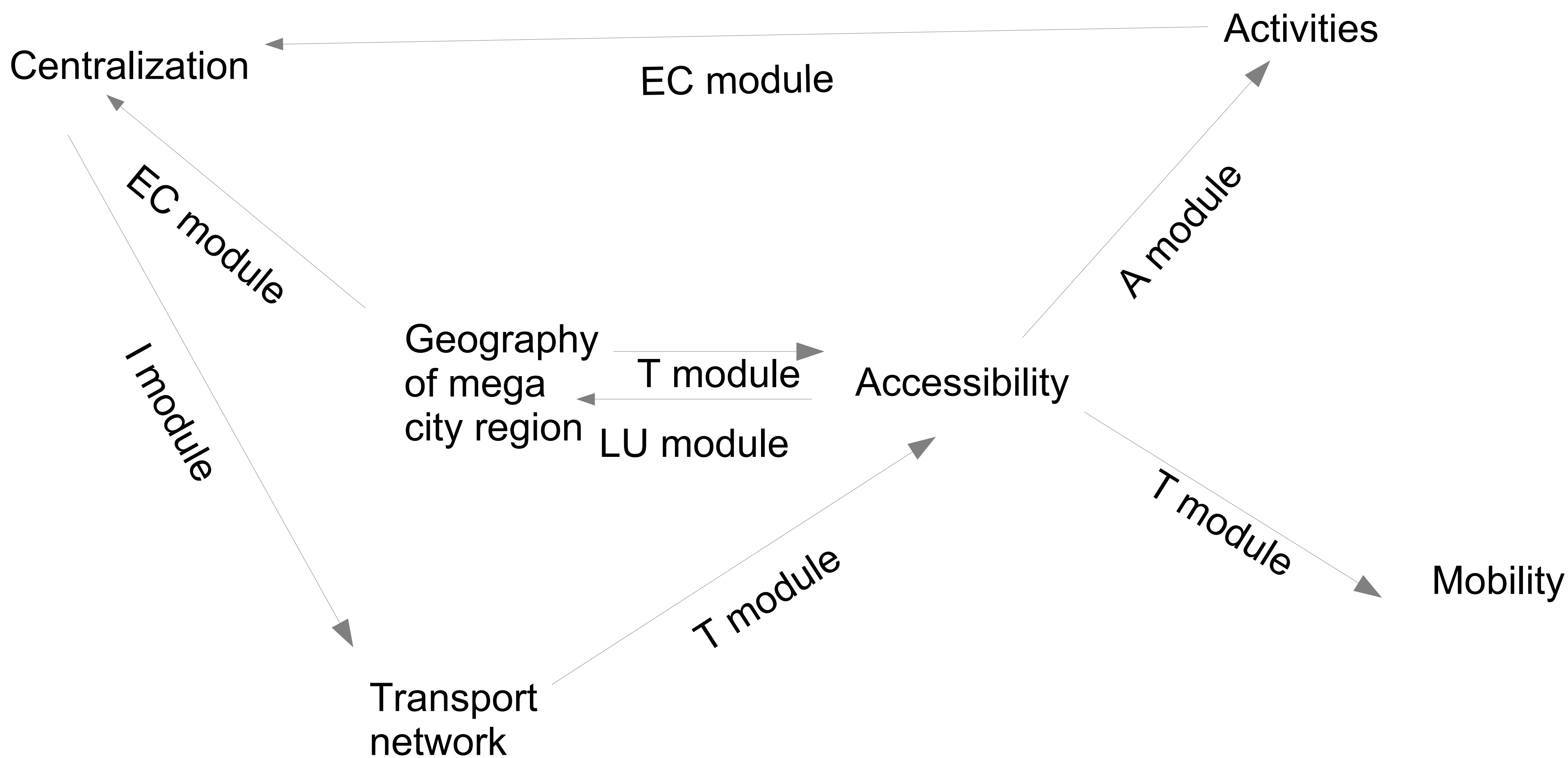


Transport network in Rhine-Ruhr region (Germany)

Modelling framework

- A LUTI + infrastructure provision model (LUTECIA)
  - Coevolution transport / urbanism (LUTI model with endogeneous transport infrastructure provision)
  - Concentration / dispersion forces (Krugman)
  - Game theory framework to predict emergence of centralized decision within a polycentric region
- Competition for external ressource
  - Importance of accessibility at MCR scale

Overview of model LUTECIA



Very simplistic assumptions about geography
> only workers
> only one type of job
> only one type of transport infrastructure

« Open » model : total ressources is not fixed
a new infrastructure is created at each timestep

LU : Land Use module
T : Transport module
EC : Evaluation of Centralized decision module
I : Infrastructure provision module
A : Agglomeration economies module

Infrastructure provision submodel

At each timestep, a new infrastructure is built (Le Néchet, 2011)

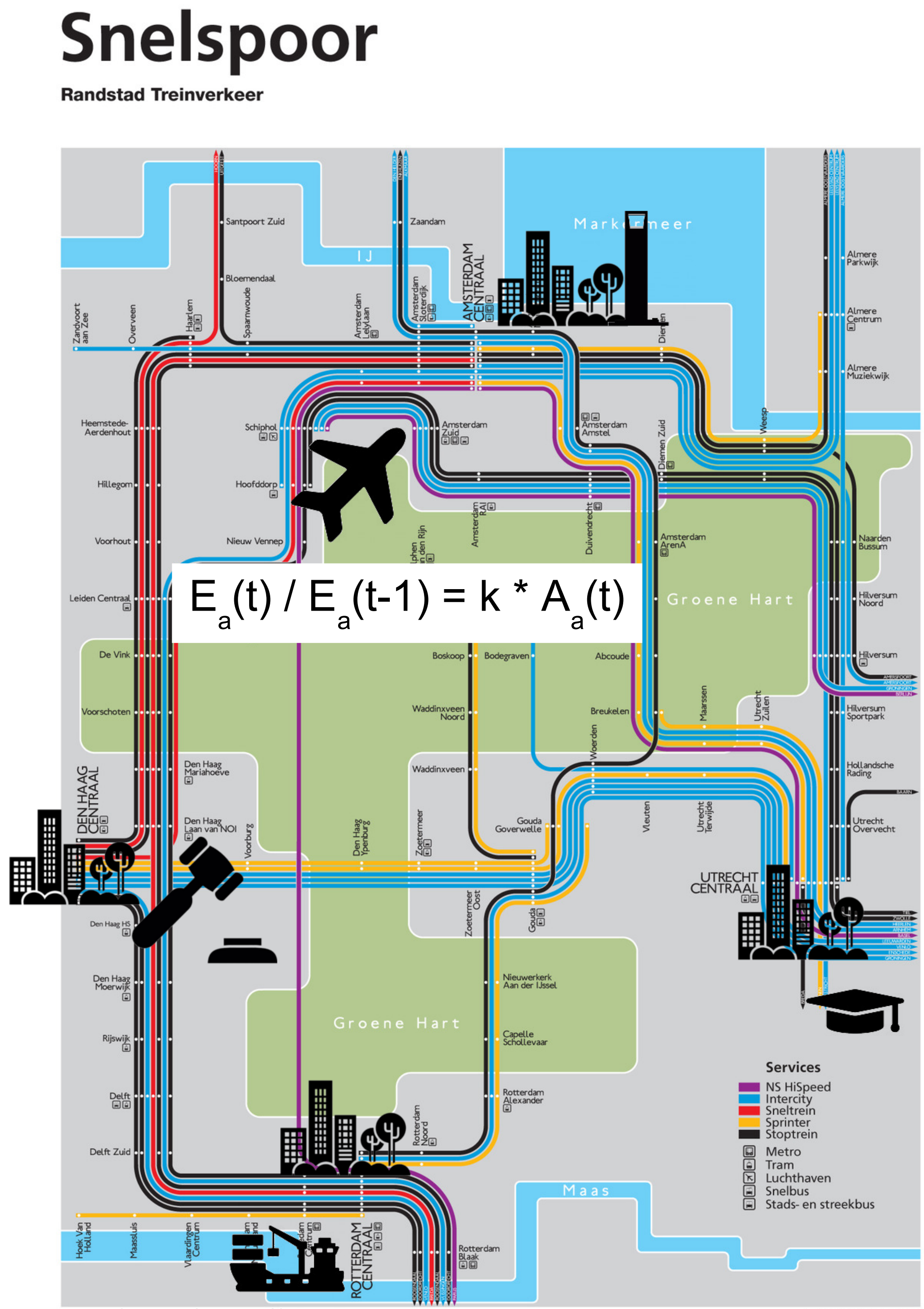
Choice is made by actor T, which is endogeneously chosen by the model

Simplistic hypothesis : governor agents seek to maximize the accessibility for inhabitants within territory T

$$\Omega_T = \sum_{i \in T, j} A_i E_j e^{-\lambda g_{ij}}$$

Scenario « central amenity»

- Reformulation of the thematic question in the « model world »
  - what factors can favour emergence of centralized provision of transport infrastructure ?
  - what impact does it have on employment of a « central super amenity » ?



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Game Theory framework

- Infrastructure planning module implements a game between actors to simulate their choices in the frame of Game Theory (Ordeshook, 1986), already widely used to tackle transportation problems (Roumboutsos and Kapros, 2008).
- Decisions are f rst attributed to global level (centralized decision, global optimization) or local level (game between actors), uniformaly following a parameter p_reg.
- In the case of a local game, probabilities of collaborative / non-collaborative behaviors are determined as described later, and infrastructures are optimized and constructed locally.

Governance Game

Matrix of actors utilities, depending on respective choices

	B Cooperate	B Defect
A Cooperate	$U_A = \Delta X_A(Z_C) - I - J$	$U_A = \Delta X_A(Z_A \cup Z_B) - I - J$
	$U_B = \Delta X_B(Z_C) - I - J$	$U_B = \Delta X_B(Z_A \cup Z_B) - I$
A Defect	$U_A = \Delta X_A(Z_A \cup Z_B) - I$	$U_A = \Delta X_A(Z_A \cup Z_B) - I$
	$U_B = \Delta X_B(Z_A \cup Z_B) - I - J$	$U_B = \Delta X_B(Z_A \cup Z_B) - I$

Where J is the cost of cooperation, I the cost of construction,
$\Delta X(Z)$ accessibility differences for the corresponding infrastructure and area.

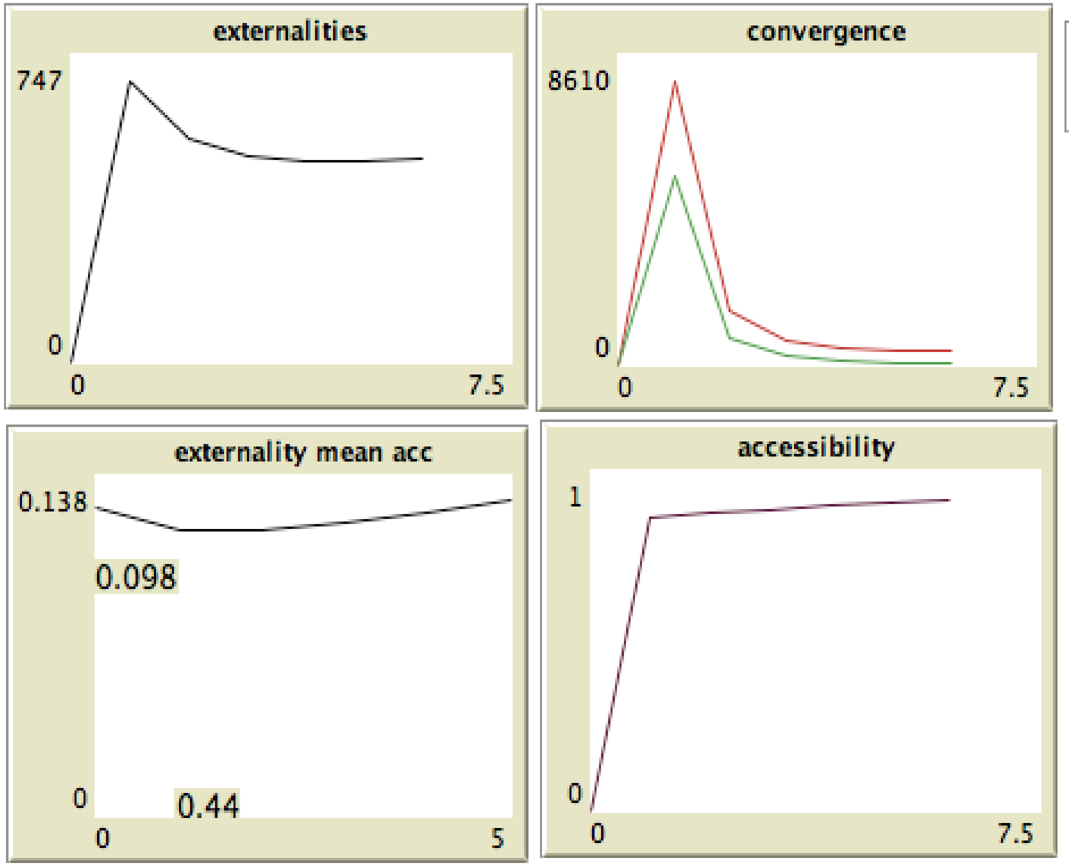
Two types of games are implemented, with different thematic meanings :

- One mixed Nash equilibrium, where actors compete and « try to win »
- One Rational Discrete Choice equilibrium, where players choose to collaborate or not depending on the value of the difference of utilities.

Implementation

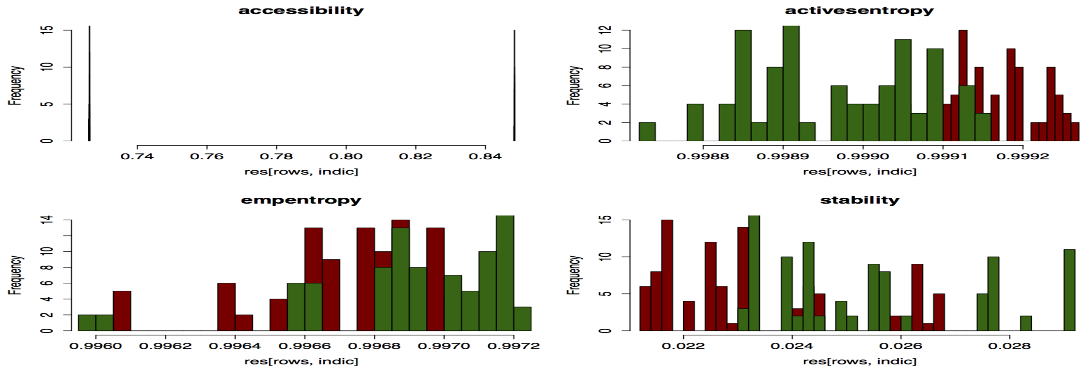
- Implemented in NetLogo (Wilenski, 2004) : practical for ABM/visualization but difficult to have a modular architecture (no object-agent hydrid language, (Rey, 2015)).
- Available under CC licence for reproducibility at https://github.com/JusteRaimbault/MetropolSim
- Specific dynamic programming implementation for network/effective shortest paths (planning module demands recomputation for each potential infrastructure).
- Model explored using OpenMole (Reuillon & al., 2013), allowing extensive exploration through parallel computing.

Run Example


externalities
747
0
0
7.5
convergence
8610
0
0
7.5
externality mean acc
0.138
0.098
0
0.44
0
5
accessibility
1
0
0
7.5

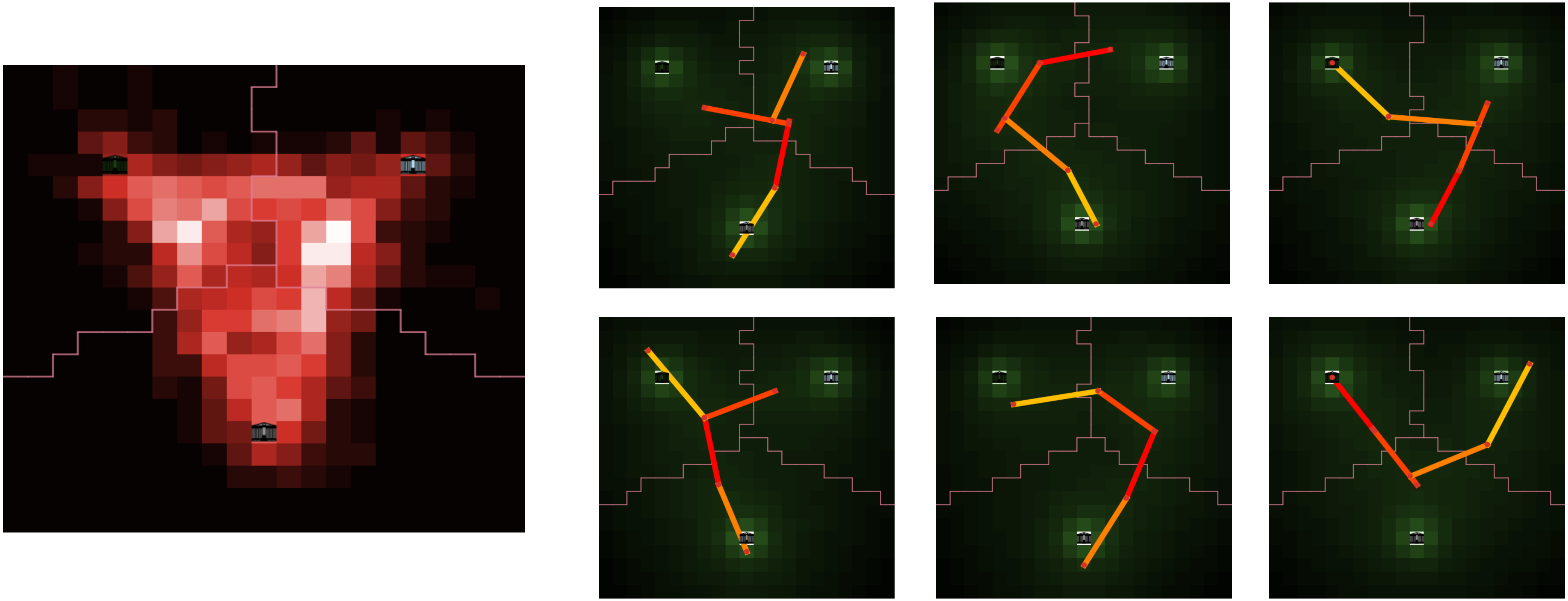
Validation of the model

- External Validation : reproduction of stylized facts for endogeneous dynamics
  - General dynamic of Urban Sprawl over time
  - Travel distances increase (vs ~ stability of travel times)
  - Probability to collaborate increases
- Internal Validation : consistence regarding stochasticity



Validation of the model

- Internal Validation : Infrastructure exploration heuristic. Repetitions on a fixed initial configuration



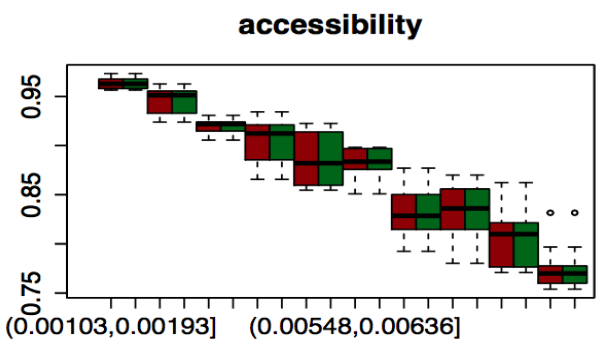
Indicators

Outputs to quantify behavior of the model and to compare different configurations :

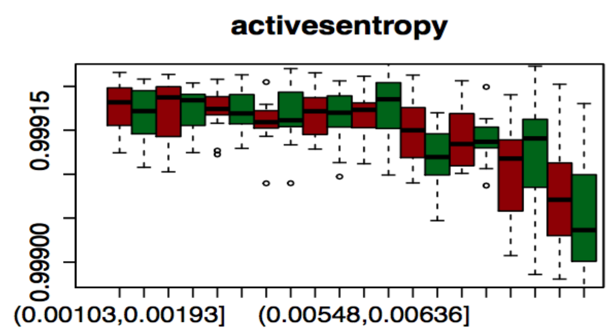
- Actives/Employments final entropy (~ city sprawl)
- Mean Accessibility and travel distance (infra performance)
- Expected probability of collaboration
- Amenity evolution : $E_a(tf)/E_a(t0)$
- Cumulated stability of actives and employments

Results (without central amenity)

- Control parameters such as cost of energy or euclidian pace have expected effect



Lambda Accessibility



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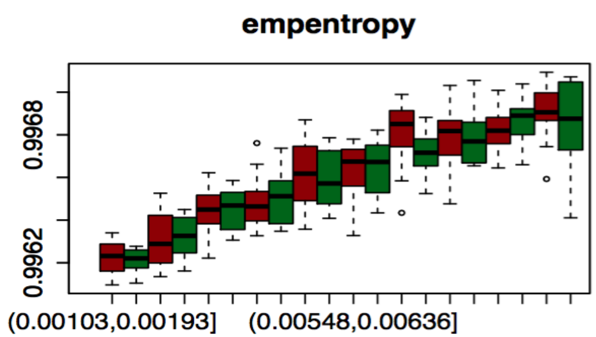

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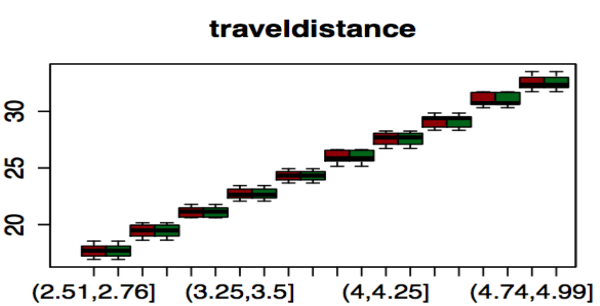
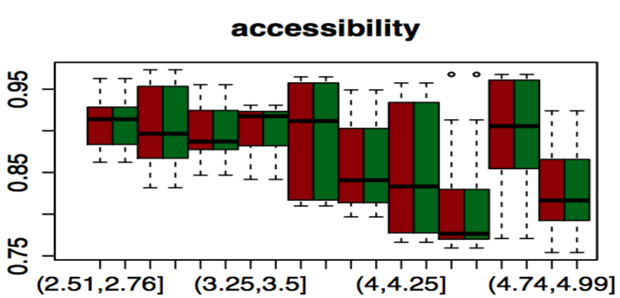


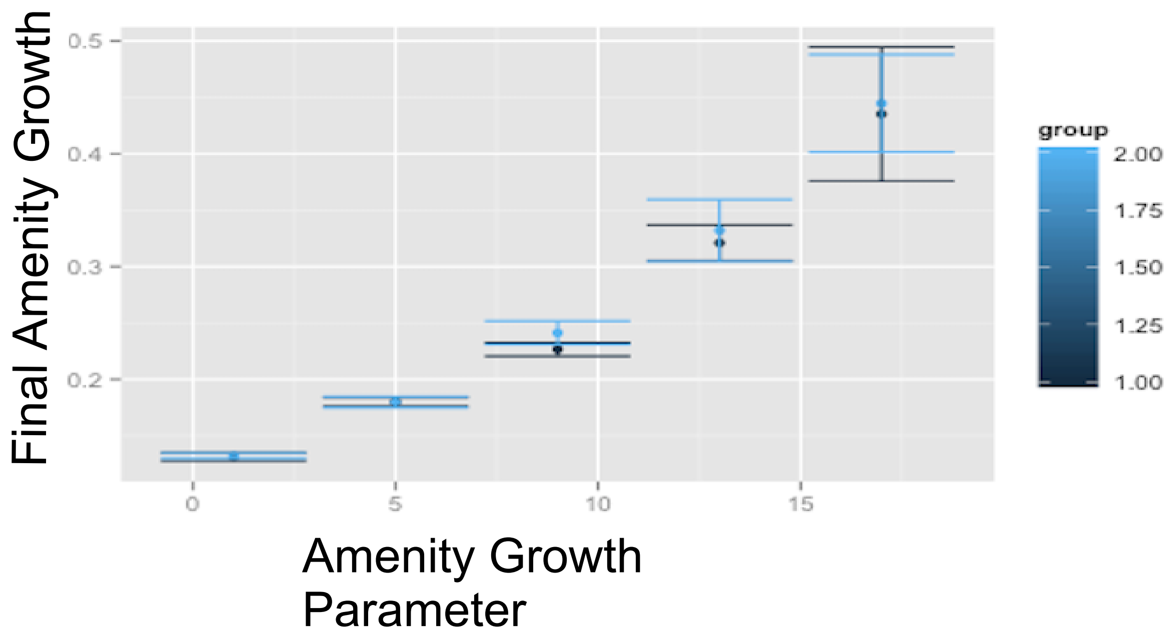
Network speed



Network speed

Results (with central amenity)

- Growth parameter controls facility growth, but has an influence on its volatility

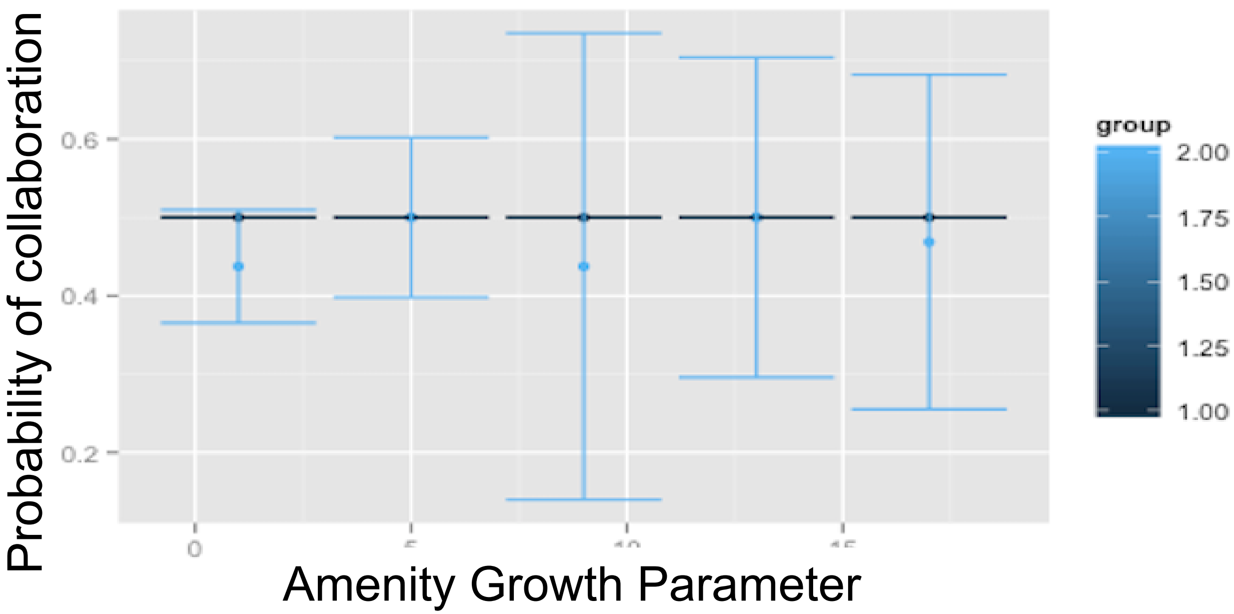


	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.1128552	0.0040352	27.967	< 2e-16	***
collcost	0.1608364	2.7895649	0.058	0.954	
euclpace	-0.0020140	0.0004832	-4.168	3.43e-05	***
extgrowth	0.0183610	0.0001395	131.640	< 2e-16	***
gametype	-0.0011768	0.0015780	-0.746	0.456	
lambdaacc	-1.2892851	0.2789565	-4.622	4.48e-06	***

→ preferential attachment scheme for volatility ?

Results (with central amenity)

- No significant influence of facility growth on collaboration for both games

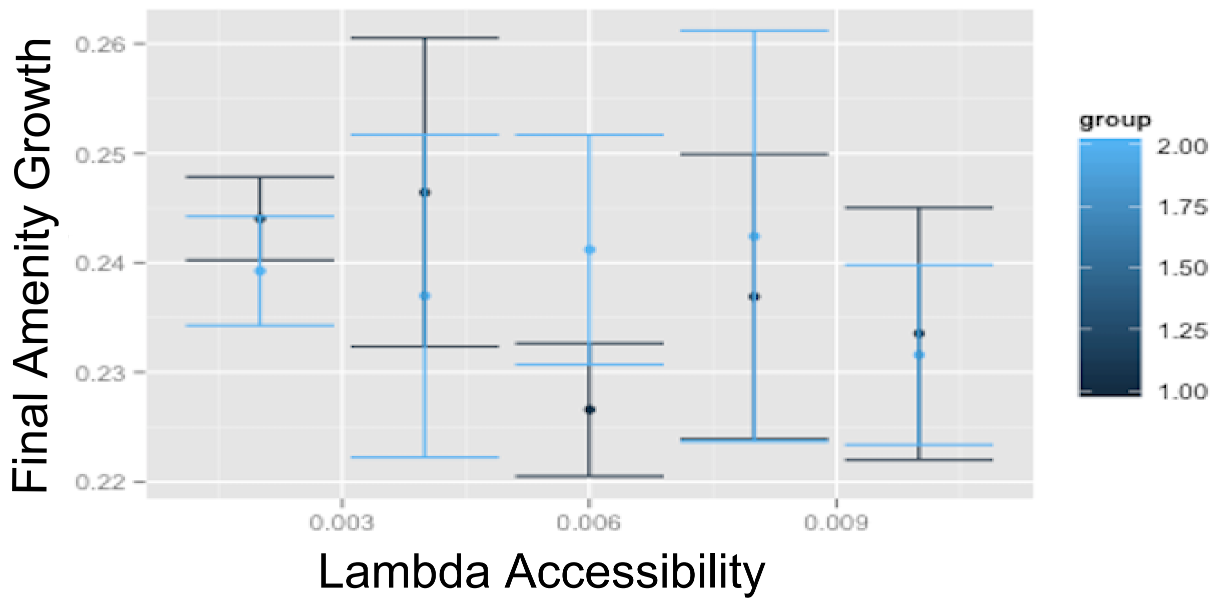


	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	4.907e-01	1.196e-02	41.017	< 2e-16	***
collcost	-6.932e+01	8.271e+00	-8.381	2.61e-16	***
euclpace	-7.500e-04	1.433e-03	-0.524	0.601	
extgrowth	3.490e-04	4.136e-04	0.844	0.399	
gametype	4.283e-02	4.679e-03	9.155	< 2e-16	***
lambdaacc	1.562e-01	8.271e-01	0.189	0.850	

→ further study needed to confirm or find bias origin (exploration heuristic, too few repetitions, wrong value for controlling parameter ?)

Results (with central amenity)

- Does cost of energy sligthly decrease facility growth ?



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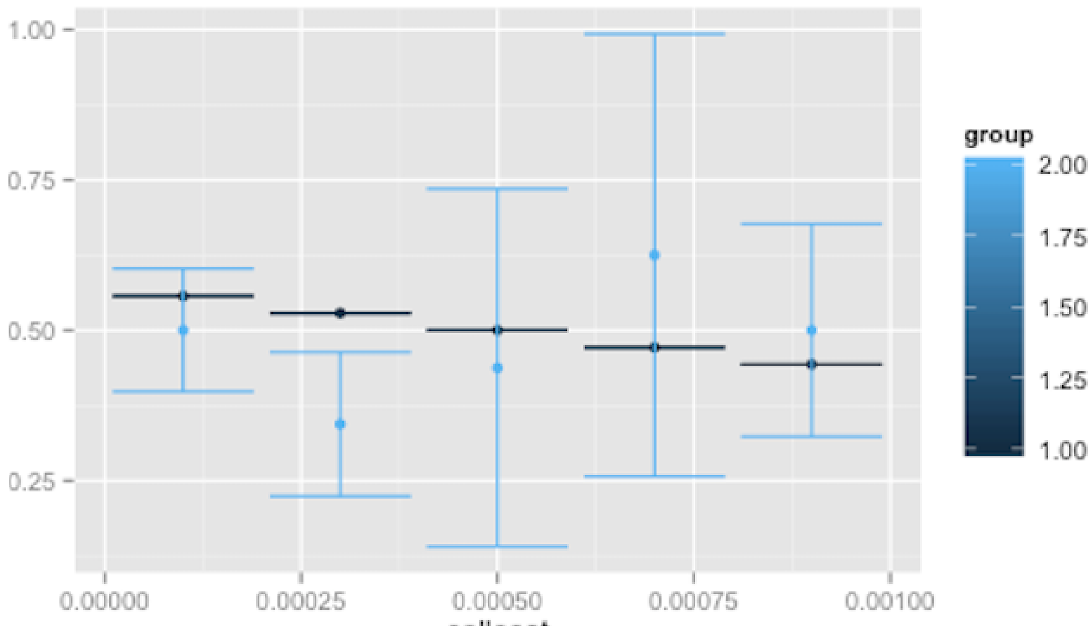
→ feedback of accessibility on relocation ?

Results (with central amenity)

- Influence of collaboration cost

Probability of collaboration



Collaboration Cost

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→ Nash game is chaotic, we do not converge towards E[1/(ΔXc-ΔXi)]. (why?)

Main Conclusions of Experiments

- Optimized operational implementation.
- Expected influence of « main » parameters and expected behavior of the extended Luti model.
- Difficult to extract the role of secondary parameters, that must be hidden in noise at this level of statistical significance → only a large scale exploration (order of 10^7 simulations ~ 10^9s CPU time) will allow to obtain exploitable thematic conclusion through robust model behavior knowledge, see (Schmitt & al., 2015).
- Further themetical experiment to be conducted :
  - Influence of initial urban form ?
  - Influence of continued National planning ?

Concluding discussion

- Path dependancy in infrastructure construction : final result does not globally optimize, since it is built step by step.
- Question of applicability : possibility of going further than a toy model (Banos, 2013) ?
  - More realistic urban forms ?
  - More detailed LUTI module structure.
- Step towards the integration of endogeneous governance in models coupling network growth with city growth (models which are quite rare (Raimbault, 2015))

Reserve Slides

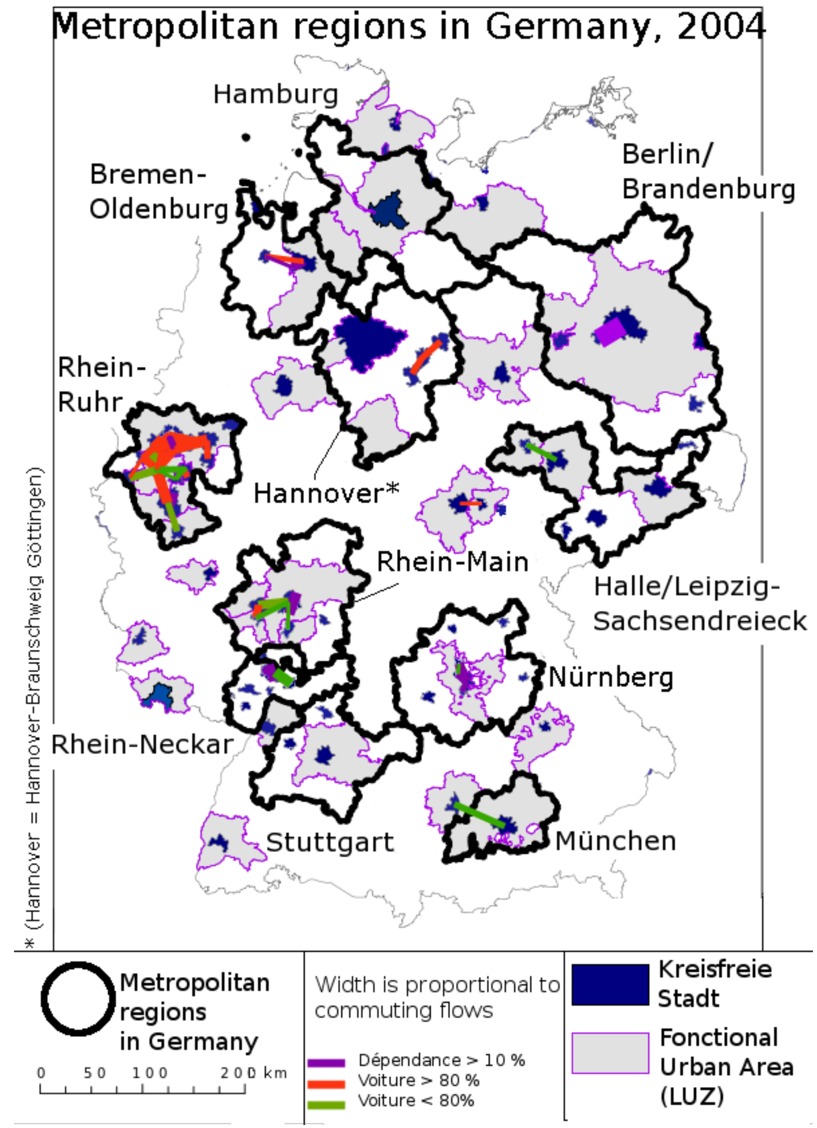
Cities, states and mega city regions

Tenfold increase in mobility

	1960	1990	2020	2050
World population	3	5	7,5	9,5
Total distance (x10^12 km)	5	25	55	105
Distance per person per year (km)	1700	5000	7300	11000

Source Schaefer & Victor, 2000 + UN + own computation

Impact at all spatial scales :
- intra urban
- inter urban, within Mega City Regions
- inter urban, world wide



Polycentric network of cities

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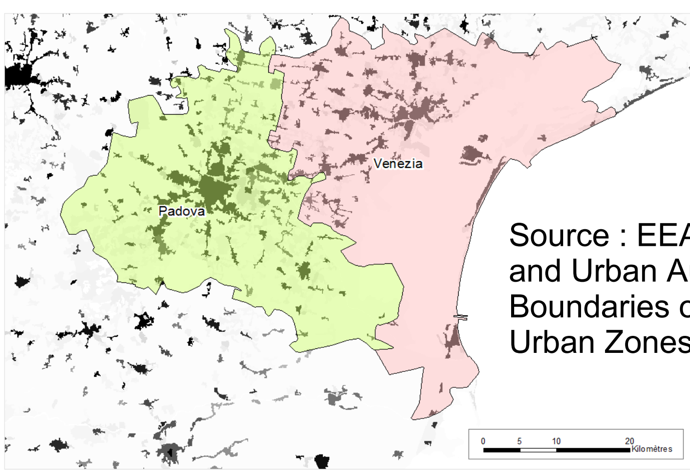
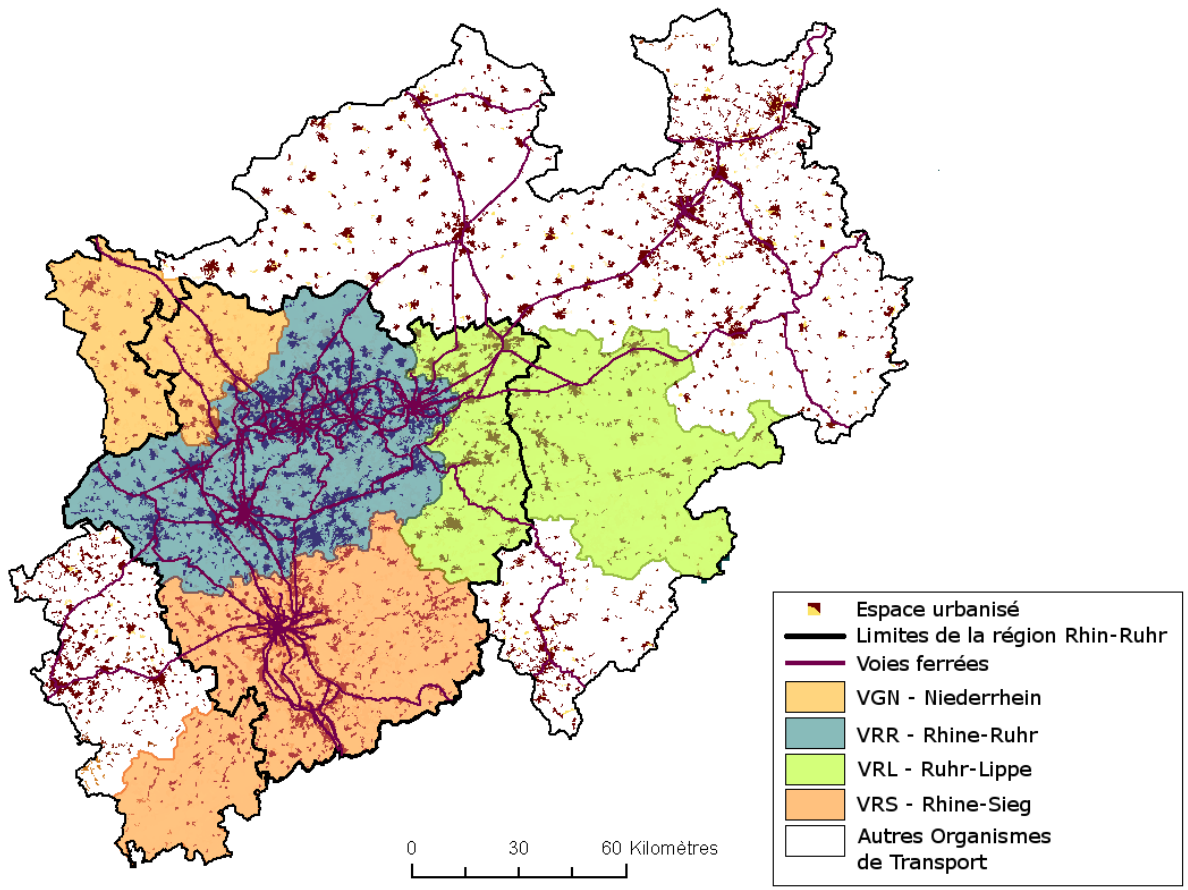


Source : EEA (2002) and Urban Audit. Boundaries of « Larger Urban Zones »

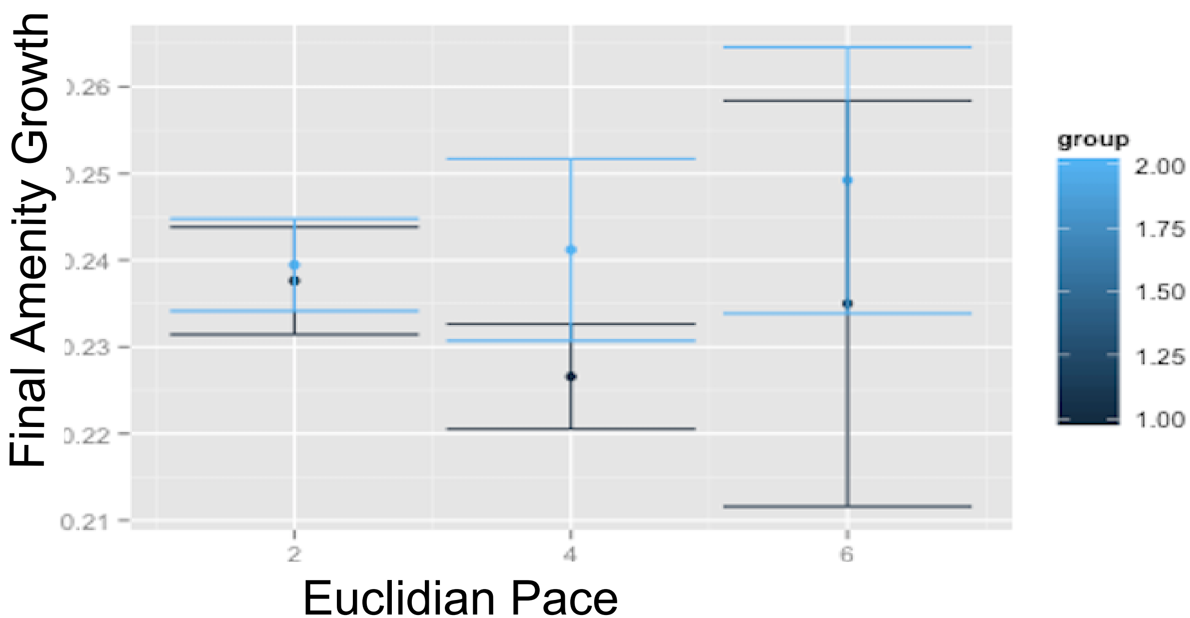
Rhine-Ruhr area

- 12 M inhabitants
- Local cities has important planning power (Knapp & Schmitt)
- Historical cultural differences (Blotevogel)
- 4 transport autorithy with fare integration



Results (with central amenity)

- Euclidian Pace : inverse effect for two games, but not significant



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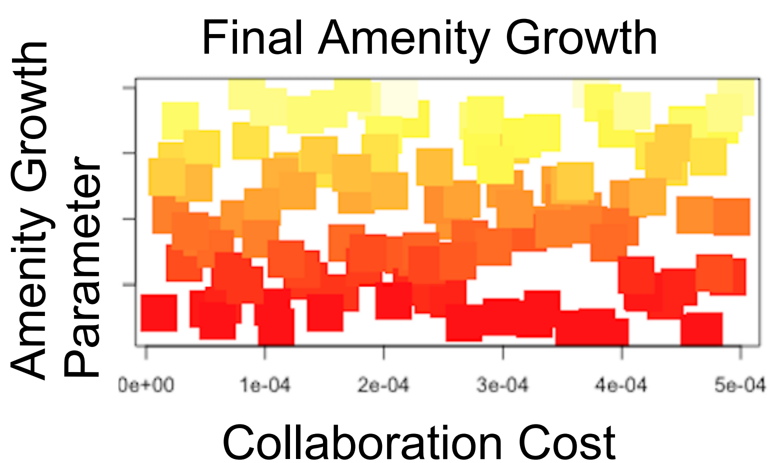
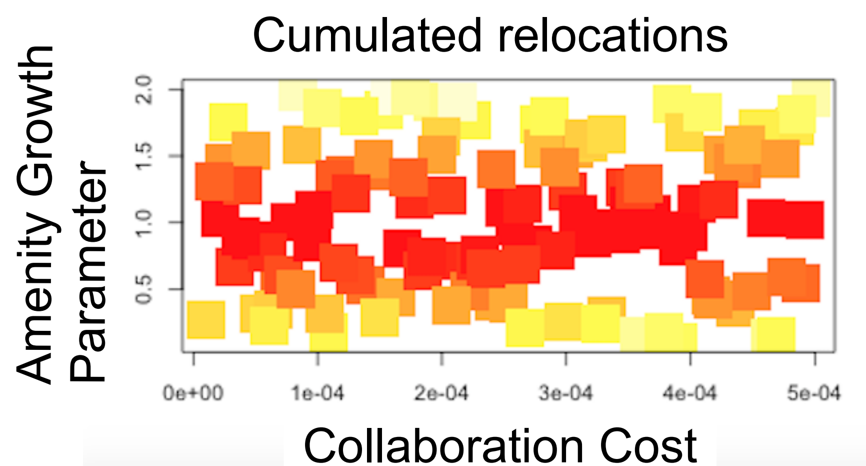
Results (without central amenity)

- Collaboration cost vs growth parameter : independance of their influence on stability and facility growth for these settings





→ Need of more computations to regress statistical models and achieve control.

Equations for Games

Probability of collaboration in mixed Nash case :

$$p_i = \frac{J}{\Delta X_{\bar{i}} Z_C^\star - \Delta X_{\bar{i}} Z_{\bar{i}}^\star}$$

Difference of utilities in DC game yields the corresponding equation to solve to obtain probability to cooperate :

$$U_i(C) - U_i(NC) = p_{\bar{i}} \left(\Delta X_i Z_C^\star - \Delta X_i Z_i^\star\right) - J$$

$$p_i = \frac{1}{1 + \exp\left(-\beta_{DC} \cdot \left(\frac{\Delta X_i Z_C^\star - \Delta X_i Z_i^\star}{1 + \exp\left(-\beta_{DC}(p_i \cdot (\Delta X_{\bar{i}} Z_C^\star - \Delta X_{\bar{i}} Z_{\bar{i}}^\star) - J)\right)} - J\right)\right)}$$

Initial distribution of Actives and Employments around governance centers at positions $\vec{x}_i$ by

$$A(\vec{x}) = A_{max} \cdot \exp\left(\frac{\|\vec{x} - \vec{x}_i\|}{r_A}\right); E(\vec{x}) = E_{max} \cdot \exp\left(\frac{\|\vec{x} - \vec{x}_i\|}{r_E}\right)$$

For facility patches, employments are added by $E(\vec{x}) = E(\vec{x}) + \frac{k_{ext} \cdot E_{max}}{n_{ext}}$.

Transportation module : computation of flows ϕ_{ij} by solving on p_i, q_j by a fixed point method (Furness algorithm), the system of gravital flows

$$\begin{cases} \phi_{ij} = p_i q_j A_i E_j \exp\left(-\lambda_{tr} d_{ij}\right) \\ \sum_k \phi_{kj} = E_j ; \sum_k \phi_{ik} = A_i \\ p_i = \frac{1}{\sum_k q_k E_k \exp\left(-\lambda_{tr} d_{ik}\right)} ; q_j = \frac{1}{\sum_k p_k A_k \exp\left(-\lambda_{tr} d_{kj}\right)} \end{cases}$$

Trajectories then attributed by effective shortest path, and corresponding congestion c obtained (no Wardrop equilibrium).
Speed of network given by BPR function $v(c) = v_0 \left(1 - \frac{c}{\kappa}\right)^{\gamma_c}$. Congestion not used in current studies (infinite capacity κ).

Land-Use module : we assume that residential/employments relocations are at equilibrium at the time scale of a tick, that corresponds to transportation infrastructure evolution time scale which is much larger (Bretagnolle, 2009).
We take a Cobb-douglas function for utilities of actives/employments at a given cell

$$U_i(A) = X_i(A)^{\gamma_A} \cdot F_i(A)^{1-\gamma_A}; F_i(A) = \frac{1}{A_i E_i}$$

$$U_j(E) = X_j(E)^{\gamma_E} \cdot F_j(E)^{1-\gamma_E}; F_j(E) = 1$$

where $X_i(A) = A_i \cdot \sum_j E_j \exp\left(-\lambda \cdot d_{ij}\right)$ and $X_j(E) = E_j \cdot \sum_i A_i \exp\left(-\lambda \cdot d_{ij}\right)$.
Relocations are then done deterministically following a discrete choice model :

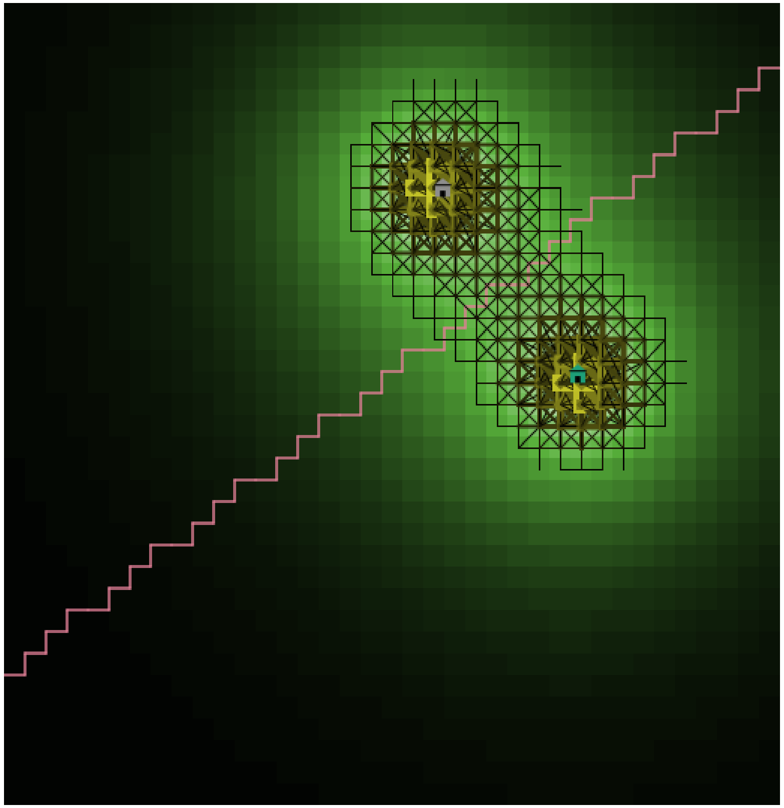
$$A_i(t+1) = \sum_i A_i(t) \cdot \frac{\exp\left(\beta U_i(A)\right)}{\sum_i \exp\left(\beta U_i(A)\right)}$$

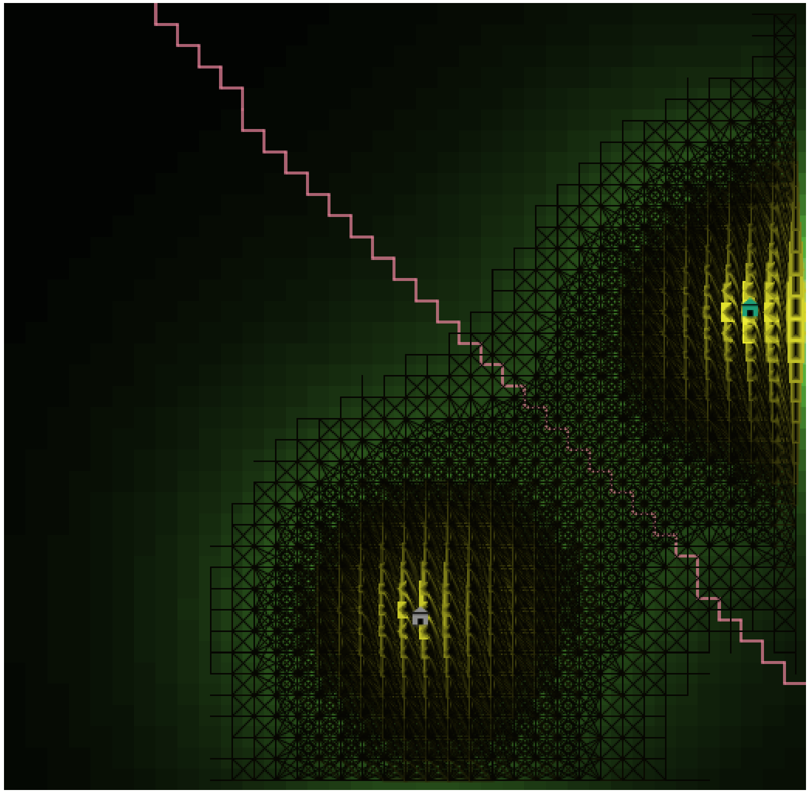
$$E_j(t+1) = \sum_j E_j(t) \cdot \frac{\exp\left(\beta U_j(E)\right)}{\sum_j \exp\left(\beta U_j(E)\right)}$$

Effective distances computation

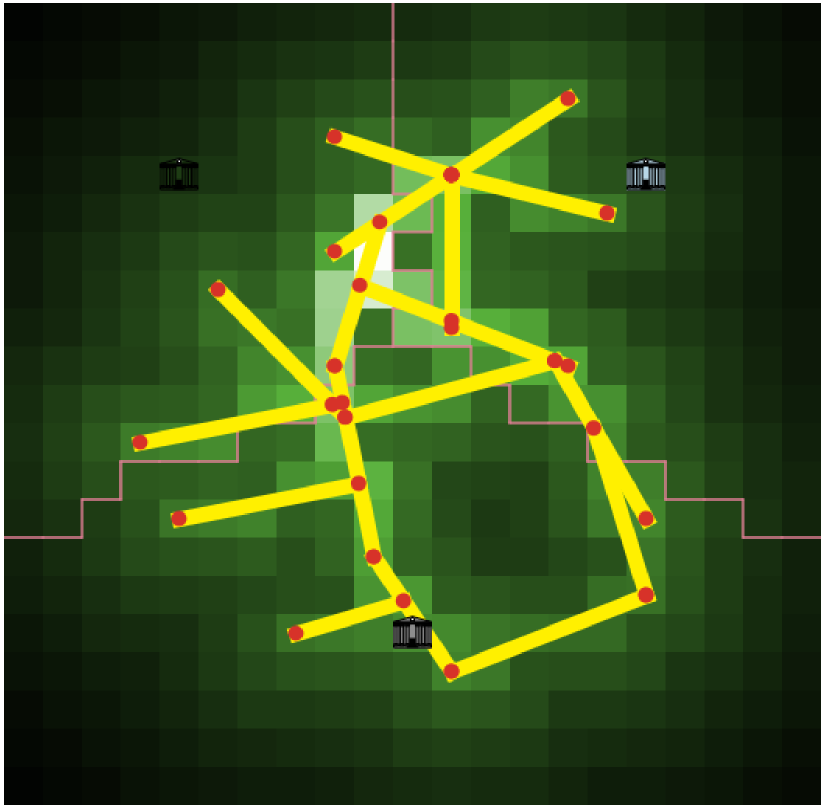
- Euclidian distance matrix $d(i,j)$ computed analytically
- Network shortest paths between network intersections (rasterized network) updated in a dynamic way (addition of new paths and update/change of old paths if needed when a link is added), correspondance between network patches and closest intersection also updated dynamically ; $O(N_{inters}^3)$
- Weak component clusters and distance between clusters updated ; $O(N_{nw}^2)$
- Network distances between network patches updated, through the heuristic of only minimal connexions between clusters ; $O(N_{nw}^2)$
- Effective distances (taking paces/congestion into account) updated as minimum between euclidian time and $\min_{C,C'} d(i,C) + d_{nw}(p_C(i), p'_C(j)) + d(C',j)$; $O(N_{clusters}^2 \cdot N^2)$ [Approximed with $\min_C$ only in the implementation, consistent within the interaction ranges ~ 5 patches taken in the model].

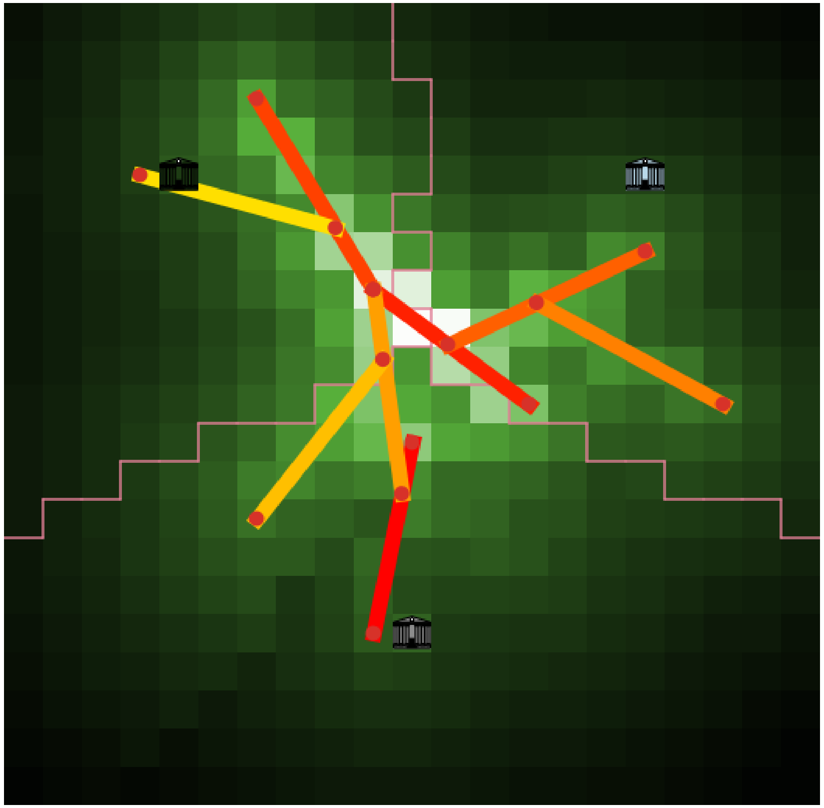
Flows Visualization Example





Long-time Limits for Network Examples





Accessibility

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.114e+00	3.898e-03	285.731	<2e-16	***
collcost	-7.470e-03	2.695e+00	-0.003	0.998	
euclpace	-3.162e-02	4.667e-04	-67.749	<2e-16	***
extgrowth	4.689e-07	1.347e-04	0.003	0.997	
gametype	5.338e-06	1.524e-03	0.004	0.997	
lambdaacc	-2.133e+01	2.695e-01	-79.164	<2e-16	***

Actives Entropy

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	9.991e-01	1.102e-05	90646.920	<2e-16	***
collcost	6.219e-04	7.619e-03	0.082	0.935	
euclpace	-2.098e-05	1.320e-06	-15.898	<2e-16	***
extgrowth	6.307e-08	3.810e-07	0.166	0.869	
gametype	-4.320e-06	4.310e-06	-1.002	0.316	
lambdaacc	-1.245e-02	7.619e-04	-16.337	<2e-16	***

Employment Entropy

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	9.959e-01	2.331e-05	42729.105	<2e-16	***
collcost	2.573e-03	1.611e-02	0.160	0.8732	
euclpace	9.001e-05	2.791e-06	32.255	<2e-16	***
extgrowth	1.398e-06	8.056e-07	1.735	0.0831	.
gametype	-8.347e-06	9.114e-06	-0.916	0.3601	
lambdaacc	6.544e-02	1.611e-03	40.617	<2e-16	***

Collaboration

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	4.907e-01	1.196e-02	41.017	< 2e-16	***
collcost	-6.932e+01	8.271e+00	-8.381	2.61e-16	***
euclpace	-7.500e-04	1.433e-03	-0.524	0.601	
extgrowth	3.490e-04	4.136e-04	0.844	0.399	
gametype	4.283e-02	4.679e-03	9.155	< 2e-16	***
lambdaacc	1.562e-01	8.271e-01	0.189	0.850	

Amenity Growth

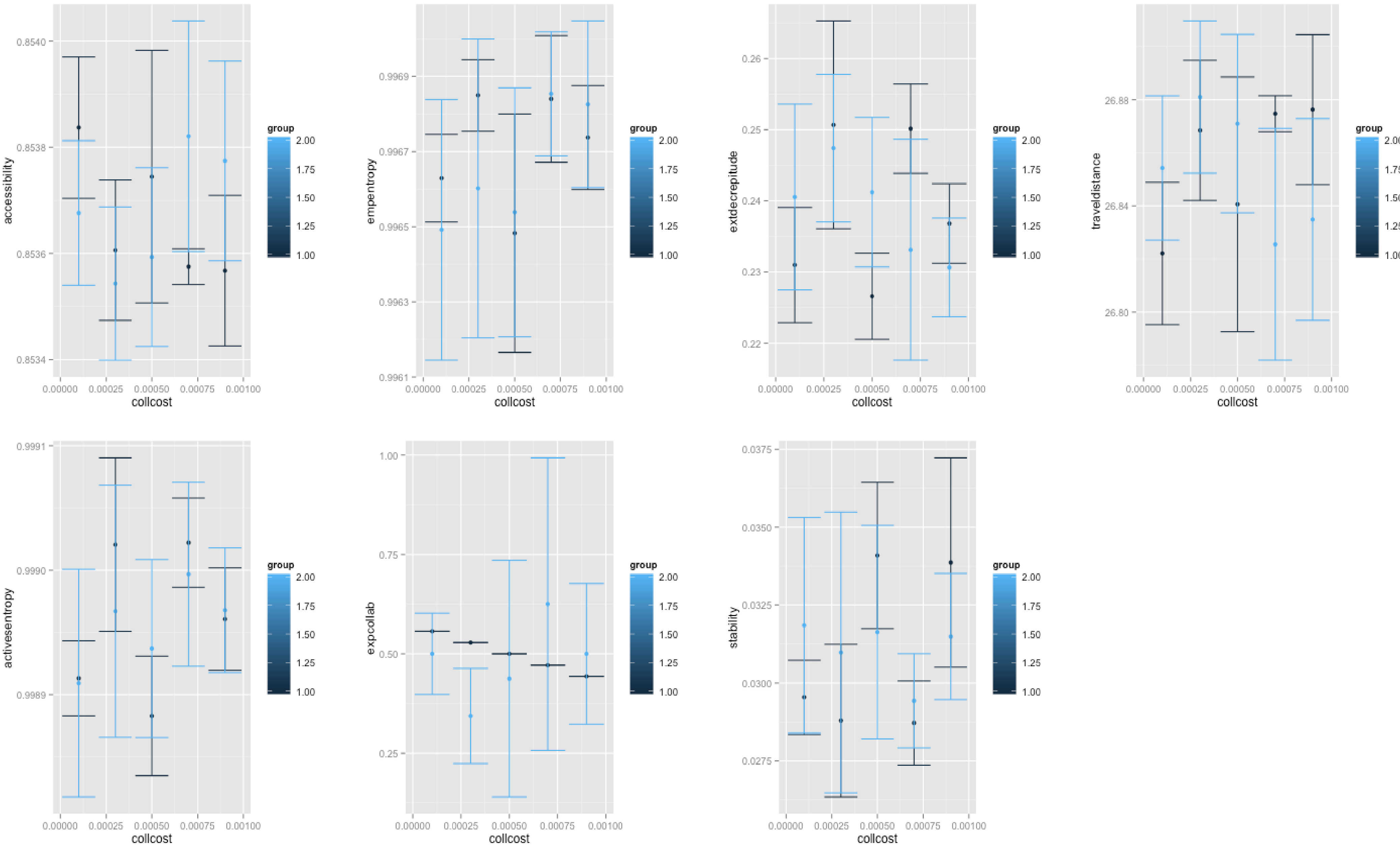
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.1128552	0.0040352	27.967	< 2e-16	***
collcost	0.1608364	2.7895649	0.058	0.954	
euclpace	-0.0020140	0.0004832	-4.168	3.43e-05	***
extgrowth	0.0183610	0.0001395	131.640	< 2e-16	***
gametype	-0.0011768	0.0015780	-0.746	0.456	
lambdaacc	-1.2892851	0.2789565	-4.622	4.48e-06	***

Stability

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.0543238	0.0037410	14.521	< 2e-16	***
collcost	0.4375431	2.5861754	0.169	0.865697	
euclpace	-0.0001573	0.0004479	-0.351	0.725596	
extgrowth	0.0004962	0.0001293	3.837	0.000135	***
gametype	-0.0002884	0.0014630	-0.197	0.843766	
lambdaacc	-0.0804337	0.2586175	-0.311	0.755877	

Travel Distance

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.1128552	0.0040352	27.967	< 2e-16	***
collcost	0.1608364	2.7895649	0.058	0.954	
euclpace	-0.0020140	0.0004832	-4.168	3.43e-05	***
extgrowth	0.0183610	0.0001395	131.640	< 2e-16	***
gametype	-0.0011768	0.0015780	-0.746	0.456	
lambdaacc	-1.2892851	0.2789565	-4.622	4.48e-06	***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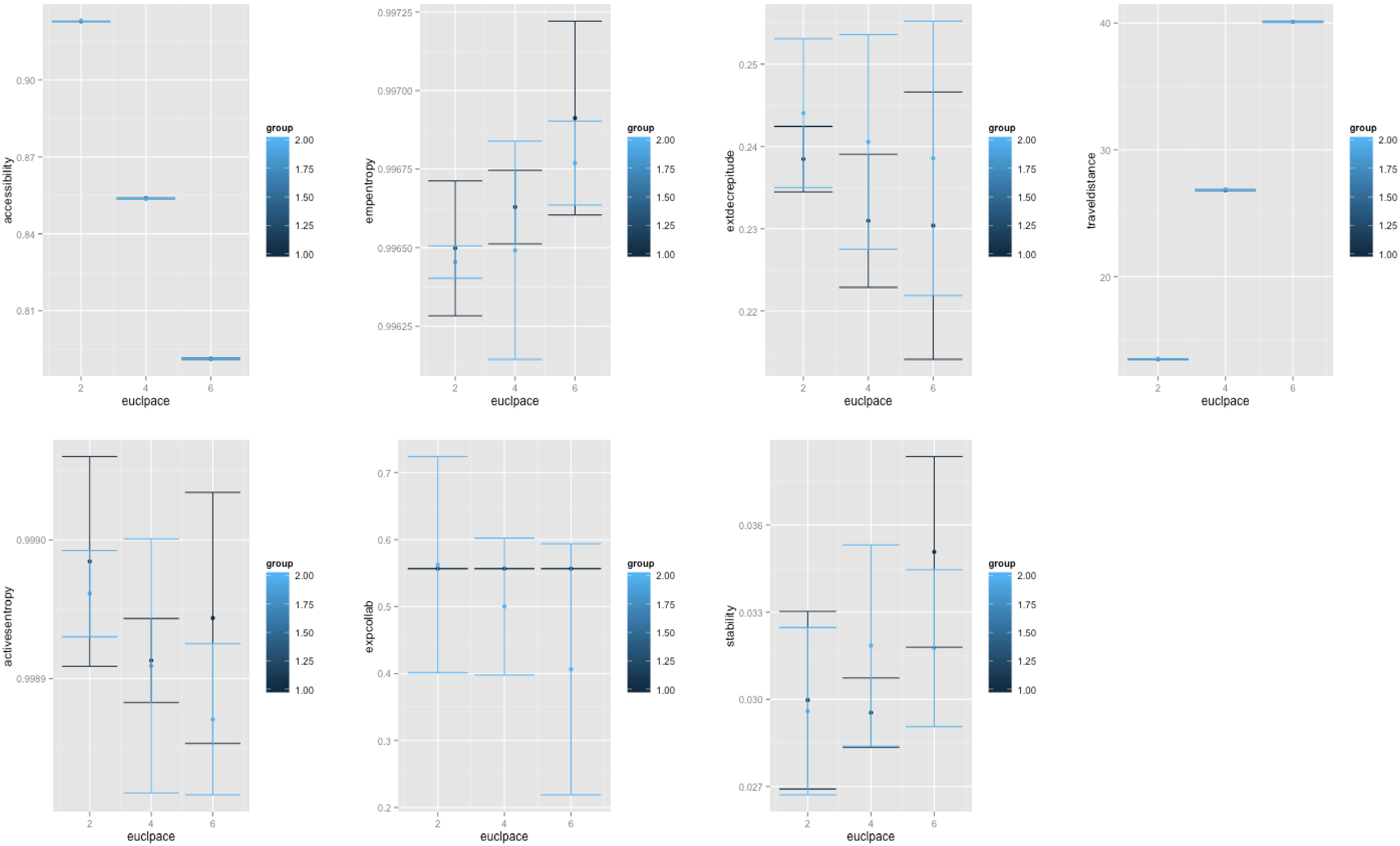
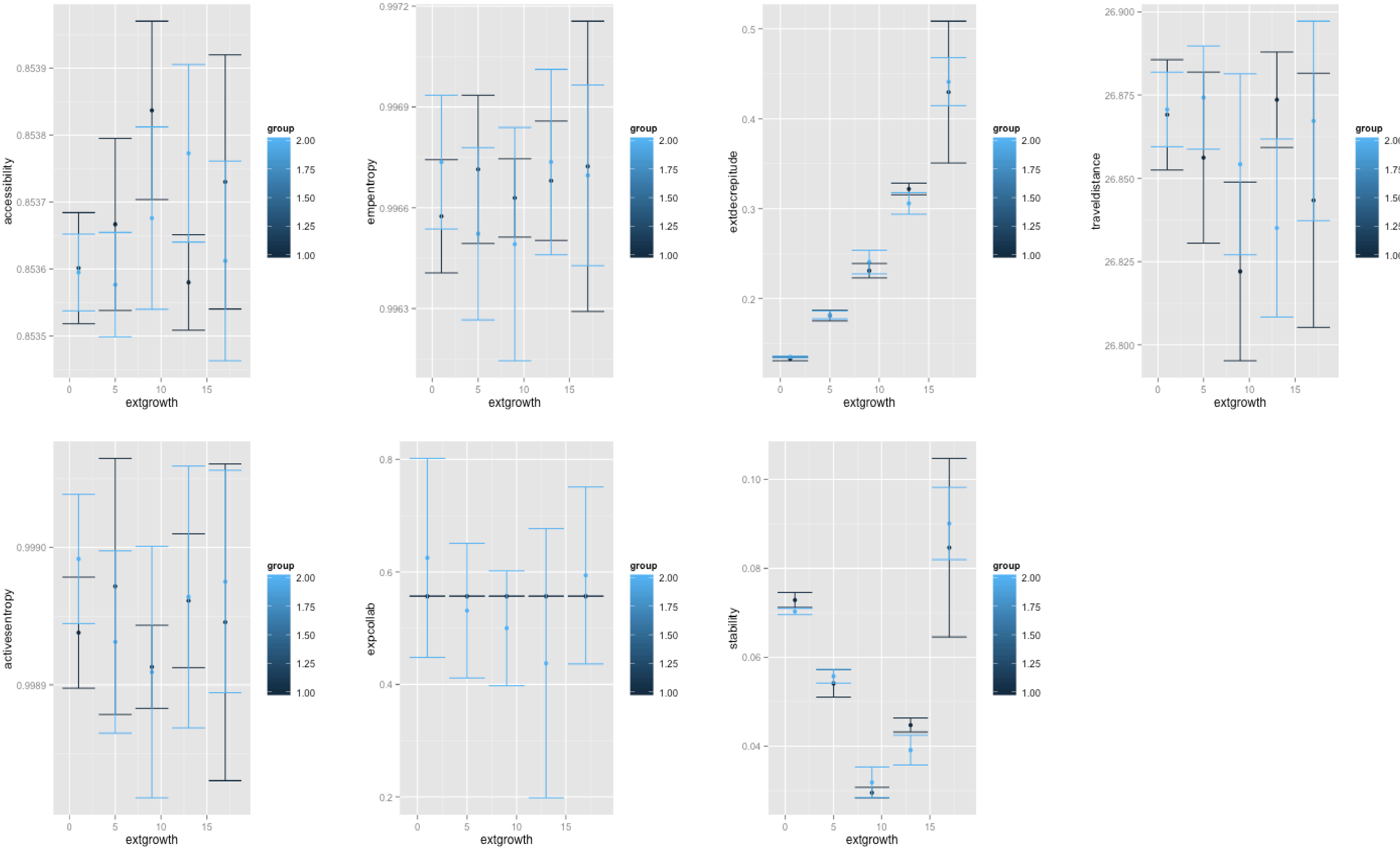
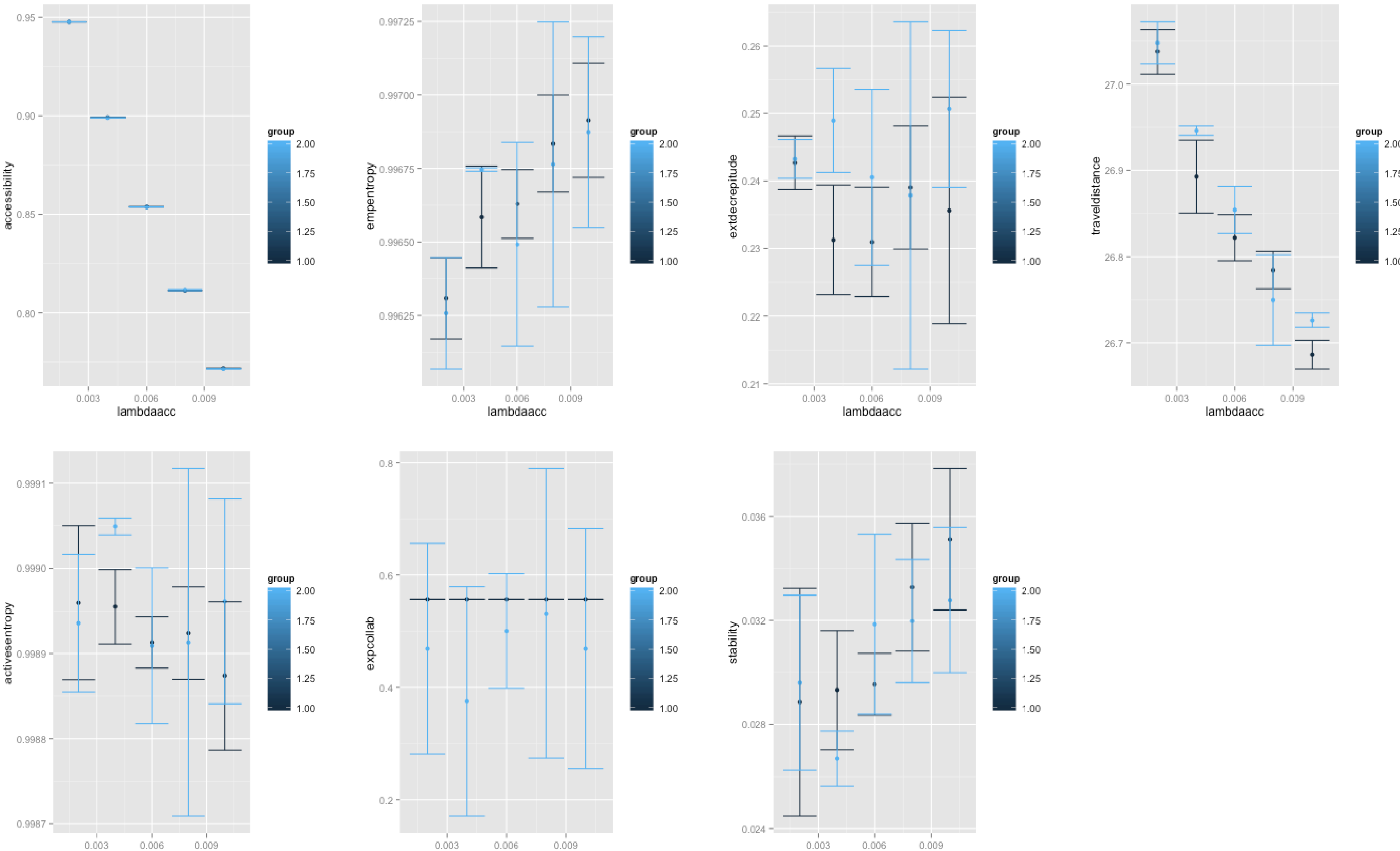
0.8536
0.8534
empentropy
0.9969
0.9967
0.9965
0.9963
0.9961
extdecrepitude
0.26
0.25
0.24
0.23
0.22
traveldistance
26.88
26.84
26.80
activesentropy
0.9991
0.9990
0.9989
expcollab
1.00
0.75
0.50
0.25
stability
0.0375
0.0350
0.0325
0.0300
0.0275
0.00000 0.00025 0.00050 0.00075 0.00100
collcost
group
2.00
1.75
1.50
1.25
1.00


accessibility
0.90
0.87
0.84
0.81
euclpace
group
2.00
1.75
1.50
1.25
1.00
empentropy
0.99725
0.99700
0.99675
0.99650
0.99625
extdecrepitude
0.25
0.24
0.23
0.22
traveldistance
40
30
20
activesentropy
0.9990
0.9989
expcollab
0.7
0.6
0.5
0.4
0.3
0.2
stability
0.036
0.033
0.030
0.027
2
4
6


accessibility
0.8535
0.8536
0.8537
0.8538
0.8539
extgrowth
empentropy
0.9963
0.9966
0.9969
0.9972
extdecrepitude
0.2
0.3
0.4
0.5
traveldistance
26.800
26.825
26.850
26.875
26.900
activesentropy
0.9989
0.9990
expcollab
0.2
0.4
0.6
0.8
stability
0.04
0.06
0.08
0.10
0
5
10
15
group
2.00
1.75
1.50
1.25
1.00


accessibility
0.95
0.90
0.85
0.80
0.003
0.006
0.009
lambdaacc
group
2.00
1.75
1.50
1.25
1.00
empentropy
0.99725
0.99700
0.99675
0.99650
0.99625
extdecrepitude
0.26
0.25
0.24
0.23
0.22
0.21
traveldistance
27.0
26.9
26.8
26.7
activesentropy
0.9991
0.9990
0.9989
0.9988
0.9987
expcollab
0.8
0.6
0.4
0.2
stability
0.036
0.032
0.028
0.024