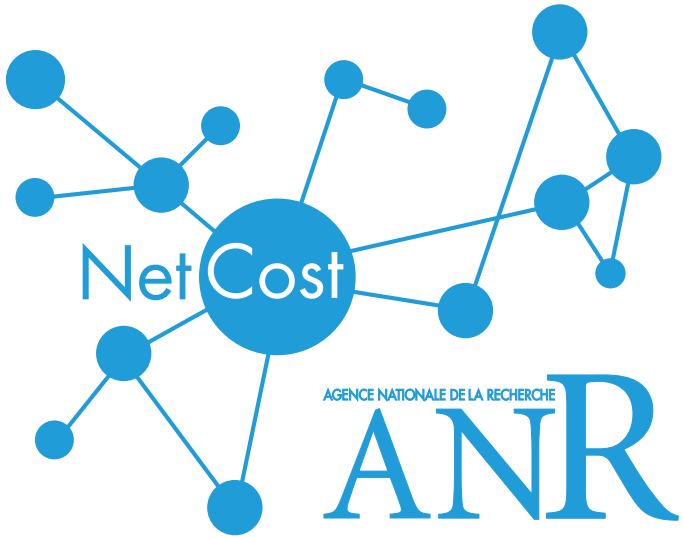
Trajectoires individuelles et réseaux spatiaux
Du territoire au système complexe



Maxime Lenormand
UMR TETIS, Irstea, France

Gestion Optimisée de l'espace:
des villes aux systèmes naturels

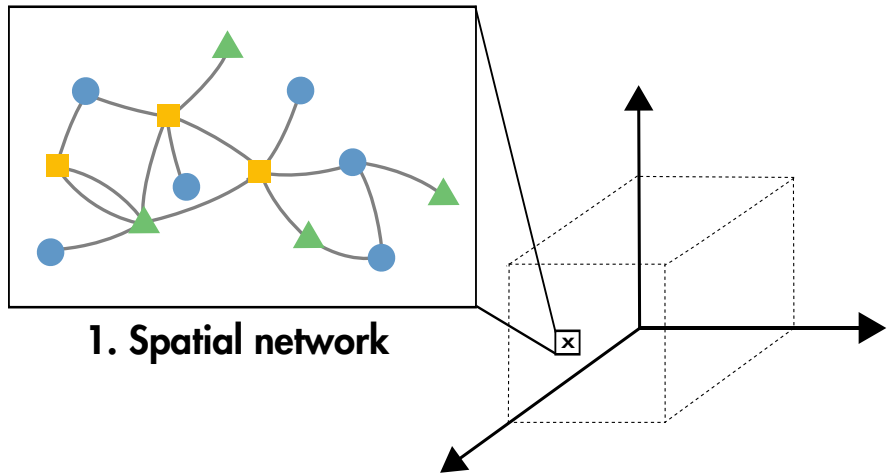
13-14 décembre 2017 | Lyon, France

irstea

Thèmes & méthodes

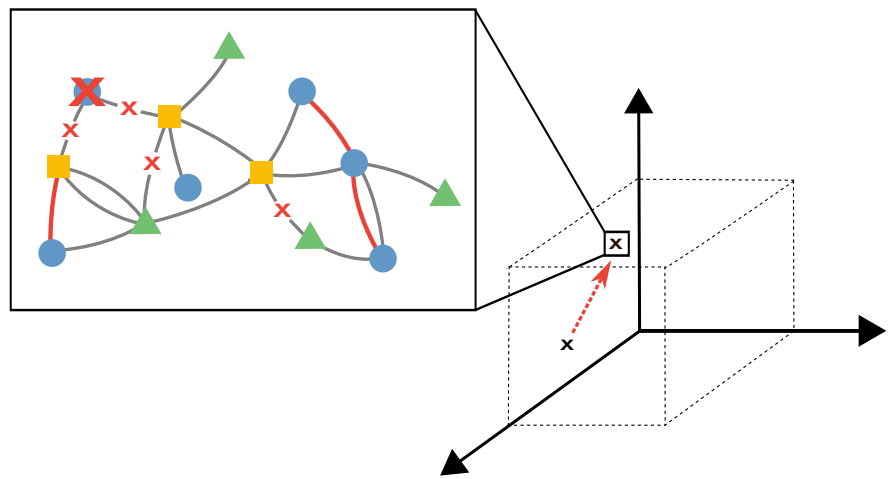
1. Représentation des systèmes complexes
   - Comment modéliser/représenter les territoires et ce qui s'y passe ?
   - De quel(s) territoire(s) parle-t-on ?
2. Compréhension/caractérisation des systèmes
3. Optimisation des systèmes
   - Distance à l'optimum - aux optima
   - Concept de carte des possibles

2. Develop a set of indicators to assess the actual network configuration



1. Spatial network

3. (Temporal) network reconfiguration respecting a set of constraints



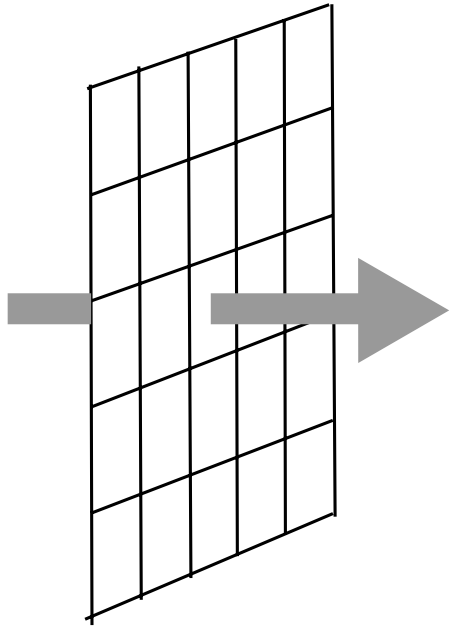
4. Measure the impact of change at different scale (particularly at the individual level)

Terminologie

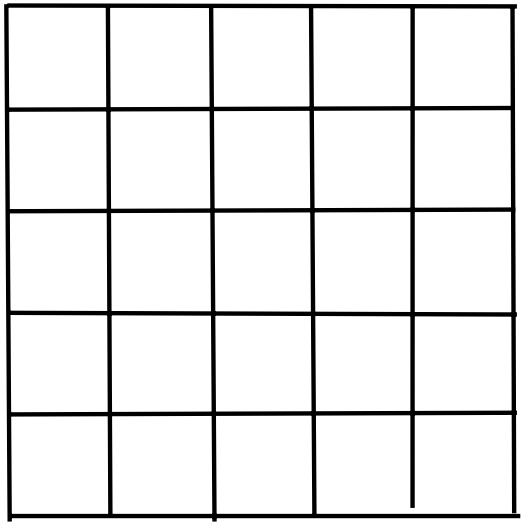
- Statique
- Individu-centrée
- Aléatoire - stochasticité
- Intra/inter - ouvert/fermé
- Réseau complexe : abstraction <-> données

Représentation du "réel"

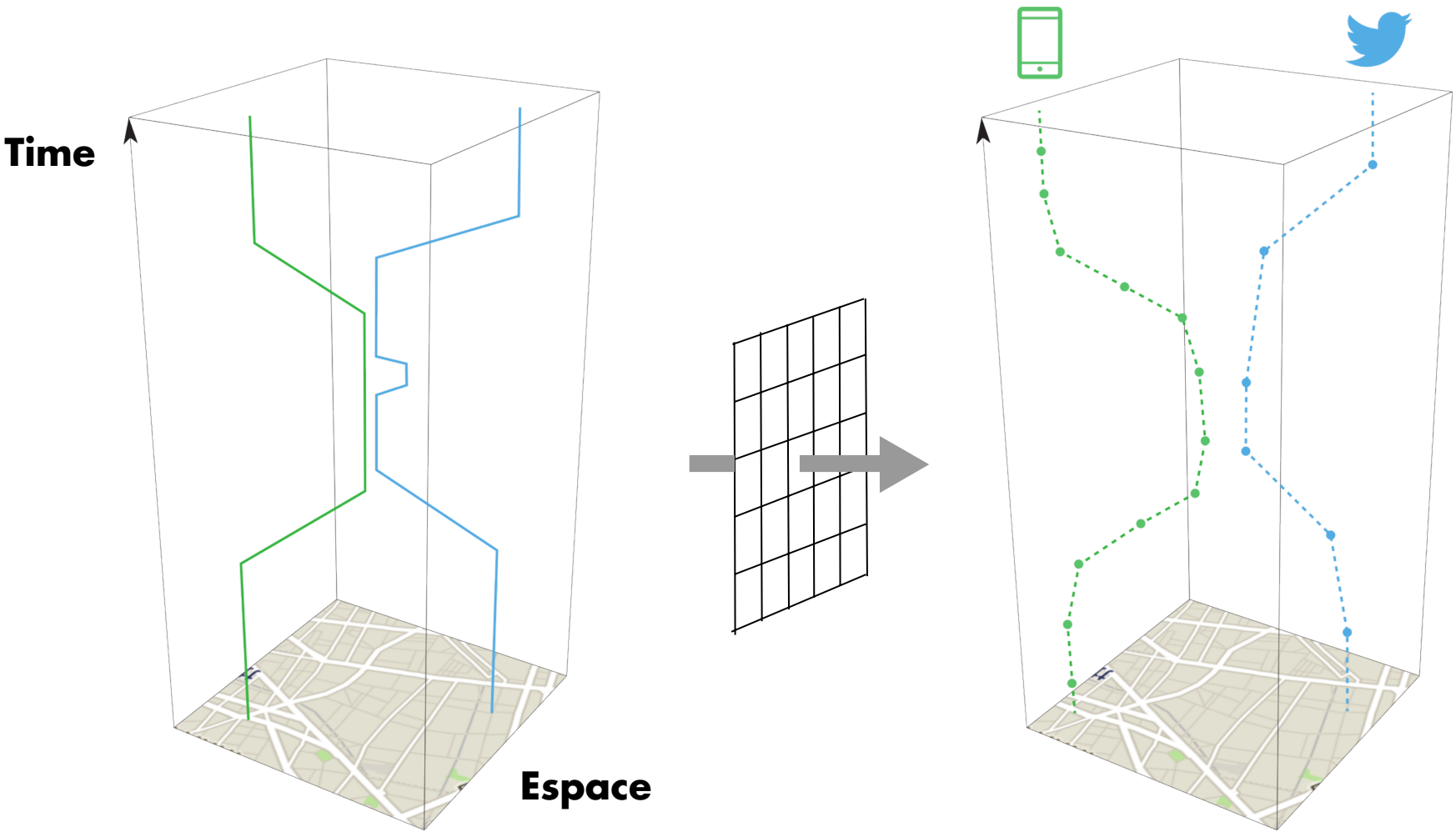
"Réalité"



Modèle(s)



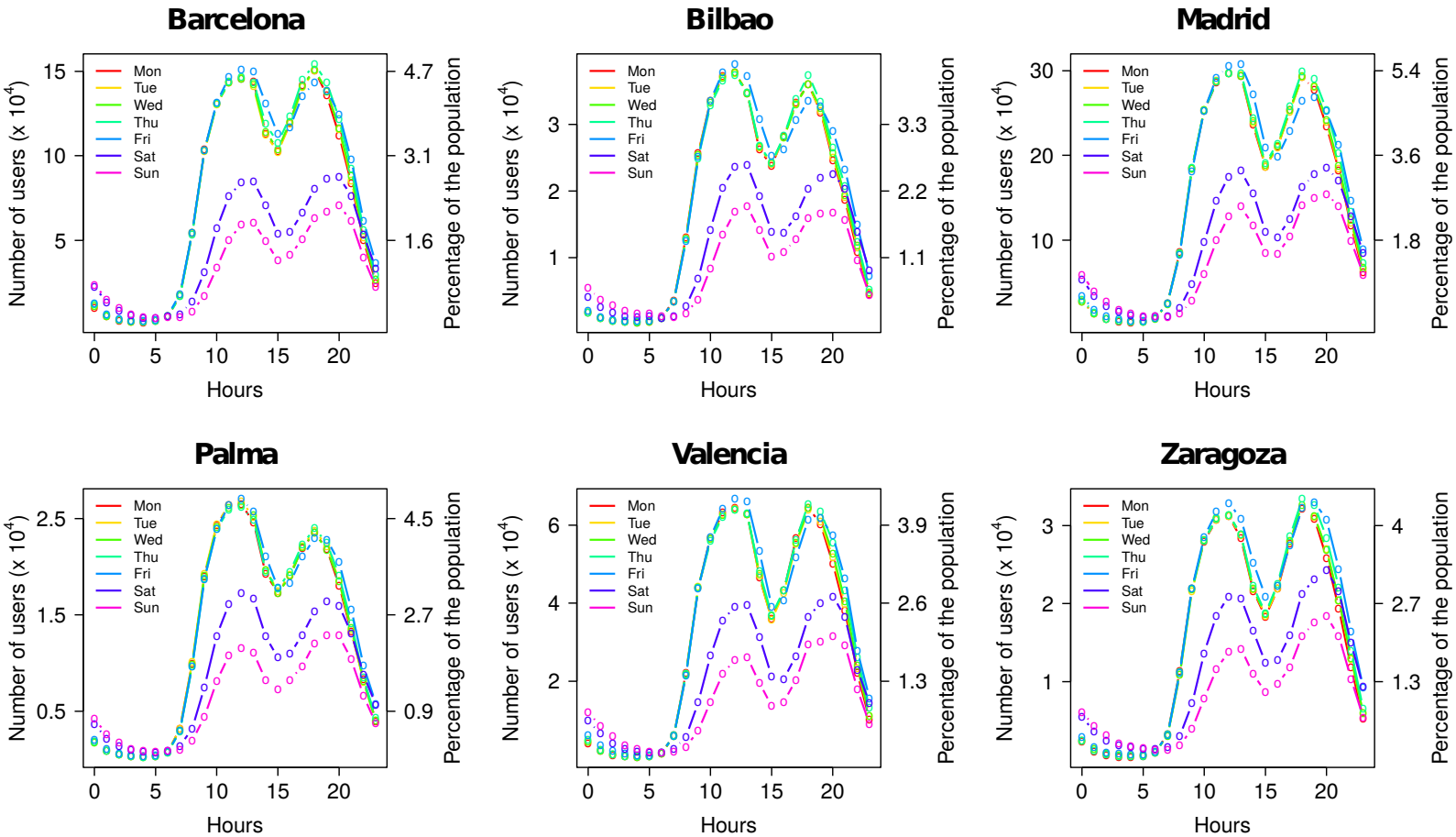
Reconstruction du "réel"



Echantillonnage

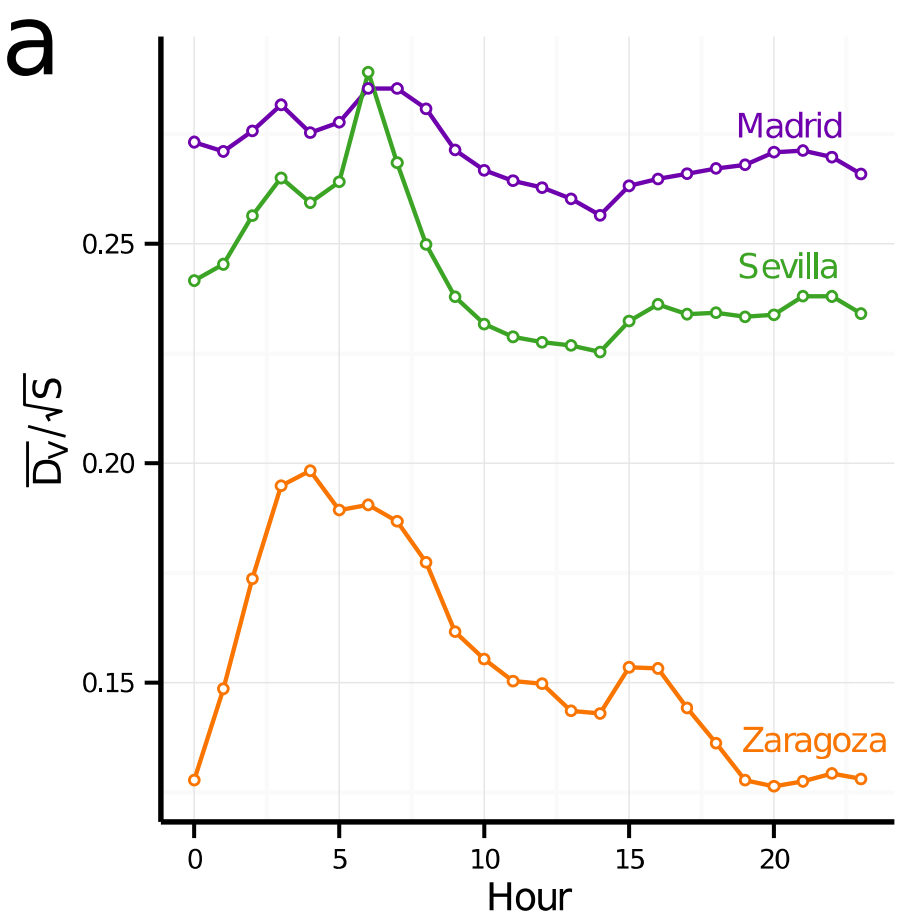
Structure spatiale

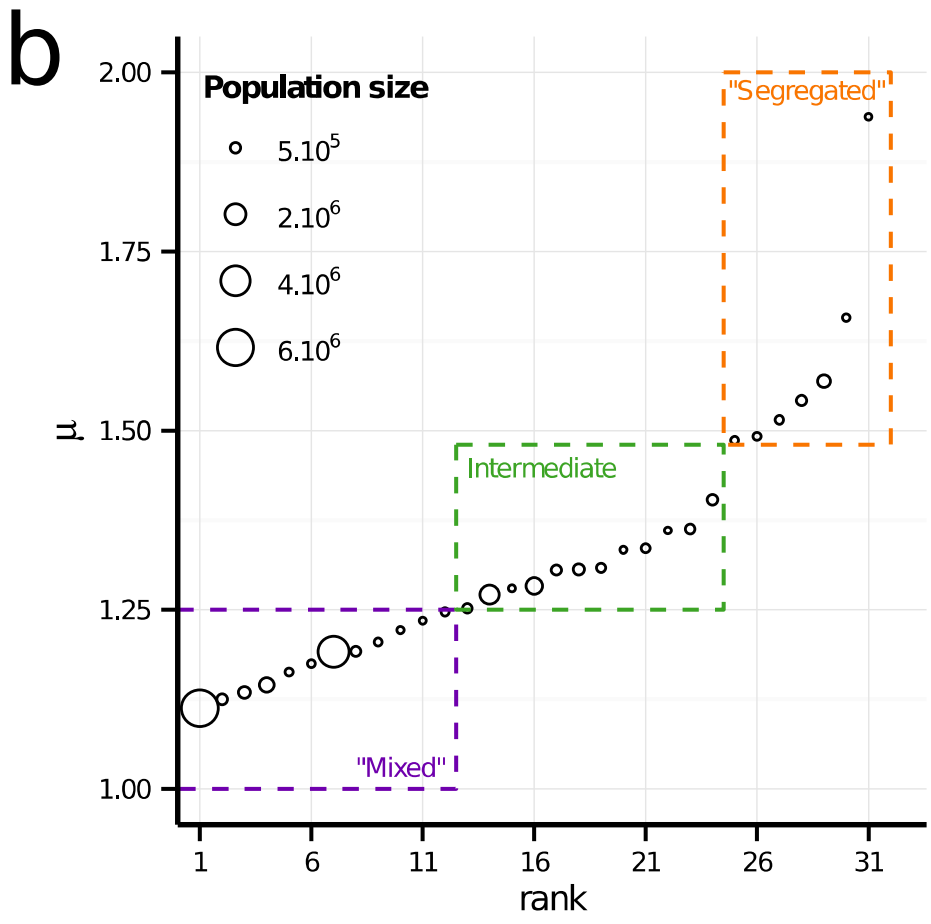
- 50M d'utilisateurs
- Métropoles - Espagne
- Relevés téléphoniques



Louail *et al.* (2014) From mobile phone data to the spatial structure of cities. *Scientific Reports*, 4 5276.

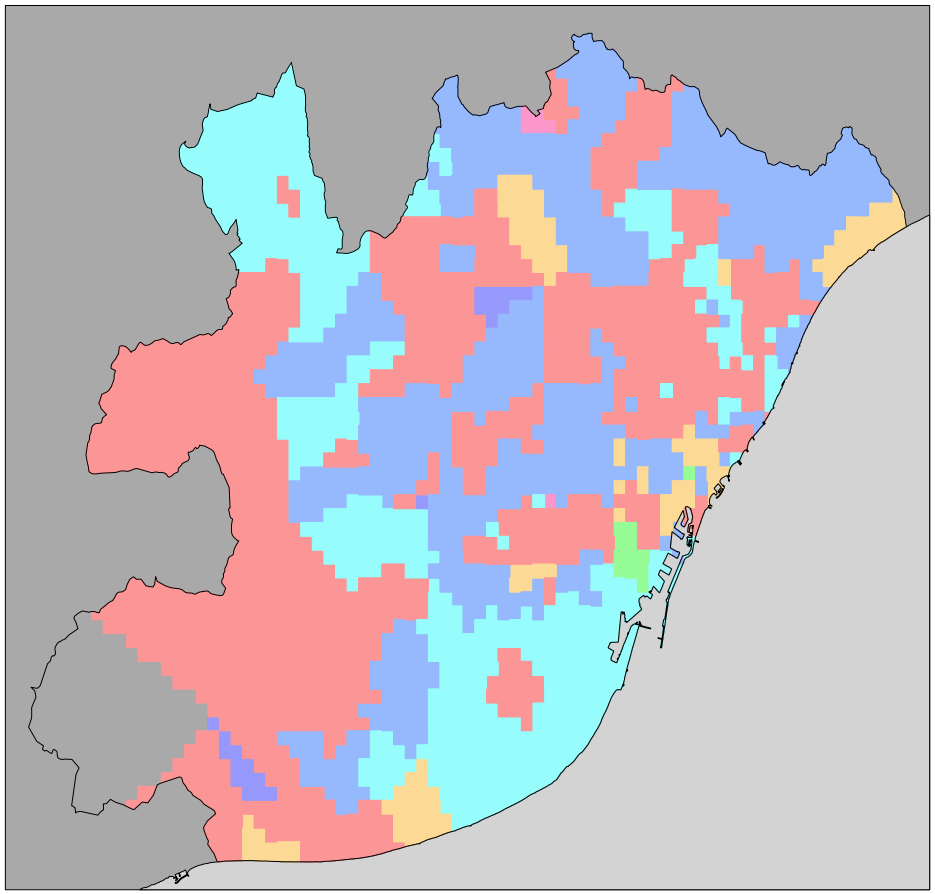
Structure spatiale

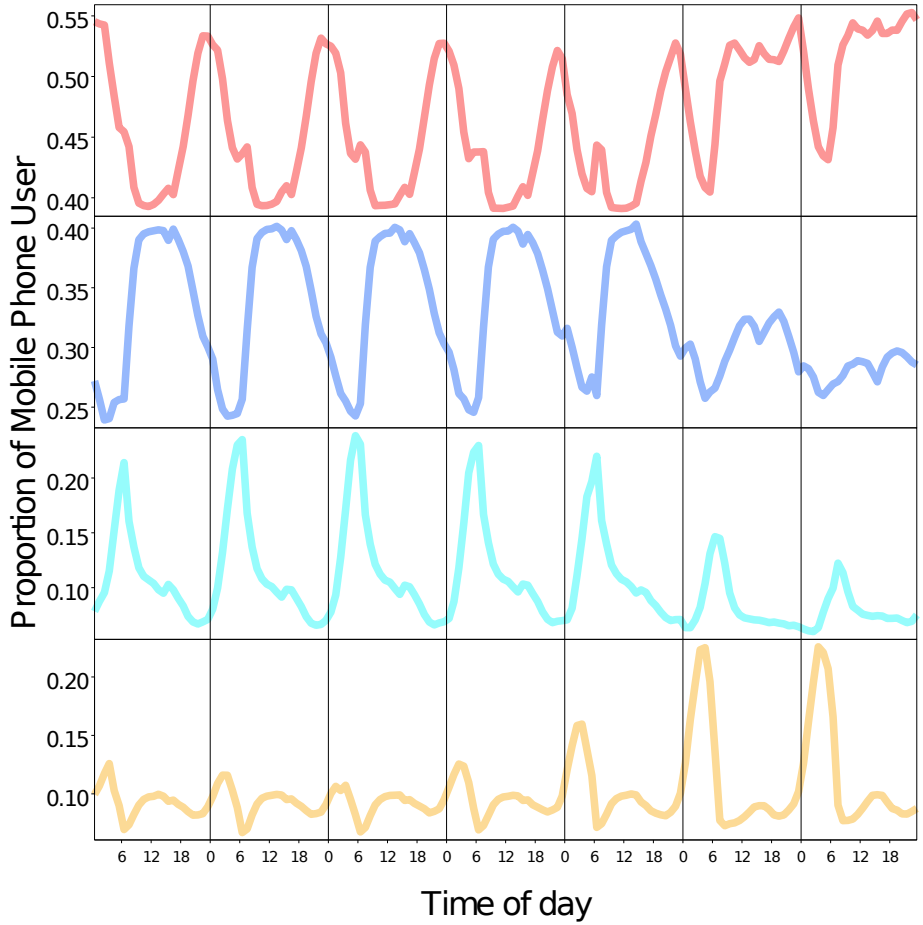




Louail *et al.* (2014) From mobile phone data to the spatial structure of cities. *Scientific Reports*, 4 5276.

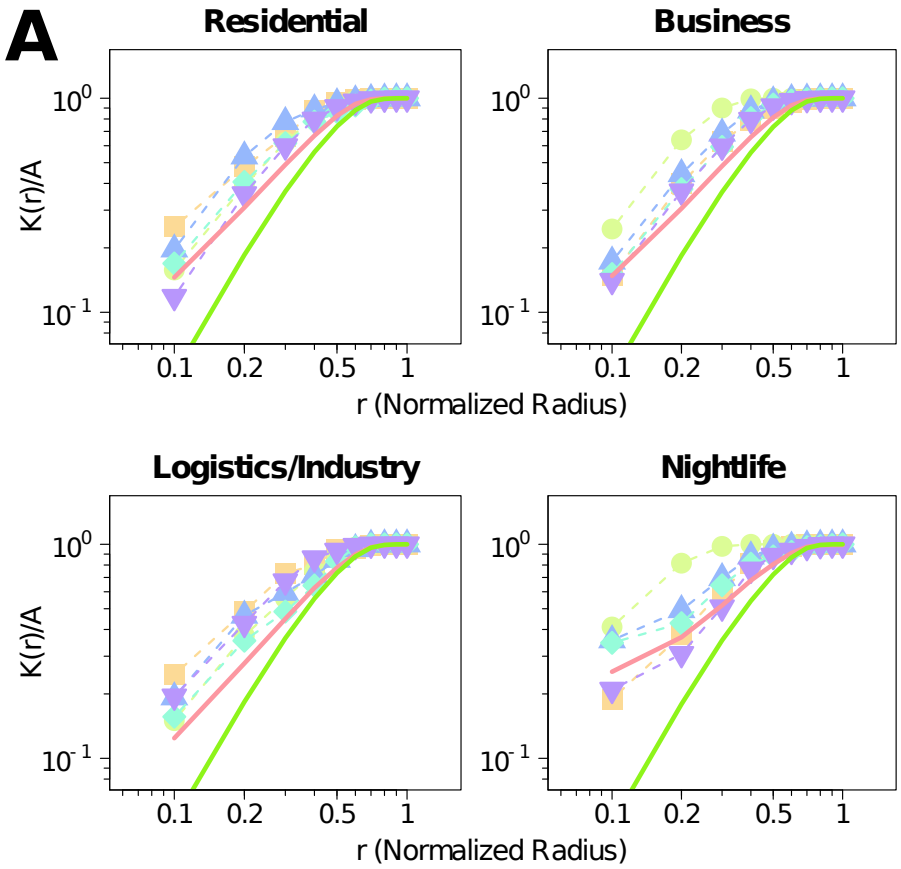
Fonction des territoires





Lenormand *et al.* (2015) Comparing and modeling land use organization in cities. Royal Society Open Science 2, 15052015.

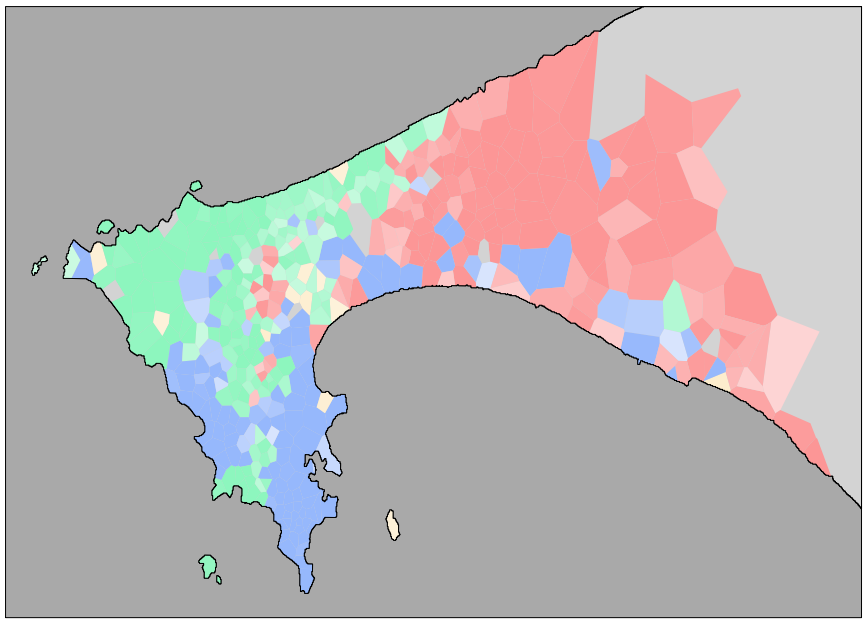
Fonction des territoires

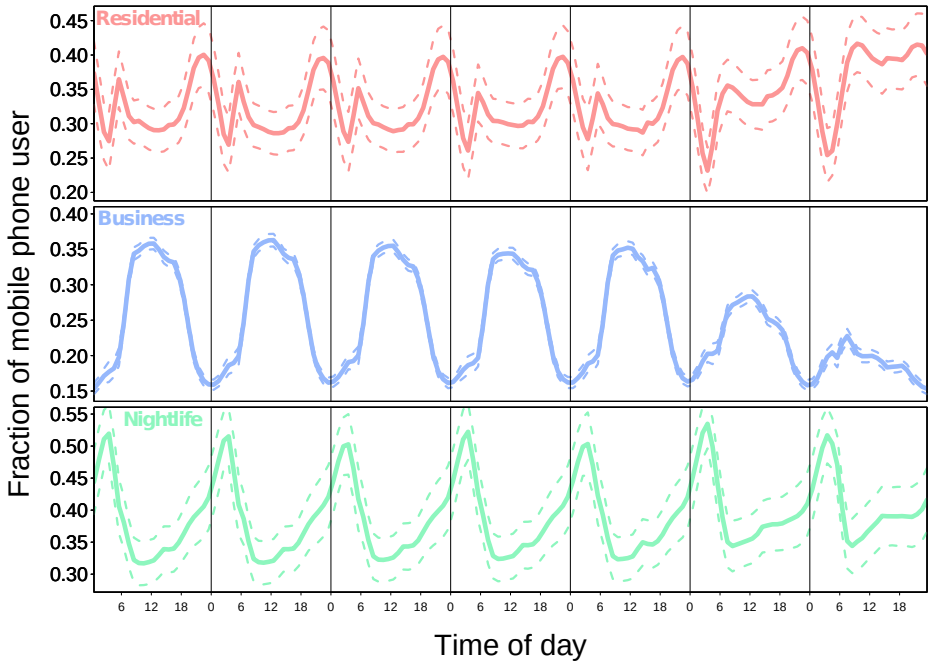


Lenormand *et al.* (2015) Comparing and modeling land use organization in cities. Royal Society Open Science 2, 15052015.

Fonction des territoires

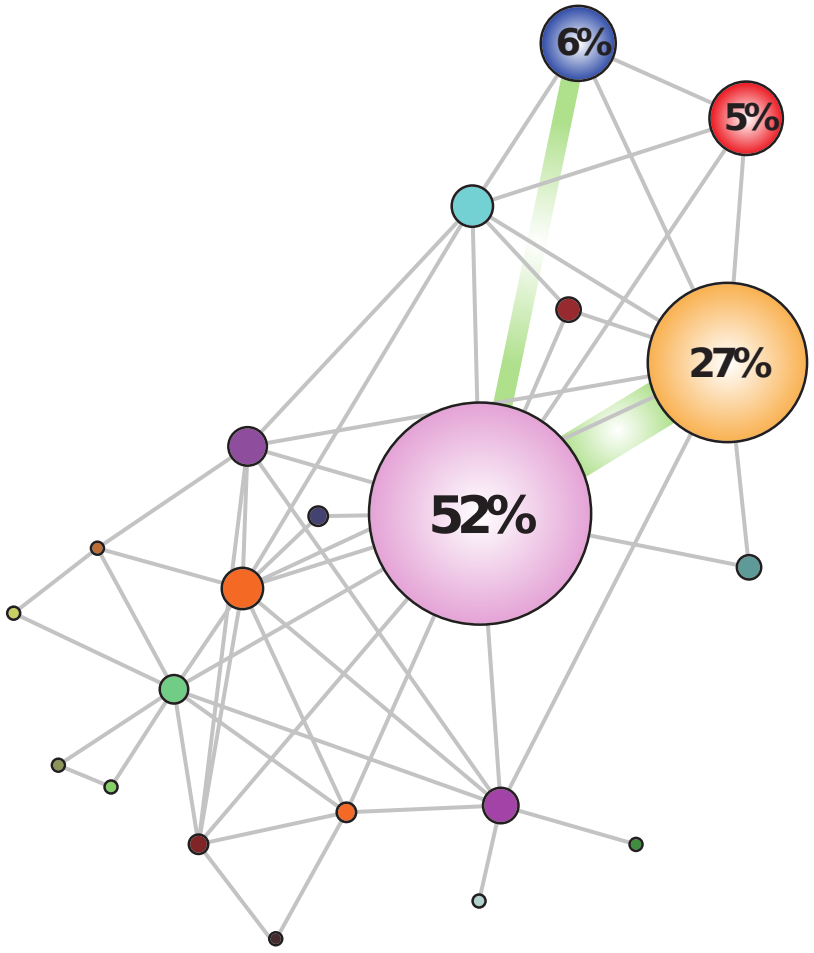
Extraction de 50 échantillons indépendants
de 150,000 utilisateurs





Lenormand *et al.* (2016) Is spatial information in ICT data reliable?
Proceedings of the 2016 Spatial Accuracy Conference, p 9-17, Montpellier, France.

Lieux les plus fréquentés



Maison

Lieu le plus fréquenté entre 19h et 7h

+

Travail

Lieu le plus fréquenté entre 8h et 17h en semaine

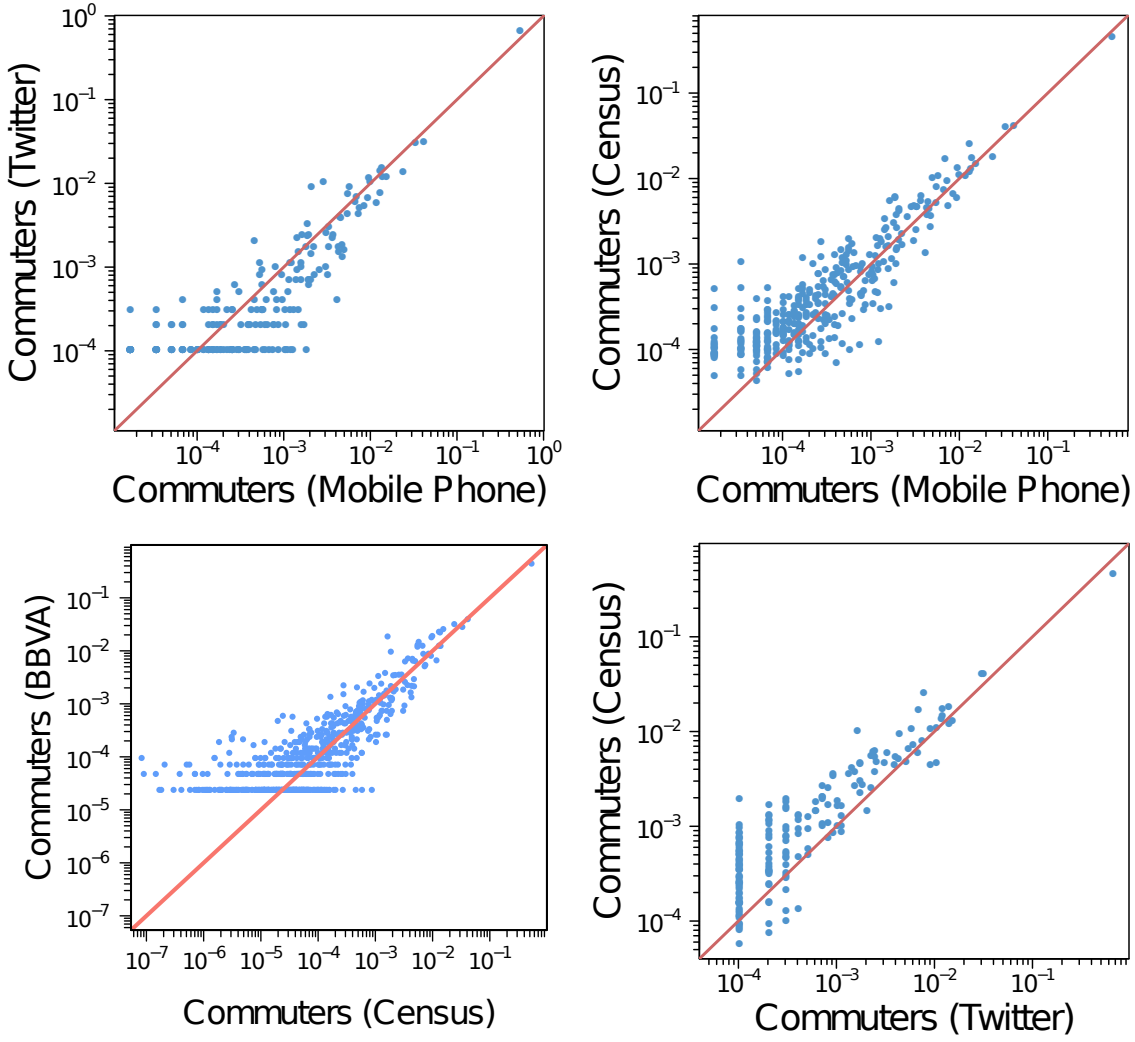
↓

Origin-Destination Matrice

Tij: *nombre d'individus vivant en* ***i*** et travaillant en ***j***

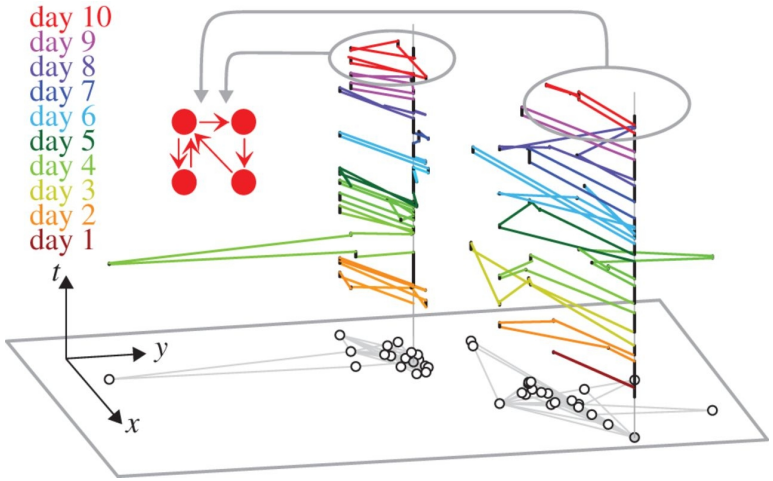
Song et al. (2010) Limits of predictability in human mobility. *Science* 327, 1018-1021.

Matrice Origine - Destination

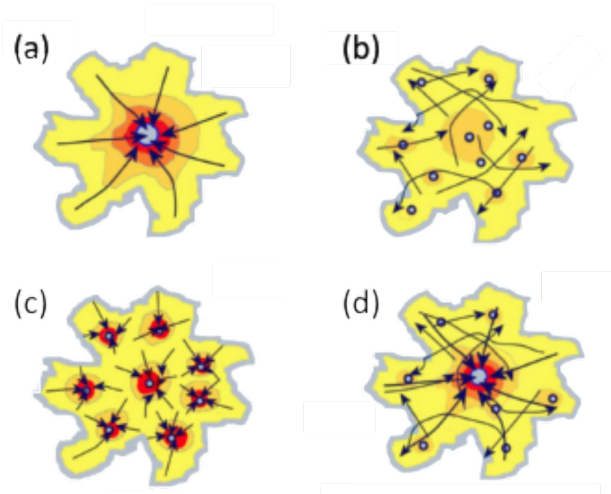


Lenormand *et al.* (2014) Cross-checking different sources of mobility information. *PlosOne*, 9(8):e105407.

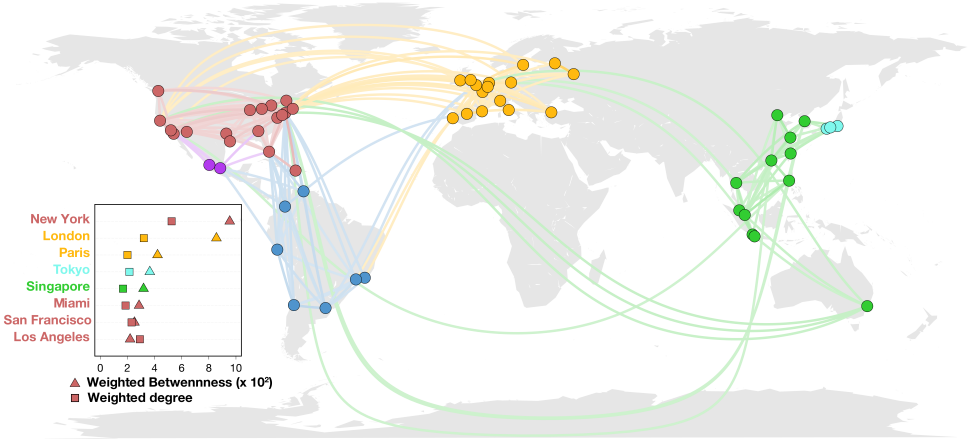
Matrice Origine - Destination



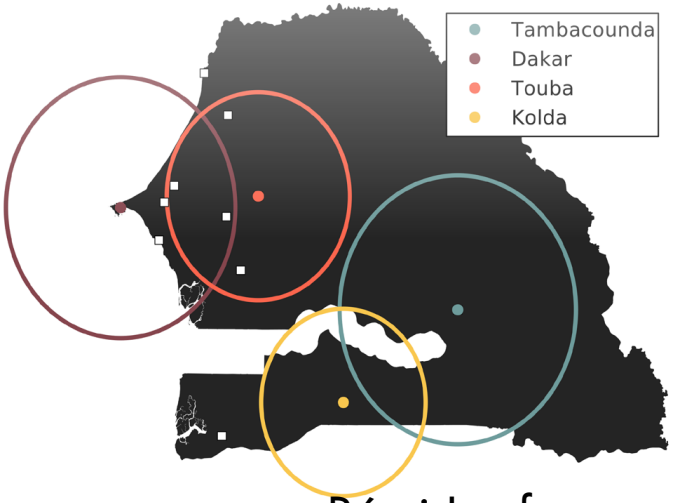
Schneider *et al.* (2013)



Bertaud et Malpezzi (2003)



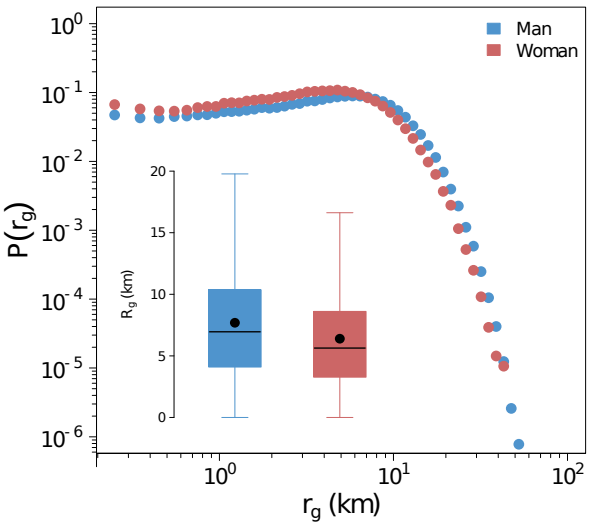
Lenormand *et al.* (2015)



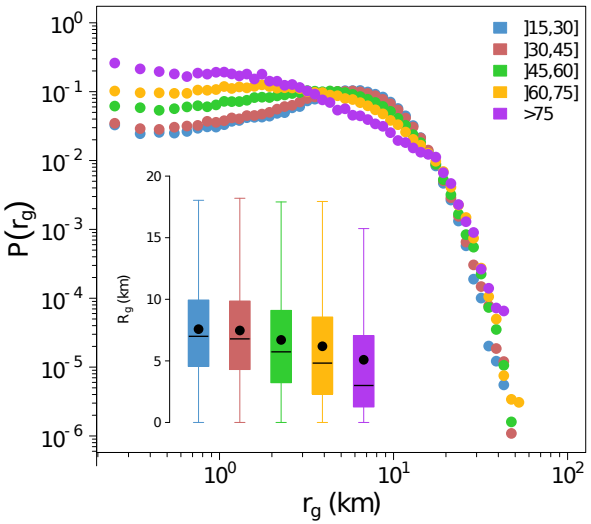
Rémi Louf

Socio-démographiques

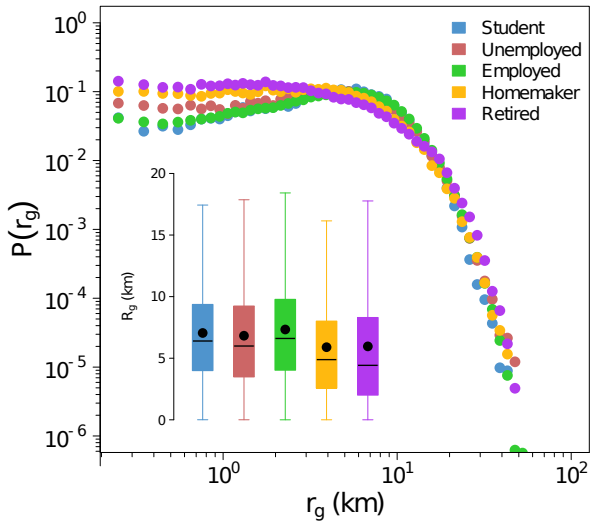
Genre

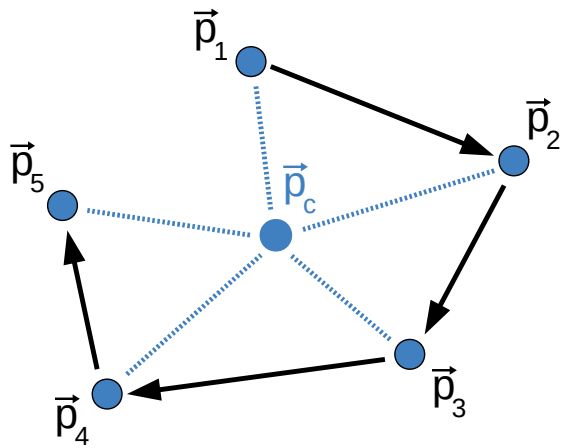


Age



CSP

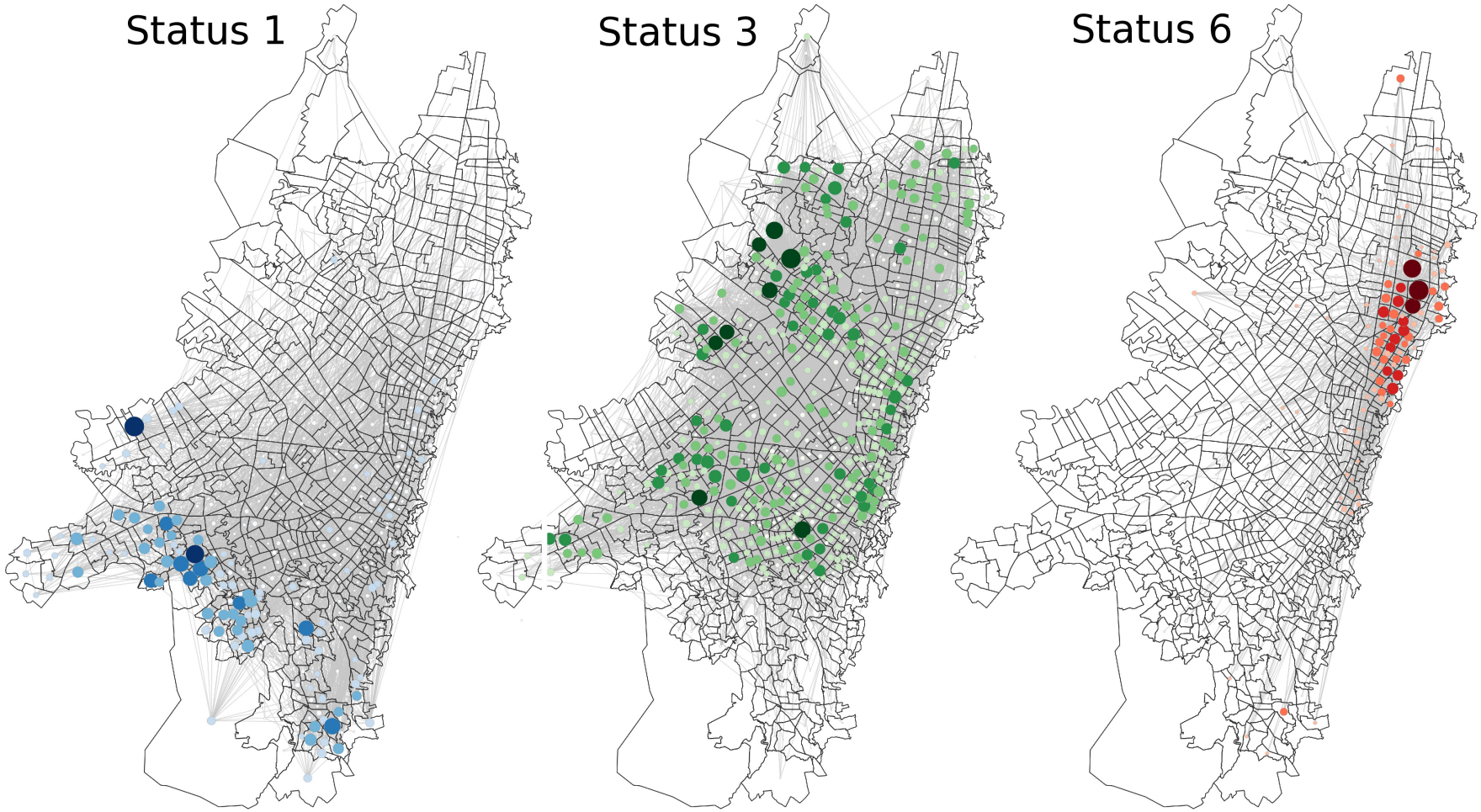




- 5M d'utilisateurs
- Métropoles - Espagne
- Relevés bancaires

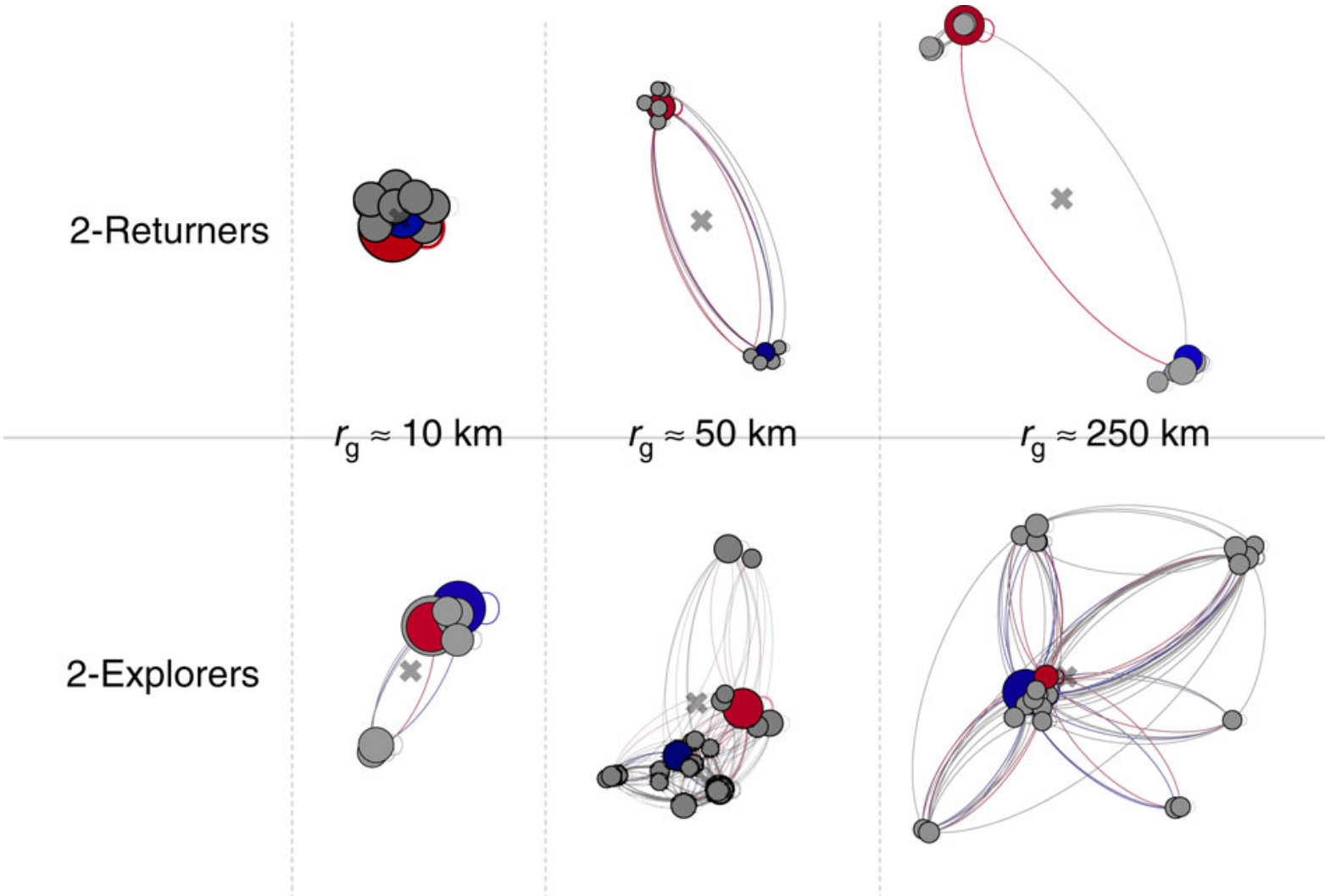
Lenormand *et al.* (2015) Influence of sociodemographic characteristics on human mobility. *Scientific Reports* 5, 10075.

Socio-démographiques



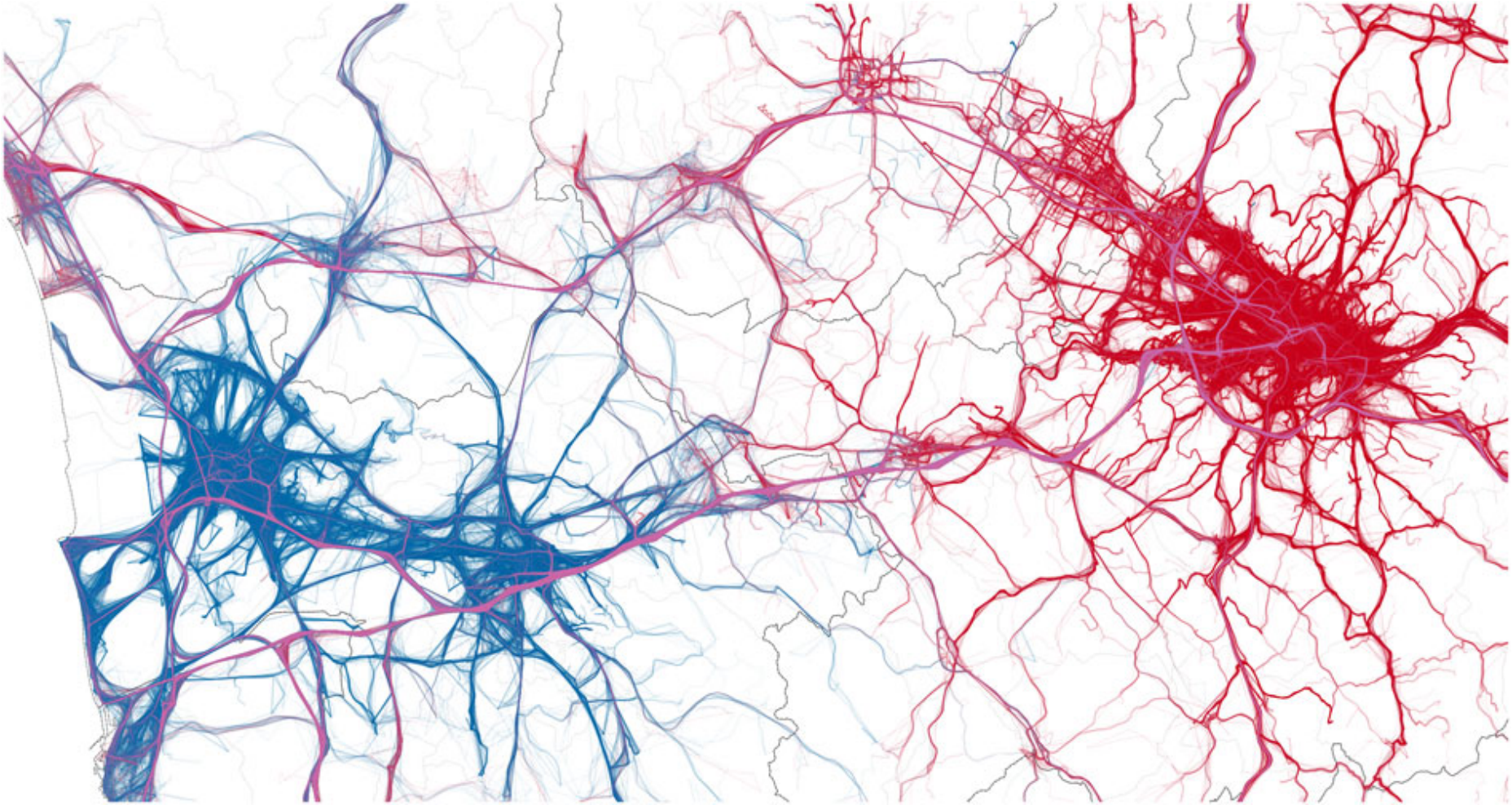
Lotero et al. (2014) Several multiplexes in the same city: The role of socioeconomic differences in urban mobility. I*nterconnected Networks*, 149-164.

Returners & Explorers



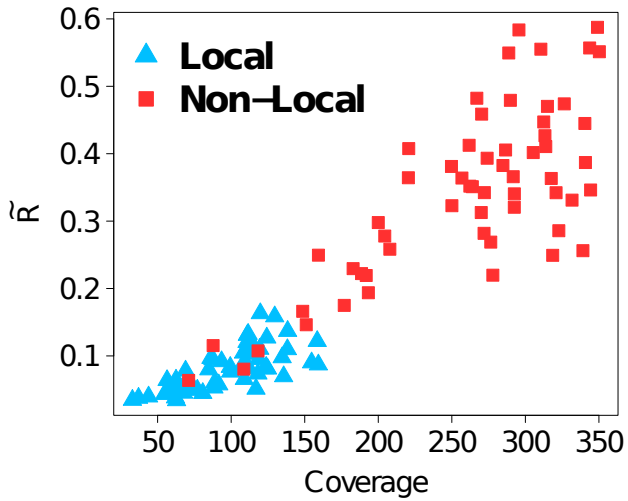
Pappalardo *et al.* (2015) Returners and explorers dichotomy in human mobility. *Nature Communications* 6, 8166.

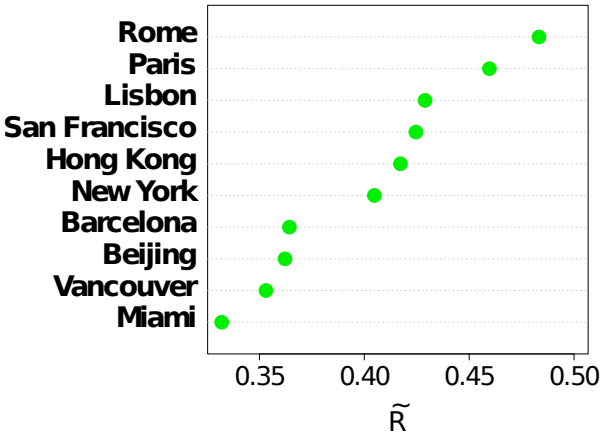
Compétition entre territoires

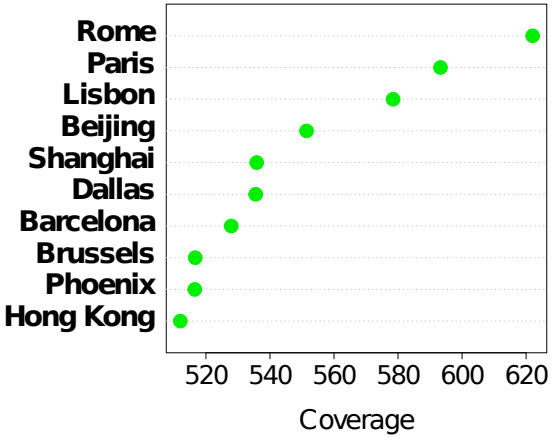


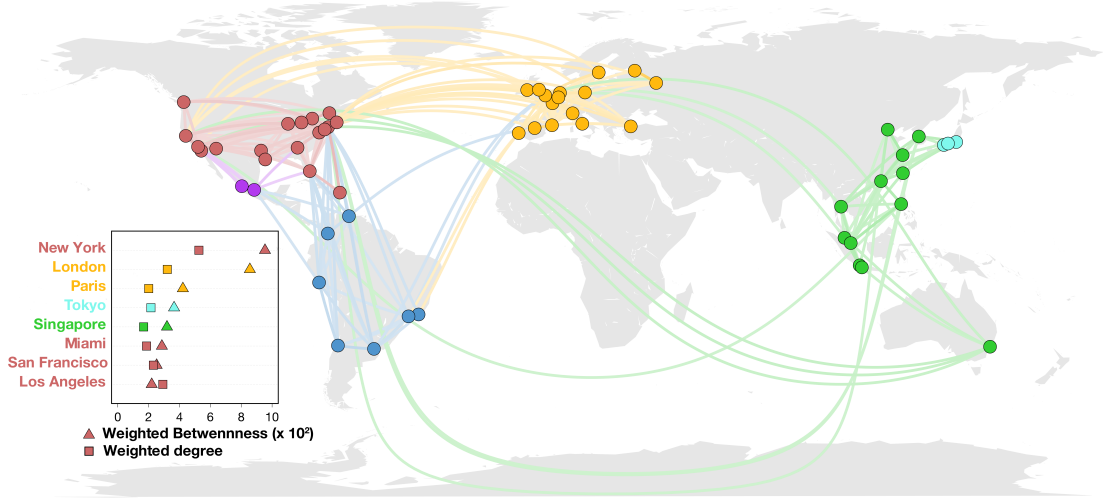
Pappalardo *et al.* (2015) Returners and explorers dichotomy in human mobility. *Nature Communications* 6, 8166.

Monde & territoires





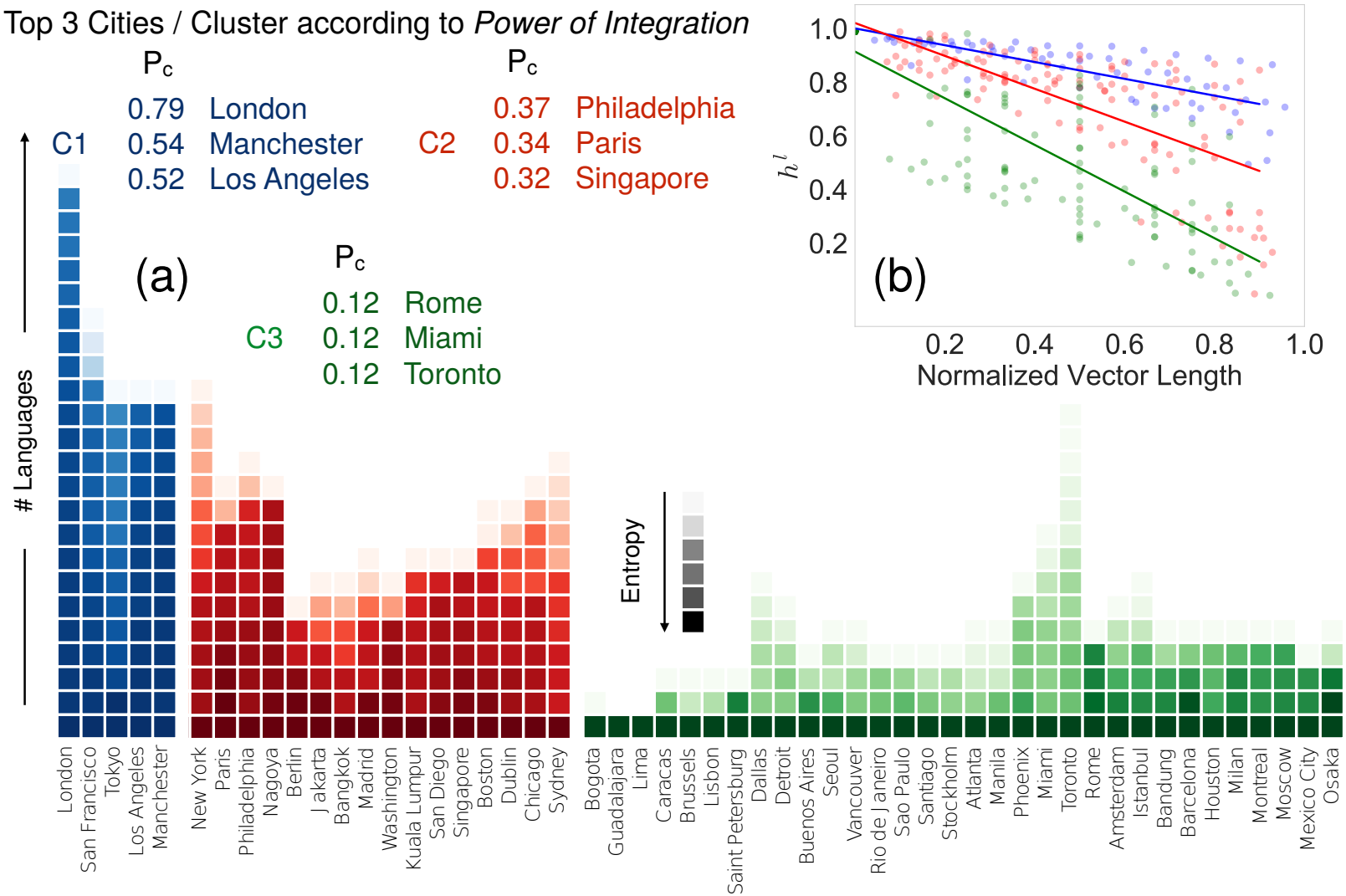




Lenormand *et al.* (2015) Human diffusion and city influence. *Journal of Royal Society Interface* 2, 14052015.

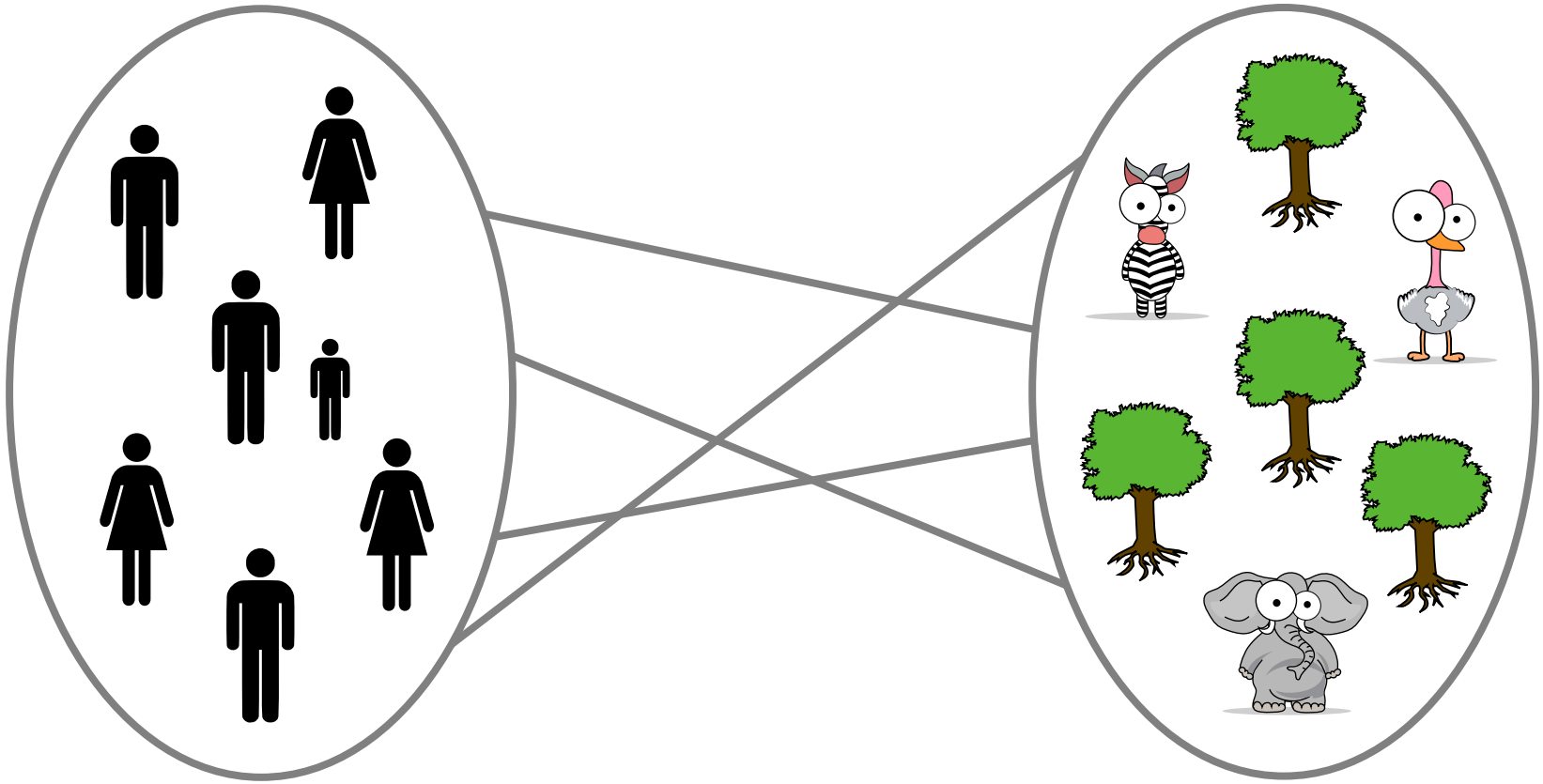
- 1M d'utilisateurs
- Métropoles - Monde
- Twitter

Intégration de communautés



Lamanna *et al.* (2018) Immigrant community integration in world cities. *Plos One (in press)*.

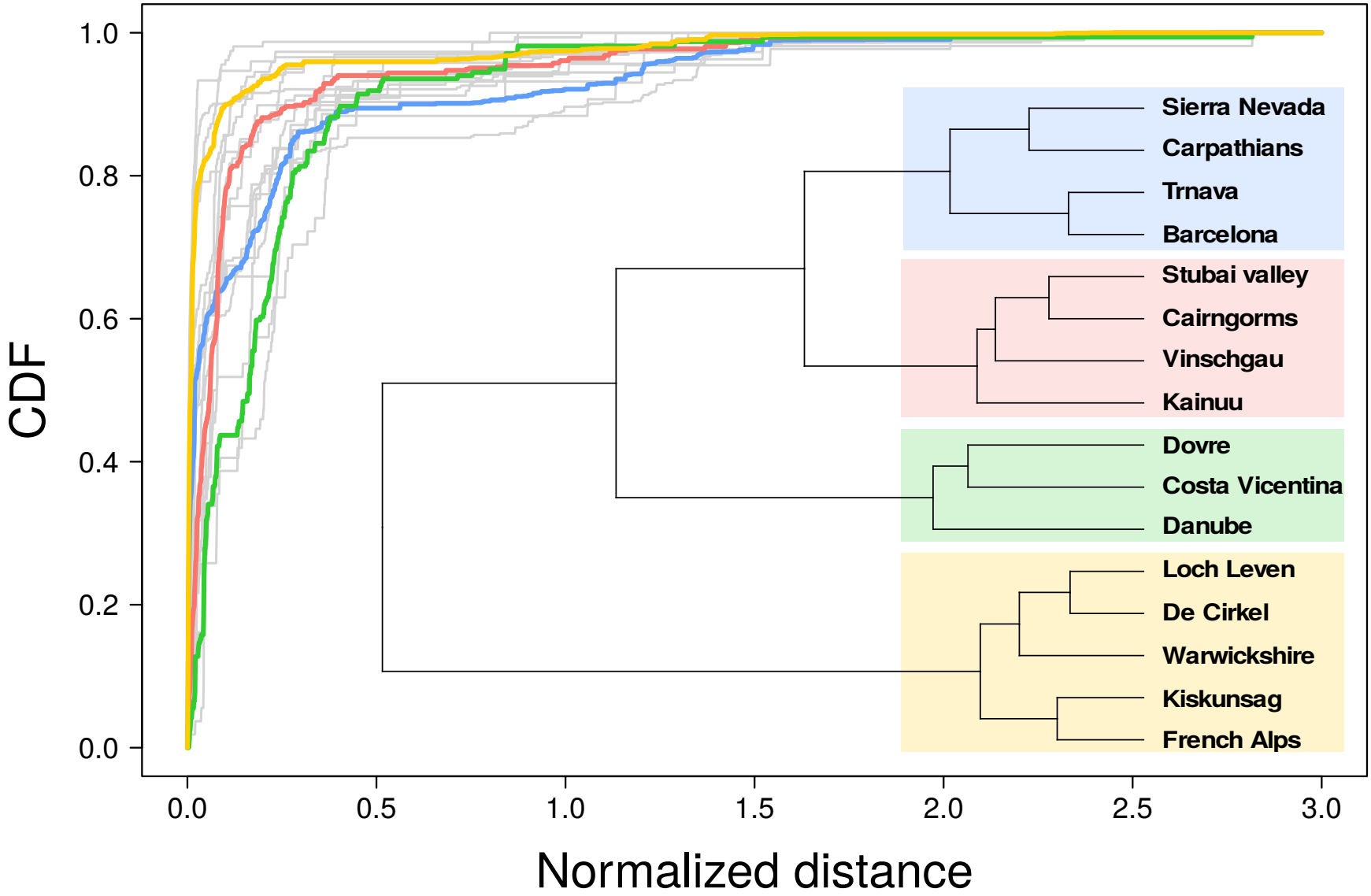
Interactions socio-écologiques



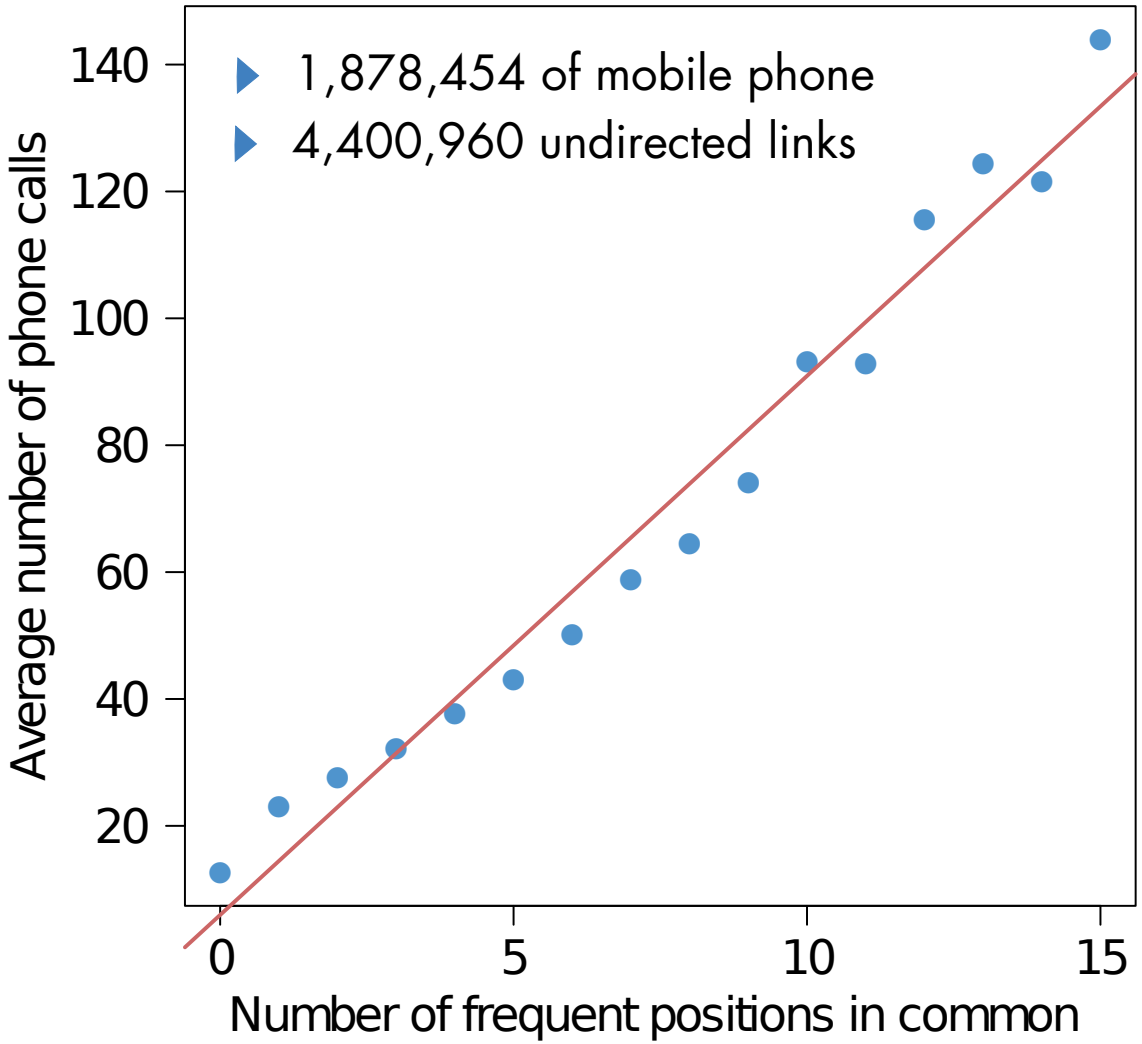
Δ_t Time window

- 10,000 utilisateurs
- Sites naturels - Europe
- Flickr

Interactions socio-écologiques

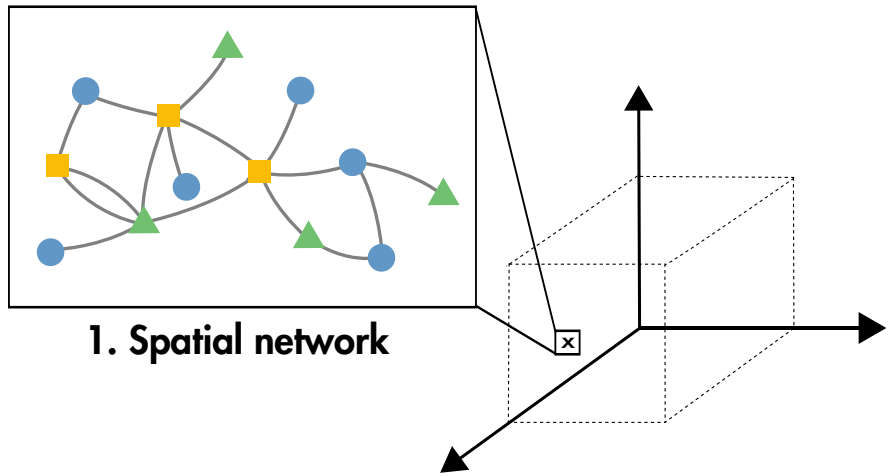


Réseaux socio-spatiaux



Picornell *et al.* (2015) Exploring the potential of phone call data to characterize the relationship between social network and travel behavior. *Transportation 42,* 647-668.

2. Develop a set of indicators to assess the actual network configuration



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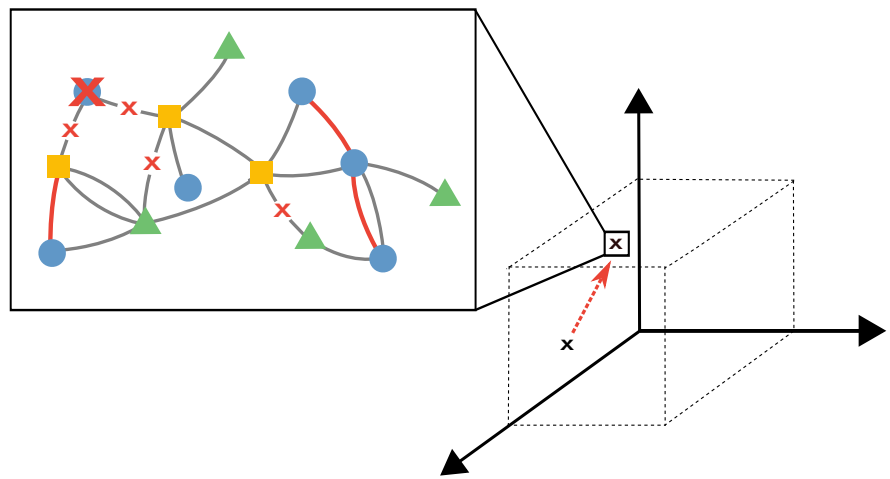
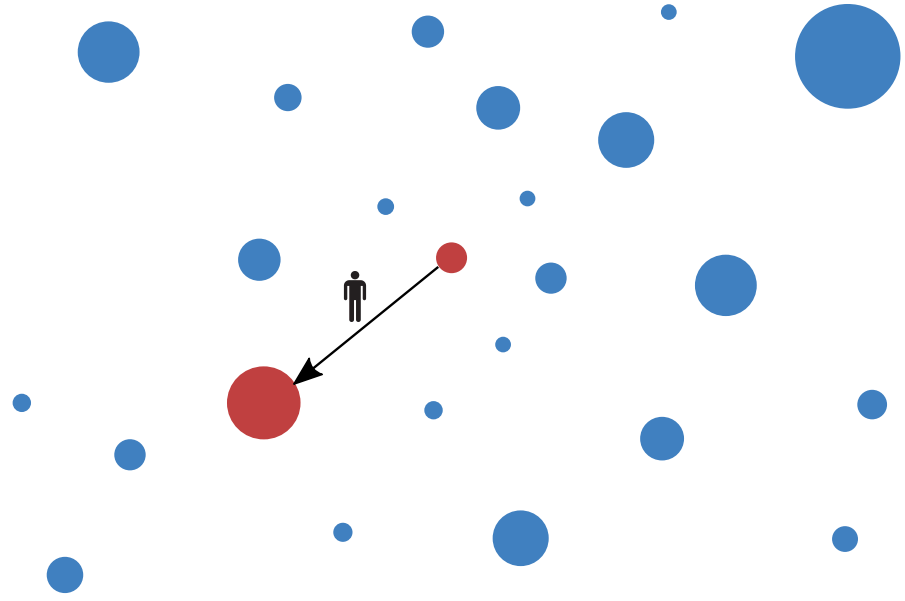


4. Measure the impact of change at different scale (particularly at the individual level)

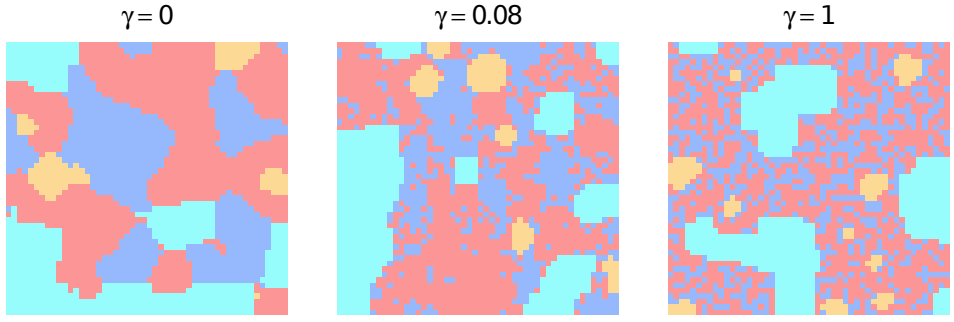
Modèles explicatifs

Spatial Interaction Models

$$p_{ij} \sim \frac{O_i D_j}{f(C_{ij})}$$



Land Use & Schelling



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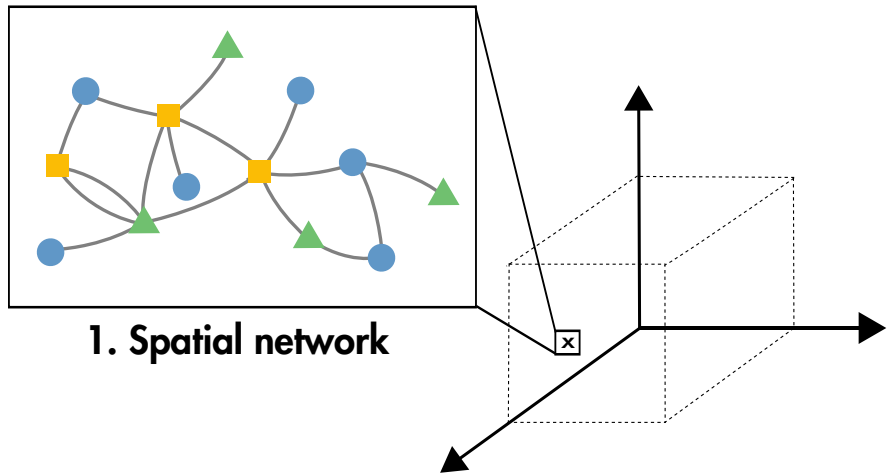

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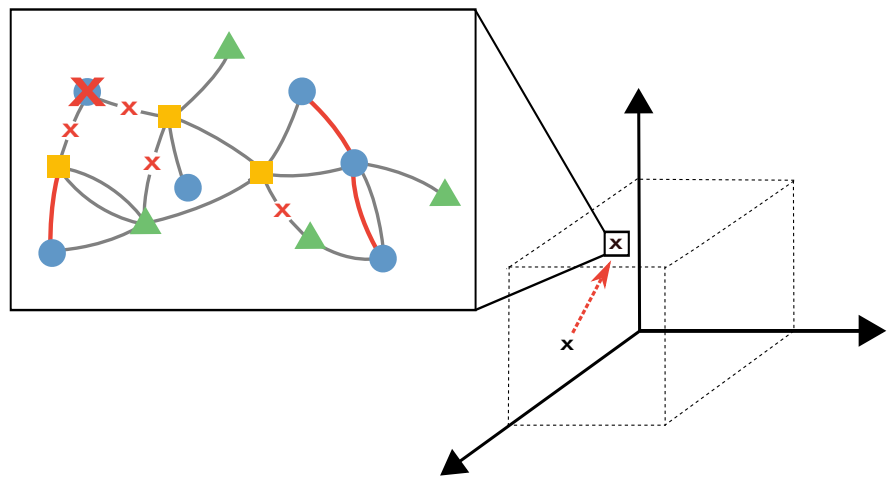


4. Measure the impact of change at different scale (particularly at the individual level)

Crowdsourcing the Robin Hood effect in cities

T Louail

Murillo A J

Ramasco JJ

IFISC
Instituto de Física Interdisciplinar y Sistemas Complejos

BBVA

irstea

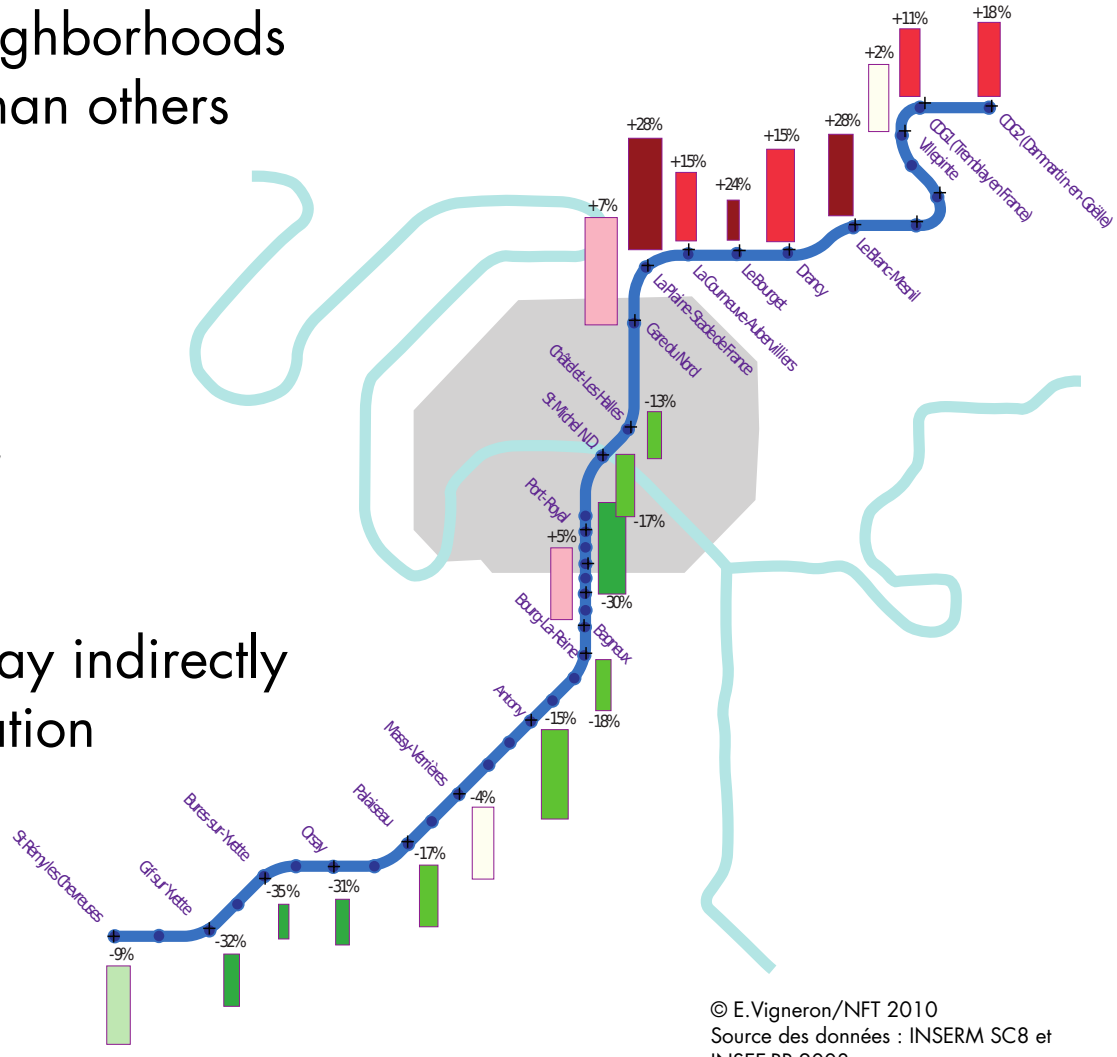
Spatial inequality in the city

- In any city there are some neighborhoods that are significantly poorer than others

- Strong inequalities have harmful consequences

  → ***Neighborhoods effect***

- Fostering comercial activity may indirectly benefits to the resident population
  - Job opportunities;
  - More transport;
  - Increased safety…

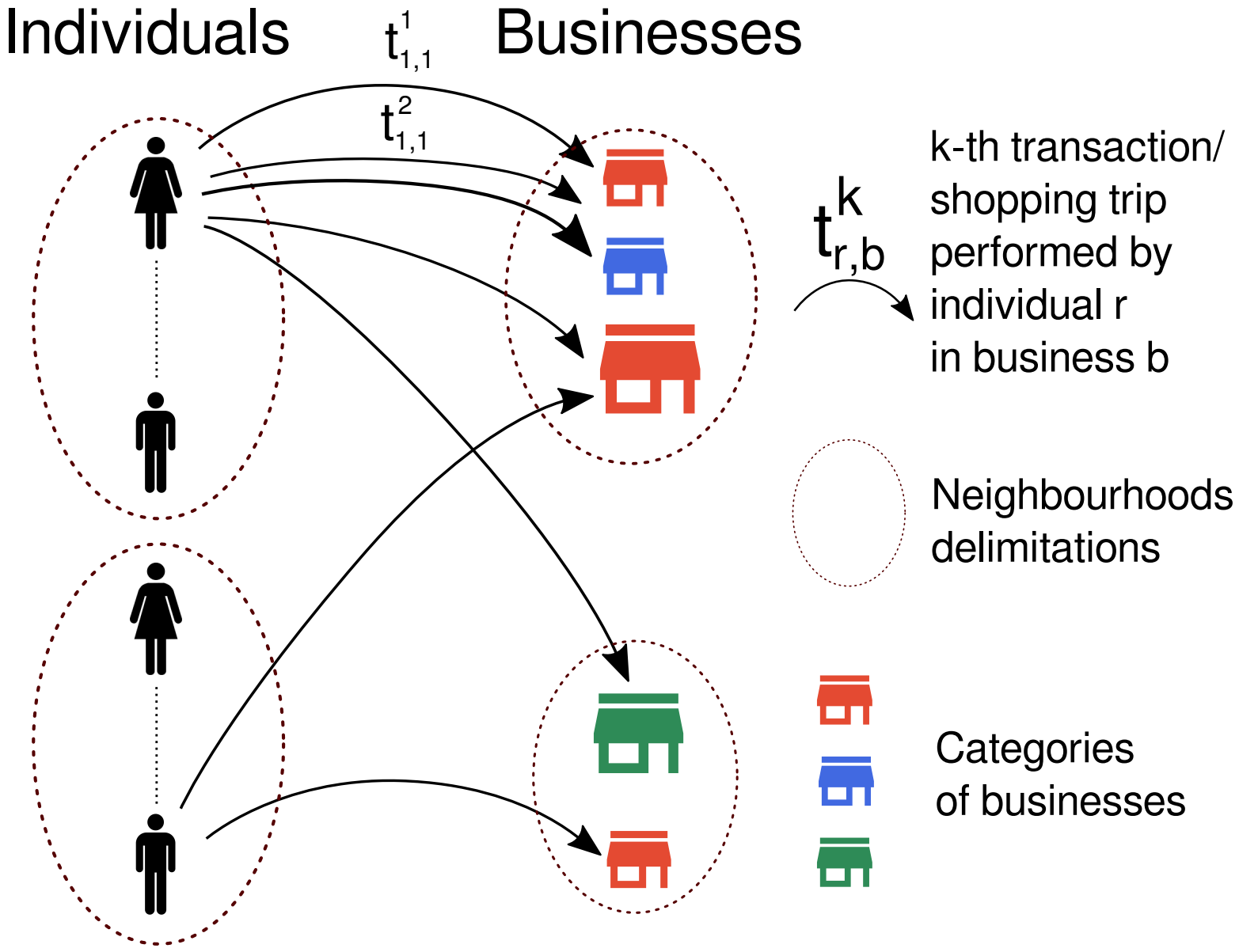


© E.Vigneron/NFT 2010
Source des données : INSERM SC8 et INSEE-RP 2008
Calculs et mise en forme : NFT 2010

Redistribution through shopping mobility

- 15 to 20% of our daily trips are shopping trips
- They convey money from one part of a city to another
- **Spatial Robin Hood effect** means taking from the rich neighborhoods to give to the poor neighborhoods

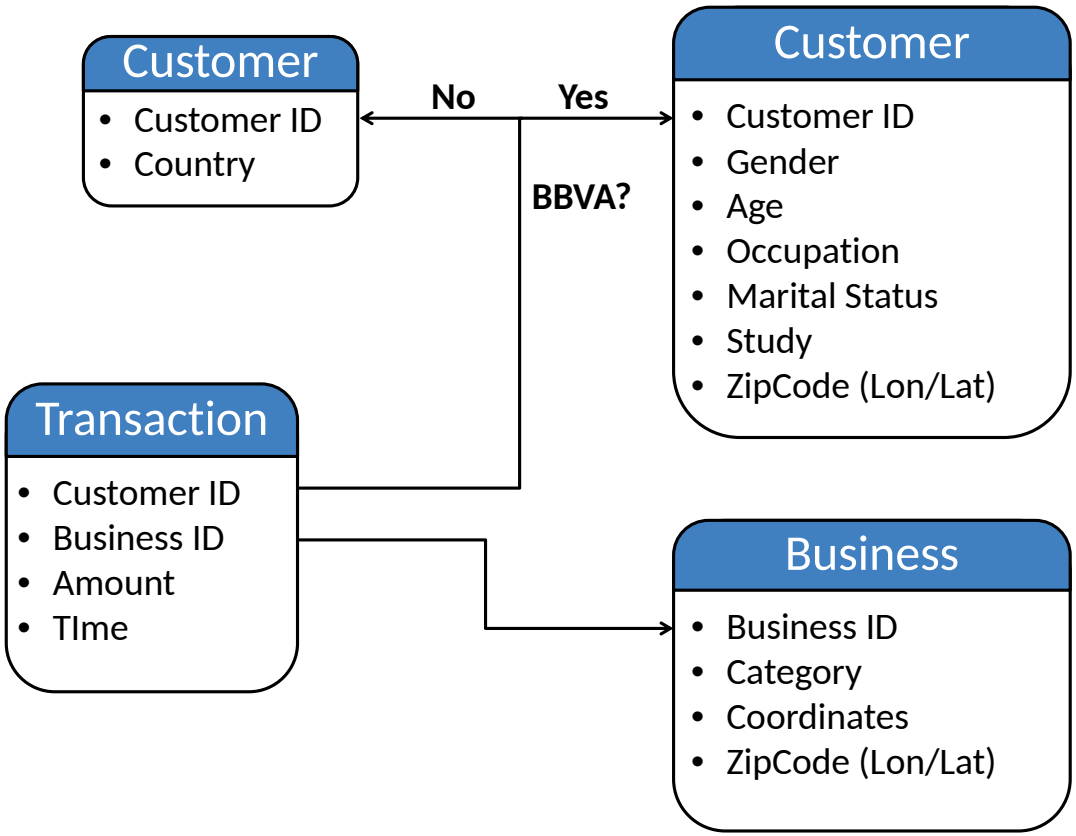
Bipartite network of shopping trips

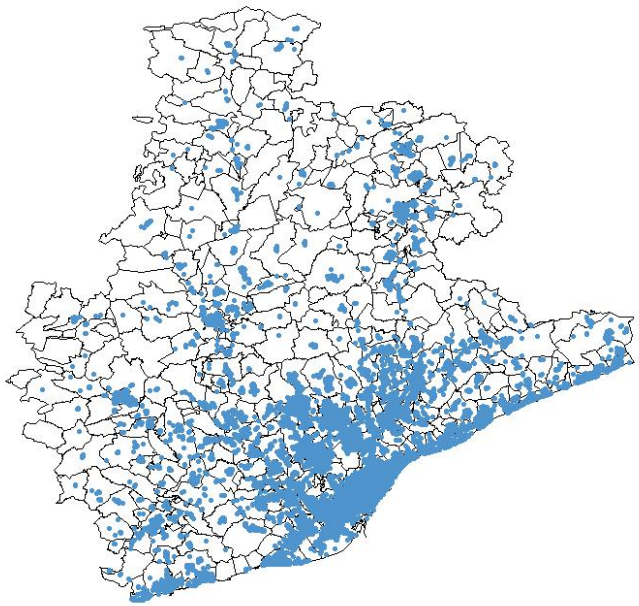


BBVA database

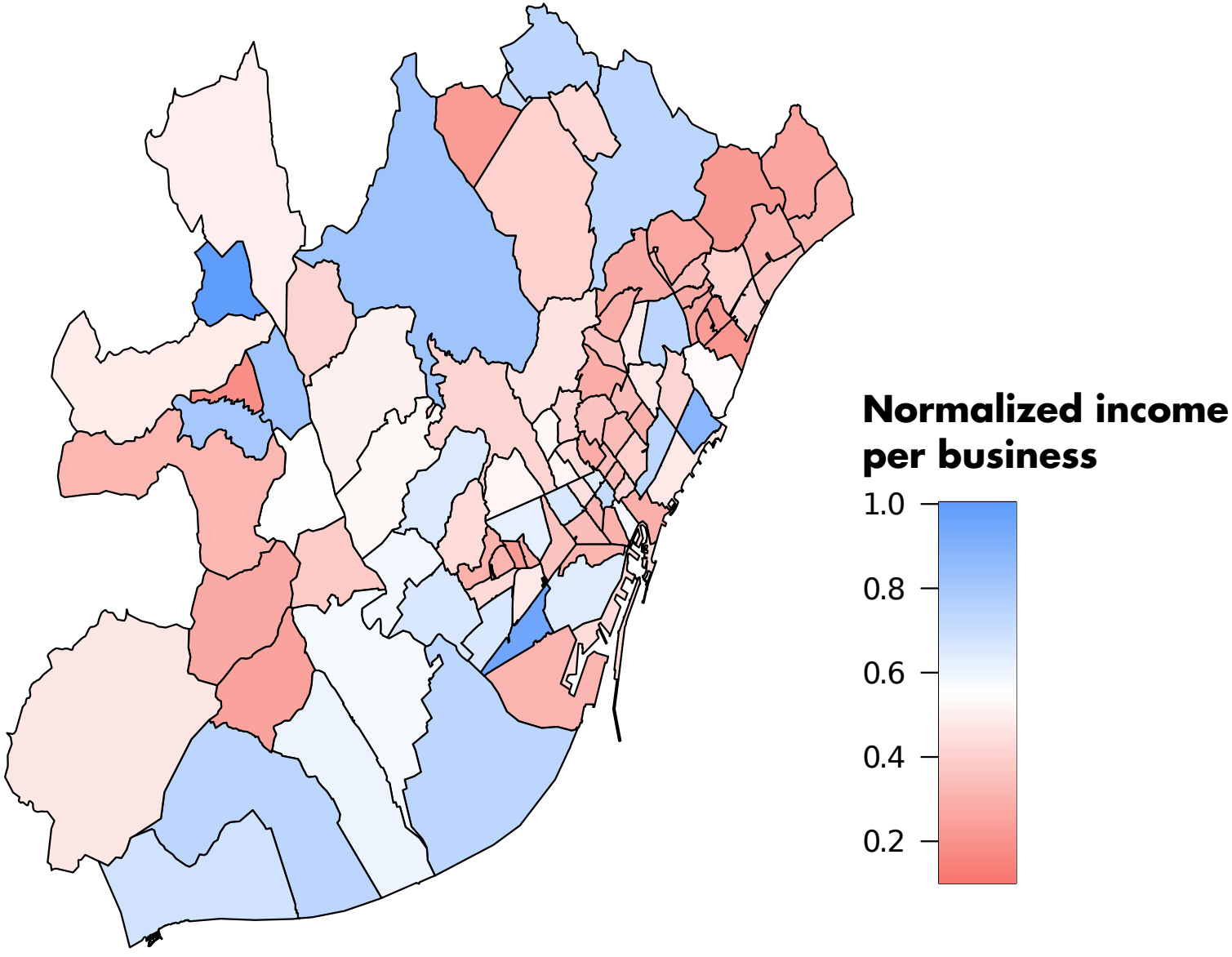
Provinces of **Madrid** (~6M inhab.) and **Barcelona** (~5M inhab.)

130M of transactions made in **2011/2012** by **3.5M of customers** in **320,000 businesses** classified in **80 categories**

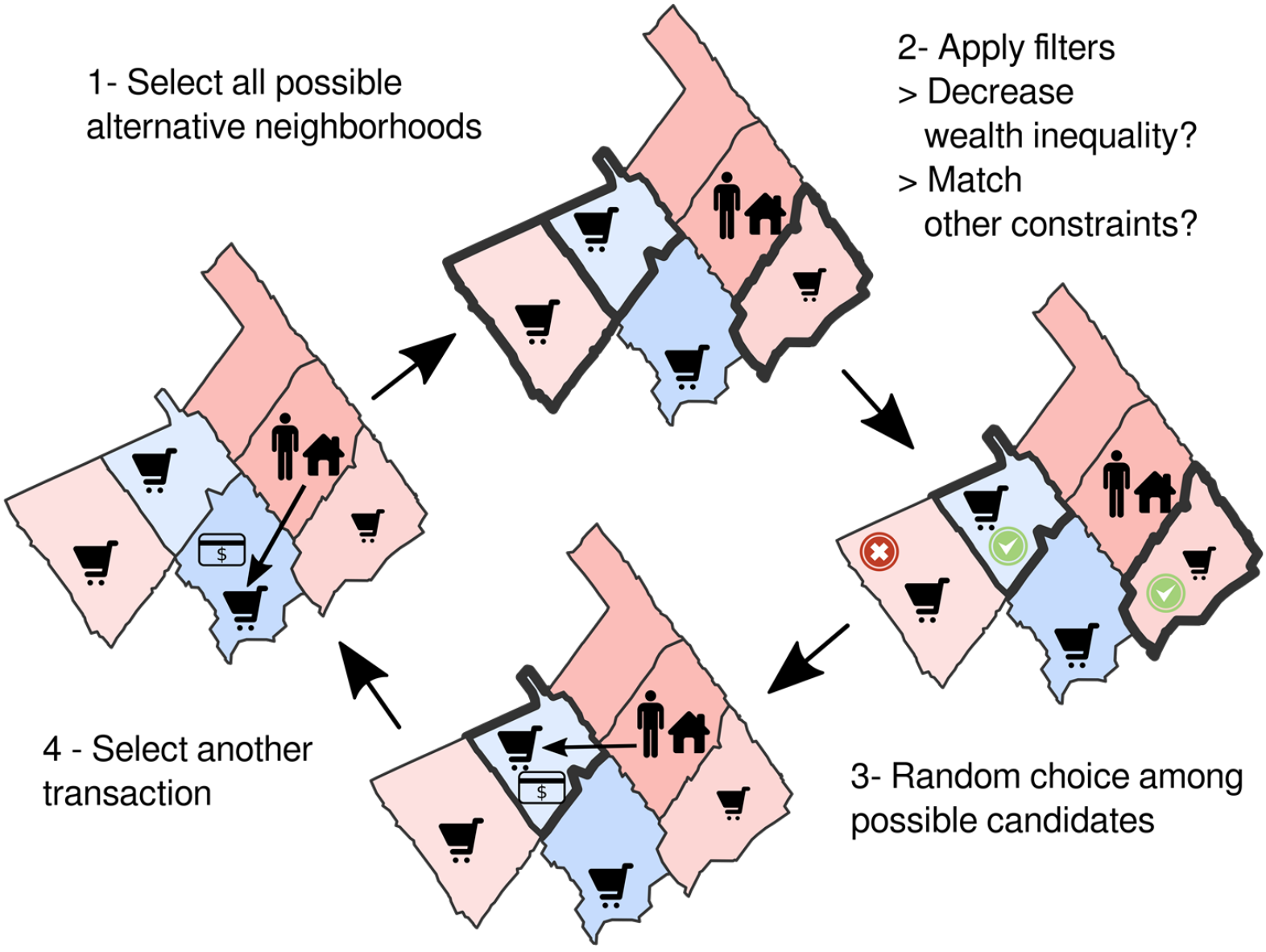




Spatial distribution of business income



Rewiring method



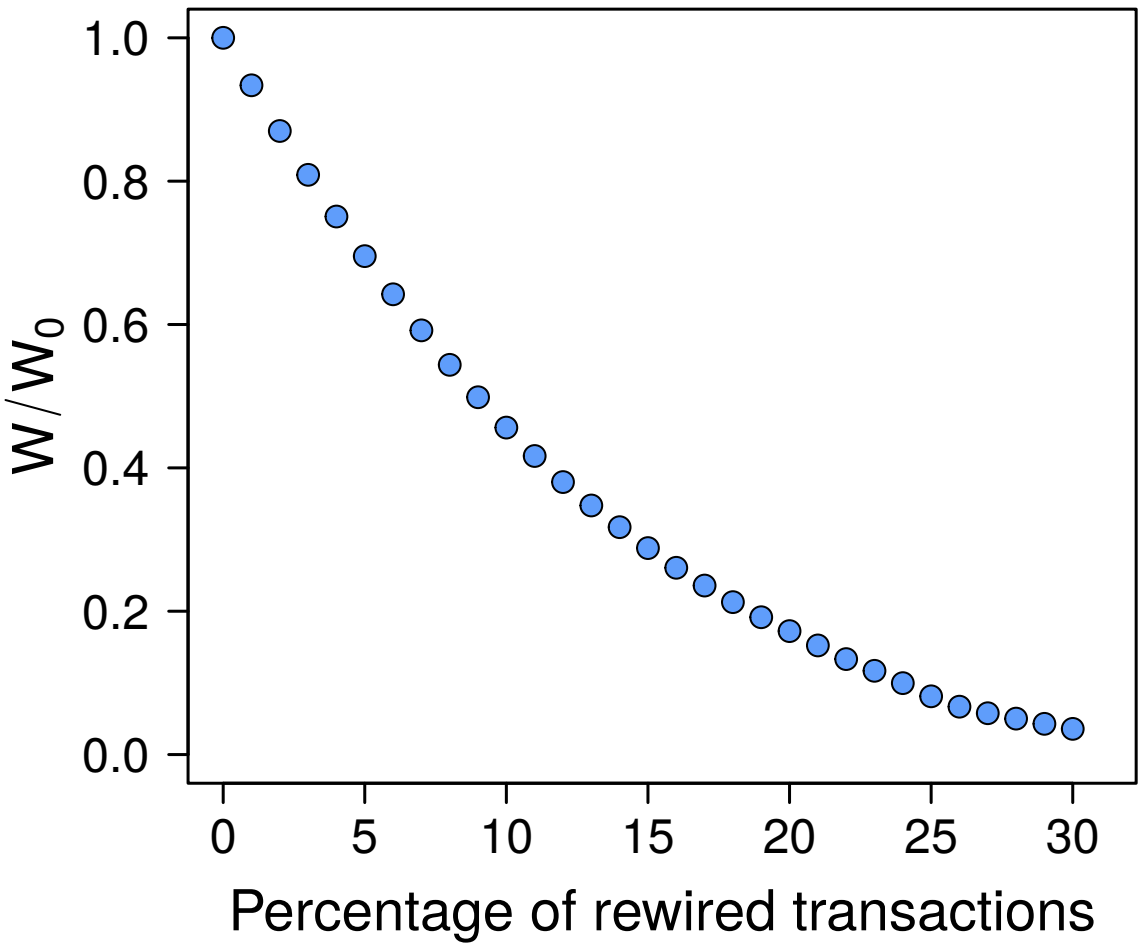
Three other key aspects

In addition to the spatial distribution of business income and its distance to the egalitarian situation **W**, we also take into consideration:

- The distance traveled **D**
- The spatial routines of individuals ρ
- The spatial mixing of individual residing in different part of the city, evaluated as the distance to a "fully mixed city" **S**

Reachability of the solution…

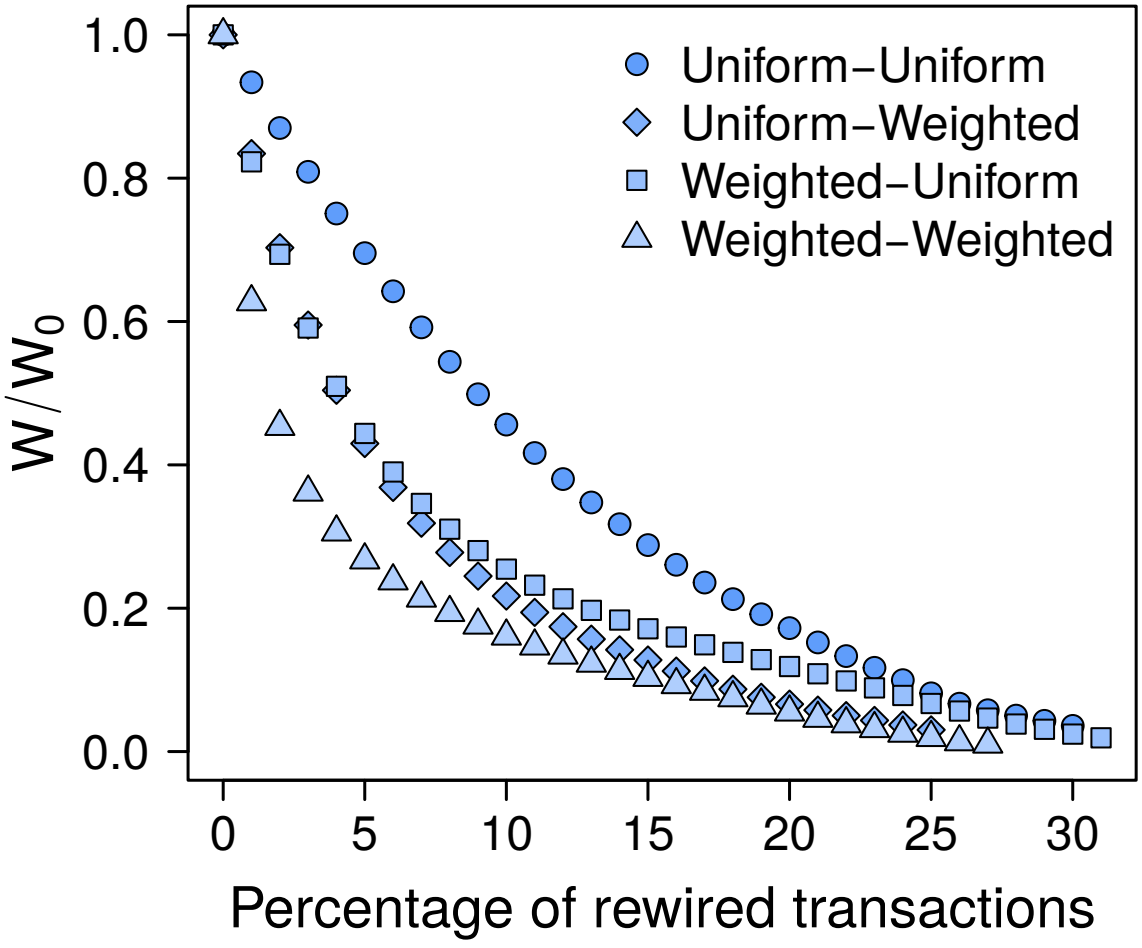
…while preserving the other key aspects



→ **Wealth inequalities between neighborhoods are reduced by 95%**

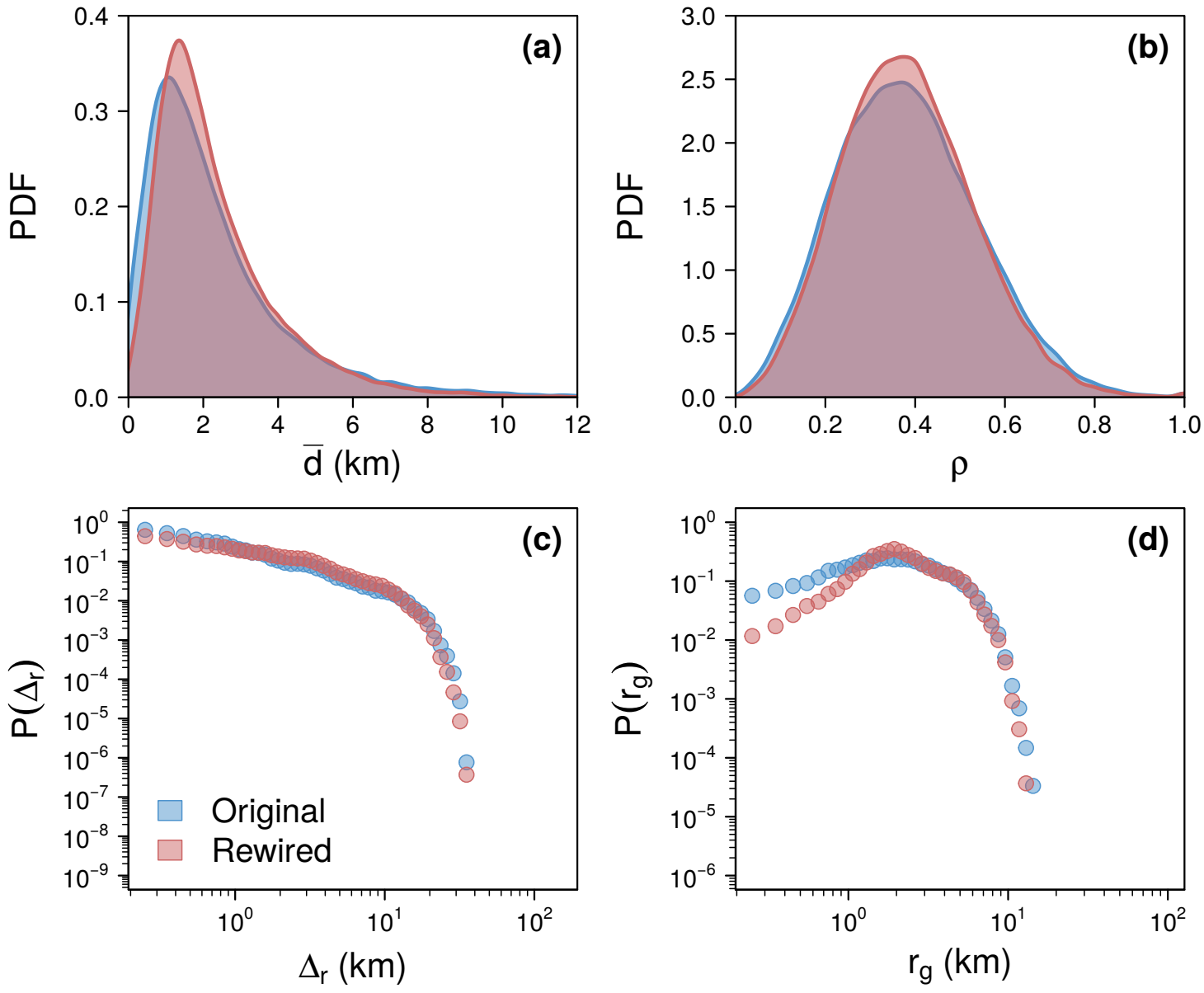
Reachability of the solution…

…while preserving the other key aspects

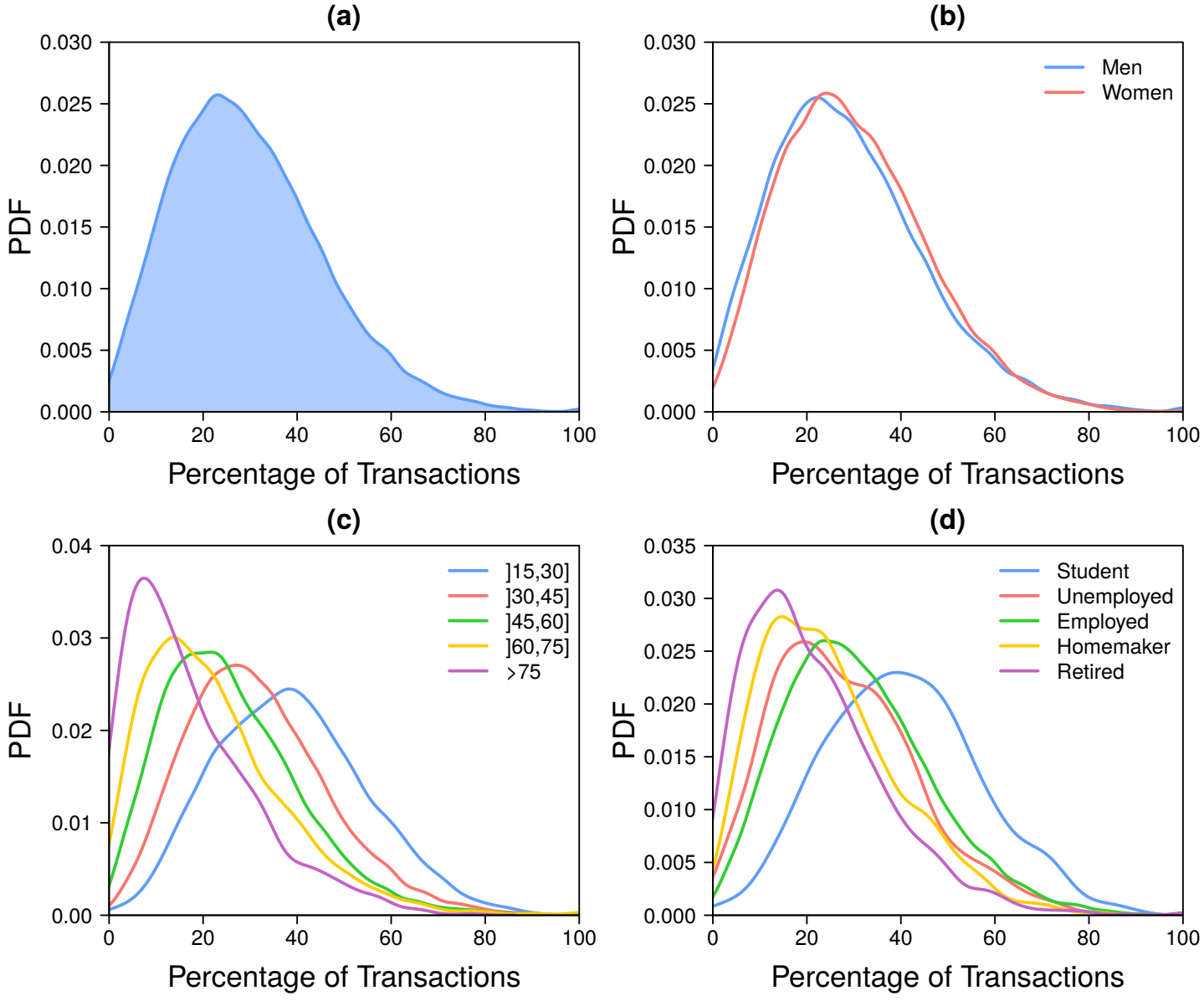


Many possible rewiring methods, the "clever" methods perform better

Individual human mobility patterns



Assessing the cost of change



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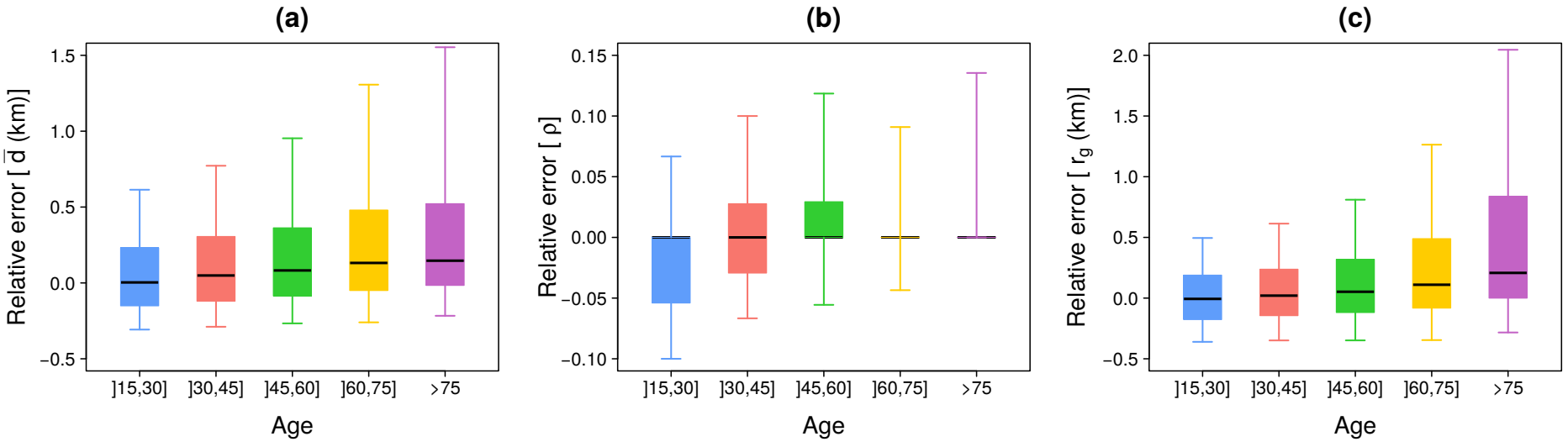
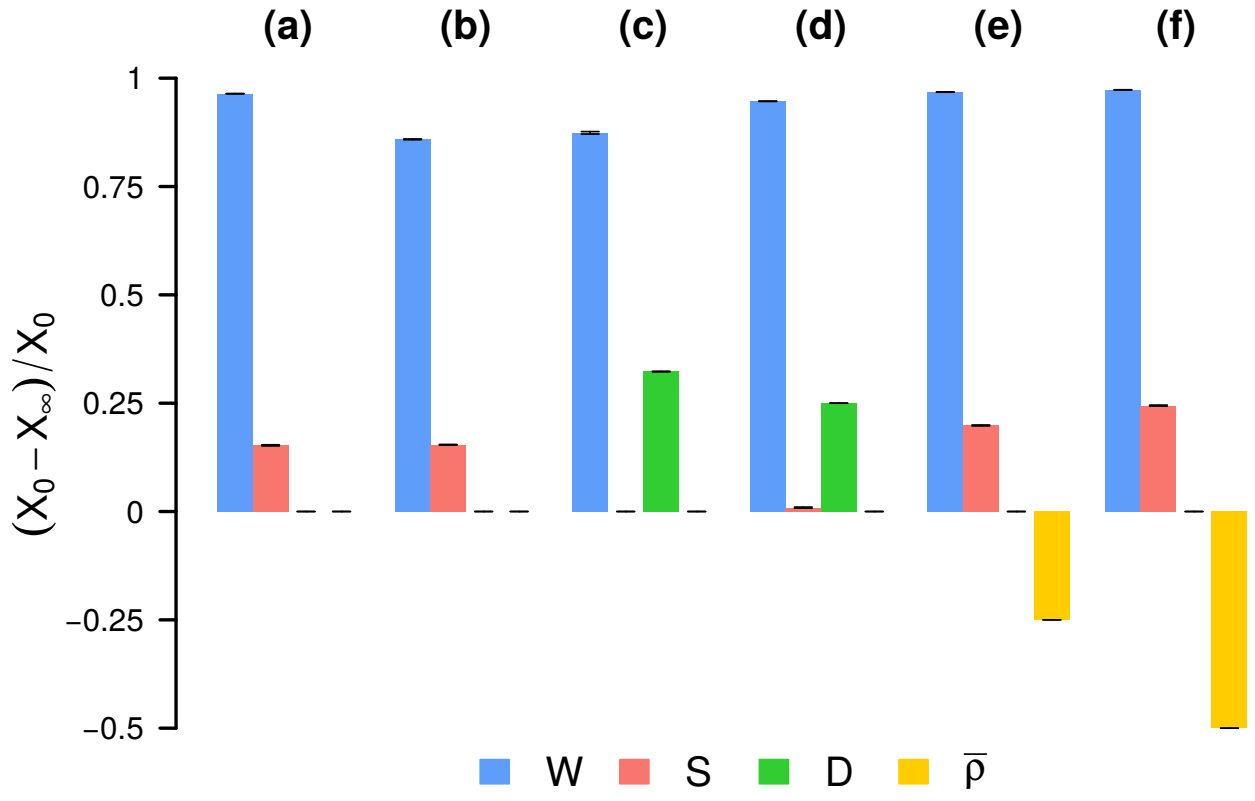


Multi-criteria improvement of shopping mobility

Experiment	α_W	α_S	α_D	$\alpha_{\bar{\rho}}$	W (B/M)
(a) Reference	0	1	1	1	96.4%/99.5%
(b) Spatial mixing ↑	0	0.75	1	1	85.9%/78.1%
(c) 50% energy savings	0	1	0.5	1	87.4%/84.8%
(d) 25% energy savings	0	1	0.75	1	94.7%/98.8%
(e) Exploration rate ↑	0	1	1	1.25	96.8%/99.9%
(f) Exploration rate ↑↑	0	1	1	1.5	97.3%/100%



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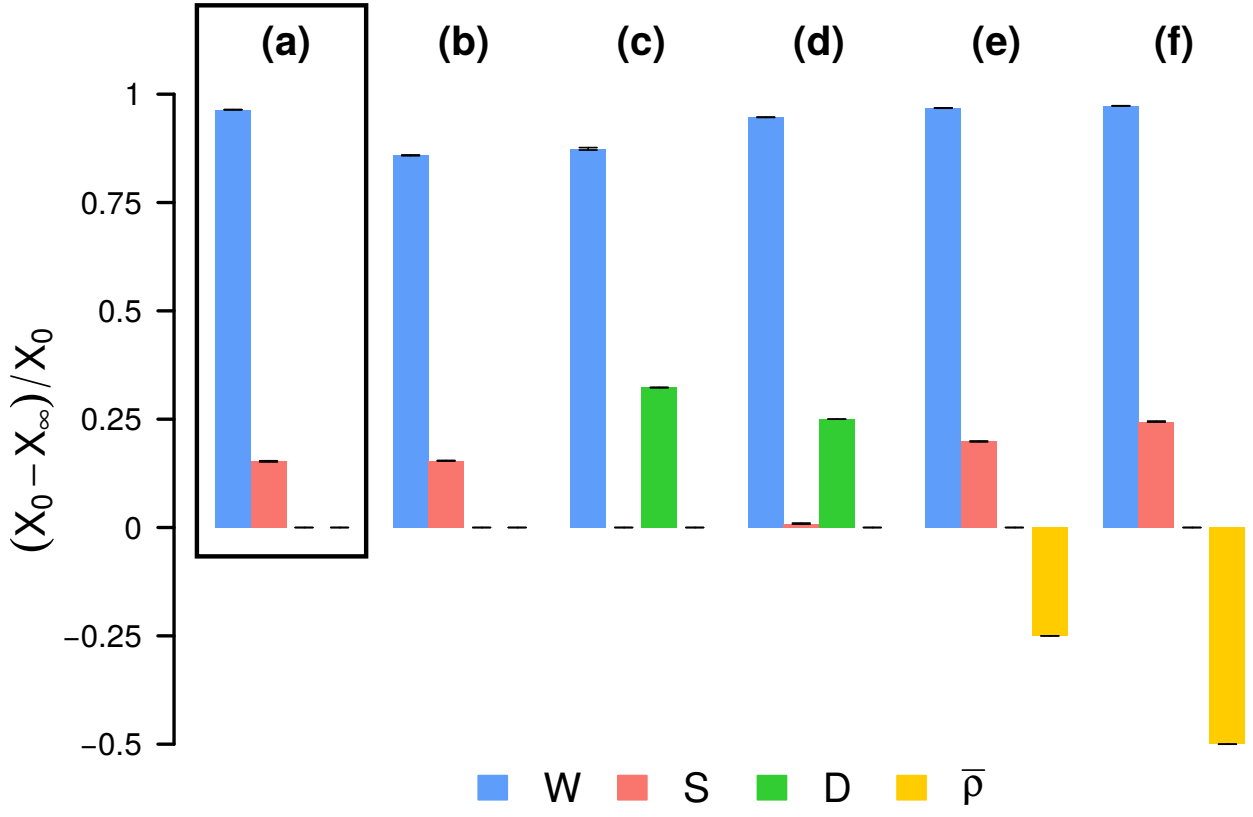

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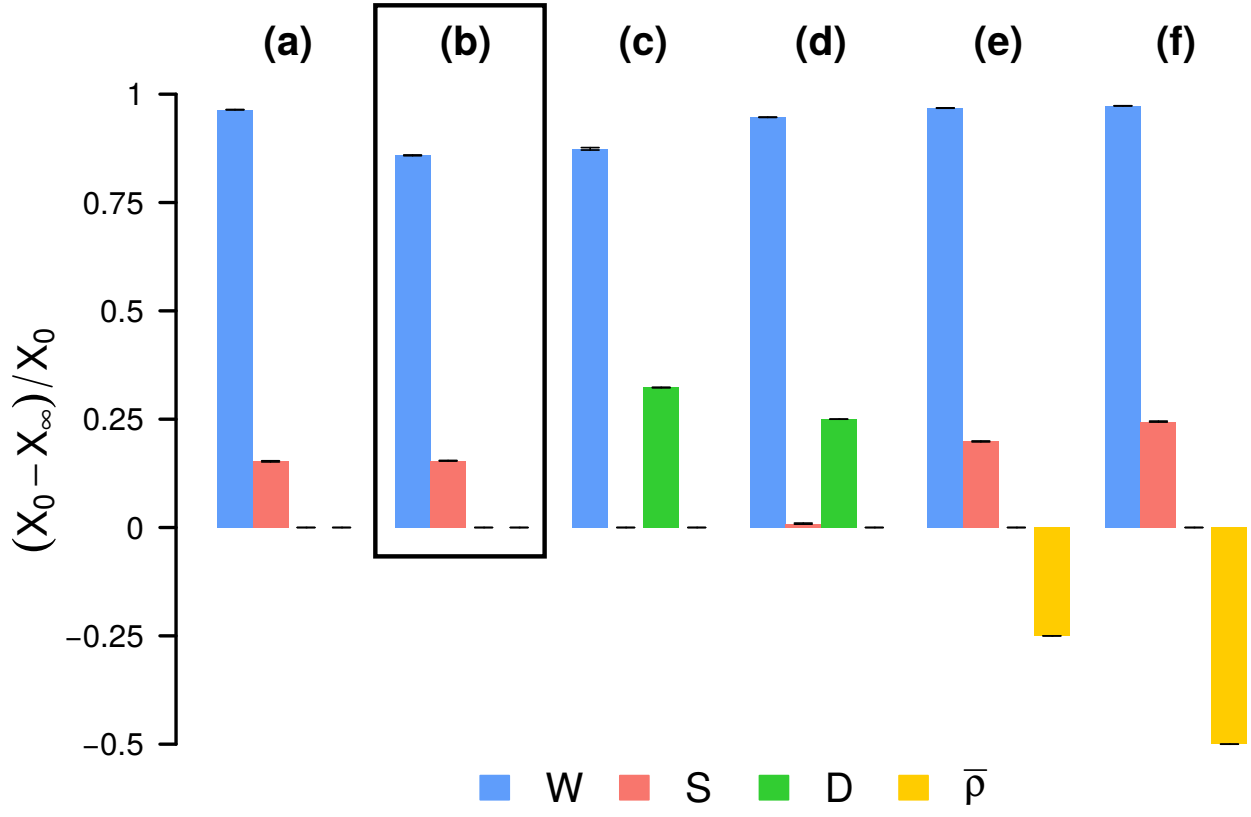

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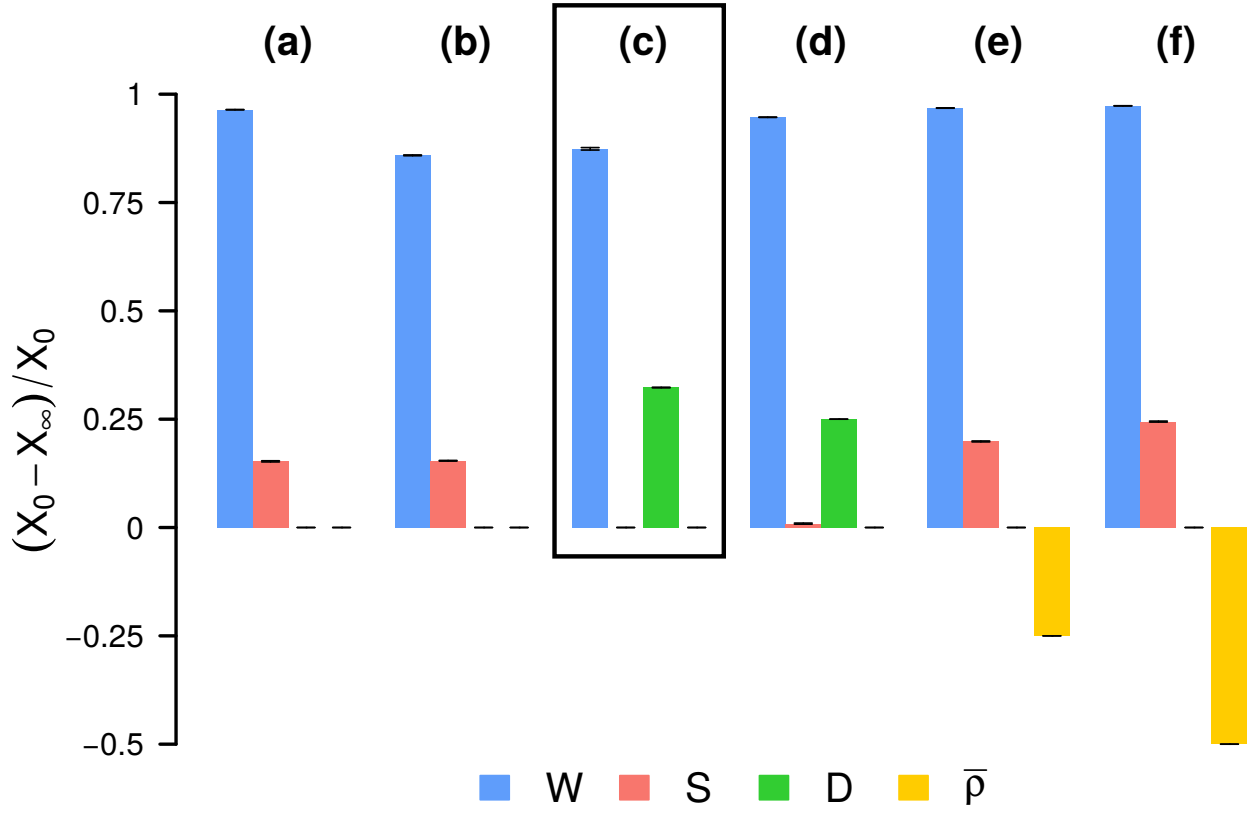

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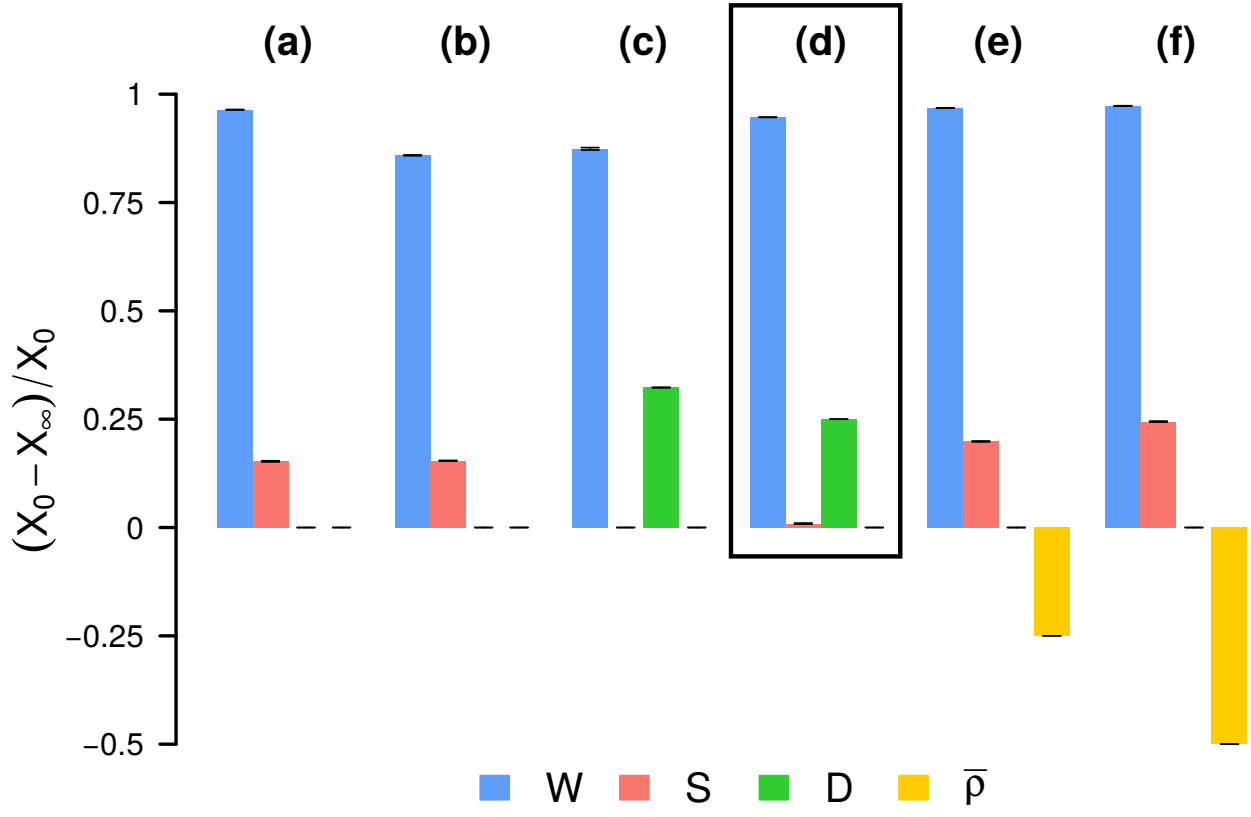

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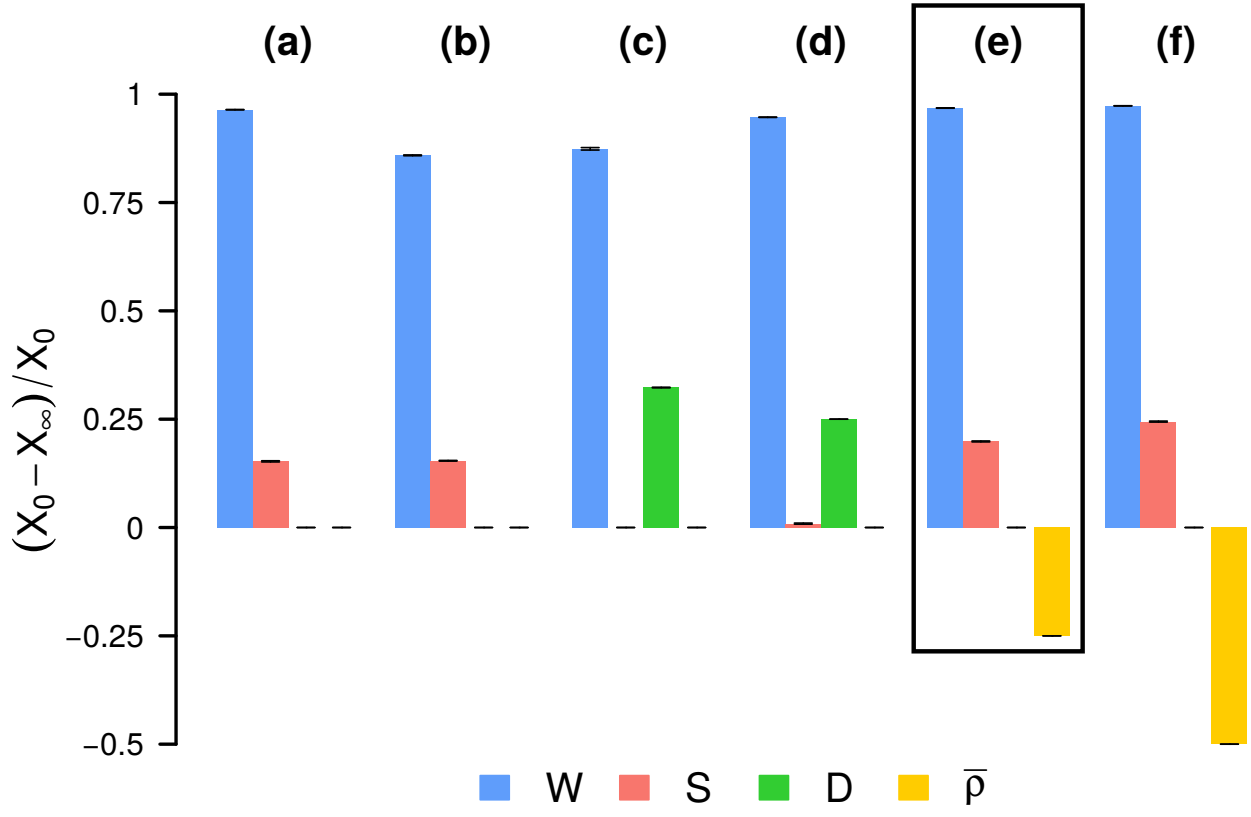

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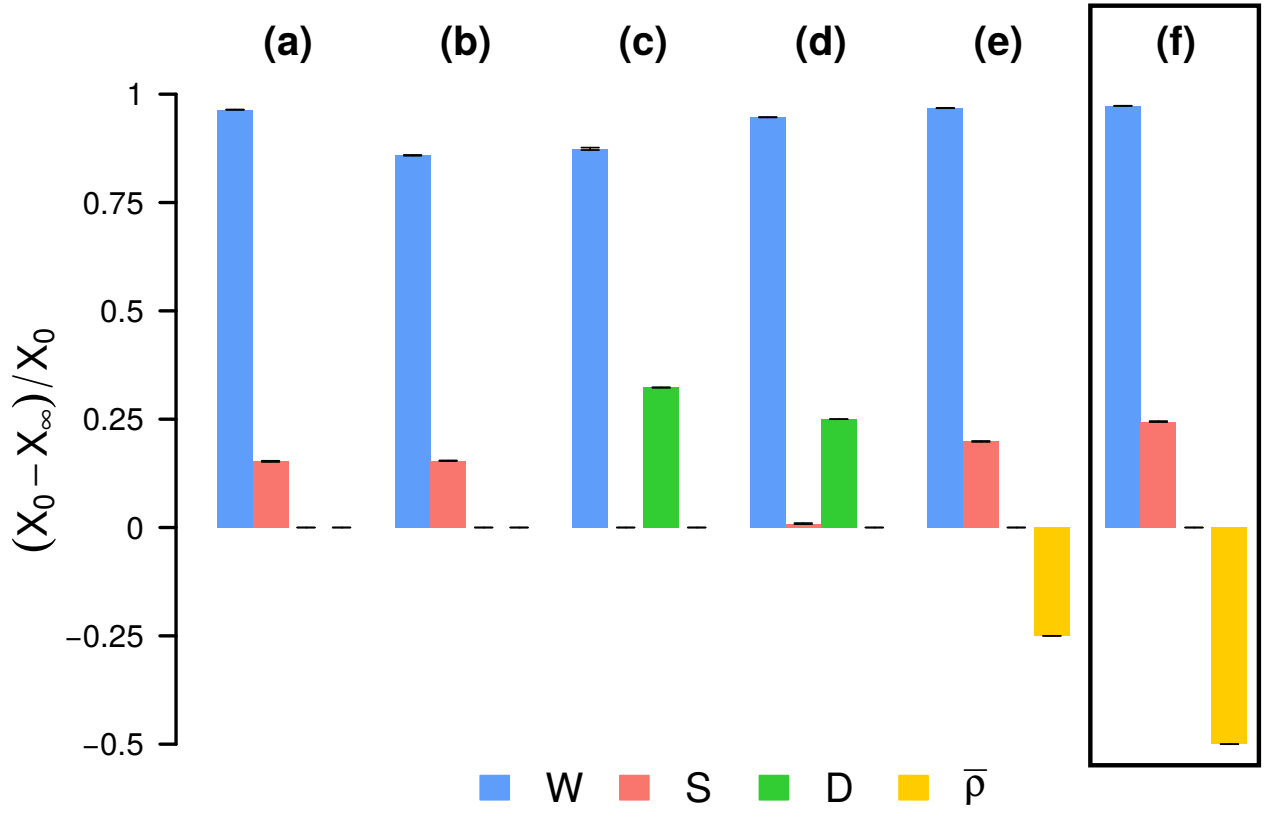


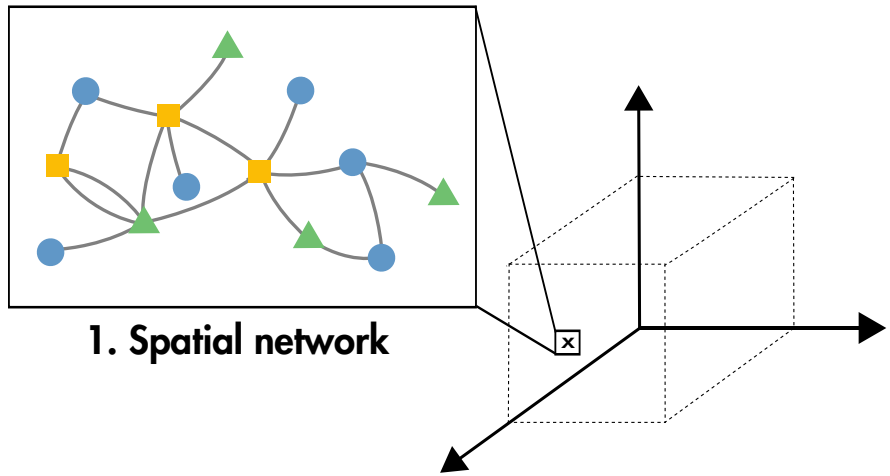
Take home messages

- **Rewiring ~10 % of all individual shopping trips might result in a 80+ % decrease of business income inequality among neighborhoods, in Barcelona and Madrid**

- Situations where ICT data bypass top-down planning policies and foster distributed, bottom-up approaches of city-scale hard problems

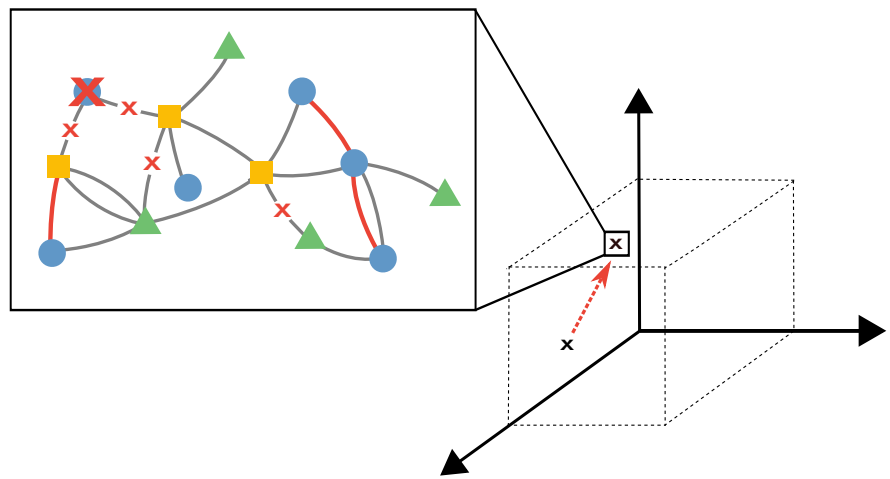
- Urgent need to relate ICT data to social equity and spatial justice and such apps would rejuvenate the very meaning of the so-called « sharing economy »

2. Develop a set of indicators to assess the actual network configuration



1. Spatial network

3. (Temporal) network reconfiguration respecting a set of constraints



4. Measure the impact of change at different scale (particularly at the individual level)