Gravity & the Big Bang

in the Context of Epidemics:

How Mobility Impacts Epidemics & Vice Versa

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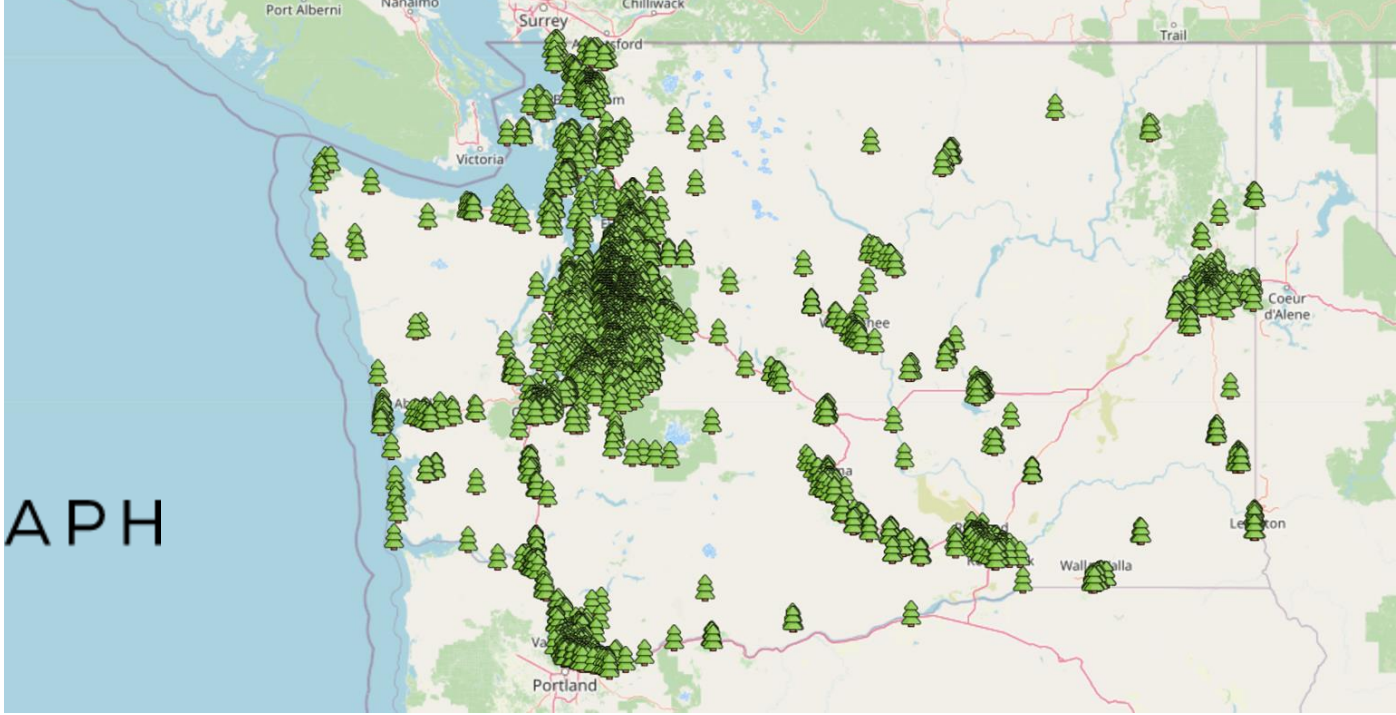
Gravity

how epidemic impacts mobility

(Nature) Communications Physics volume 7, Article number: 55 (2024)

Data

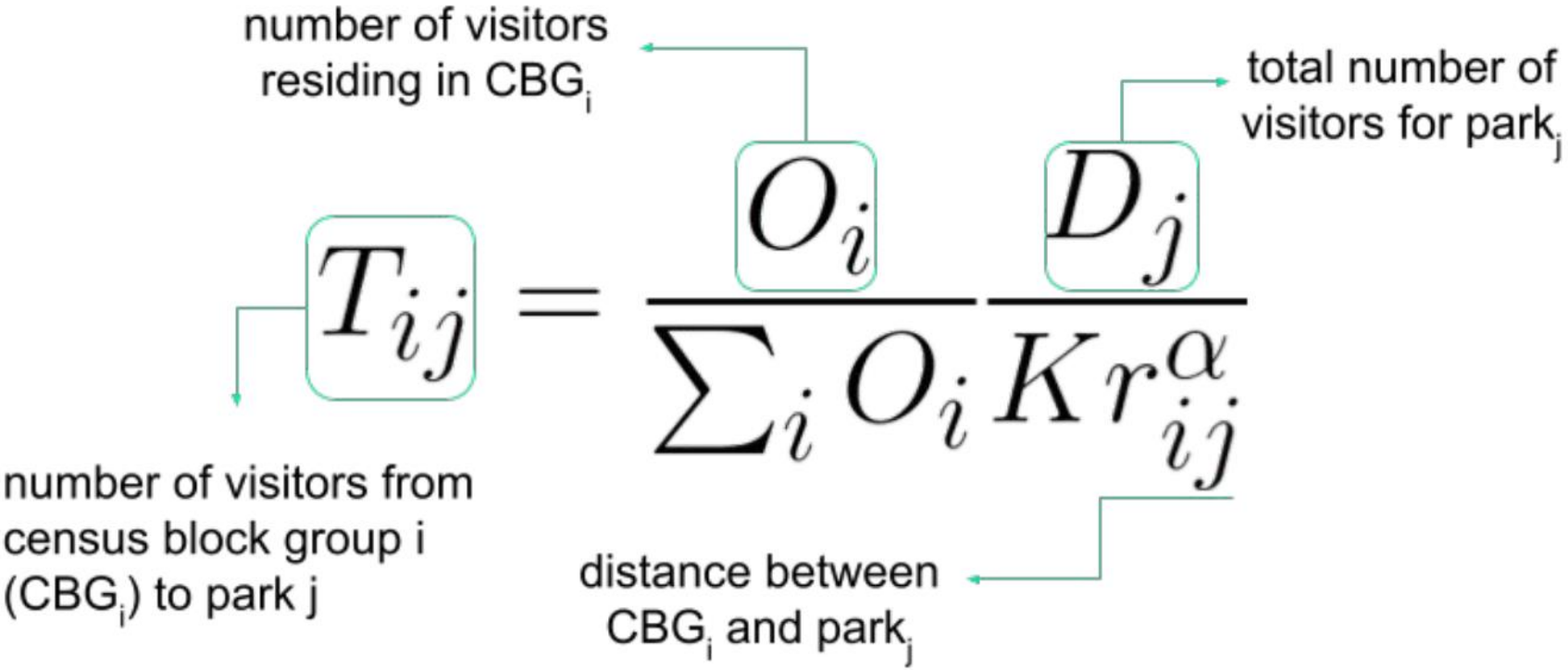


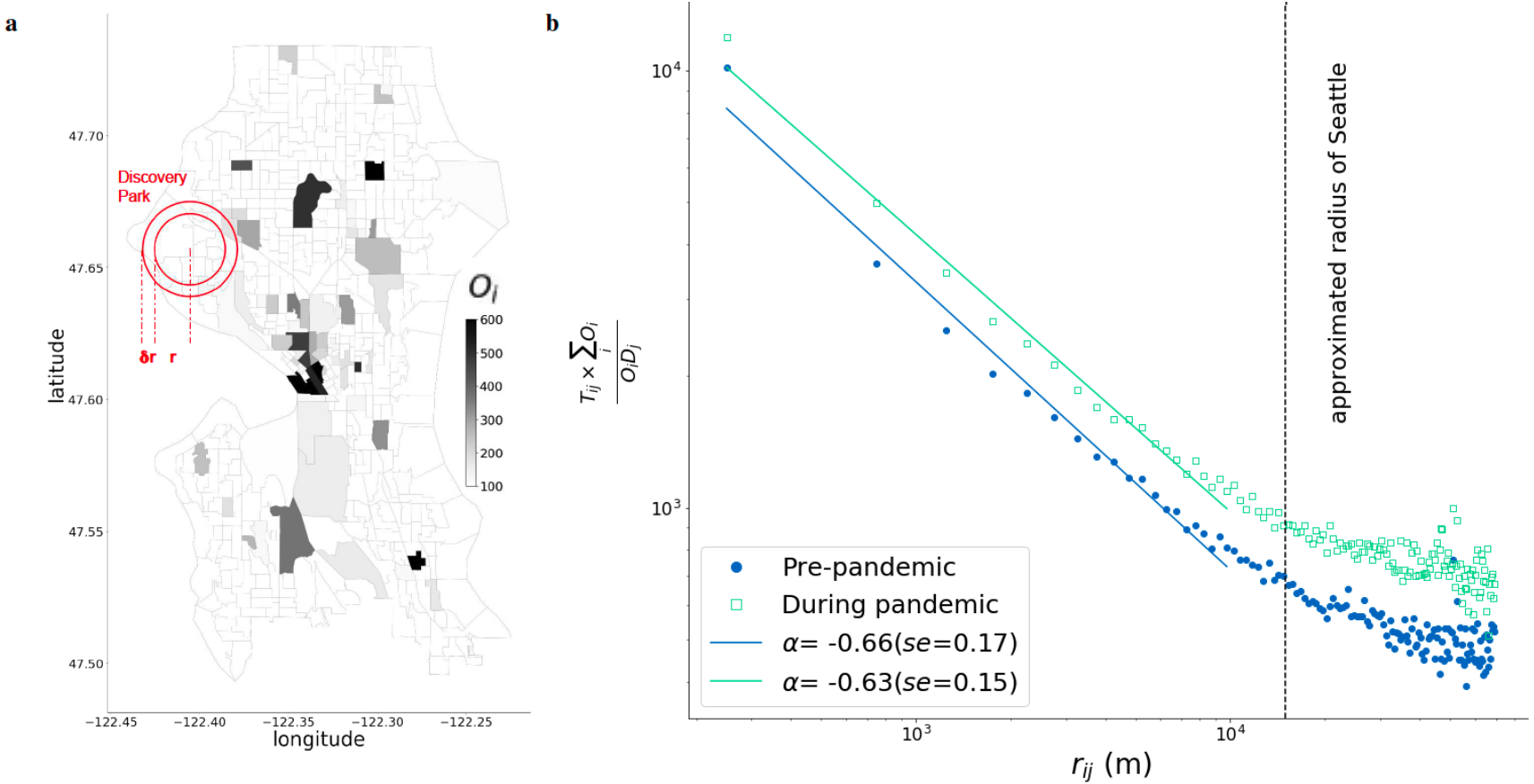
SAFEGRAPH

Weekly visitation patterns from census block groups to the Washington state urban parks

SAFE GRAPH: https://docs.safegraph.com/docs/weekly-patterns

The Gravity Model




a
Discovery Park
δr
r
O_i
600
500
400
300
200
100
47.70
47.65
47.60
47.55
47.50
latitude
−122.45
−122.40
−122.35
−122.30
−122.25
longitude
b
10^4
10^3
$\frac{T_{ij} \times \sum_i O_i}{O_i D_j}$
approximated radius of Seattle
Pre-pandemic
During pandemic
α= -0.66(se=0.17)
α= -0.63(se=0.15)
10^3
10^4
r_{ij} (m)

Question: Changes in Park Visitation Pattern

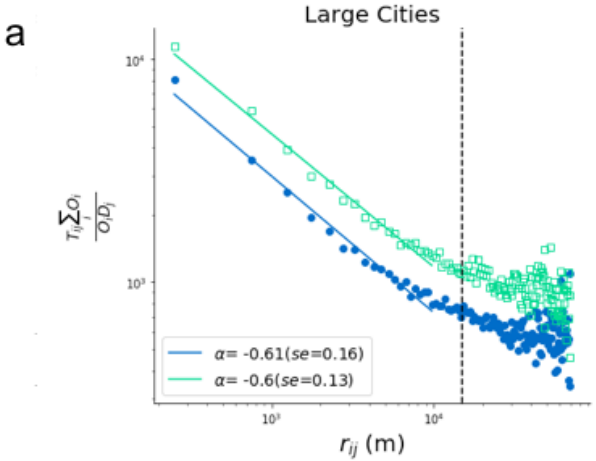
- What is the **pattern** that the park visitation obeys from?

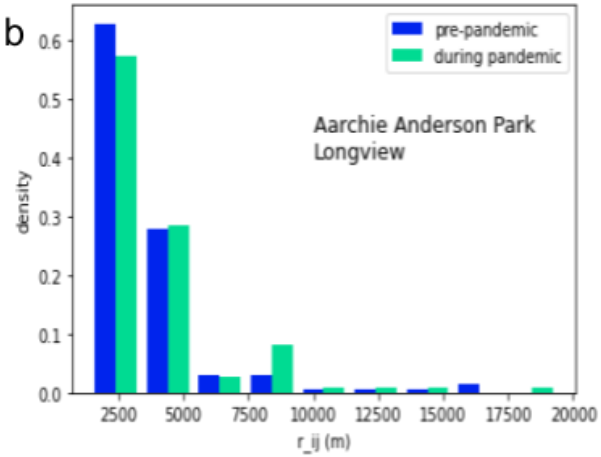
- How the park visitation pattern has **changed** due to the **COVID-19 pandemic**?

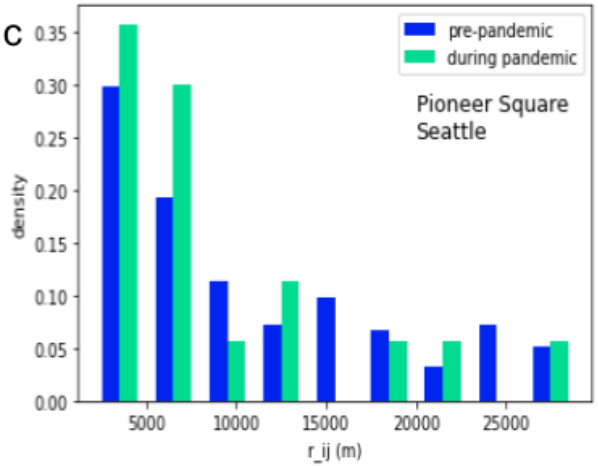
- How the change in park visitation patterns varies between different
  - **seasonal patterns**,
  - **socio-economic groups**,
  - and **size of cities**?

Different Cities' Reaction (Equality)

Large vs Small Cities







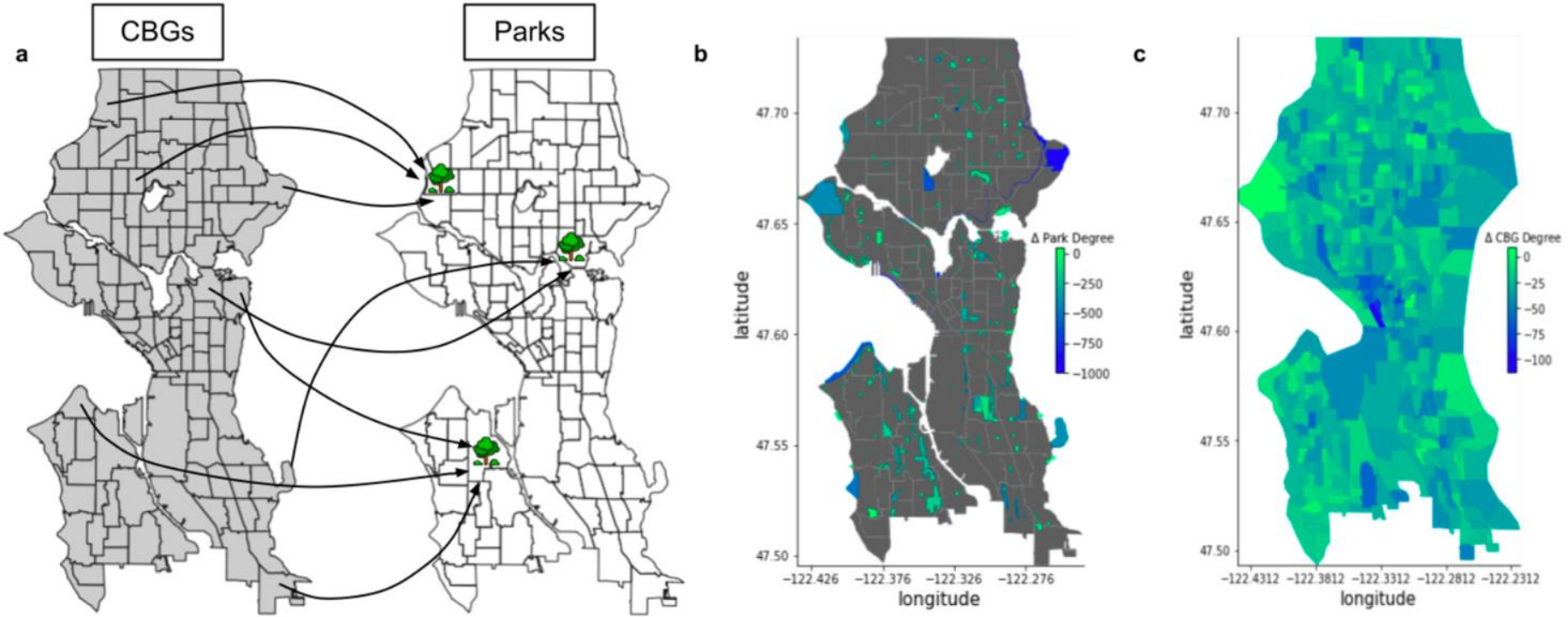
Different Groups' Reaction (Equality)

During (2020) vs Pre (2019) Pandemic:

- Gravity model is a robust pattern.
- The slope changes.
- People visit closer parks during pandemic, in both warm and cold seasons.
- Different socio-economic groups:
  - Closer parks become more popular among the least vulnerable visitors
  - The most vulnerable visitors have more interest in visiting distant parks
- Large vs small cities
  - Visitors from smaller cities prefer visiting further distance
  - Visitors from larger cities prefer closer parks

Propensity & Diversity of the visits

Park Visitation Network



Correlations:

Degree CBG	pre-pandemic	During the pandemic	Change in degree
SVI	**-0.93**	-0.9	0.87

Degree Park	pre-pandemic	During the pandemic	Change in degree
visitor/area	0.67	**0.94**	-0.72

- The higher the social vulnerability of an area, the residents of that area exhibit a lower propensity in park visitation.
- The parks in richer areas of Washington State did not exhibit a significant difference in their visitors' diversity.

The big bang of an outbreak

how mobility impacts epidemics

arXiv:2405.03703v1

COVID-19 in Iran?

Where? When? How?

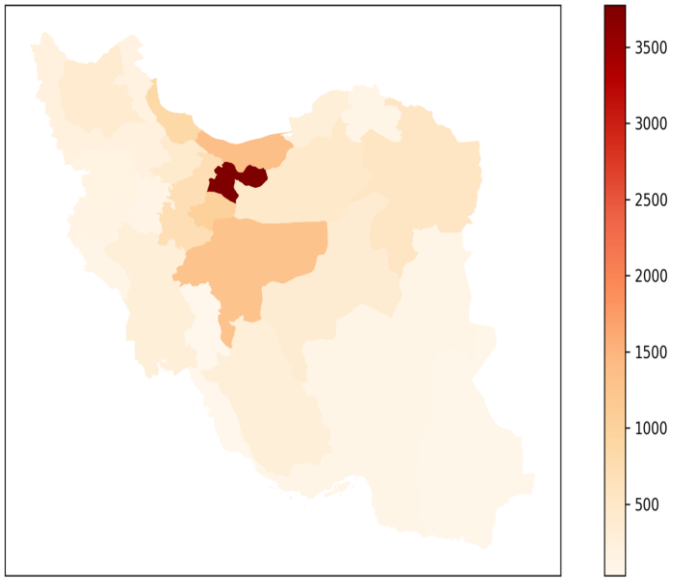
What Was the Challenge?

- **Iran's** population is almost **83 million** with almost **3 million** daily travels between its provinces.
- **Tehran** is the capital city of Iran whose population is around **15 million**.
- **Qom** is a relatively small province near Tehran, with almost **3 million** population.
- Imam Khomeini Airport (IKA) is a major international airport in Iran, located between **Qom** (89 km away) and **Tehran** (55 km away).

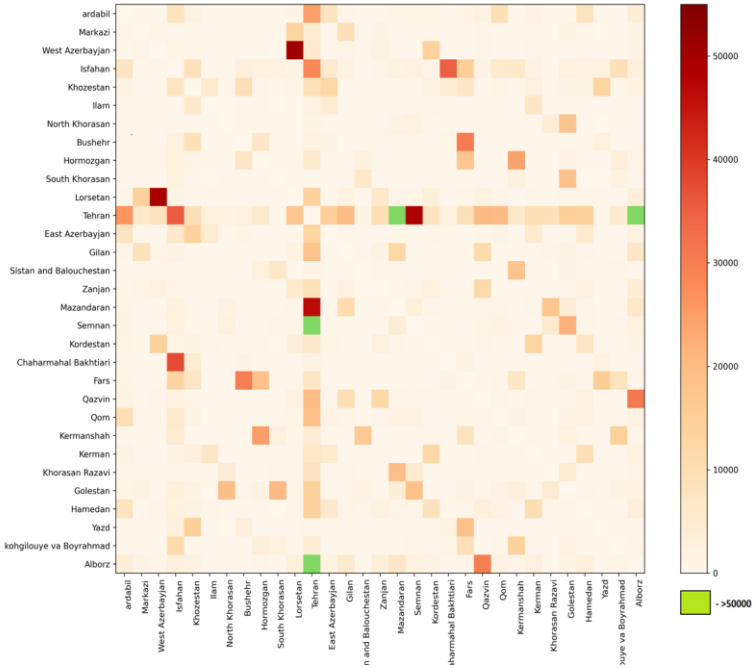
Isolate Qom or Tehran?

Our Data (23th February 2020):

A



B



# of Coronavirus active cases

Daily passenger flow

A Well-Visualized Approach

Effective Distance

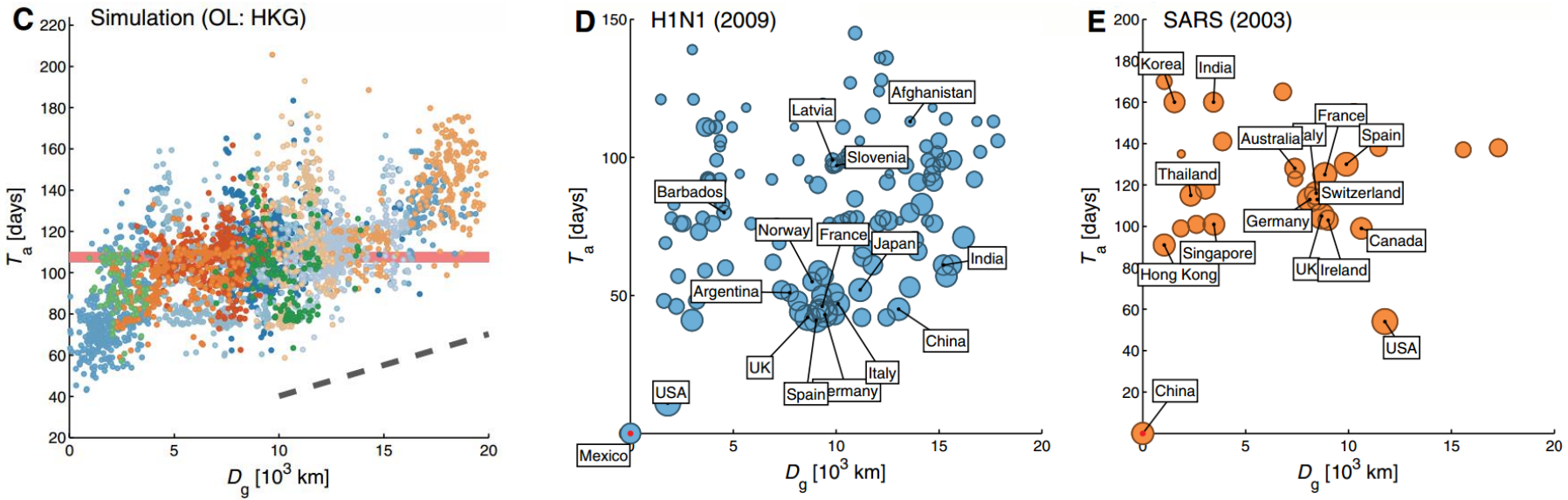
The Hidden Geometry of Complex, Network-Driven Contagion Phenomena
Dirk Brockmann and Dirk Helbing
Science **342**, 1337 (2013);
DOI: 10.1126/science.1245200

Empirical Data I: The Mobility Network

Empirical Data II: The Active Cases

105 days < T_arival <110 days

Geographic Distance

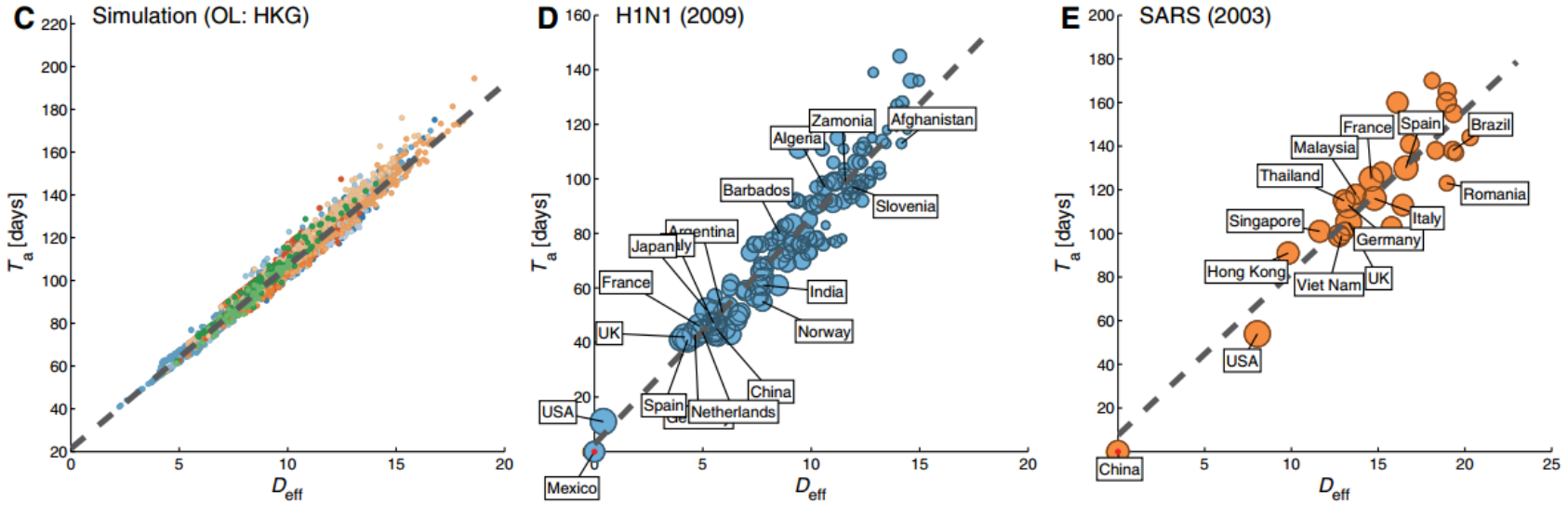


Effective Distance

$$d_{mn} = (1 - \log P_{mn}) \geq 1 \qquad P_{mn} = F_{mn}/F_n$$

indirect flights

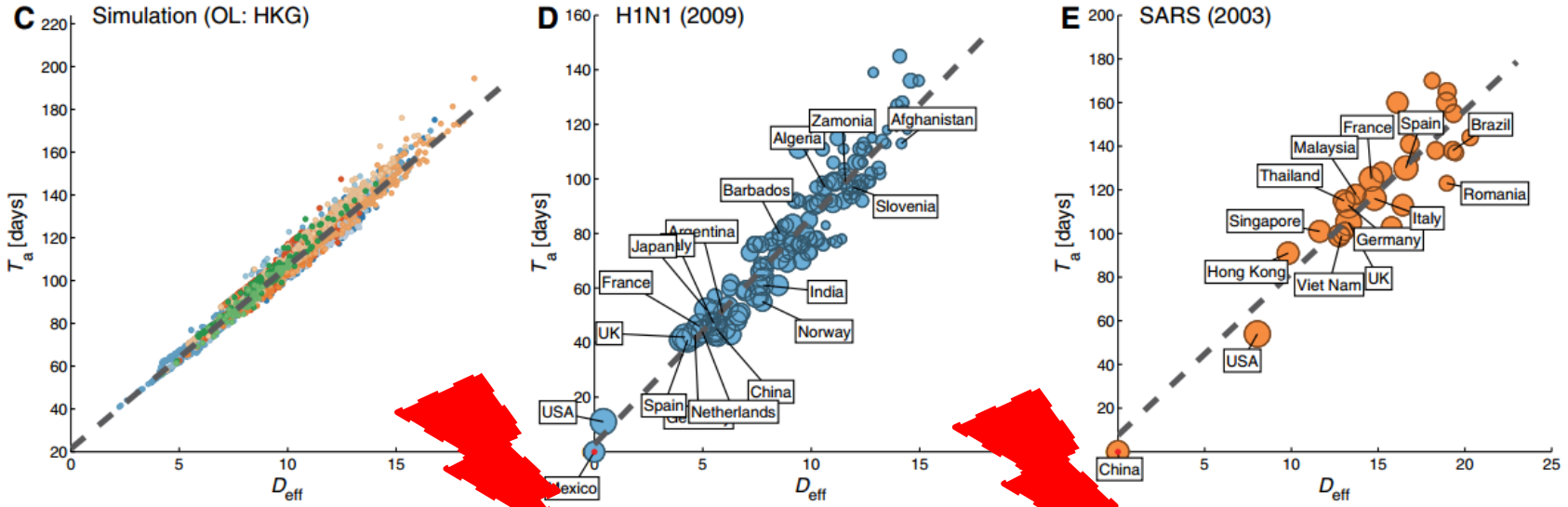
$$D_{mn} = \min_{\Gamma} \lambda(\Gamma)$$



$$T_a = \underbrace{D_{\text{eff}}(\boldsymbol{P})}_{\text{eff. distance}} / \underbrace{v_{\text{eff}}(\alpha, R_0, \gamma, \varepsilon)}_{\text{eff. speed}}$$

Effective Distance

$$d_{mn} = (1 - \log P_{mn}) \geq 1 \qquad P_{mn} = F_{mn}/F_n \qquad D_{mn} = \min_{\Gamma} \lambda(\Gamma)$$



$$T_a = \underbrace{D_{\text{eff}}(\boldsymbol{P})}_{\text{eff. distance}} / \underbrace{v_{\text{eff}}(\alpha, R_0, \gamma, \varepsilon)}_{\text{eff. speed}}$$

Arrival Time?

Science
AAAS

The Hidden Geometry of Complex, Network-Driven Contagion Phenomena

Dirk Brockmann and Dirk Helbing

Science **342**, 1337 (2013);
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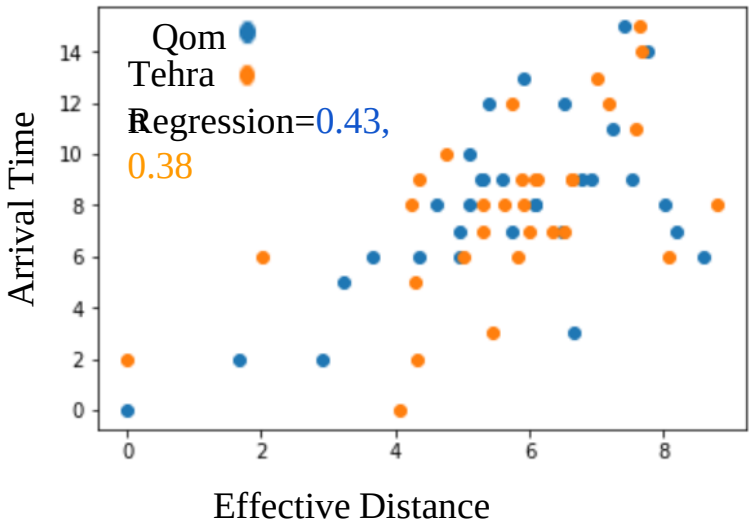
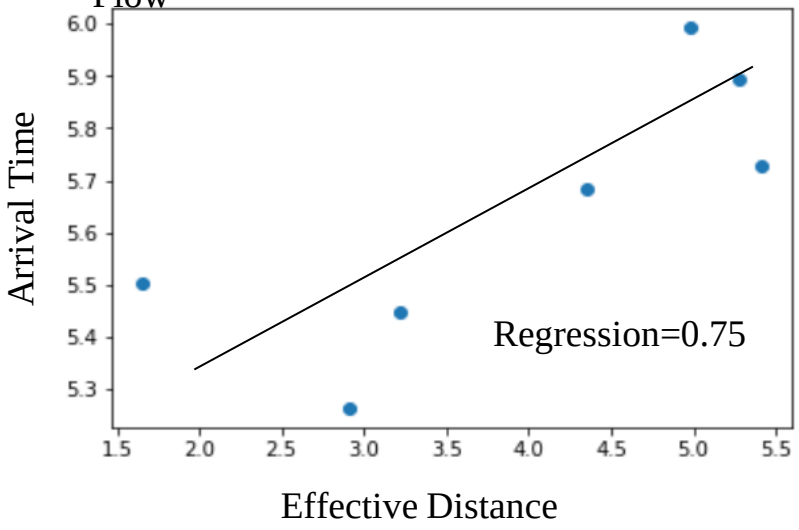
$$T_a = \underbrace{D_{\text{eff}}(\boldsymbol{P})}_{\text{eff. distance}} / \underbrace{v_{\text{eff}}(\alpha, R_0, \gamma, \varepsilon)}_{\text{eff. speed}}$$

DB & DH's Algorithm + data: I & Flow



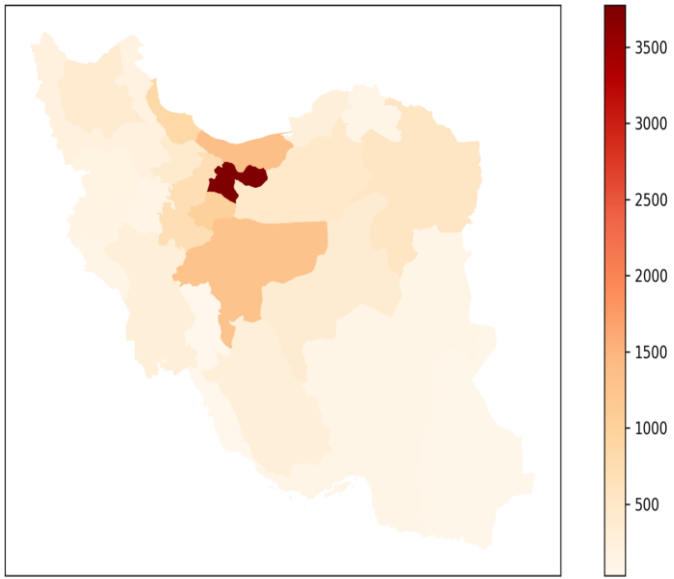
DB & DH's Algorithm + Cleaned data: I & Flow



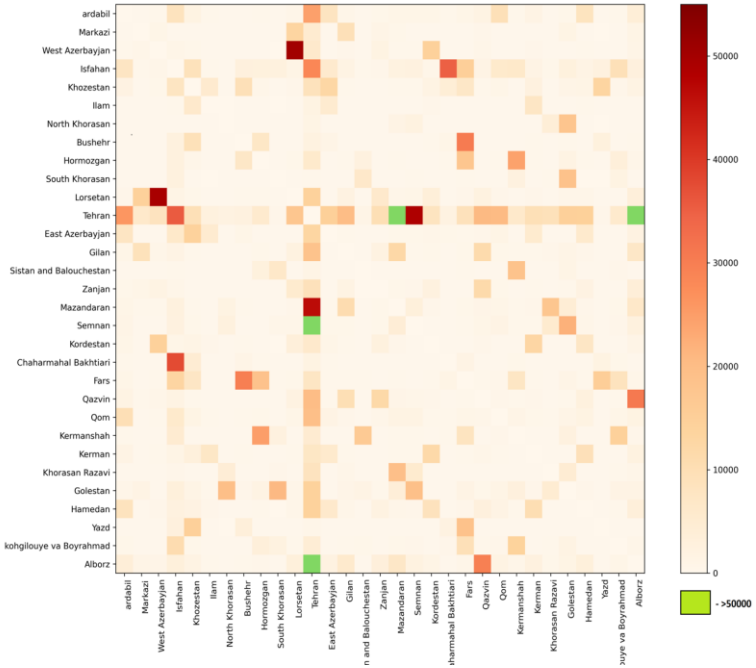
Our Approach?

Our Data (23th February 2020):

A



B



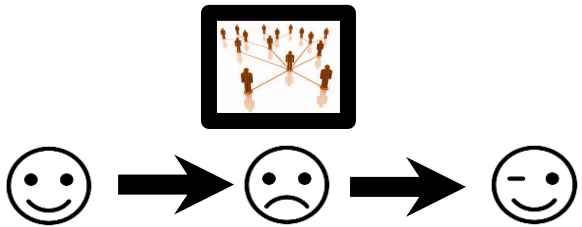
# of Coronavirus active cases

Daily passenger flow

Our Mathematical Formalism

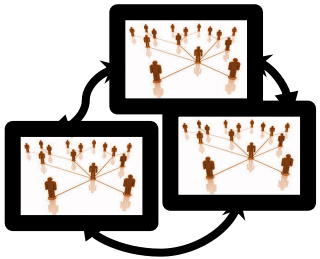
$$I^e(\vec{t}_e) = (I_1^e(t_e), I_2^e(t_e), ..., I_n^e(t_e)),$$

$$\frac{dI_i}{dt} =$$



[Intra population (HMFA, SIR)]

+

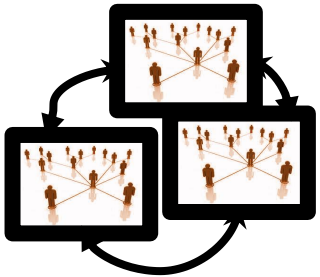


[InterPopulations (MetaPopulation)]

Intra population:
SIR (Homogenous Mean Field Approximation)

$$\frac{dI_i}{dt} = [\beta_i S_i I_i - \gamma_i I_i]$$

Inter population:
Mobility (passengers flow)



$$\frac{dI_i}{dt} = [\sum_j pP_{ji}I_j - pI_i]$$

Our Mathematical Formalism

$$I^e(\vec{t}_e) = (I_1^e(t_e), I_2^e(t_e), ..., I_n^e(t_e)),$$

$$\frac{dI_i}{dt} = [\beta_i S_i I_i - \gamma_i I_i] + [\sum_j pP_{ji} I_j - pI_i]$$

[Inter population (HMFA, SIR)]+ [Intra Populations (MetaPopulation)]

Our Mathematical Formalism

$S_i \sim N_i$

$$\frac{dI_i}{dt} = [\beta_i S_i I_i - \gamma_i I_i] + [\sum_j pP_{ji} I_j - pI_i]$$

$$I(\vec{t}) = e^{\hat{B}pt} I(\vec{0})$$

$$I(\vec{t}) = (\hat{I} + \hat{B}pt + \frac{(\hat{B}pt)^2}{2} + ...) I(\vec{0}),$$

Where?

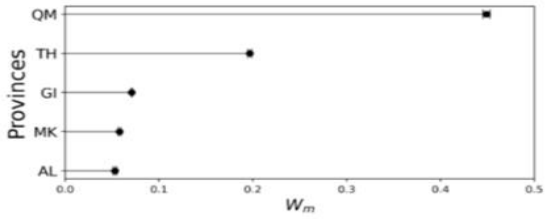
Basis of the space

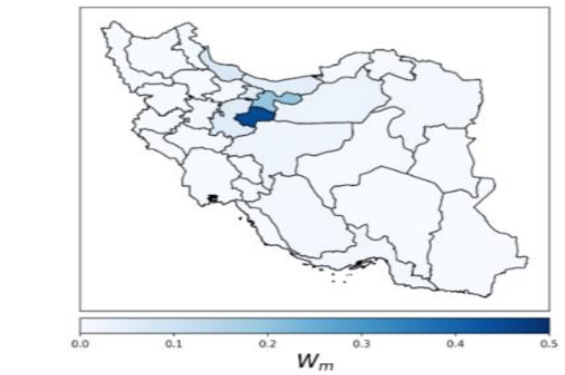
$$\hat{m} = (0, 0, ..., 1, ..0)$$

$$\hat{m}' = e^{\hat{B}pt}\hat{m}$$

$$W_m = \frac{\hat{m}'.I(\vec{t})}{\sum'_n \hat{n}'.I(\vec{t})}$$

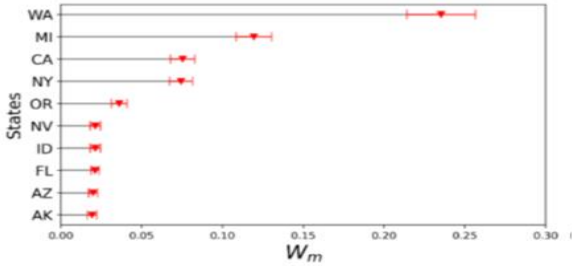
Data: Day = 5

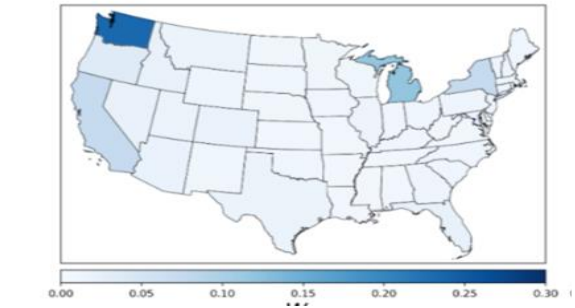




Where?

Data: Day = 5

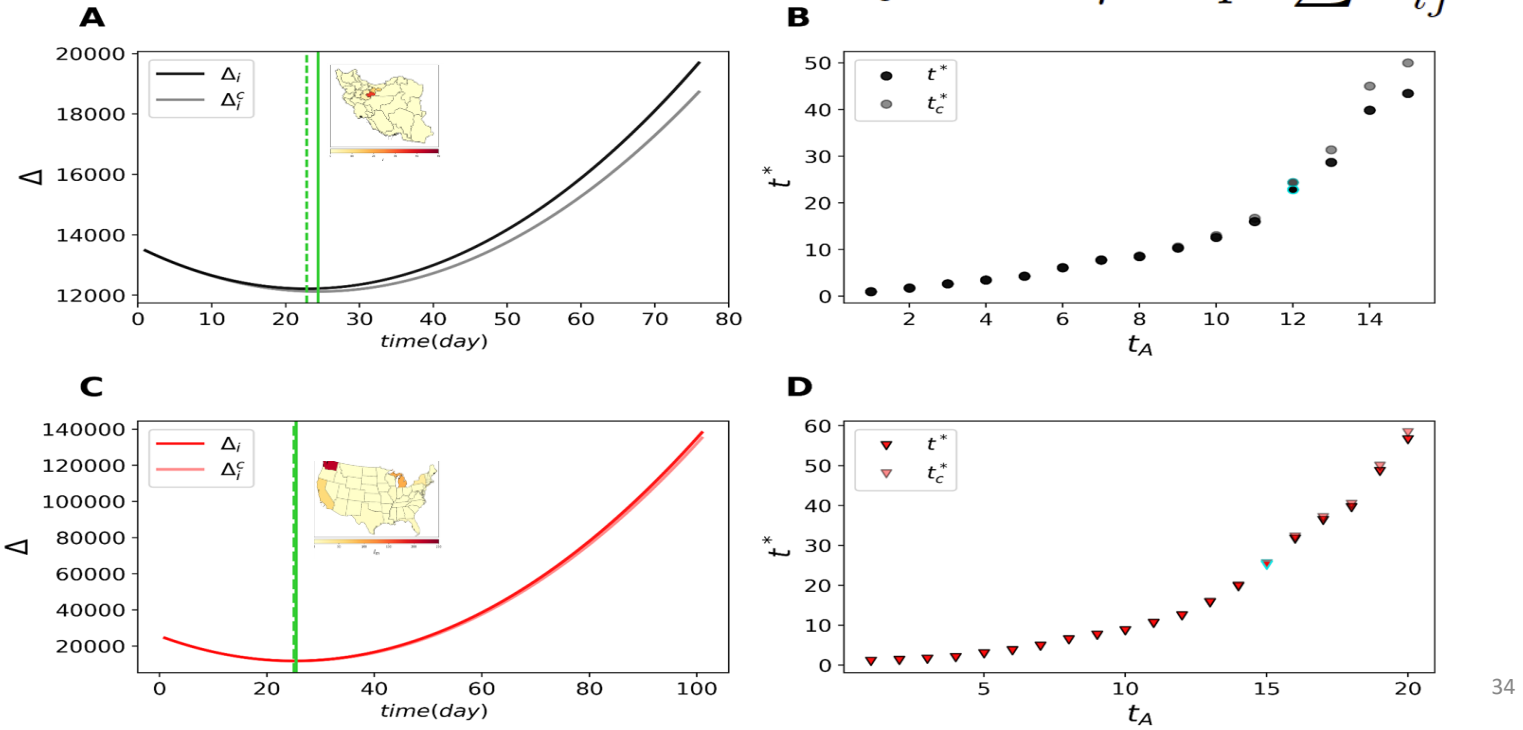




When?

$$\Delta_i(t) = \frac{\sum_{j=1}^{n}(I_j(t) - I_j^e(t_e)^2}{n}$$

$$t_i^* = \frac{1}{i_0}\frac{-\eta(i_0 - I_i^e) + p\sum(P_{ij}I_j^e)}{\eta^2 + p^2\sum P_{ij}^2}$$



How? Overtaking Time

$$(N_j\beta_j - \gamma_j)I_j = p(\sum P_{kj}I_k - I_j)$$

$$\vec{I(t)} = (\hat{I} + \hat{B}pt + \frac{(\hat{B}pt)^2}{2} + ...)\vec{I(0)},$$

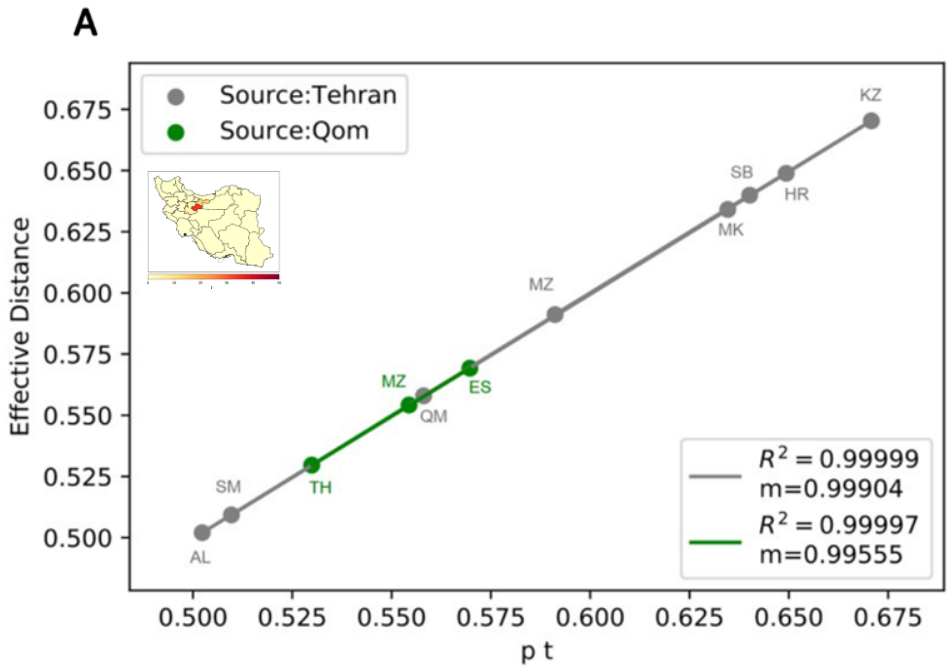
$$t^j = \frac{1}{p}\frac{1}{(2 - q_i - q_i) - \frac{P^1_{ij}}{P_{ij}}}$$

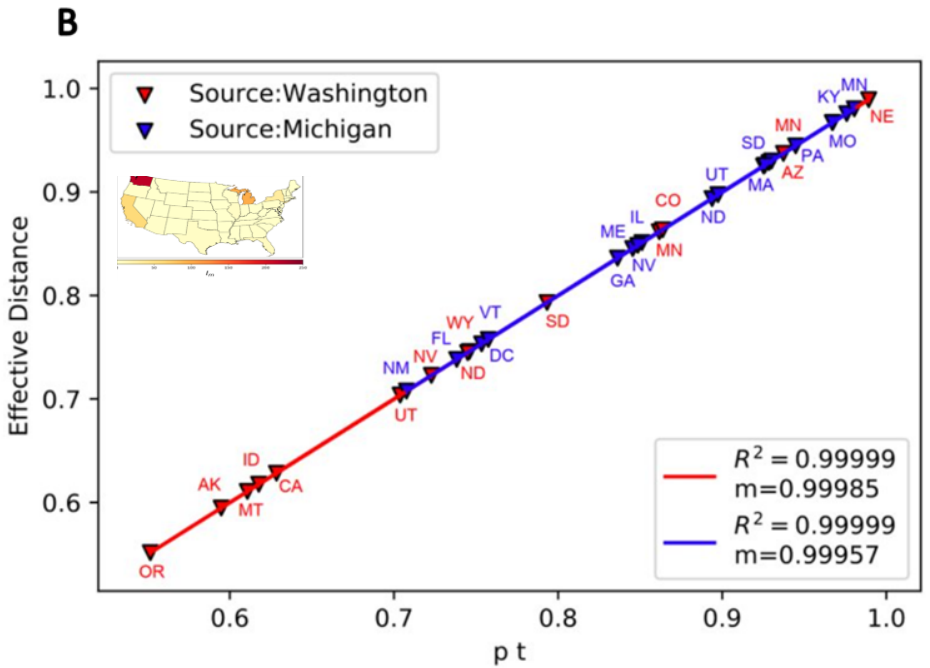
$$D_{ij} = \frac{1}{(2 - q_j - q_i) - \frac{P^1_{ij}}{P_{ij}}}$$

Effective Distance vs Overtaking Time

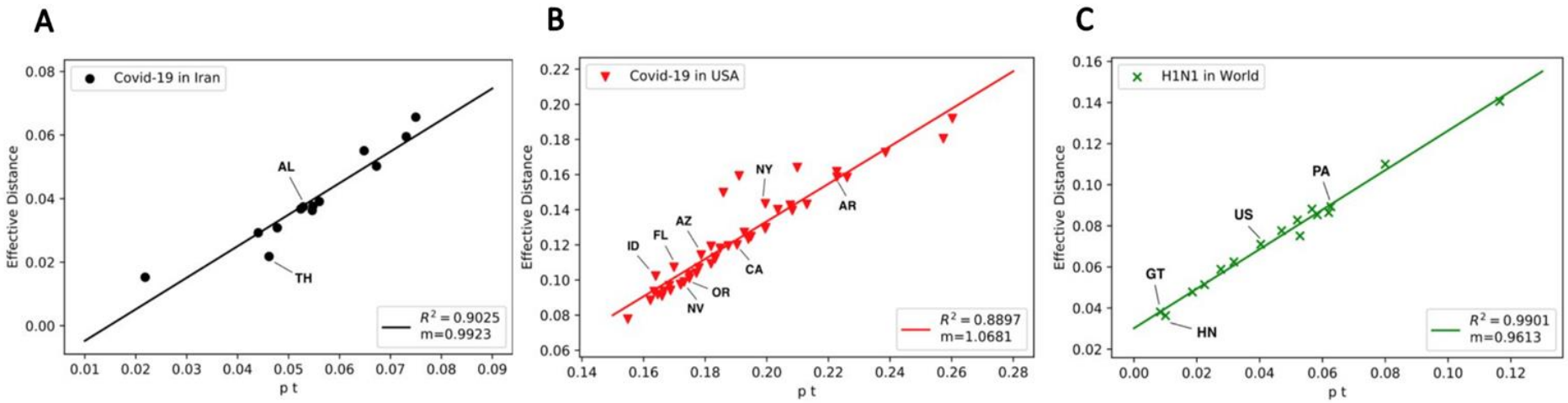
D = pt

Effective Distance vs Overtaking Time, Simulated I + Empirical Mobility Data





The Universal Geometry & Slope: Empirical Data



Thank you!

DPG deadline 01.12.2024! Join SOE session!
Looking for Lecturer/TA at SRH, Leipzig Campus

Gravity Team:




Zahra Ghadiri, Afra Mashhadi, Marc Timme & Fakhteh Ghanbarnejad

Big Bang Team:



Yazdan Babazadeh, Amin Safaeesirat, Fakhteh Ghanbarnejad

Reaction to the pandemic

Gravity model
Socio-economic groups
Small vs. large cities

(Nature) Communications Physics volume 7, Article number: 55 (2024)

The big bang of an outbreak

Where was the origin?
When did it begin?
How does it spread?
data: 2 snapshots: active cases & mobility
cut-off errors
Multi sources

arXiv:2405.03703v1

Socio-economic Vulnerability

The Social Vulnerability Index uses U.S. Census data to determine the relative social vulnerability of every census tract.