Green Connections : A Network Economics Approach to the Energy Transition

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Soutenance de thèse - Jeudi 3 Décembre 2020

Motivations (I)

- To limit global warming to less than 2°C by the end of the century, economies worldwide must reach carbon neutrality by 2050 (*IPCC, 2018*);
- Large-scale diffusion of low-carbon technologies represents an important component of international strategies to achieve such a target, largely driven by environmental policies (*Grantham Research Institute, 2018*; *OECD, 2018*).
    - Green transition is about diffusion of technologies, policies and ... economic shocks.

Motivations (II)

- How could *Network Economics* enhance our understanding of diffusion processes ? What insights can be drawn from a policy-making perspective ?
  - Network Economics (e.g. *Acemoglu, Bromley-Trujillo et al., Beaman, Centola, Jackson, Lim and Teytelboym*);
  - Environmental Economics (e.g. *Farmer and Lafond, Halleck-Vega and Mandel, Godin et al.*).

Structure of the Manuscript

- *Chapter 1 : Network Structures, Environmental Technology and Social Contagion* (Forthcoming in Climate Policy);
- *Chapter 2 : How do Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.* *with A. Creti and A. Mandel (FAERE WP series - 2020.12)*;
- *Chapter 3 : Triggering Reduction of Imported Emissions in the E.U.* *with A. Creti;*
- *Chapter 4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap.* *with A. Creti.*

Chapter 1

Network Structures, Environmental Technology and Social Contagion

Forthcoming in *Climate Policy*

1 : Network Structures, Environmental Technology and Social Contagion

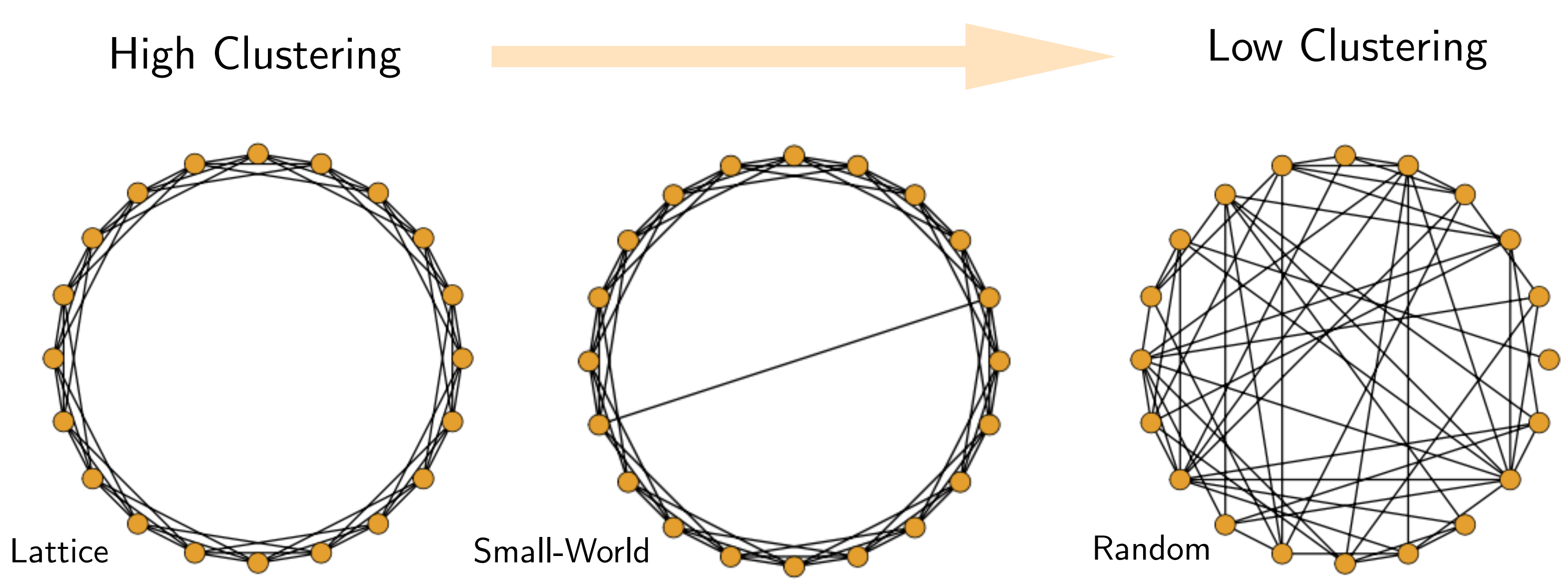
- Context :
  - Collective behaviors spread through social contact (e.g. solar PV adoption, alternative fuel vehicle; see *Bollinger and Gillingham, 2012; Richter, 2013*; *Jansson et al., 2017*);
  - Social networks : pathways in which « social contagion » propagates (*Baranzini et al., 2017;* Becker et al., 2018);
  - Simple Contagion (epidemics) vs Complex Contagion (innovation) (*Centola & Macy, 2007*).

1 : Network Structures, Environmental Technology and Social Contagion

- Research question : *How <u>network structures</u> influence the contagion of a <u>costly clean innovation</u> ?*

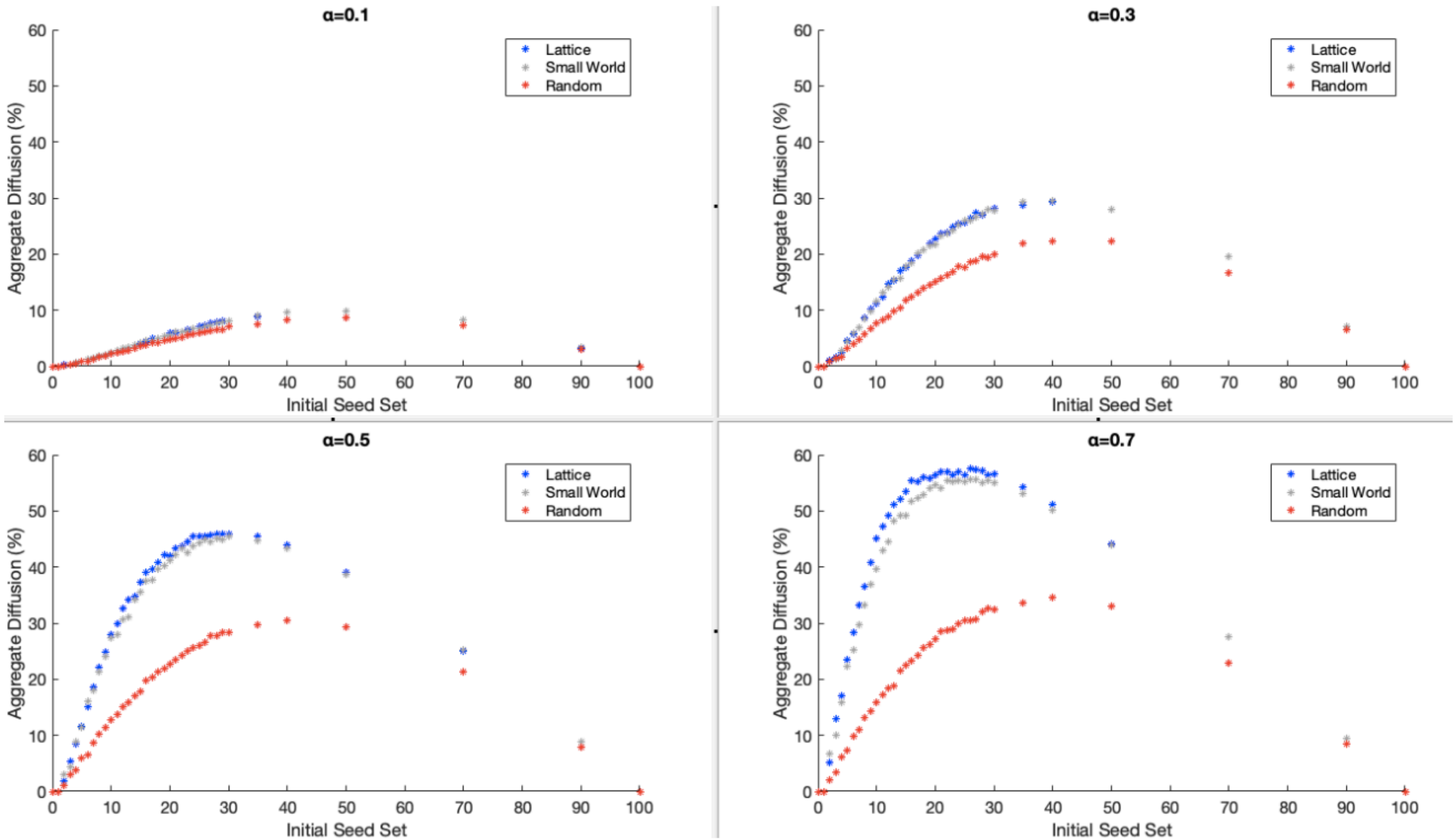
- Methodology : Agent Based Model

  - Neighborhood threshold + <u>Cost threshold</u>;
  - Learning Effects / Network structures.



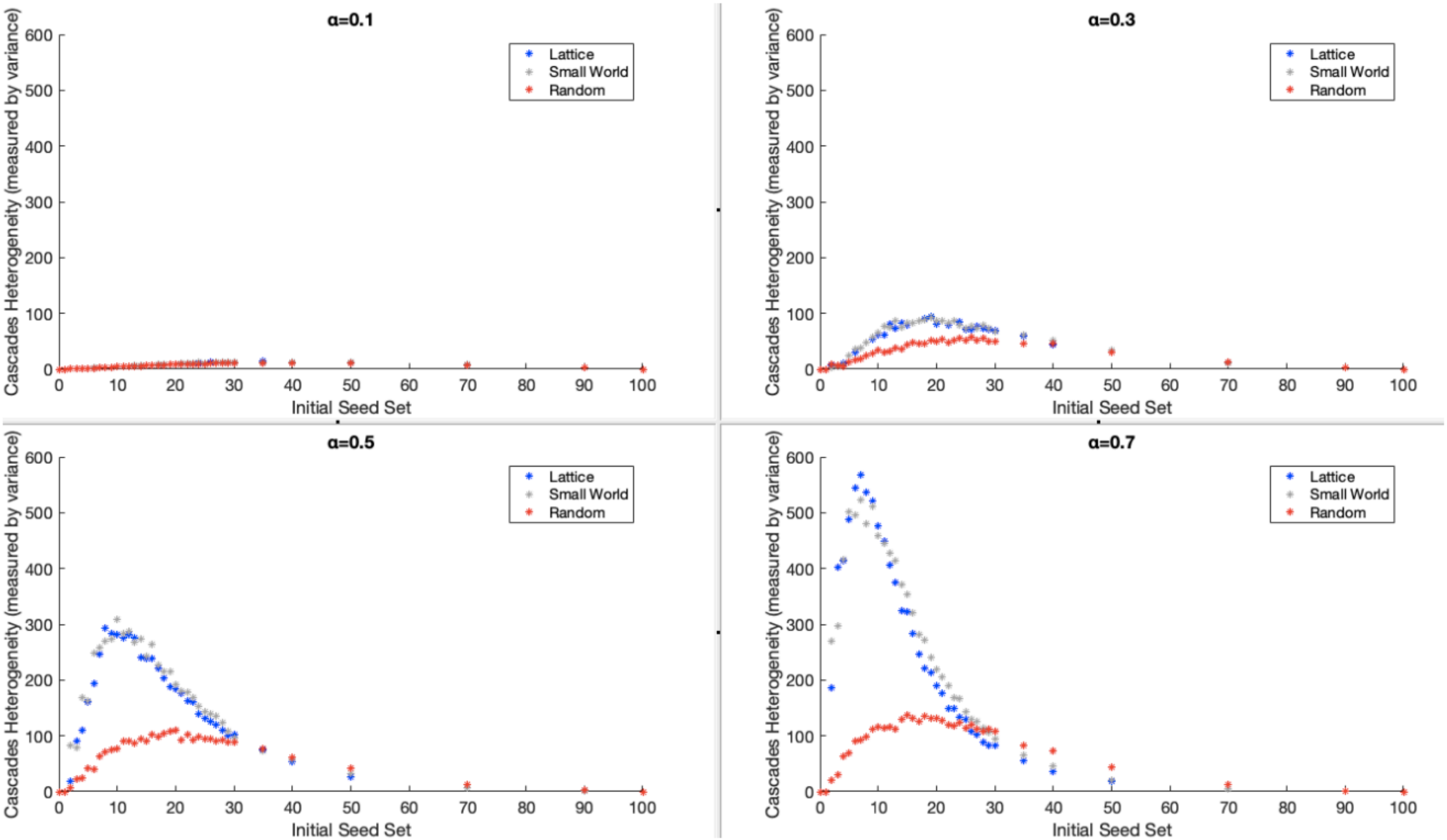
1 : Network Structures, Environmental Technology and Social Contagion

Results (1) : Aggregate diffusion as a function of initial seeds.



1 : Network Structures, Environmental Technology and Social Contagion

Results (2) : Diffusion heterogeneity measured by variance.



1 : Network Structures, Environmental Technology and Social Contagion

- Concluding remarks & policy implications
  - Clustering favours diffusion;
    - Encouraging **connections** + social platforms ?
  - Clustered networks display higher diffusion variance;
    - The case of **uncertainty**...
  - Learning effects : higher diffusion, larger aggregate gap;
    - Supporting the « good » technology !

Chapter 2

How do Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

Joint work with Anna Creti and Antoine Mandel (Université Paris-I / PSE)

FAERE Working Paper / Climate Economics Chair Working Paper

2 : How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

- American Context :
  - Federalism, a peculiar environment for policy diffusion (*Berry and Berry, 1990; Pitt, 2010*);
  - Policies regularly spread throughout the American states, driven by underlying forces (i.e. competitive, cooperative, and imitative);
  - Determinants : citizens ideology, partisan control of the state, state's economy, geographic proximity (*Matisoff, 2008; Huang et al., 2007; Matisoff and Edward, 2014; Berry & Berry, 1992*).

2 : How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

- Research question : Are there pathways of environmental policy transmission across U.S. states ? What are the determinants of such observations ?

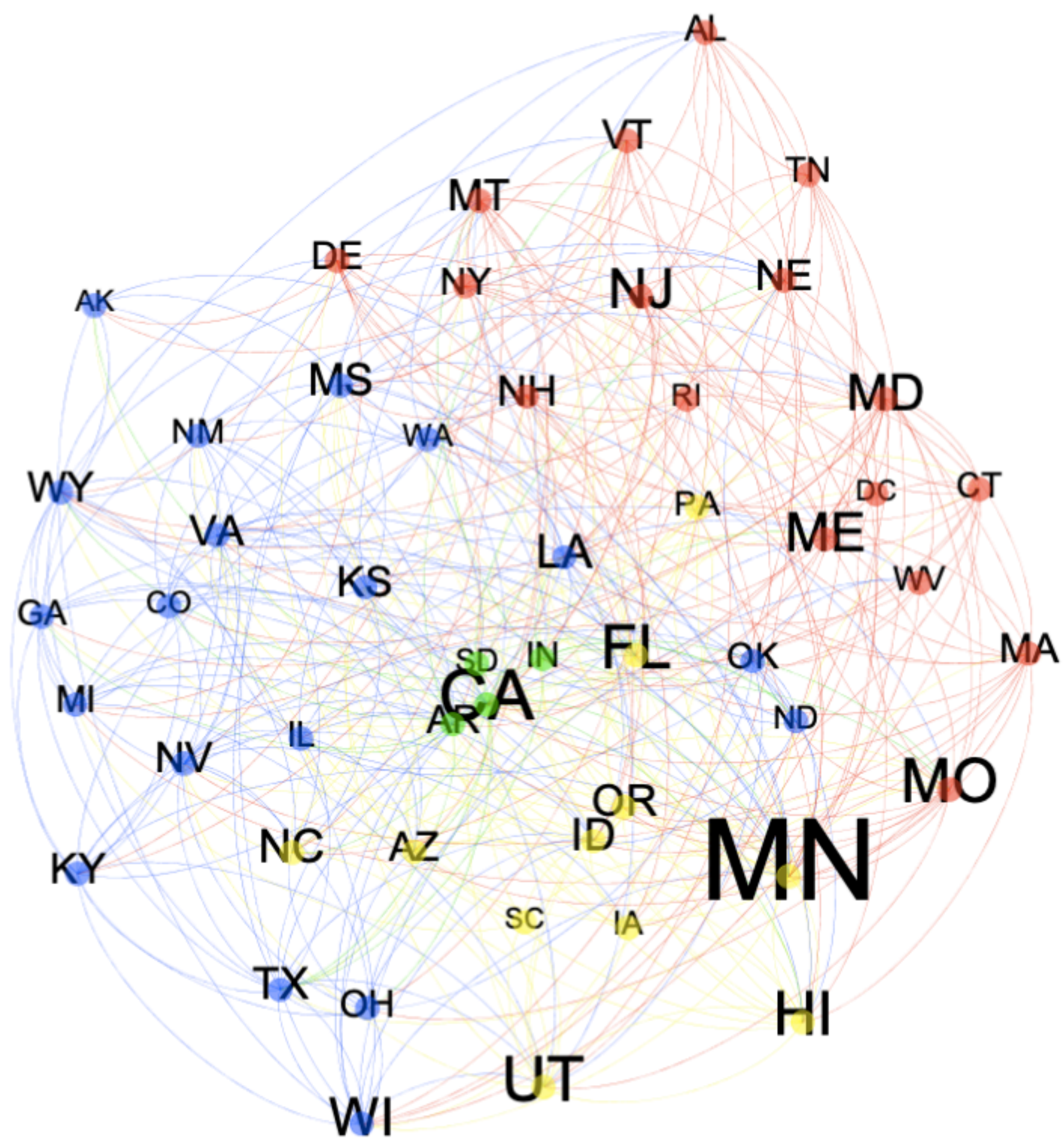
- Methodology :

  - (1) Independant Cascade Model to infer a network from series of observations, i.e. cascades *(Gomez-Rodriguez, 2010; Halleck-Vega et al, 2018)*; (2) Logistic model;

  - **Dataset** : 74 policies, 51 states, 1974/2018, three initial databases.

2 : How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

Results (1) : Reconstructed network using Force Atlas layout.



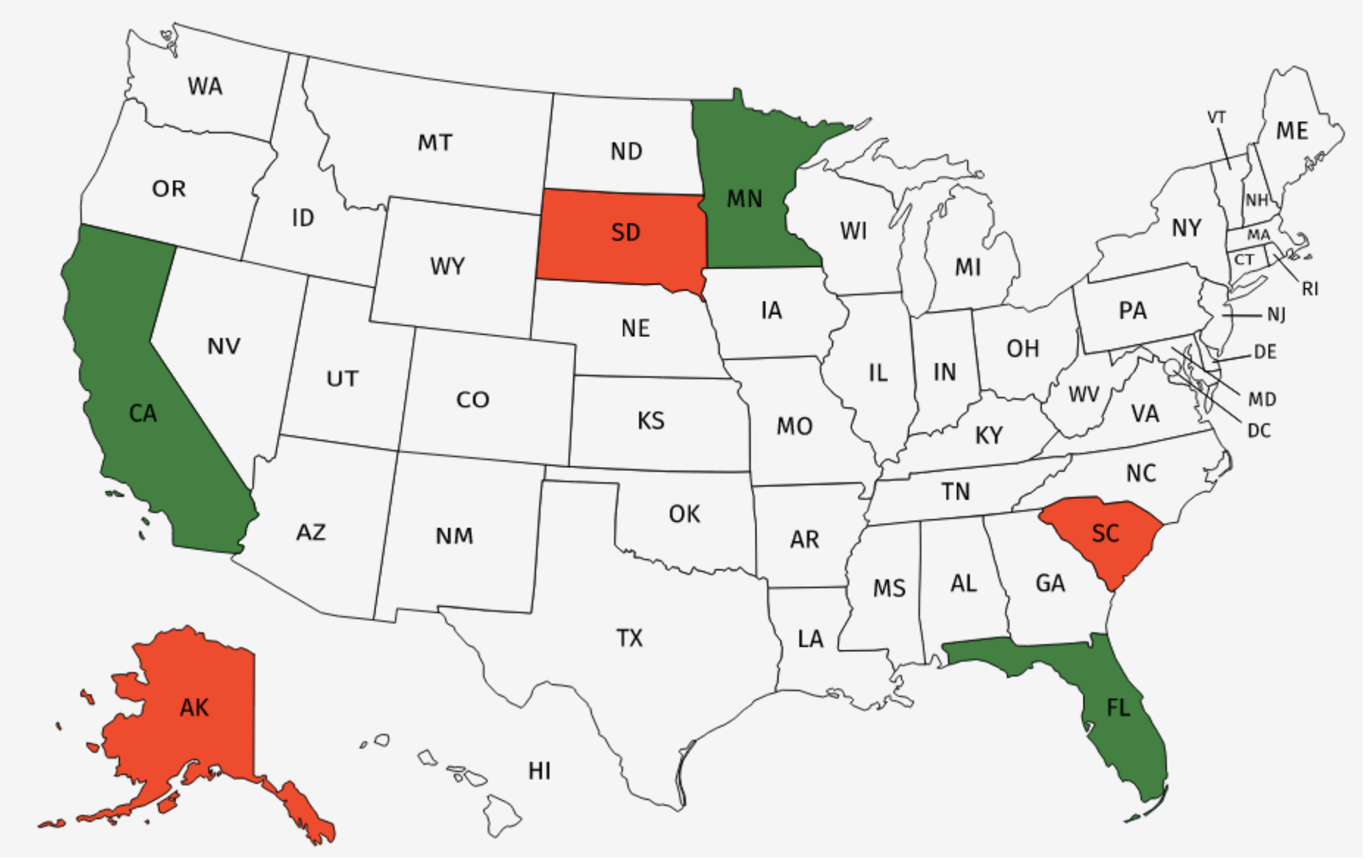
2 : How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

Results (2) : Central States vs Less integrated states.

Central States

Minnesota	**Minnesota**
California	**California**
Florida	Utah
Pensylvannia	Hawai
New York	Missouri
Wisconsin	**Florida**
...	...
...	...
...	...
West Virginia	Washington
Wyoming	Colorado
Arizona	Rhode Island
District of Columbia	**Alaska**
Alaska	**South Carolina**
South Dakota	District of Columbia

Mapping Leaders/Followers



2 : *How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.*

Results (3) : Determinants of transmission policy pathways.

Contiguity *(Relationship)*	**1.69** (41.09)**
GDP per capita *(Source)*	**0.03** (4.60)**
Population Density *(Source)*	-0.49** (-28.78)
States Governors Party	**-0.03** (-4.71)**
Federal Government Party	-0.00 (-0.62)
Citizen Ideology	-0.00** (-9.00)
Climate change Economic Impacts (>5% GDP)	**-0.34** (-21.04)**
Genuine Progress Indicator *(source)*	**0.51** (33.84)**
Coal Mining State *(Source)*	-0.04** (-2.69)

- Contiguity : *the odds of transmission are 5.41 higher compared to the reference category;*
- GDP Per capita **:** *increases the odds of transmission*;
- Climate change Economic Impacts **:** *odds of transmission are lower compared to the reference category;*
- GPI : green economic system increases the odds of transmission.

2 : *How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.*

- Concluding remarks & policy implications
  - Inefficient network organization (Minnesota, California, Florida vs. South Dakota, South Carolina, Alaska).
    - **Targeting specific states** to maximize diffusion;
  - NorthEastern States display highly concentrated diffusion;
    - Suggests **different areas** / dynamics of diffusion;
  - Contiguity, GPI, expected climate change economic losses;
    - Vulnerability does not imply transmission !

Chapter 3

Triggering Reduction of Imported Emissions in the E.U.

Joint work with Anna Creti

3 : Triggering Reduction of Imported Emissions in the E.U.

- European context : Green Deal (2019)
  - Jump from 40 % to 50% GHGs emission reduction objective; Net Zero by 2050;
  - Tackling the issue of imported Emissions;
  - Disconnection between territorial and consumption-based emissions (e.g. UK, 2014; France, 2018).

3 : Triggering Reduction of Imported Emissions in the E.U.

- Research question : What about the *dynamics of demand and supply of dirty imports* within an economy ? *And the specific role of sectors in reducing such patterns ?*

- Methodology :

  - (1) Input Output Tables, Imports distribution, Ghosh Matrix, Imported Emissions, Networks;

  - Dataset : France, Germany, Italy, Poland, U.K., OECD - 2015.

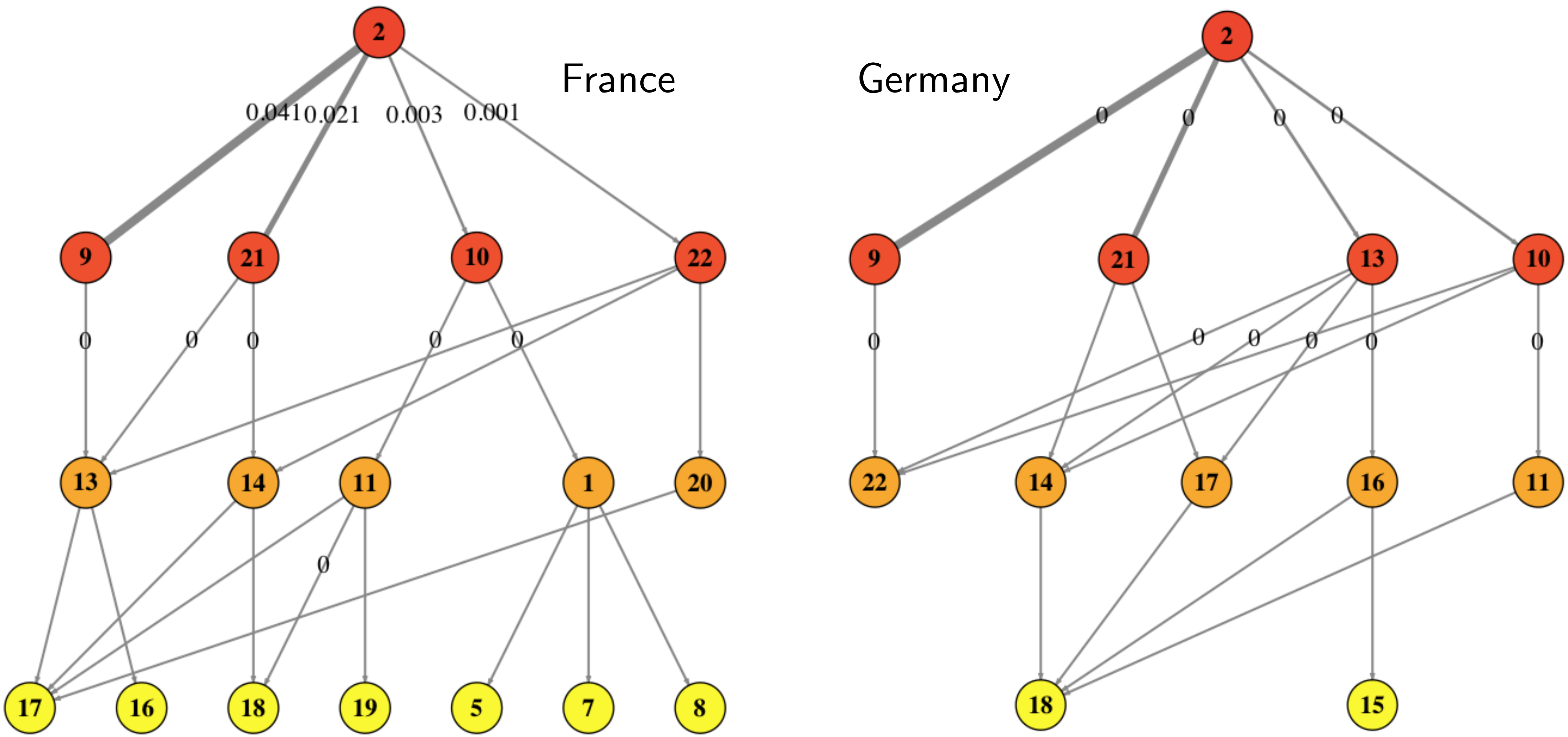
3 : *Triggering Reduction of Imported Emissions in the E.U.*

Results (1) : Emission Reduction Coefficients.

France	Germany	Italy	Poland	U.K.
External Emission Reduction Multipliers (2)				
Mining A (0.0689)	Mining A (0.0089)	Mining B (0.0081)	Mining A (0.0012)	Mining A (0.0004)
Mining C (0.0034)	Mining B (0.0018)	Mining A (0.0024)	Basic metals (0.0005)	Mining B (0.0004)
Mining B (0.0002)	Mining C (0.0008)	Mining C (0.0008)	Mining B (0.0004)	Basic metals (0.0003)
Basic metals (0.0001)	Basic metals (0.0001)	Basic metals (0.0002)	Chemicals (0.0003)	Electrical eq. (0.0003)
Electrical eq. (0.0001)	Coke-refined petrol. (0.0001)	Chemicals (0.0001)	Machinery & eq. (0.0003)	Computer-electronics (0.0002)
Exposure to Emission Reduction Multipliers (3)				
Coke & refined petrol. (0.0420)	Coke & refined petrol. (0.0053)	Basic metals (0.0068)	Basic metals (0.0009)	Other manufacturing (0.0004)
Electricity & gas (0.0222)	Basic metals (0.0026)	Coke-refined petrol. (0.0010)	Electricity-gas (0.0006)	Basic metals (0.0004)
Chemicals (0.0027)	Chemicals (0.0011)	Mining A (0.0009)	Electrical eq. (0.0003)	Coke-refined petrol. (0.0003)
Construct. (0.0026)	Electricity & gas (0.0009)	Chemicals (0.0008)	Machinery-eq. (0.0003)	Other transport eq. (0.0002)
Basic metals (0.0011)	Mining A (0.0007)	Other non-met. min. (0.0007)	Coke-refined petrol. (0.0003)	Electrical eq. (0.0002)

3 : *Triggering Reduction of Imported Emissions in the E.U.*

Results (2) : Hierarchical network of imported emission reduction cascades across economic sectors in France.



3 : Triggering Reduction of Imported Emissions in the E.U.

- Strongest immediate emission reductions :
  - Coke and Refined Petroleum Products (C19) (France, Germany, Poland, U.K.);
  - Basic metals (C24) - well connected ! (Germany, Italy, Poland);
    - Fabricated metal products, machinery and equipment, electrical equipment, motor vehicles and other transport equipment
  - Electricity and Gas (D-E) (France, Germany, Poland, U.K.)

3 : Triggering Reduction of Imported Emissions in the E.U.

- Concluding remarks & policy implications
  - We can identify relevant cascades - but differences across E.U. countries !
    - Different levels of trade exposure across EU economies;
  - Basic Metals is a huge supplier for other industrial sectors (e.g. Germany);
    - Taxing imported carbon from basic metals —> disparities across countries — > compensation/exposure ?

Chapter 4

COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap.

Joint work with Anna Creti

4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap

- European context :
  - 81% of the global workforce hit by lockdown measures (*International Labour Office, 2020*); Consumer spending has fallen - restrictions (to travel, to shop for discretionary items, go to restaurants, or for experience-based activities (*Center for Economic Policy Research, 2020*));
  - 2020 : A contraction of 7.4 per cent in the EU economy (*European Commission, 2020*);
  - Recovery plans could be either "brown" or "green" (*IFRI, 2020*).

4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap

- Research question : What about the *dynamics of demand and supply of dirty products* within an economy ? *And the specific role of sectors in reducing such patterns ?*

- Methodology :
  - (1) Input Output Tables, Ghosh Matrix and Emissions, cascades/networks;
  - Dataset : France, Germany, Italy, Poland, Spain, OECD - 2015.

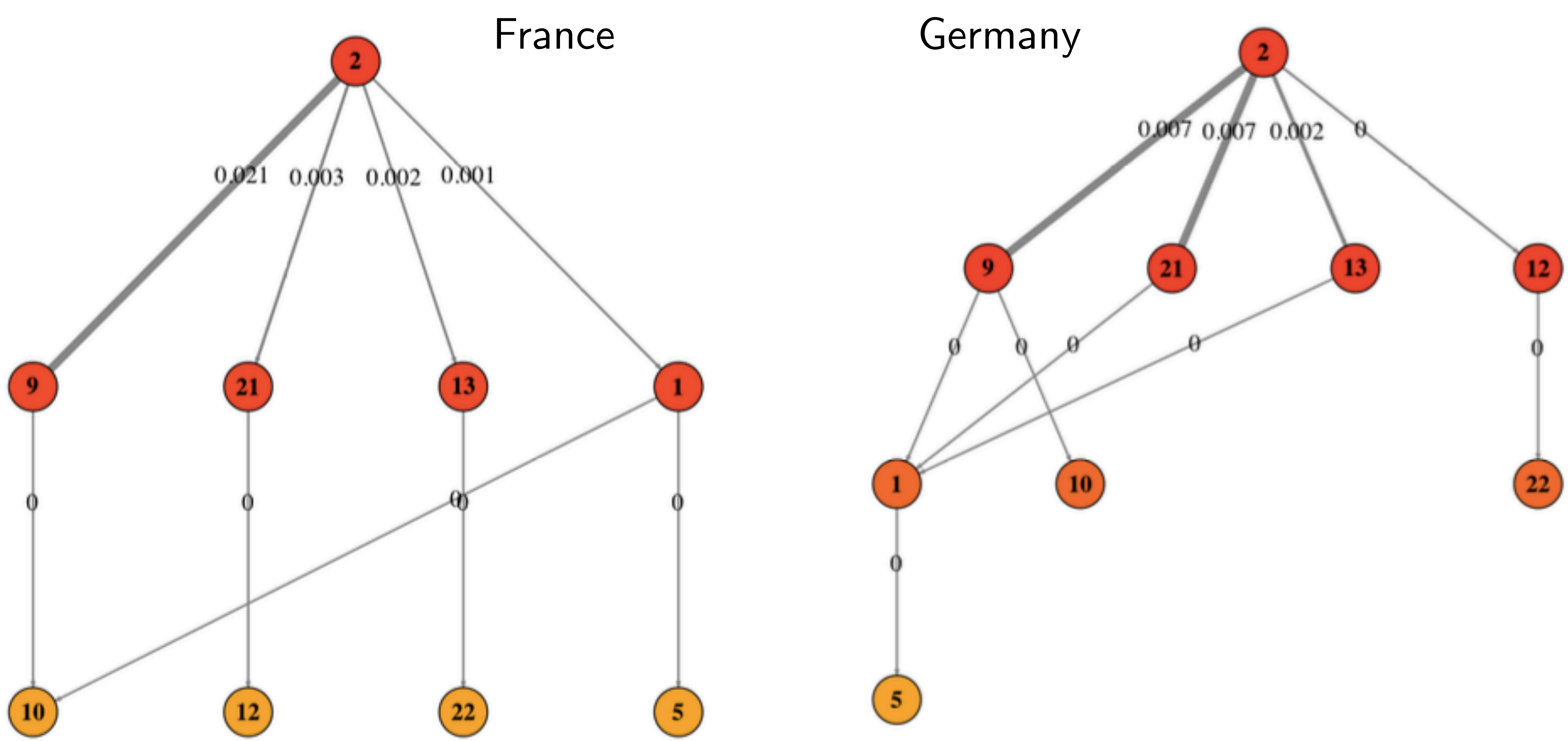
4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap

Results (1) : Emission Reduction Coefficients.

France	Germany	Italy	Poland	Spain
External Emission Reduction Multipliers (2)				
Mining (0.0287)	Mining (0.0178)	Mining (0.0359)	Mining (0.0088)	Mining (0.0280)
Electricity & gas (0.0004)	Coke & petrol. (0.0008)	Prof., Scient., Techn. act. (0.0007)	Chemicals (0.0019)	Chemicals (0.0008)
Coke & refined petrol. (0.0004)	Wholesale retail trade (0.0005)	Financ. services (0.0007)	Coke & refined petrol. (0.0016)	Electricity & gas (0.0008)
Rubber & plastics (0.0004)	Prof., Scient., Techn. act. (0.0004)	Basic metals (0.0006)	Basic metals (0.0015)	Rubber & plastics (0.0007)
Fab. metal (0.0004)	Fab. metal (0.0004)	Coke & refined petrol. (0.0006)	Machinery & eq. (0.0013)	Financ. services (0.0006)
Exposure to Emission Reduction Multipliers (3)				
Coke & petrol. (0.0225)	Electricity & gas (0.0114)	Coke & petrol. (0.0268)	Electricity & gas (0.0142)	Coke & petrol. (0.0205)
Electricity & gas (0.0042)	Coke & petrol. (0.0083)	Electricity & gas (0.0141)	Coke & petrol. (0.0058)	Electricity & gas (0.0104)
Basic metals (0.0029)	Basic metals (0.0036)	Basic metals (0.0026)	Agricult. (0.0053)	Basic metals (0.0039)
Agricult. (0.0026)	Agricult. (0.0017)	Oth. non-met. min. (0.0016)	Basic metals (0.0029)	Oth. non-met. min.(0.0031)
Oth. non-met. min. (0.0012)	Oth. non-met. min. (0.0017)	Chemicals (0.0009)	Oth. non-met. min. (0.0021)	Agricult. (0.0015)

4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap

<u>Results (2)</u> : Hierarchical network of emission reduction cascades across economic sectors in France.



4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap

- Concluding remarks & policy implications
  - Electricity & gas / Coke and refined petroleum products largely depend on dirty inputs (Germany, Poland);
  - Chemicals as well as basic metals have significant impacts on emissions too;
    - EU Recovery Packages should ensure these sectors to divest;
    - Carbon pricing to create incentives to shift from dirty to clean inputs ?
  - Common patterns of cascades across EU countries;
    - Regional strategy to clean carbon-intensive sectors ?

General Conclusion

- *Chapter 1 : The **structure** of underlying social networks is key in the diffusion of clean technologies*;
    - The disclosure of social data to target clusters;
- *Chapter 2 : The **location** of agents in the networks is fundamental to capture diffusion patterns across U.S. states;*
    - *Targeting key states to foster diffusion;*
- *Chapter 3* and *Chapter 4* : ***Neighborhood connections** matter when it comes to economic interactions;*
    - *Connectedness = Exposure of sectors...*

Thank you for your attention !

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Soutenance de thèse - Jeudi 3 Décembre 2020

Appendices

From Networks to Diffusion (1)

- Node : One of many points in a Network;
- Edge : Link connecting nodes in a Network;
- Network : A set of nodes and edges.

- Applications : Social networks (eg. Pierri et al. 2020), banking system (Battiston et al., 2016), epidemics (Block et al., 2020).
- Diffusion... processes are not equivalent !
  - Epidemics ≠ Technology; Idea ≠ Behaviors ≠ Policies etc...

Chapter 1

INTRODUCTION

Basics and Generalities on Networks

- Recap on definitions :
  - Node : One of many points (eg. agents) in a Network;
  - Edge : Vertices connecting nodes in a Network;
  - Network : A set of Nodes (eg. agents) and Edges (eg. relationships).
- Possible applications :
  - **Social networks**, **Viral marketing**, **Rumors, Internet, Bank failures systemic risks, Technology etc...**

Context (1) - Contagions in Networks

- Different dynamics of diffusion : epidemics ≠ technology, idea ≠behaviors etc...

Simple contagions

"Simple contagions" require only one contact for transmission (eg. information, disease). Since a connection is "infected", her contact follows with probability P.

Complex contagions

"Complex contagions" need multiple sources of reinforcement to induce adoption (eg. large range of behaviors). To switch, an agent must have a certain proportion of her contacts who has previously adopted the behavior (Linear Threshold Model (Granovetter, 1978)).

Centola and Macy, 2007.

The role of network's topology is critical for diffusion : Some underlying structures could favor/hamper diffusion processes.

Main Literature (1) - Diffusion in Networks

- Key observations for simple/complex contagions in clustered/ random networks :
  - Simple contagion : Short path length favor diffusion (Granovetter, 1974);
  - Complex contagion : Clustering is critical (Centola and Macy, 2007; Centola, 2010; Centola, 2018);
  - Useful to cluster seeds in the same part of the network otherwise no one crosses the threshold and we observe no adoption (Beaman, 2018);

Main Literature (2) - Diffusion in Networks

- Clustering fosters diffusion if at least one seed is placed in the community (Acemoglu, 2011);
- Low speed of diffusion under complex contagion — takes time to join different nodes in the network (Delre et al., 2006). Lower in random networks — Lower probability of being exposed to an adopter.

Gap in the literature :

- **Questions about products/technologies subject to a cost function ?**
- **Once a costly technology is introduced, how would (irreversible) diffusion occur with respect to clustering and path length ?**

Main Contributions & Objectives (1)

- **This paper contributes to the literature by :**
  - Being the first to consider a network based approach to technology diffusion and its associated decreasing cost function (Moore's Law) - in a complex contagion setting;
  - Extending the original LTM and introducing a second threshold dealing with the associated technology cost function subject to learning effects;
  - Assuming irreversibility to cascade process (ie. diffusion) (Blume, 1993; Ellison, 1993; Montanari ad Saberi, 2010; Adam et al. 2012).

Main Contributions & Objectives (2)

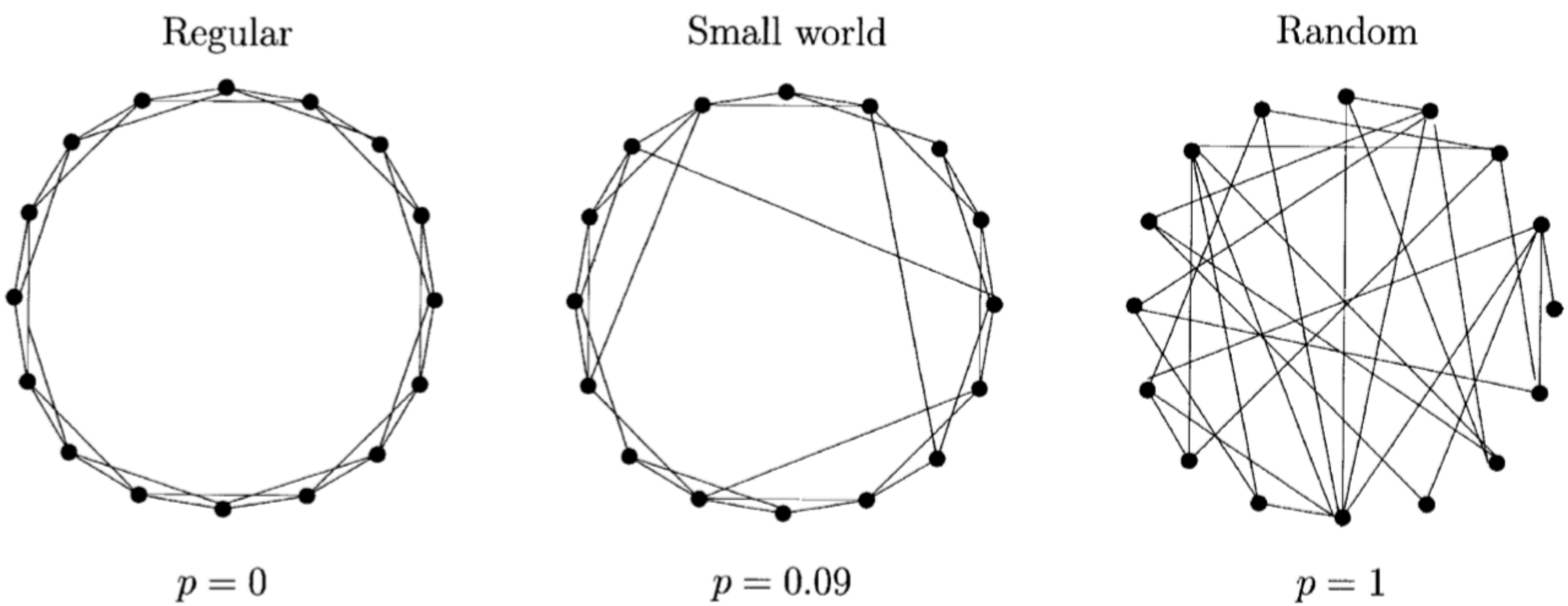
- **Objectives are** :
  - Estimating the impacts of clustering, path length and technological learning effect on technology diffusion;
  - Comparing aggregate levels of diffusion, associated speeds and time of convergence for the expected number of switches in three classes of finite networks (lattice, SW and random graphs) with any initial seeds.

Model

Networks : Watts Strogatz (1)

- Global clustering : tendency for nodes to form knit groups (ie. cliquishness); Average path length : average distance between two nodes;

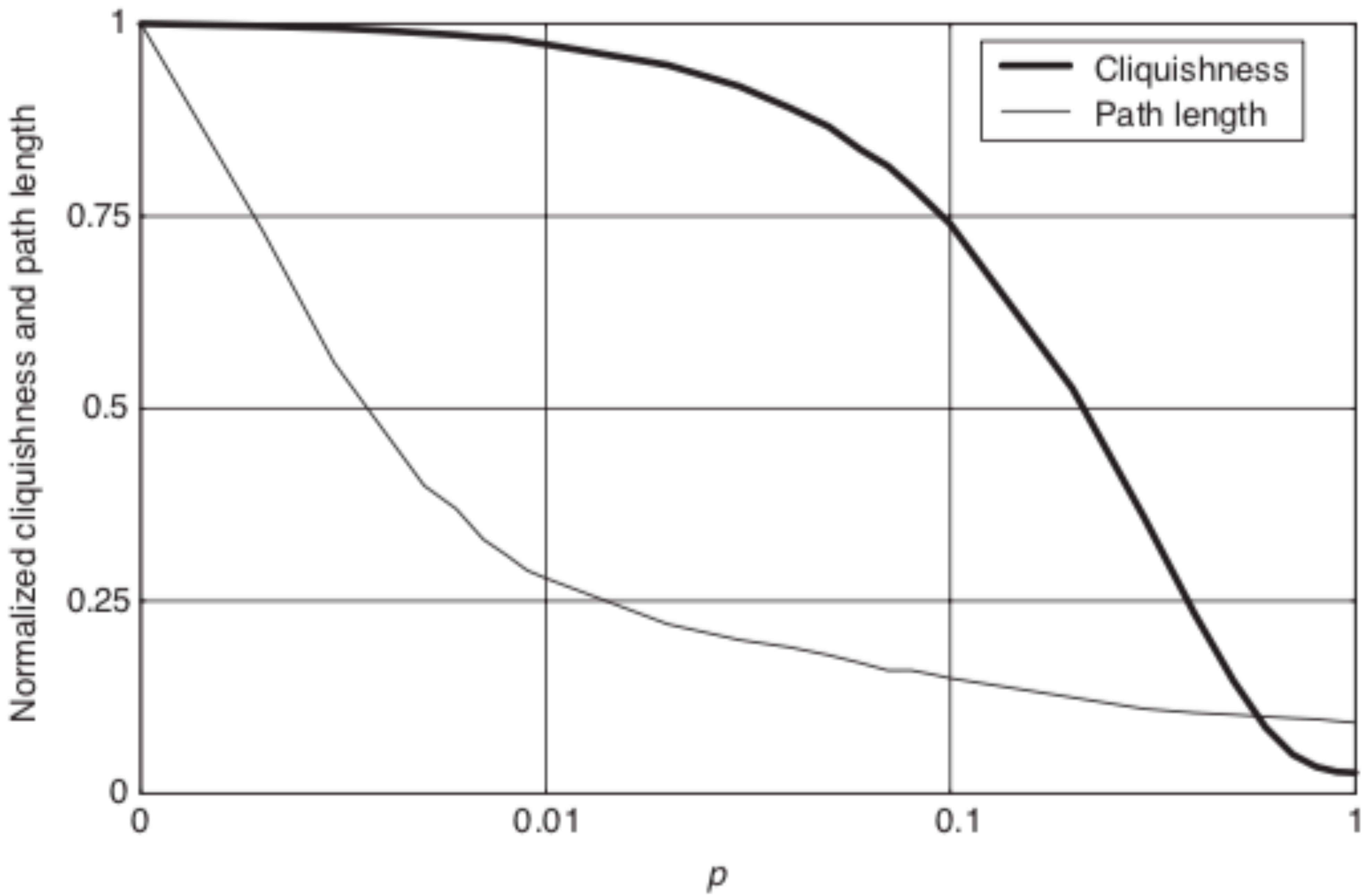
- For N=16, k= 4 and p=probability of rewiring, we have :



The transition from a locally ordered structure to a disordered one via a small world.

Cowan, 2004.

Networks : Watts Strogatz (2)



Average cliquishness and average path length as function of p.

Cowan, 2004.

Model : Preliminaries (1)

- Simple, undirected graph *G(V,E)* with a set of *n* agents $V := \{1,\ldots, n\}$ and a set of *m* links E;
- Neighbors of $i \in V$ denoted $N_i(G) := \{j | (j,i) \in E\}$ and the degree of *i* as $d_i := |N_i(G)|$;
- Agent *i* is assigned two *thresholds* μ_i and θ_i, drawn independently, uniformly at random from probability distributions with support [0, 1];
- Define the threshold profile of agents $\boldsymbol{\mu} := (\mu_i)$, $i \in V$ and $\boldsymbol{\theta} := (\theta_i)$, $i \in V$;
- A **network** $G_{\mu,\theta}$ is a graph endowed with the two thresholds profiles.

Model : Preliminaries (2)

- C_t : cost function of the technology at time t, bounded between [0, 1].
- $S_t(G_{\mu,\theta})$: the set of additional switches in network G at time t.
- α : technological learning effect on cost taking the respective values [0.1; 0.3; 0.5; 0.7] - meaning that technology cost decreases from 1 to 0 with respect to the number of adopters S.
- **That is :** $$C_t = C_0 \times \left(|U_{\tau=0}^{t-1} S_\tau|\right)^{-\alpha}$$

Model : Dynamics (1)

- At time $t = 0$, a subset of agents $S_0 \subseteq V$ is selected as a seed set. We assume that at $t = 0$ agents switch if and only if they are in the seed set.

- Hence, at $t = 1$, any $i \in V \setminus S_0(G_{\mu,\theta})$ will switch, i.e., $i \in S_1(G_{\mu,\theta})$ if :

$$|C_t(S_0(G_{\mu,\theta}))| \leq \mu_i, \qquad \text{and} \qquad \frac{|S_0(G_{\mu,\theta}) \cap N_i(G_{\mu,\theta})|}{|N_i(G_{\mu,\theta})|} \geq \theta_i.$$

- Then, for a given period $t \geq 0$ and node $i \in V \setminus \cup_{\tau=0}^{t-1} S_\tau$ will switch at t, i.e., $i \in S_t(G_{\mu,\theta})$ if :

$$(1) \quad |C_t(\cup_{\tau=0}^{t-1} S_\tau(G_{\mu,\theta}))| \leq \mu_i, \quad \text{and} \quad (2) \quad \frac{|\{\cup_{\tau=0}^{t-1} S_\tau(G_{\mu,\theta})\} \cap N_i(G_{\mu,\theta})|}{|N_i(G_{\mu,\theta})|} \geq \theta_i.$$

Model : Dynamics (2)

- Necessary Conditions for a global cascade :
  - Achieving a global cascade (ie. every agents adopt the technology) requires, for at least one agent *i* at each period *t*, two conditions to hold :

$$(3) \qquad \forall t, \exists i \in V \setminus U_{\tau=0}^{t} \; S_\tau \text{ such that } \mu_i \geq C_{t+1}$$

$$(4) \qquad \frac{|\{\cup_{\tau=0}^{t-1} S_\tau(G_{\mu,\theta})\} \cap N_i(G_{\mu,\theta})|}{|N_i(G_{\mu,\theta})|} \geq \theta_i .$$

- For a given network $G_{\mu,\theta}$, define the fixed point of the process such that :

$$S_0(\mathrm{X}) = S(G_{\mu,\theta},\, S_0) \longrightarrow S_t(\mathrm{G}_{\mu,\theta}) = \emptyset \text{ for all } t > 0.$$

Model : Agent Based Model (1)

- We apply our theoretical model to large complex networks with 100 agents (Cowan, 2004), assigning random thresholds' values;

- These networks exhibit high levels of complexity; meaning that it is hard to derive any analytical rule as possible combinations are too large (as for most ABM);

- As carried out in the literature, we use simulations to get our findings (Cowan, 2004; Delre et al., 2006; Akbarpour et al. 2017).

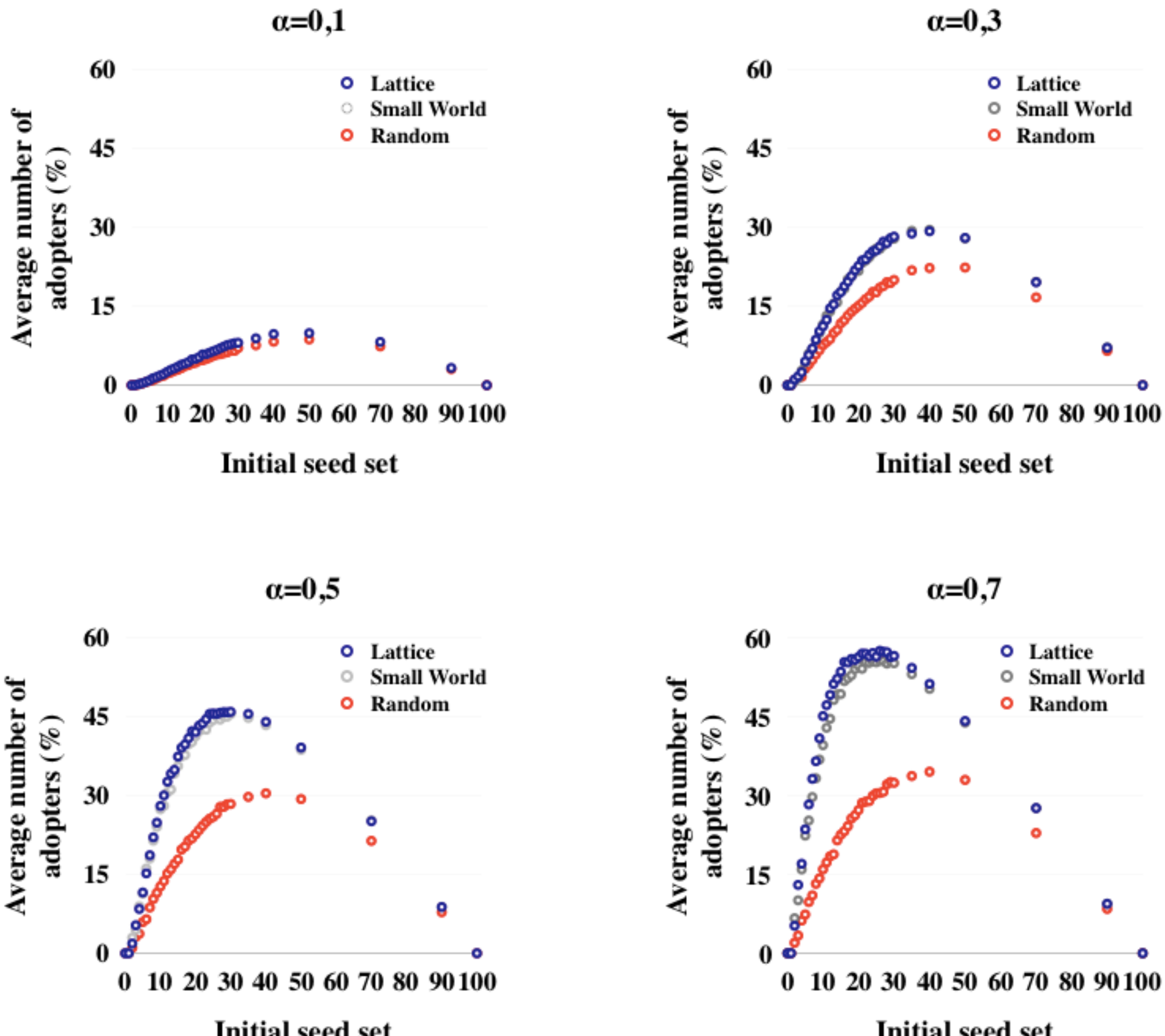
Model : Agent Based Model (2)

- N=100, n=10 (eg. Cowan, 2004);
- Each agents is endowed with two thresholds profiles μ_i and θ_i, drawn independently from a uniform probability distribution with support [0, 1];
- Agents placed on lattice, SW and random graphs according to the WS algorithm;
- At t_0, we set the number of initial seeds $S_0 \in [0,\ldots, 100]$, randomly selected, to launch the cascade process. Tests on four learning scenarios α=[0.1; 0.3; 0.5; 0.7];
- 1000 different graphs are created and on each graph a single history is run. The graph is unchanged within a history. We randomized the agents in the seed set and the associated thresholds allocation (Watts, 2002; Lelarge, 2011).

Results & Analysis

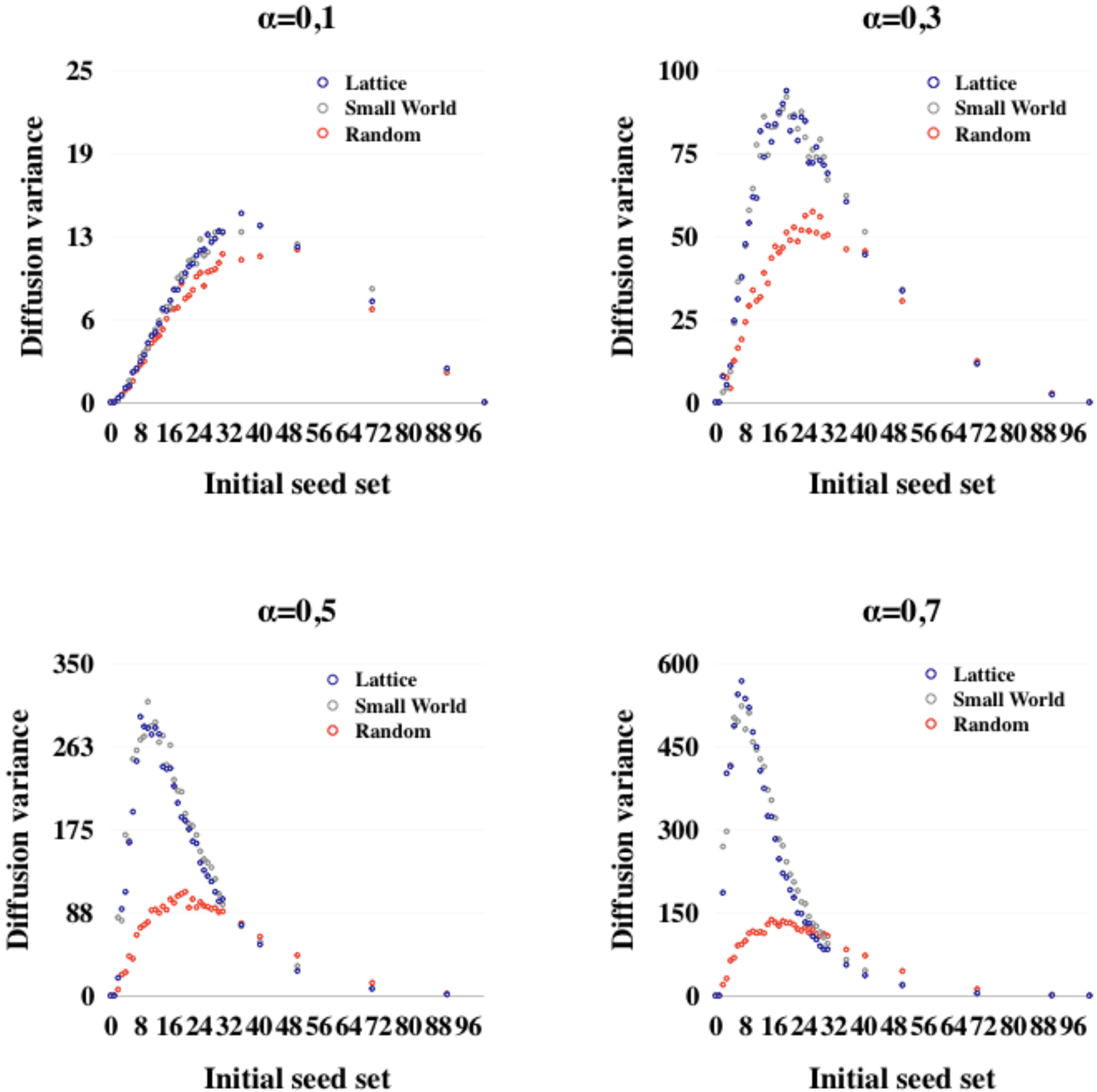
Model : Results & Analysis (1) - Agg. Diffusion

Fig.1. Aggregate diffusion as a function of initial seed sets



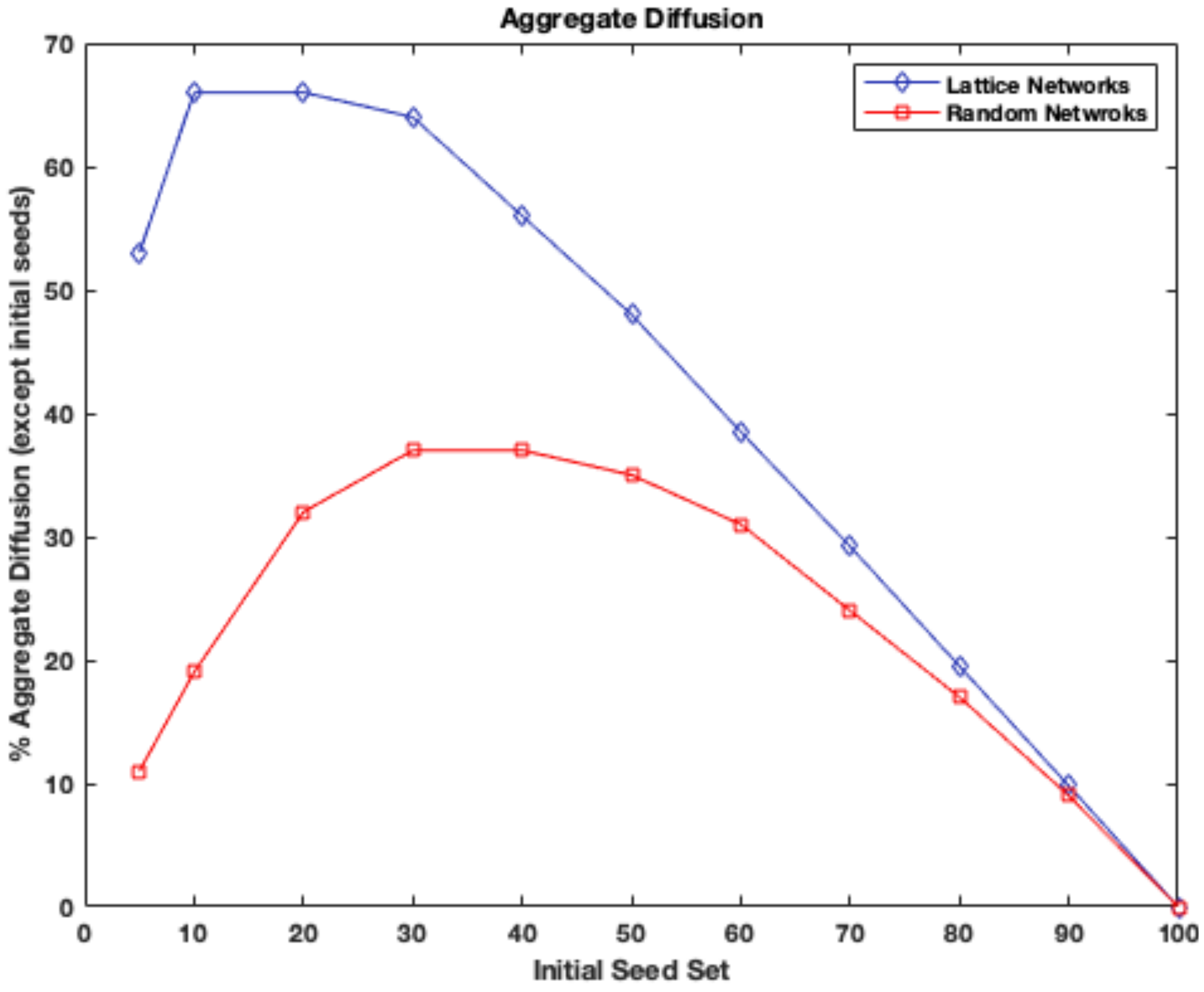
Model : Results & Analysis (2) - Heterogeneity

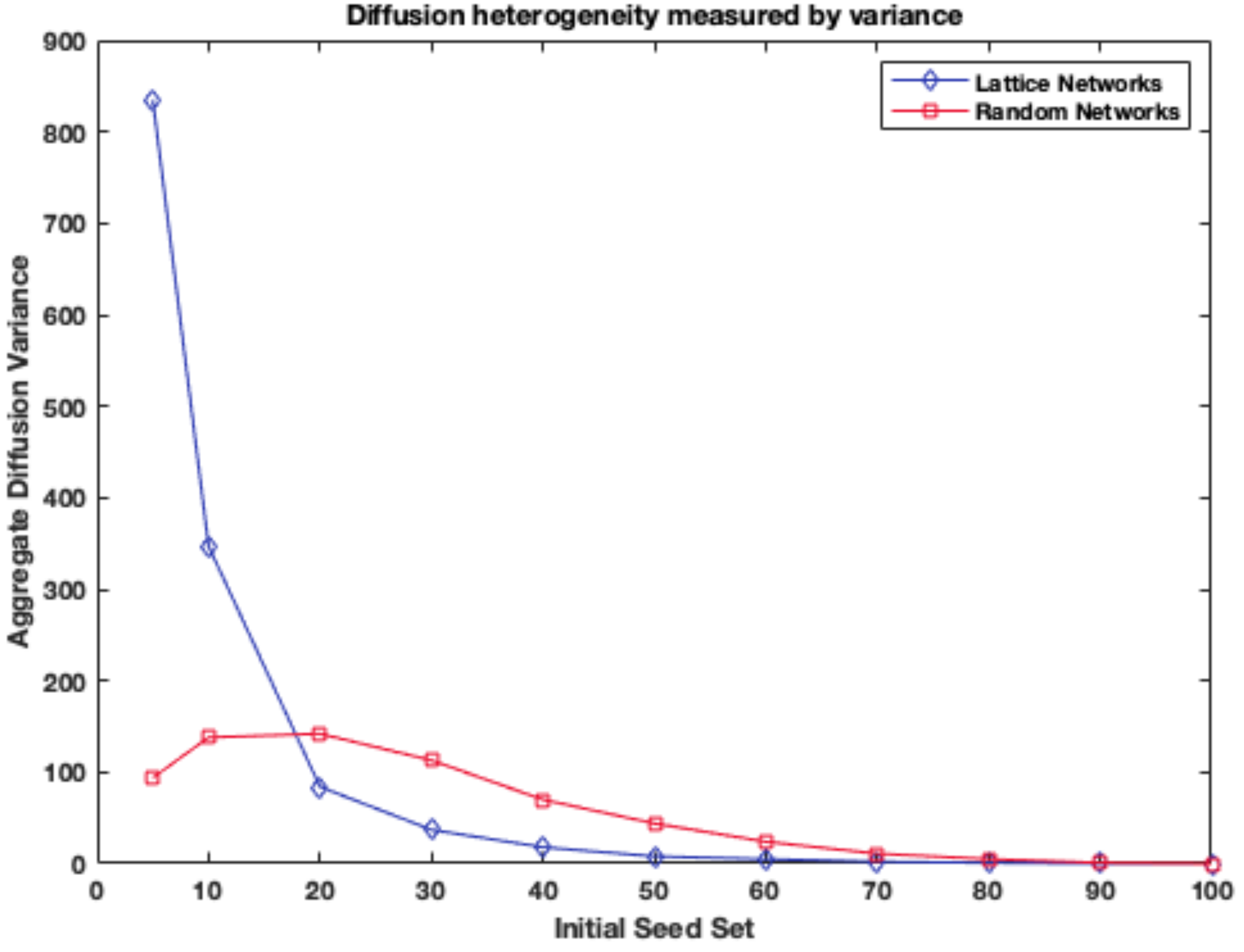
Fig.2. Diffusion heterogeneity measured by variance



Model : Results & Analysis (2) - Heterogeneity

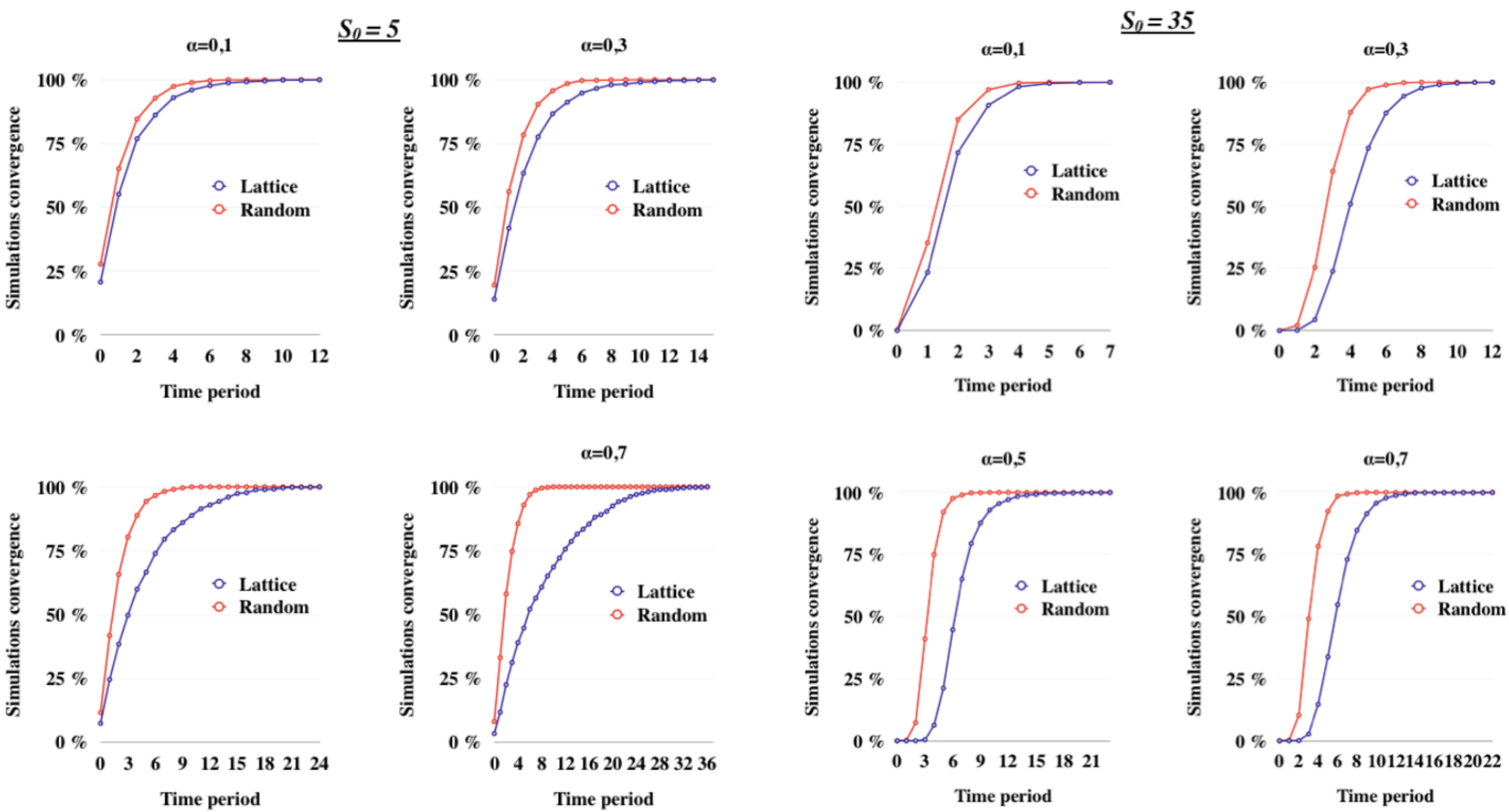
One threshold scenario θ_i





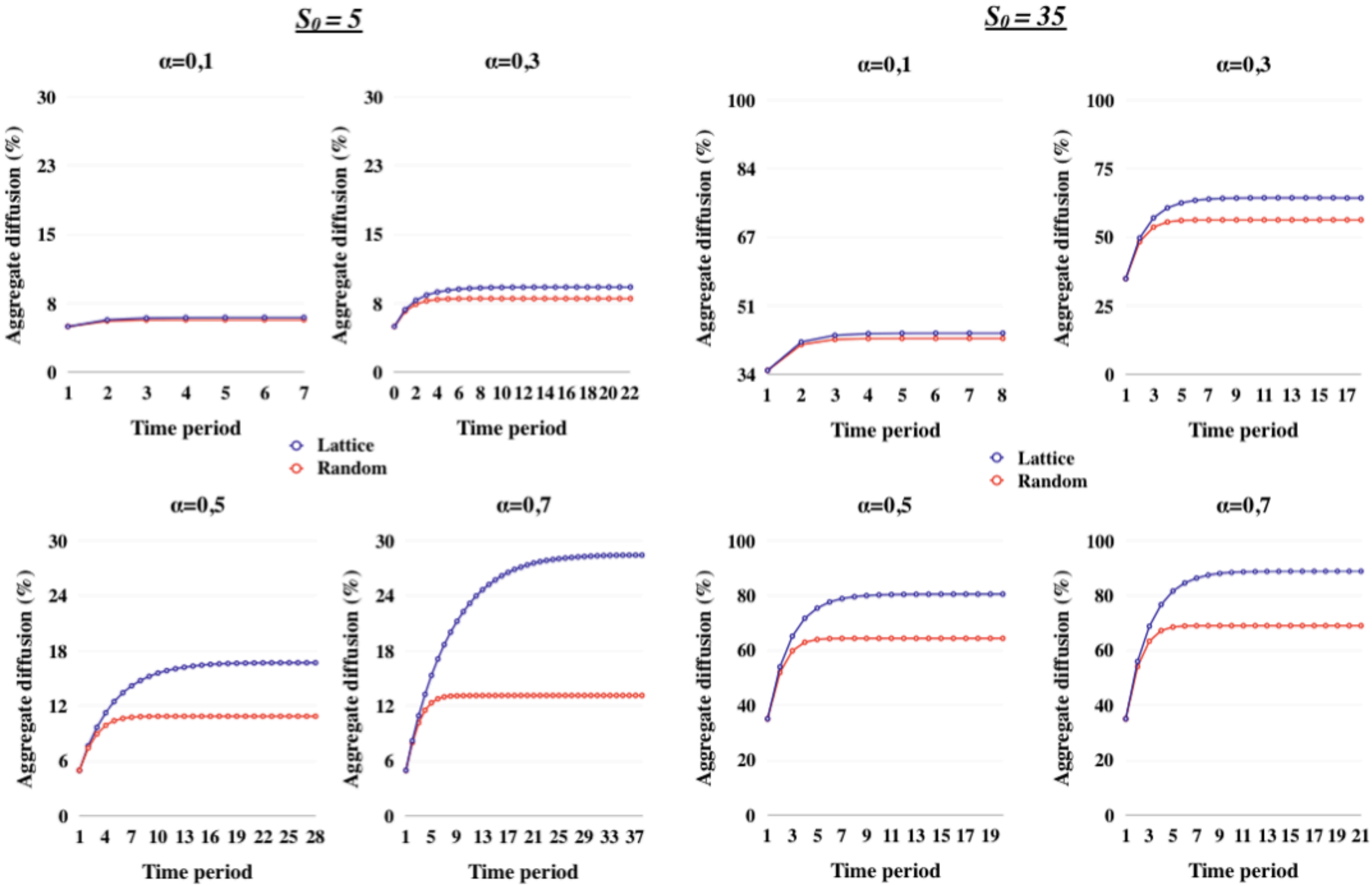
Model : Results & Analysis (3) - Diff. convergence

Fig.3. Rate of Cascades convergences as a function of time, S_0=[5;35]



Model : Results & Analysis (4) - Adoption convergence

Fig.4.(a) Adoption dynamics as a function of time



Discussion : The case of biogas technology

- Barriers : Initial investments cost + **knowledge** about the technology (Ortiz, 2017).

Our results emphasize the role of underlying networks to alleviate these constraints :

- Favouring systems of exchanges and cooperation : the role of **cooperatives** (cluster) to diffuse knowledge and invest together (Beaman, 2018);
- Perdersen et al. (2018) : More connections to biogas adopters increase the likelihood to adopt the technology (Indonesia).

Conclusions and Takeaways

- Networks : lattice and SW perform better than random networks in terms of diffusion (eg. S_0=24, α=0.7, Lat = 81%, Rand = 53%); **Policy —> Encouraging connections and exchanges (ie. coop).**

- Learning effects : 1) higher diffusion 2) larger aggregate gap - between clustered/random networks (fewer initial agents required). **Policy —> supporting the « good » technology !**

- Speed of diffusion : equivalent (random networks converge at slower aggregate adoption level);

- Clustered networks display higher levels of variance for aggregate diffusion level. **Policy —> the case of uncertainty in results ?**

- Two thresholds/one threshold frameworks : **heterogeneity behaves differently (clustered networks).**

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Backup - Networks topologies

- Networks : hierarchical, clustered, sparse, complete...
- Evaluating the influence of network's structure on diffusion :
  - Low number of nodes : Deriving local analytical rules (eg. Acemoglu et al., 2011; Teytelboym et al., 2016);
  - High number of nodes : Complex systems = numerical approaches (Cowan, 2004; Delre et al., 2006; Singh et al., 2013).

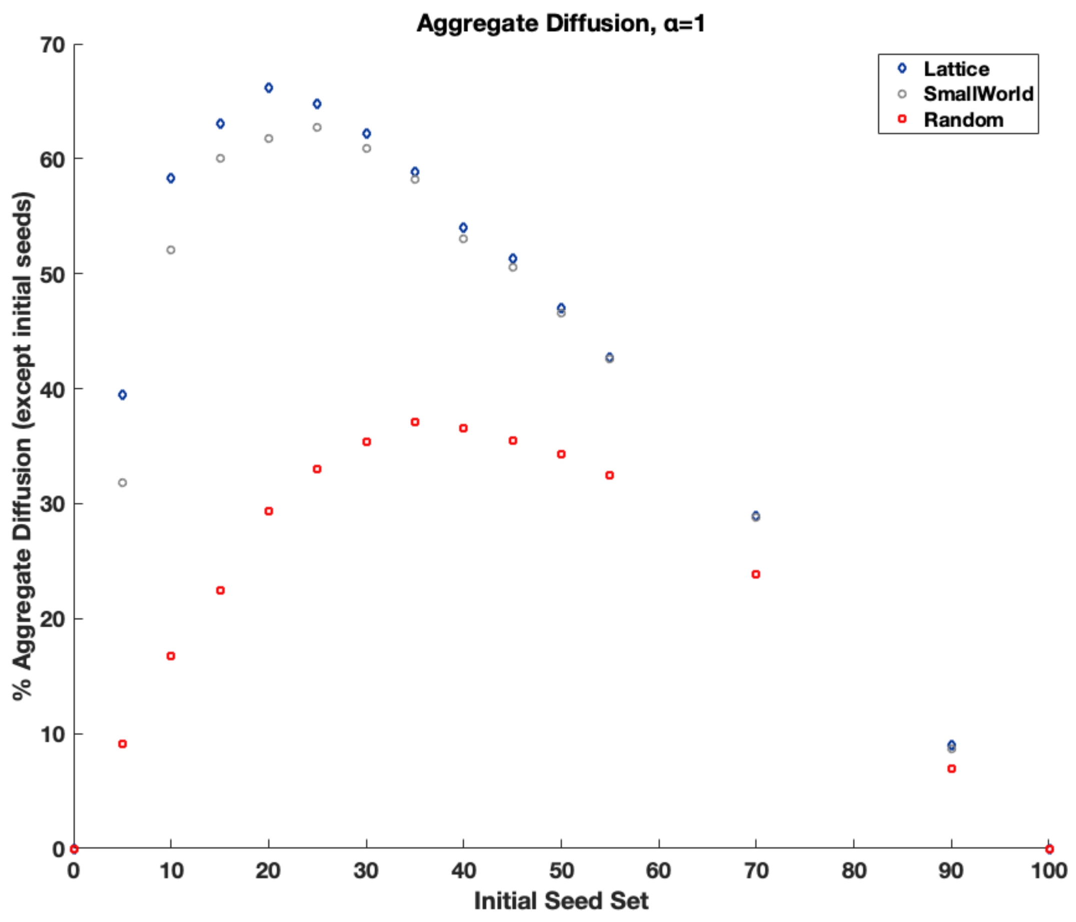
Watts Strogatz algorithm (1998) : Matching real world networks, easiness to generate networks (lattice, SW, Random), allows for comparisons through clustering and average path length.

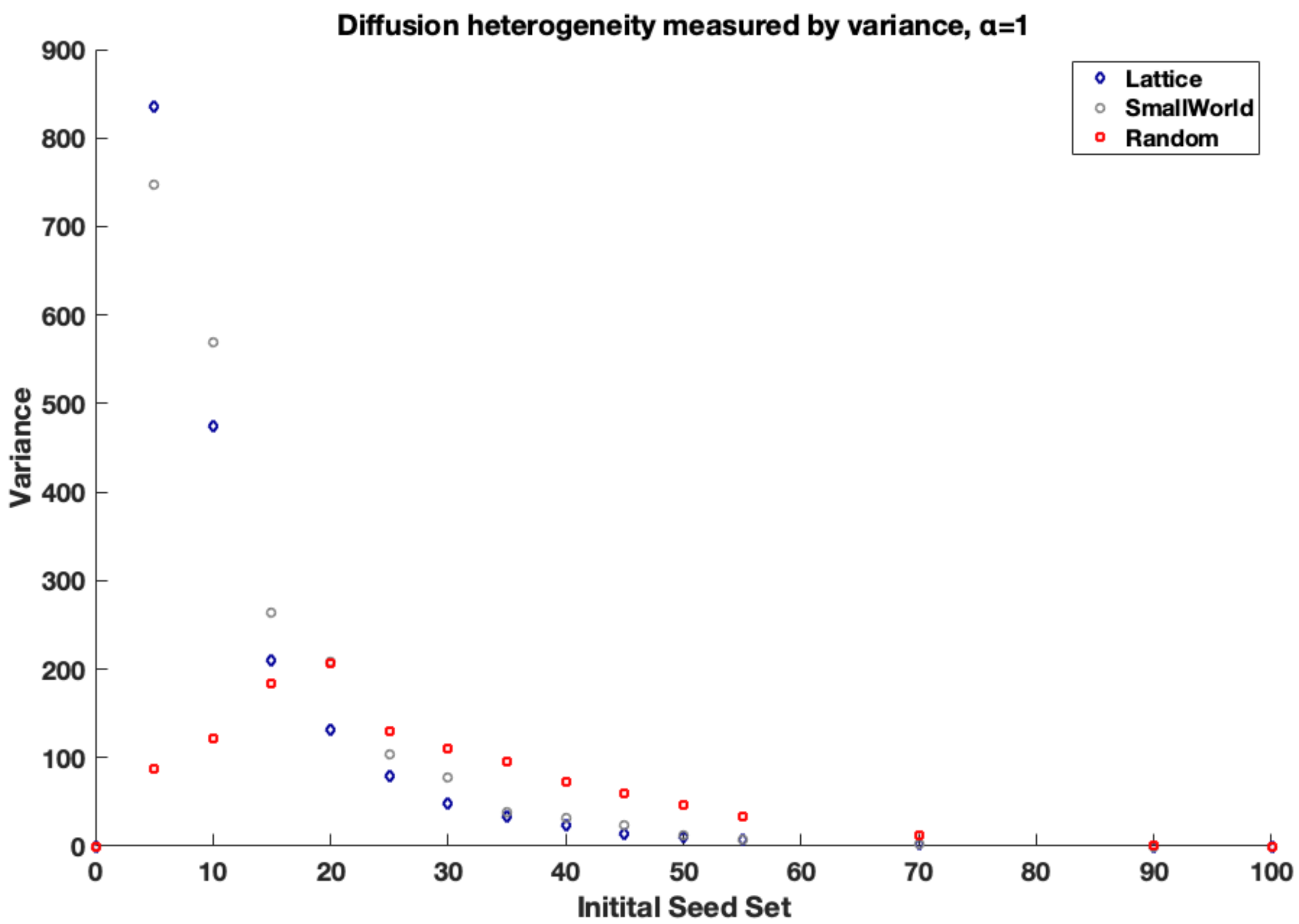
Backup (1) - α=[0;1]

1) For α=0, the cost function is :

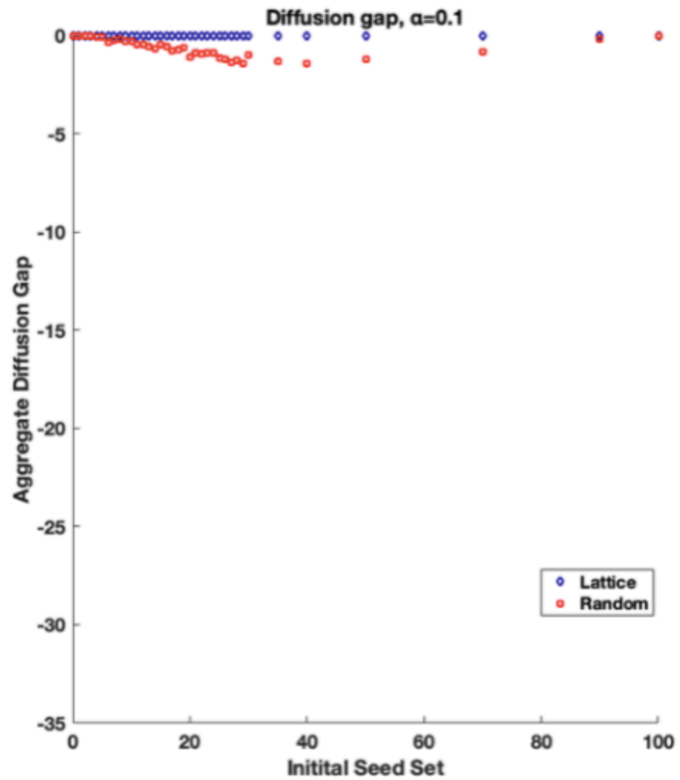
$$C_t = C_0 \times (|U_{\tau=0}^{t-1} S_\tau|)^{-0} = 1$$

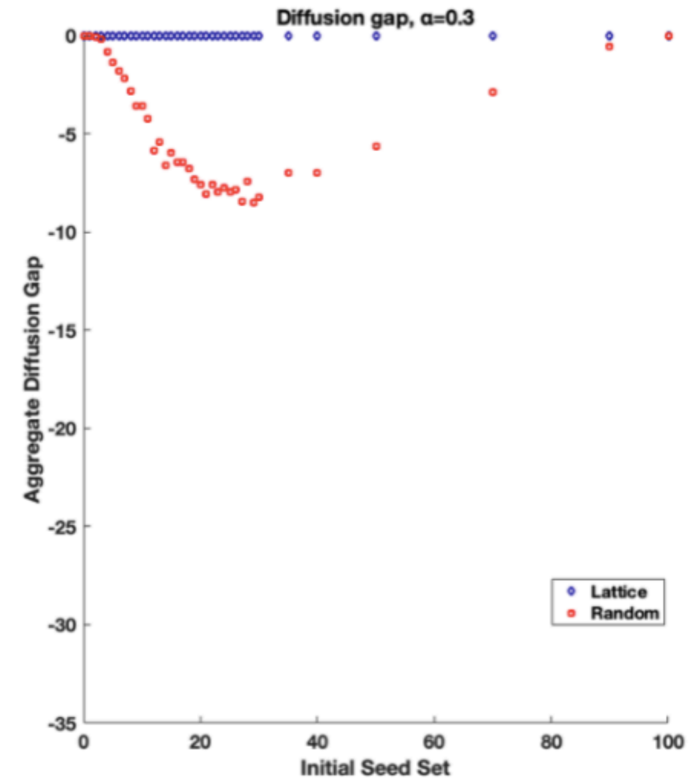
whatever the initial seed set. Then, we observe no diffusion in networks at all as the cost remains too high.

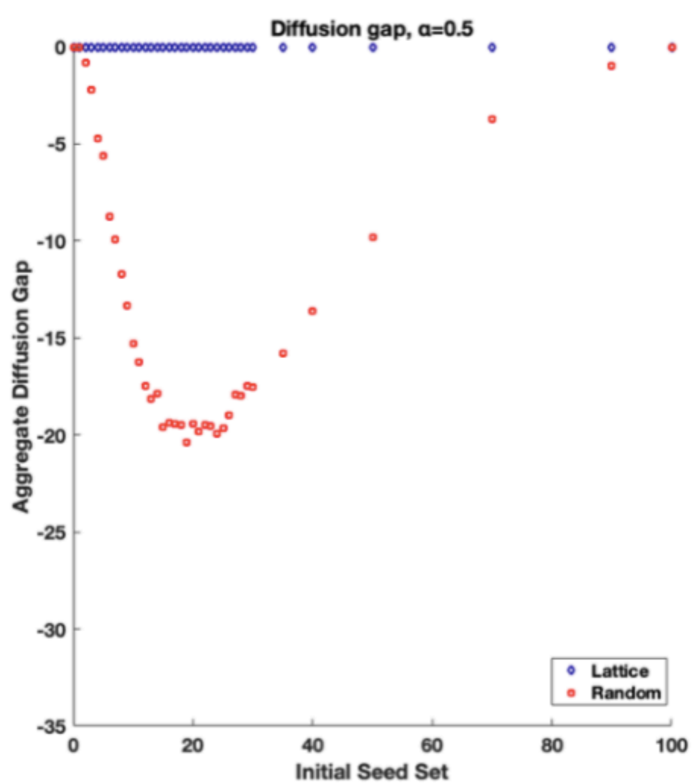


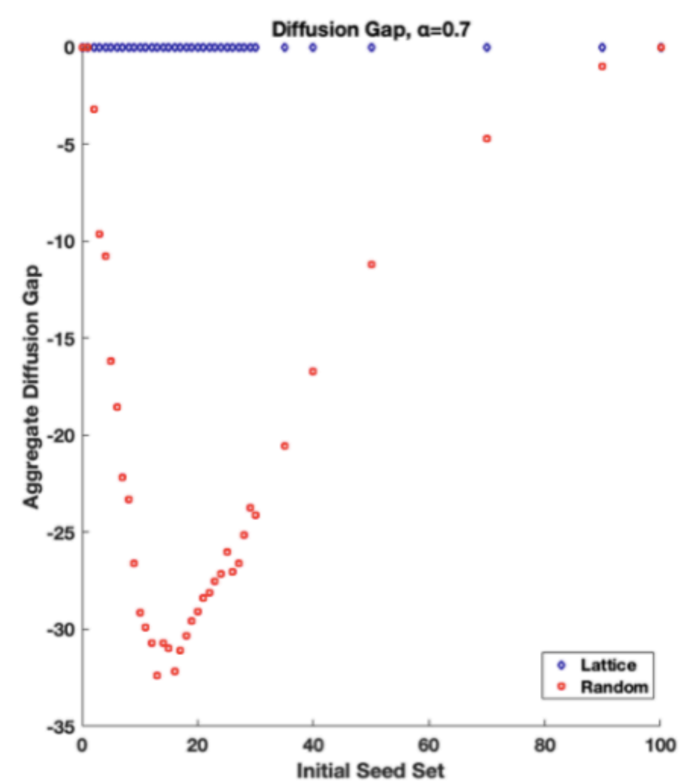


Backup (2) - Diffusion gap (baseline Lat.)

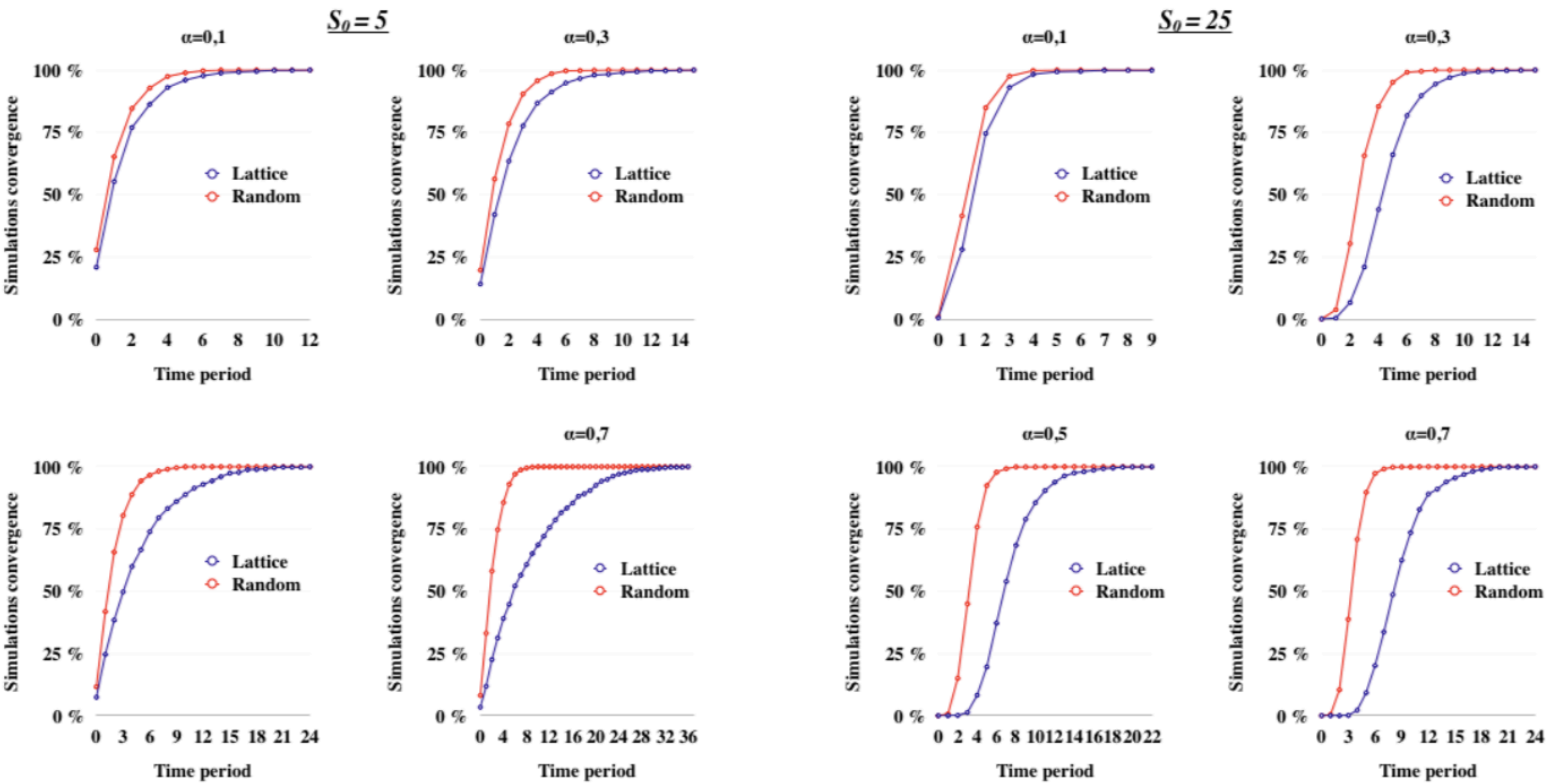




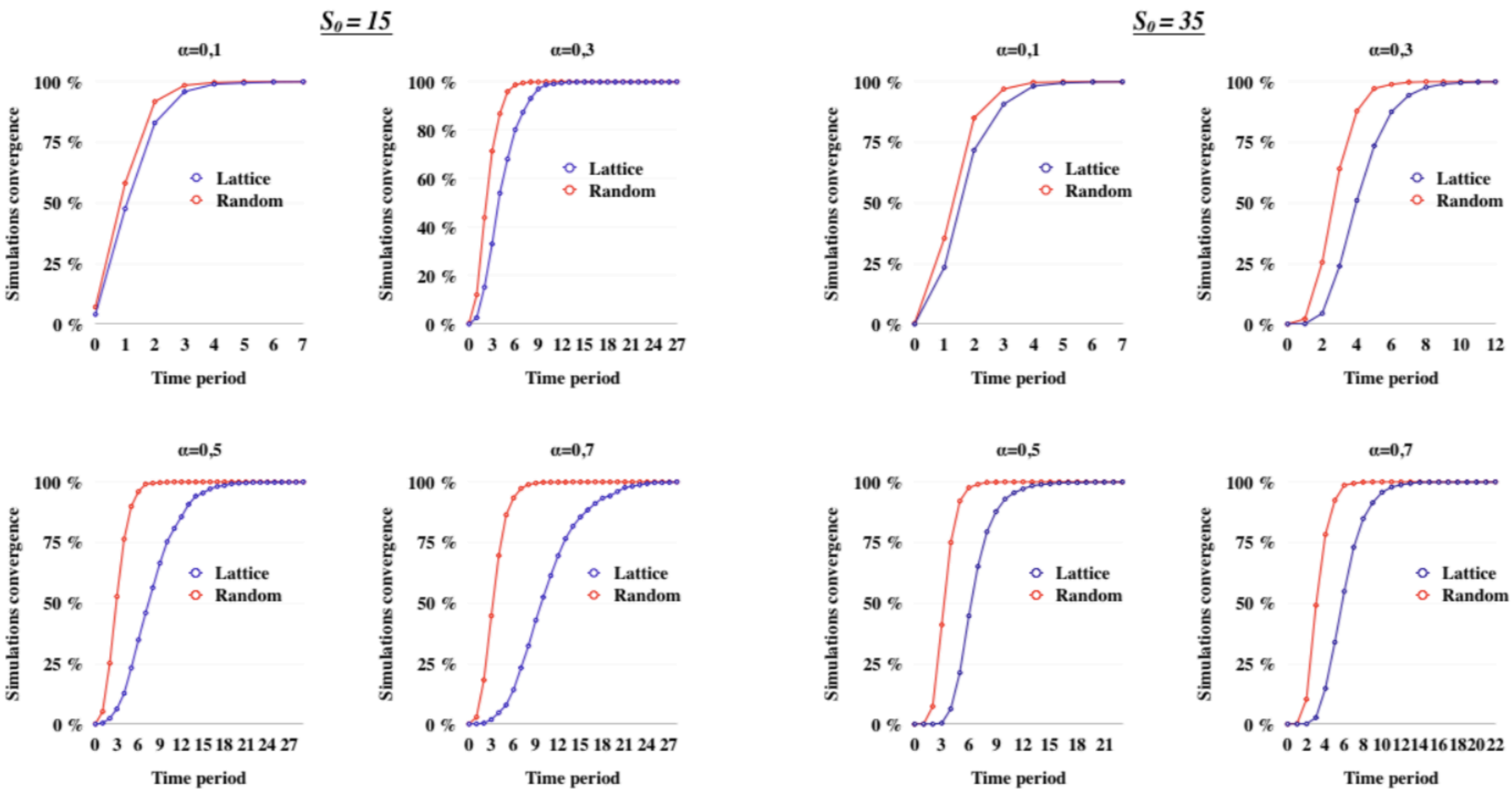




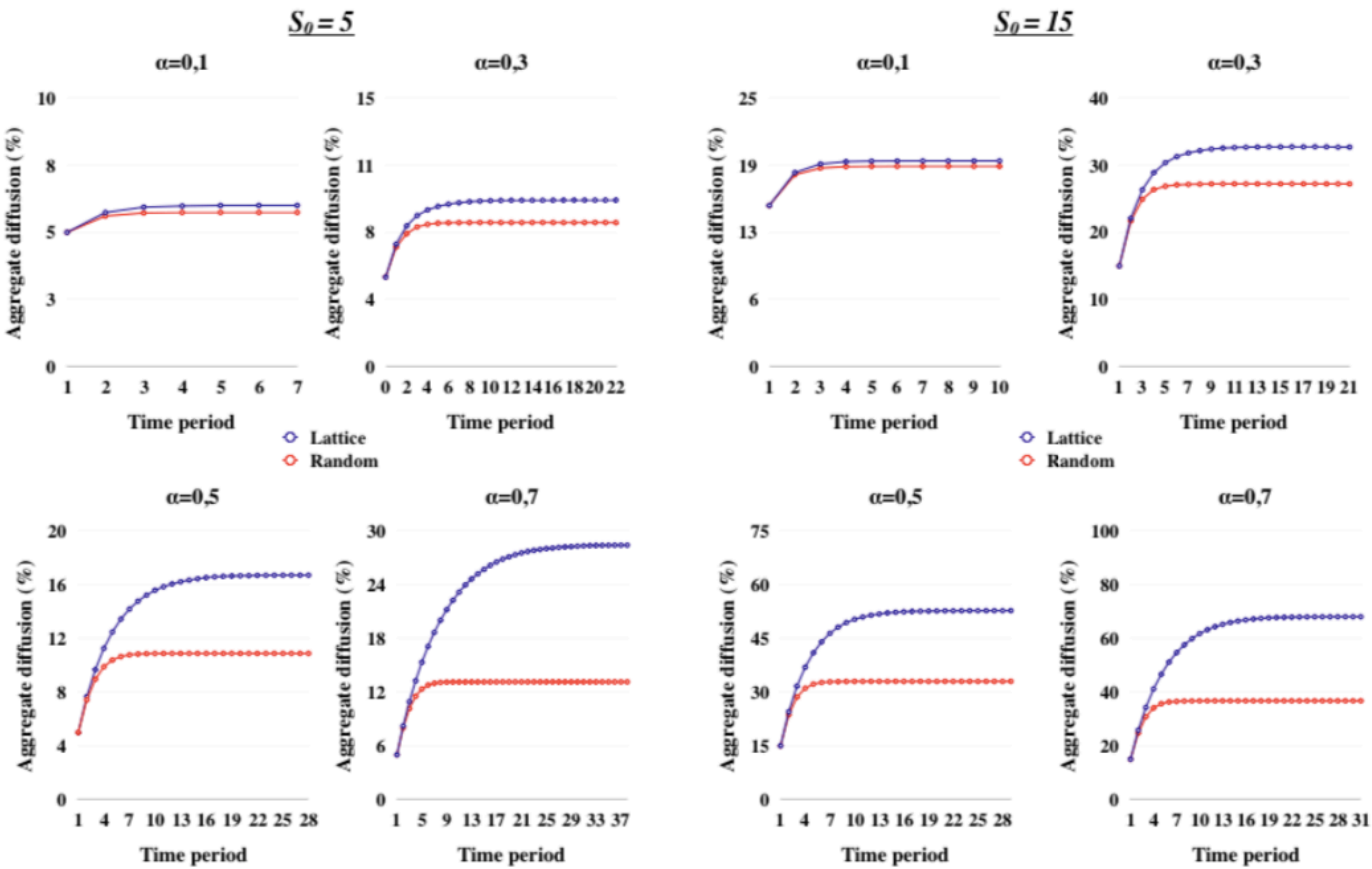
Backup (3) - Cascades convergence (1)



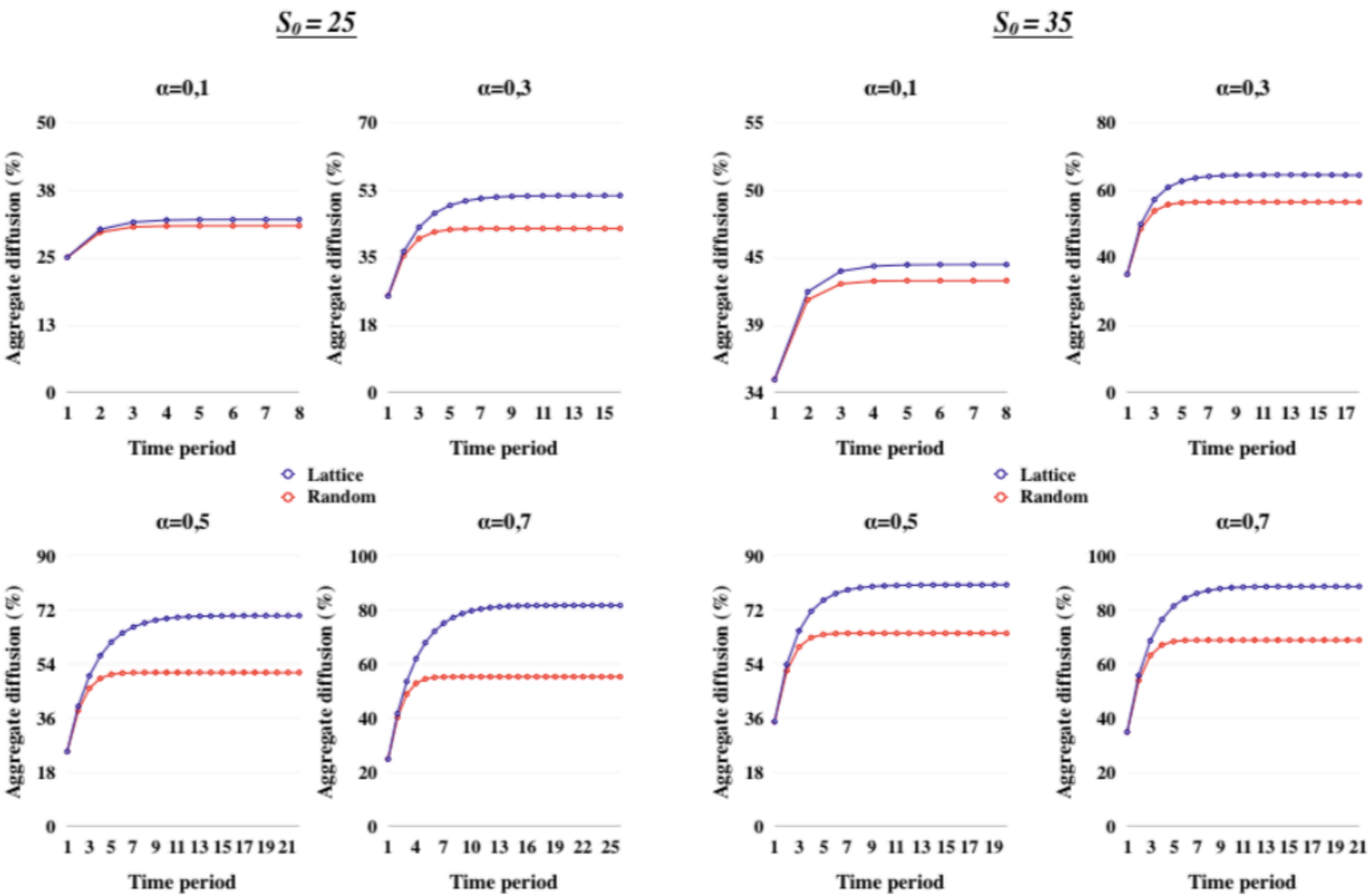
Backup (3) - Cascades convergence (2)



Backup (4) - Adoption convergence (1)



Backup (4) - Adoption convergence (2)



Chapter 2

Overview of the Presentation

- Introduction
- Modeling Strategy for Inferring Diffusion Network
- How Environmental Policies Spread ? A Network Analysis
- Determinants of Network Formation
- Conclusion

INTRODUCTION

Context (1) - Environmental Policy Needs

- Environmental and climate policies are put forward prominently
  - (eg. COP21 Paris Agreement, G7, Youth for Climate).

- Global Warming of 1.5°C - IPCC (2019) :
  - Net zero by 2050;
  - *« the need of "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities and give policymakers and practitioners the information they need to make decisions that tackle climate change [...] ».*

- 1,500 environmental laws and policies globally (GRI, 2018).
  - *« Since the Kyoto Protocol, increased by a factor of more than 20 » (Climate Change Laws of the World, Special Report, GRI, 2018).*

Context (2) - In the United States

- Contribution to Climate change
  - 14% of worldwide GHGs emissions (WRI, 2017), 2nd larger emitter today and first in history (U.N., 2017) !

- COP21 objective: « reducing U.S. emissions to at least 26% under 2005 levels by 2025 » (N.D.C.);

- Trump election (2016): withdrawal from the Paris Agreement; at least 84 environmental rules being rolled back (Harvard Law School, Columbia Law School, 2019);

- **Some U.S. states take the political lead against global warming (eg. California, New York; Climate Alliance, 2017).**

Context (3) - Federalism System (1)

- Federalism, a peculiar environment for policy diffusion :
  - States are connected in many ways (eg. history, culture, the exchange of goods, citizens' migration, media markets (Desmarais et al., 2015));
  - States tend to compete and learn from each other (Berry and Berry, 1990; Pitt, 2010);

- Policies regularly spread throughout the American states, driven by underlying forces (ie. competitive, cooperative, and imitative);

- **Scholars have mainly investigated the determinants of policy adoption and diffusion (internal, external).**

Context (3) - Federalism System (2)

- Main factors for Environmental Policy Adoption:
  - Internal : Citizens ideology (Matisoff, 2008); Partisan control of the state (Huang et al., 2007); liberalism (Matisoff and Edward*, 2014); Environmental organizations membership level (Newmark and Witko, 2007); State's economy (manufacturing & mining) and wealth (*);
  - External : Geographic proximity (Berry & Berry, 1990, 1992; Mooney & Lee, 1995; Wong & Shen, 2002); Shared characteristics (Volden, 2006); Ideological distance (Chandler, 2009; Grossback, Nicholson-Crotty, & Peterson, 2004).

Gap in the literature :

- What about ***How Environmental Policies Spread ?***
- And ***the specific role of states in the transmission process ? (key actor)***

Main Contributions & Objectives (1)

- **This paper contributes to the literature by :**
  - Being the first to consider a network based approach to environmental policies diffusion/transmission in the U.S. from 1974 onwards;
  - Understanding underlying forces that drives transmission.
- **Objectives are :**
  - Inferring the Environmental Policies Diffusion Network and identifies states facilitating the diffusion and vice versa;
  - Estimating the determinants of the inferred network (ie. those maximizing the transmission likelihood between states).

MODEL & DATA

Inferring the Network : Independent Cascade Model (1)

- Independent Cascade Model to infer a network from series of observations (Gomez-Rodriguez, 2010);

- Weights of the network are interpreted as the rates at which the policy is likely to be transferred between a states-pair;

- These weights summarize effects of latent variables that govern bilateral diffusion and systemic roles of states in the network.

Inferring the Network : Independent Cascade Model (2)

- Formally, we are given a series of observations of subsequent types **(c)** of environmental policies enacted across US. states where:
  - **c** is characterized by a cascade of adoptions $t^c = (t_1^c, \ldots, t_N^c)$, which is an N-dimensional vector of observed activation times.
  - For each node i, t_i^c is an element in $[t_0^c, t_0^c + T] \cup \{\infty\}$, which is equal to the time at which state i enacted the legislation **c** if finite and is infinite if the state did not enact during a time interval of length T starting with the first adoption at time t_0^c.
  - The data can then be represented by a set **c** of cascades, one cascade for each legislation, and denoted as $C := \{\mathbf{t}^1, \ldots, \mathbf{t}^{|C|}\}$.

Inferring the Network : Independent Cascade Model (3)

- **Objective**: **Infer a diffusion network (G,A), where G=(V,E) and A=[$\alpha_{j,i}$] is a matrix of transmission rates, i.e. $\alpha_{j,i} > 0$** *(ie. quantifies how likely it is that a policy spreads from node j to node i if (j,i) ∈ E (and $\alpha_{j,i} = 0$ if (j,i) ∉ E).*

- ICM : Infer the maximum likelihood network under the assumption that each **cascade is an independent instance** of a diffusion process drawn from a parametric model in which the probability of diffusion from node j to node i is parameterized by the transmission rate $\alpha_{j,i}$ that is to be determined.

Inferring the Network : Independent Cascade Model (4)

- Building block of our approach is $f(t_i|t_j;\alpha_{j,i})$, the probability that node *i* gets activated by node *j* at time t_i, given node *j* was activated at time t_j and assuming a transmission rate $\alpha_{j,i}$ between nodes *j* and *i*.
- Given the conditional density $f(t_i|t_j;\alpha_{j,i})$, we can infer the likelihood of a set of cascades $\{t^1,\ldots, t^{|C|}\}$ given a network $A = [\alpha_{j,i}]$ as follows :
  - First, given a cascade $\boldsymbol{t}^c = (t_1^c,\ldots,t_N^c)$, the likelihood of node *i* being activated is :

$$f(t_i|t_1,\ldots t_N \setminus t_i; A) = \sum_{j:t_j\leq t_i} f(t_i|t_j;\alpha_{j,i}) \times \prod_{j\neq k, t_{k\leq t_i}} S(t_i|t_k;\alpha_{k,i})$$

Inferring the Network : Independent Cascade Model (5)

- One can then compute the likelihood of the activations in a cascade before time T:

$$f(\mathbf{t}^c_{\leq T}; A) = \prod_{t_i \leq T} \sum_{j:t_j \leq t_i} f(t_i|t_j; \alpha_{j,i}) \times \prod_{k:t_k < t_i, k \neq j} S(t_i|t_k; \alpha_{k,i})$$

- Further, the likelihood of a cascade accounts for the fact that some nodes did not get activated (we consider that nodes not activated before time T never get activated). It is therefore given by:

$$f(\mathbf{t}^c; A) = \prod_{t_i \leq T} \prod_{t_m > T} S(T|t_i; \alpha_{i,m}) \prod_{t_i \leq T} \sum_{j:t_j \leq t_i} f(t_i|t_j; \alpha_{j,i}) \prod_{k:t_k < t_i, k \neq j} S(t_i|t_k; \alpha_{k,i})$$

- Finally, the likelihood of a set of cascades C = $\{\boldsymbol{t}^1, \ldots, \boldsymbol{t}^{|C|}\}$, assuming each cascade is independent, is the product of the likelihoods of the individual cascades given by:

$$f(\{\mathbf{t}^1, \ldots, \mathbf{t}^{|C|}\}; A) = \prod_{t^c \in C} f(\mathbf{t}^c; A)$$

Inferring the Network : Independent Cascade Model (6)

- Objective is to find $A = [\alpha_{j,i}]$ such that the likelihood of the observed set of cascades $C = \{\boldsymbol{t}^1, \ldots, \boldsymbol{t}^{|C|}\}$ is maximized. We use CVX (MATLAB) - solving convex programs (Grant and Boyd, 2015) and the algorithm NETRATE.

- Structural assumptions about the diffusion process are embedded in the functional form chosen for the function f.

- The probabilistic rate is constant over time (ie. a Poisson process —> exponential model for the conditional density (Kingman, 1993) : $f(t_i|t_j ; \alpha_{j,i}) = \alpha_{j,i} e^{-\alpha_{j,i}} (t_i - t_j)$, (if $t_j < t_i$ and zero otherwise).

Dataset of Environmental Policies

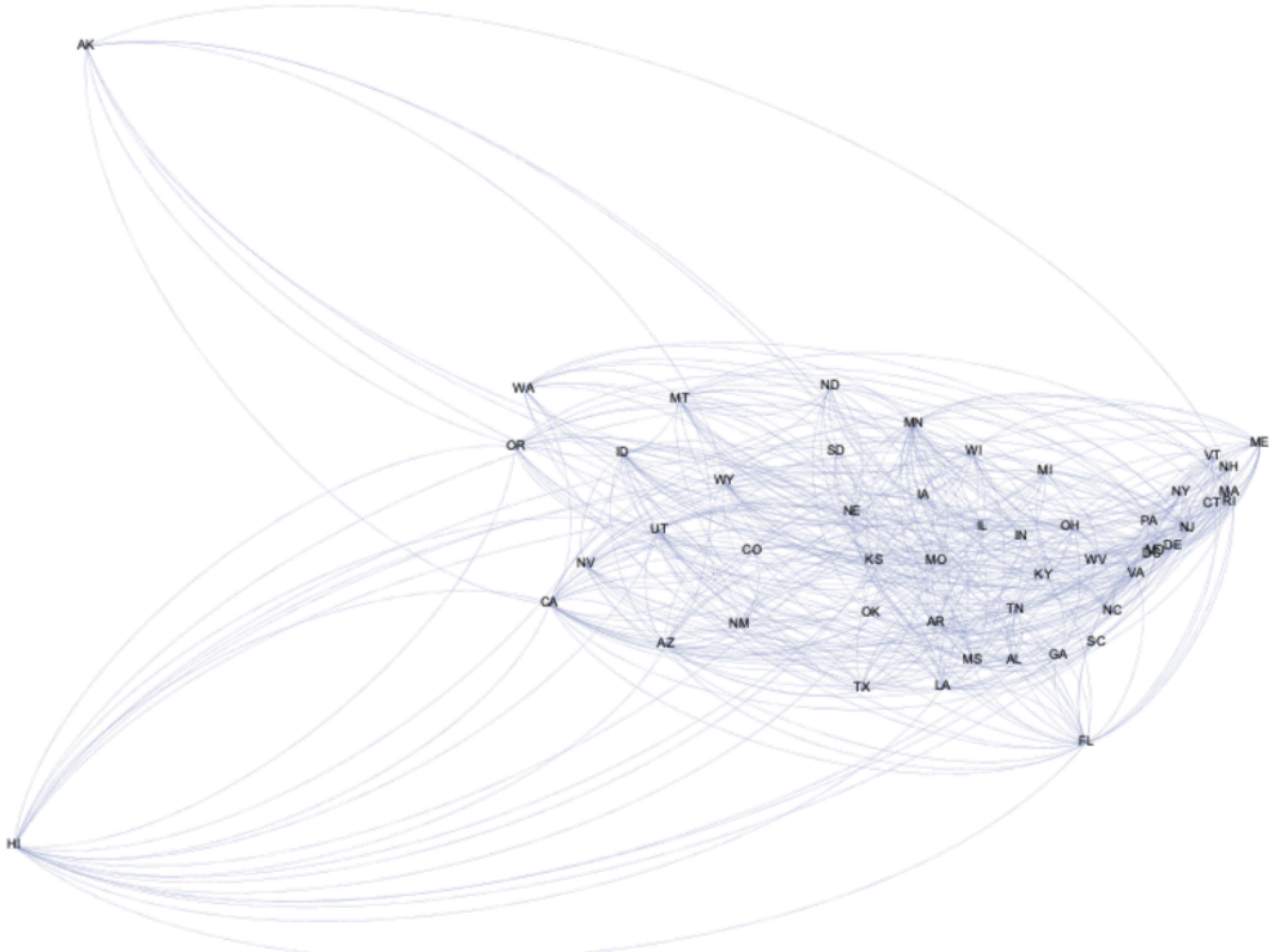
- 2 types of outputs : adjacency structure of the network; weights.
- Dataset : 74 policies, 51 states, 1974/2018, three initial databases:
  - Database of State Incentives for Renewables & Efficiency (DSIRE);
  - The Center for Climate and Energy Solution (C2ES);
  - US Congress Platform.

Scope (Number)	**Policies Description**
Climate Policies (5)	Action Plans and reduction targets
Climate Change Adaptation (9)	Plans to cope with current climate damages
Renewable support (24)	Promoting the use of clean energy
Energy Efficiency (9)	Targeting emissions in the dwelling sector
Transportation (8)	Promoting the use of clean fuels/vehicles
Circular Economy (7)	Targeting recycling/products efficient use
Environmental Concerns (12)	Regulating environment management/health

INFERRED NETWORK & ANALYSIS

Network Analysis : Generalities (1)

Fig.1. Reconstructed environmental policies diffusion network in the U.S. using geographical layout.



Network Analysis : Generalities (2)

Table 2. General Properties of the Network.

Overall Network Characteristics	**Exponential Model**
Number of Nodes	51
Number of Links	440
Network Density	0.173
Mean Degree	8.627
Mean Path Length	2.075
Network Diameter	4
Mean Clustering Coefficient	0.211

Network Analysis : Regions vs. Communities

Table 3. Regional-level statistics.

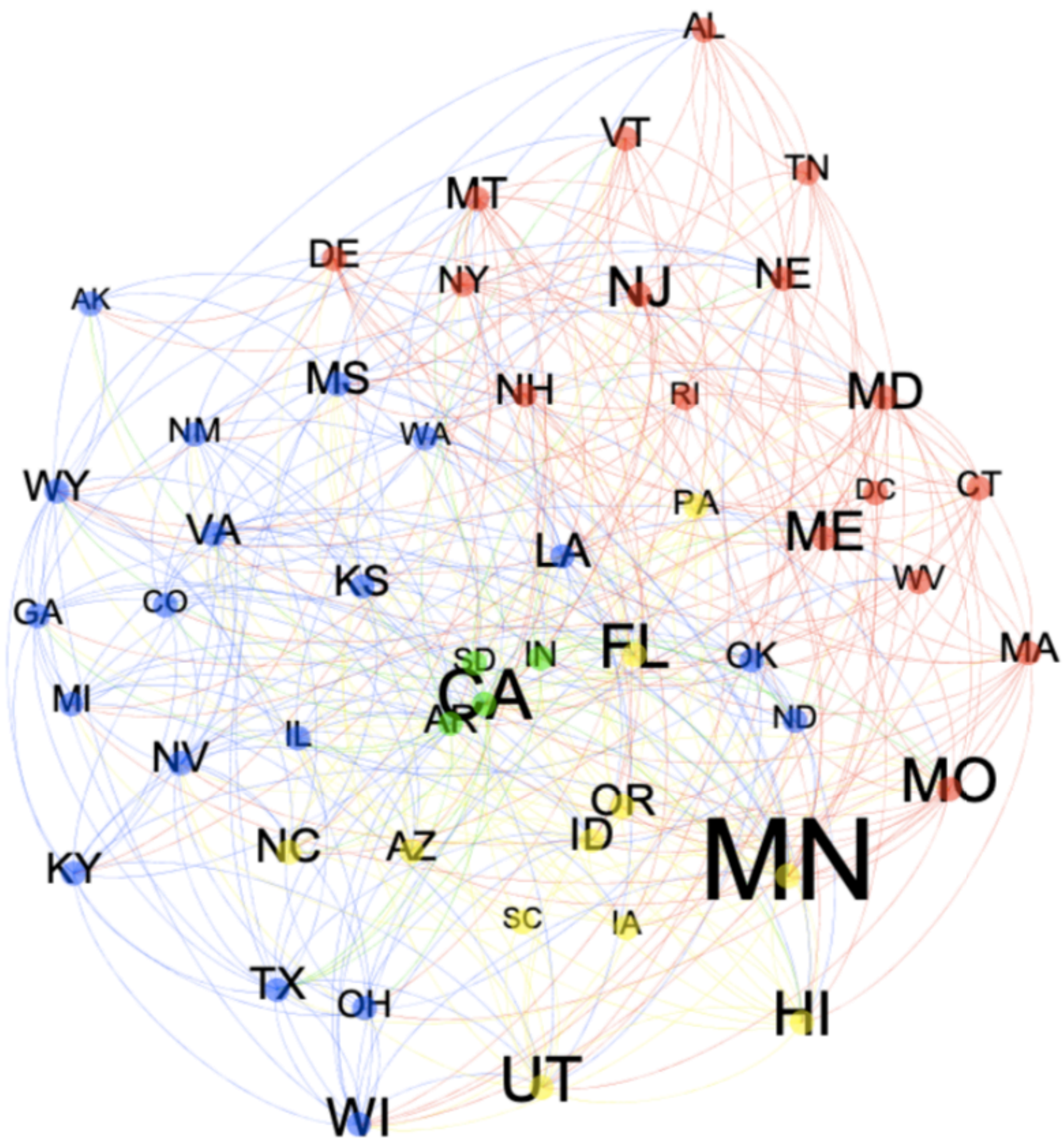
Region	No. of states	Out-degree	In-degree	Source region (%)	Target region (%)	Total degree
Northeast	9	89	59	20.23	13.41	148
Midwest	12	98	109	22.27	24.77	207
West	13	113	130	25.68	29.54	243
South	17	140	142	31.82	32.27	282

Table 4. Matrix of intra-interregional connections.

Region	Northeast	Midwest	West	South
Northeast	23	14	24	28
Midwest	10	30	29	29
West	11	29	34	39
South	15	36	43	46

Network Analysis : Regions vs. Communities

Fig.2. Reconstructed network using Force Atlas layout.



Characterization via Degree Distribution

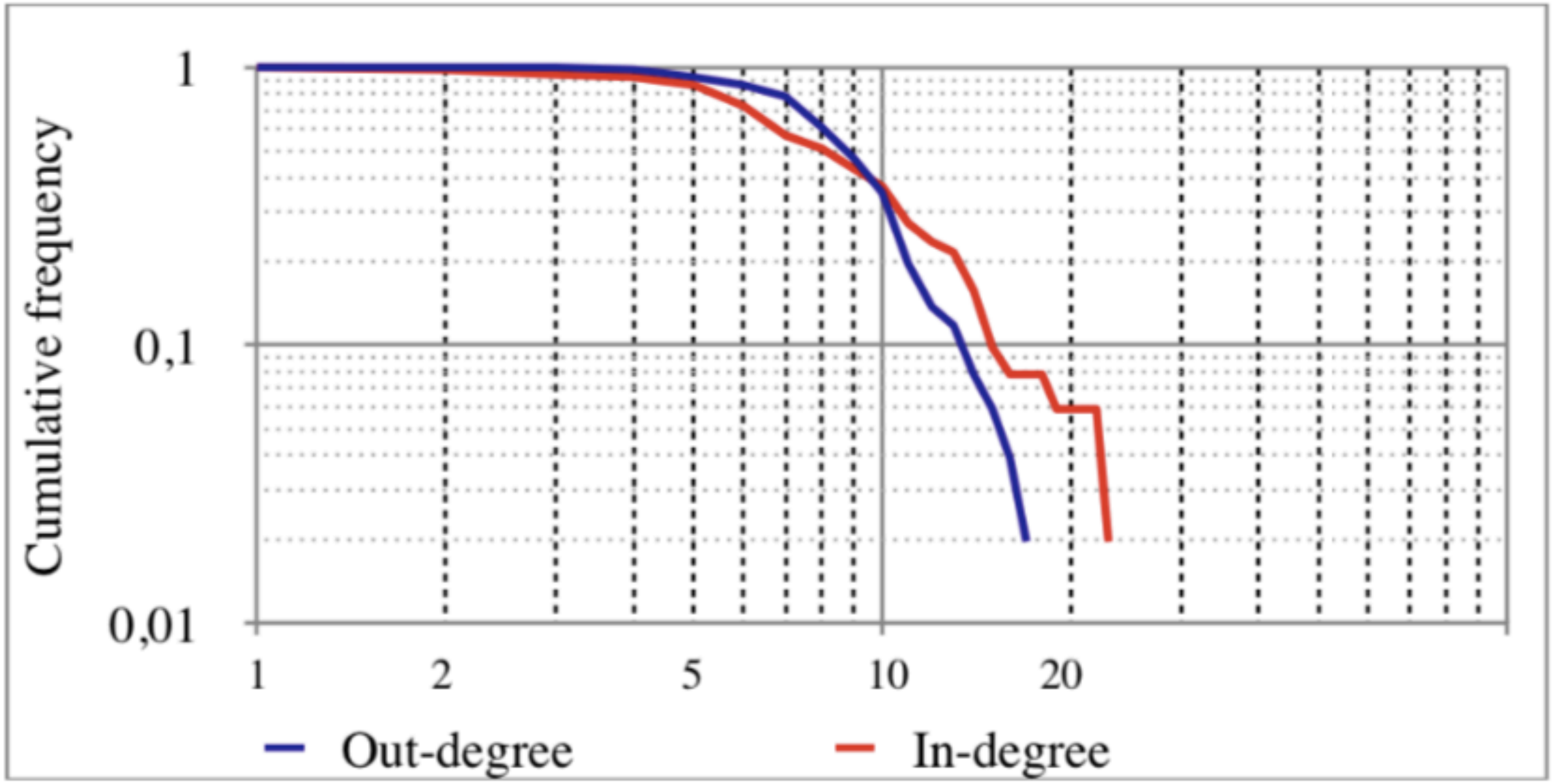


Fig.3. Cumulative distribution of states' out-degree and in-degree.

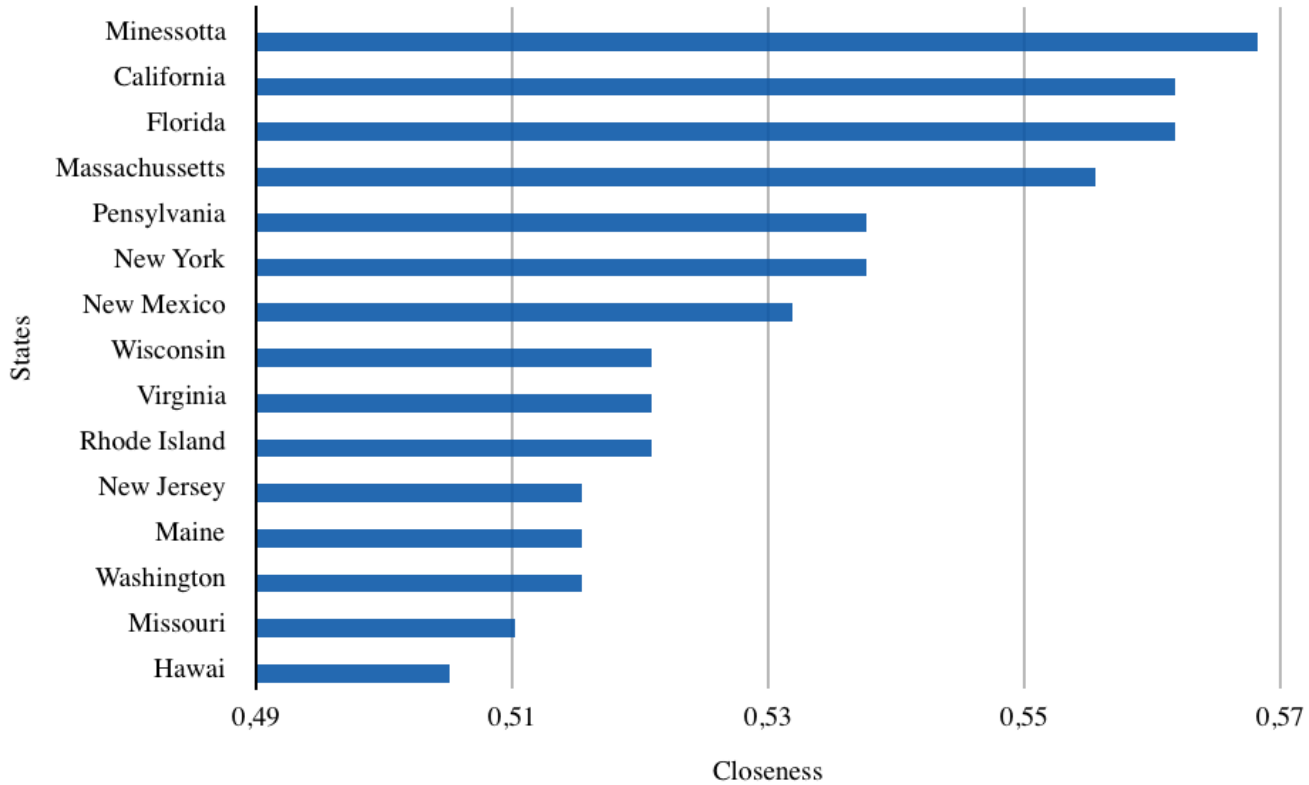
- *70 % of nodes have less than 10 out-degrees*
- *2% of nodes have more than 17 out-degrees*
- *= Highly connected nodes in the Network*

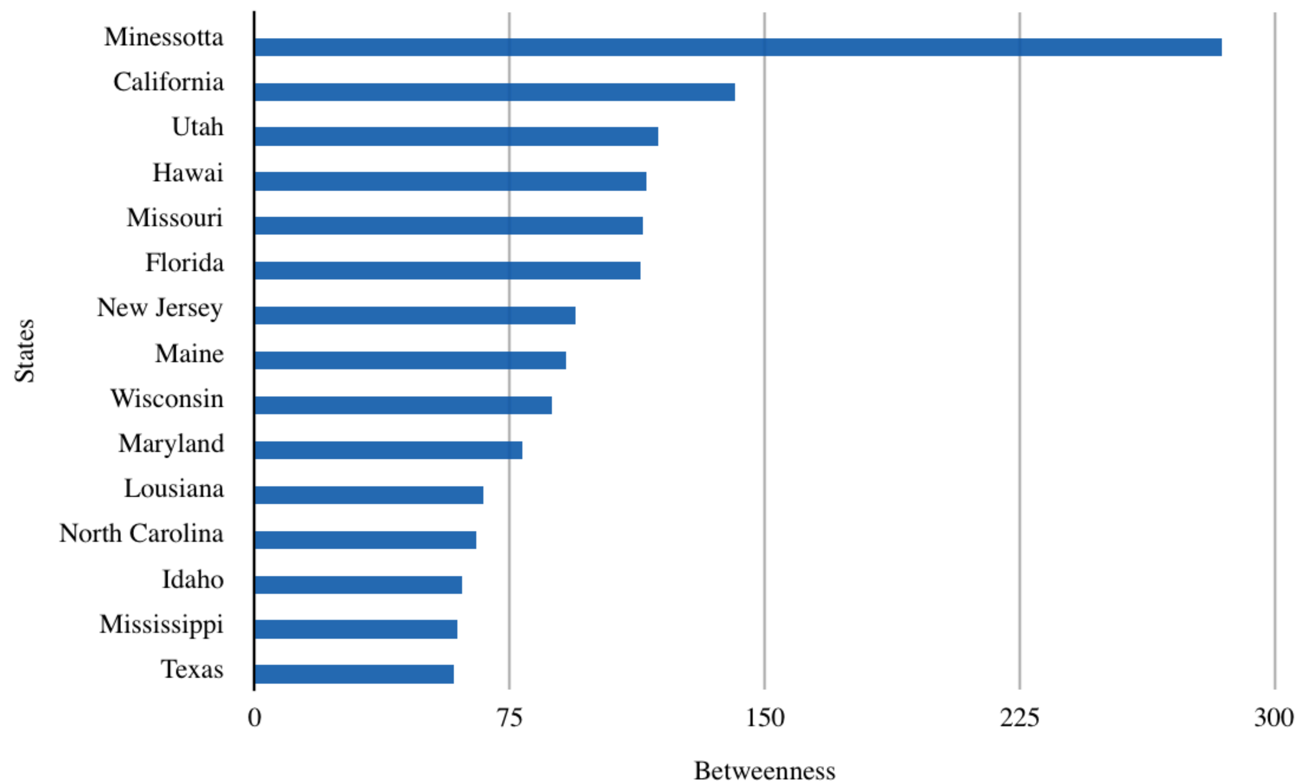
Capturing Leaders / Followers in the Network (1)

- **Centrality measures (Jackson, 2008) :**
  - Degree centrality of node *i* : its degree;
  - **The closeness** of node *i*, $1/\Sigma_j d(j,i)$, the average distance of *i*; *(ie. how fast a policy enacted in a state reaches, on average, another state).*
  - **The betweenness** centrality of node *i* : the share of shortest paths in the network on which node *i* lies *(ie. amount of flows through that state to other states in the network, thus acting as a bridge)*;
  - The eigenvector centrality : a recursive measure that assigns a high value to nodes which are connected to other important nodes.

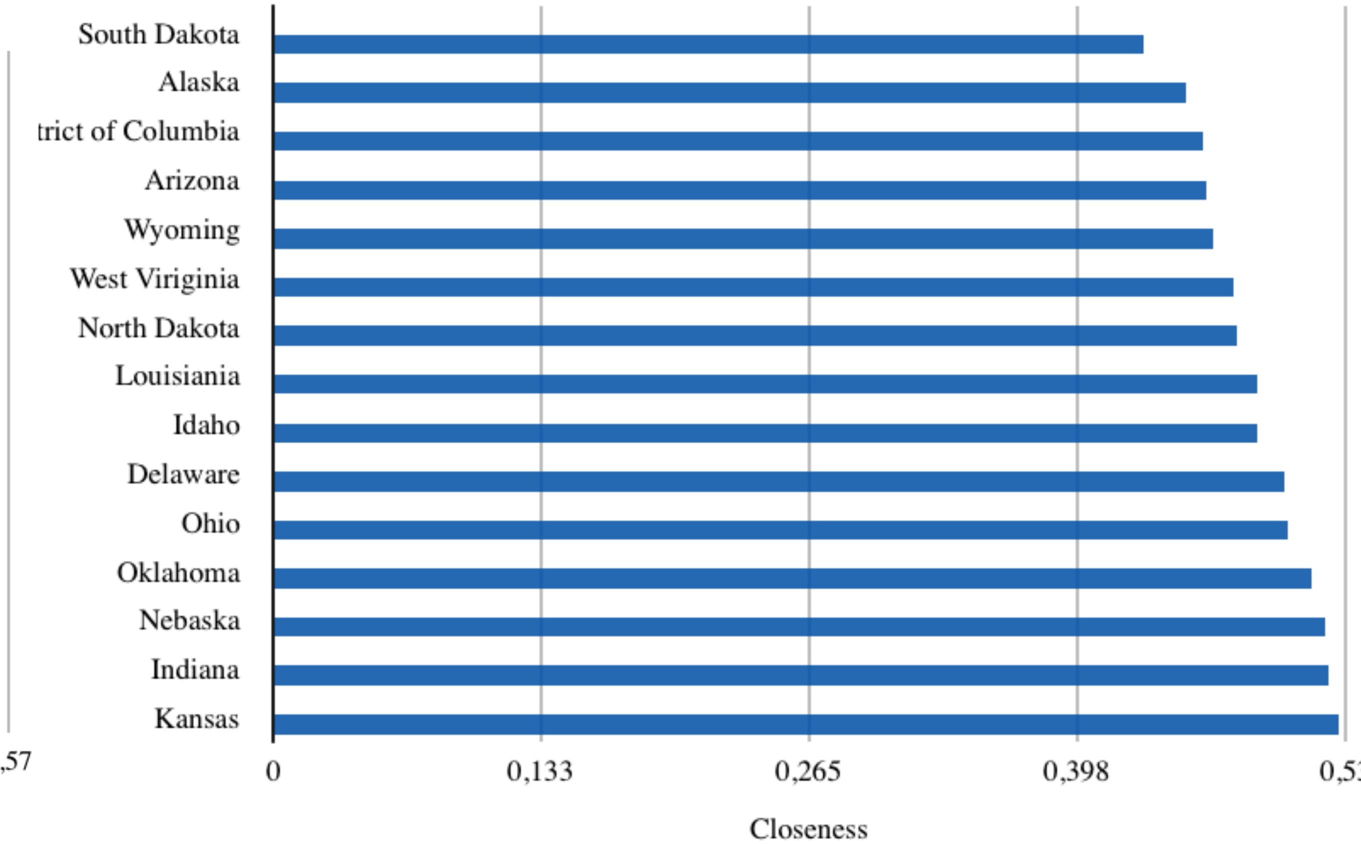
Capturing Leaders / Followers in the Network (2)

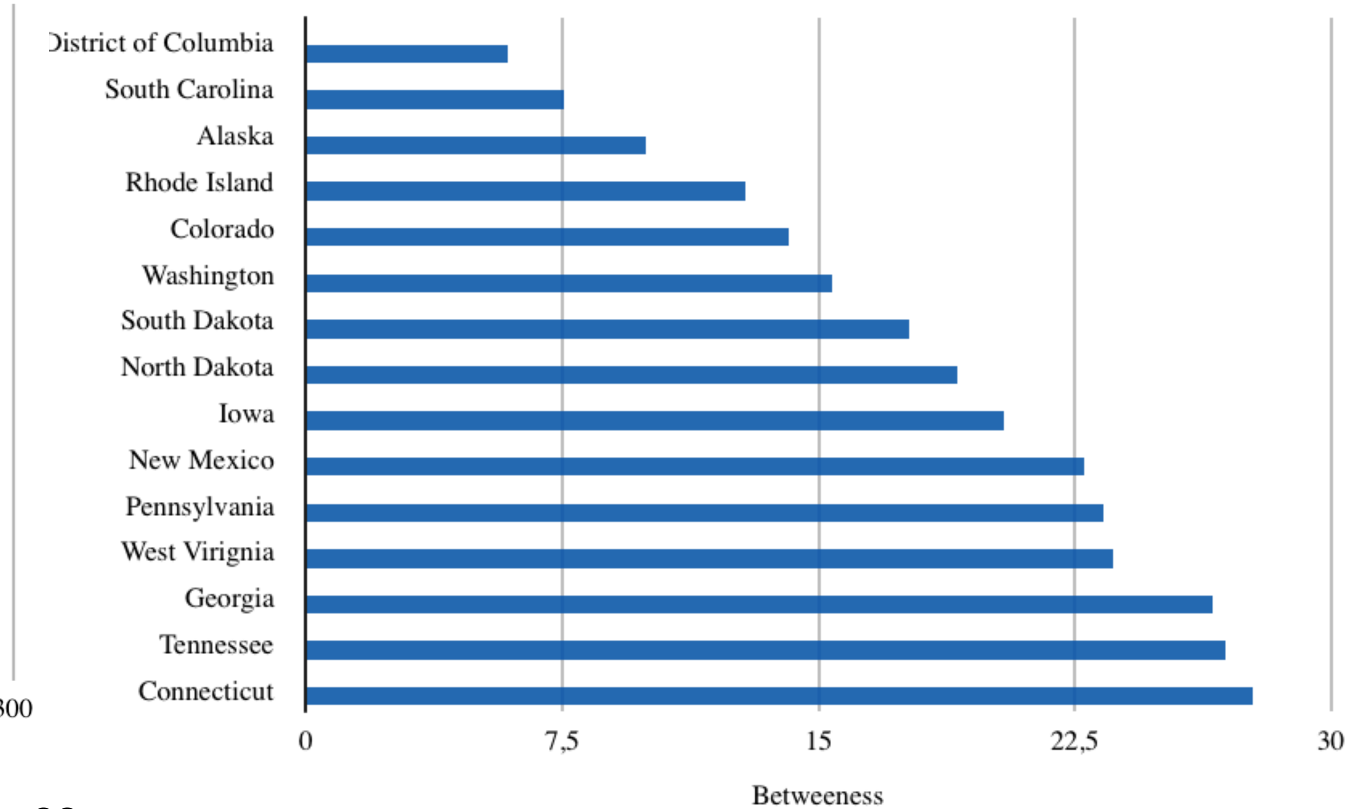
Central States





Less Integrated States





THE DETERMINANTS OF TRANSMISSION

Methodology (1)

- Given observations of a set of cascades $S=(S_v)_{v \in V}$, V different policies, we can estimate the determinants of bilateral diffusion by maximum likelihood - i.e. determine the coefficients for which the likelihood of the observed diffusion patterns is maximal.

  - Panel data about source states $X = (x_{i,t})_{i=1 \cdots N,\ t=1 \cdots T}$, target states $Y = (y_{j,t})_{j=1 \cdots N,\ t=1 \cdots T}$, and relationship characteristics $Z = (z_{(i,j)}, t)_{i=1,\cdots,N,\ j=1 \cdots N,\ t=1 \cdots T}$, one can compute the likelihood of a cascade S_v (see. Halleck Vega et al. (2018)).
  - A natural approach would then be to try to estimate the diffusion probability between country *i* and *j* using a logistic model of the form:

$$a_{i,j} = P_{(\alpha,\beta,\gamma)}(x_i, y_j, z_{i,j}) := \frac{1}{1 + e^{-(\alpha \cdot x_i + \beta \cdot y_j + \gamma \cdot z_{(i,j)})}}$$

Methodology (3)

- The default approach (Halleck Vega et al. 2018): compute the likelihood of a set of cascades using the independent cascade model of Gomez Rodriguez et al. (2010). This yields the following equation for the likelihood of the set of observed cascades $S = (S_v)_{v \in V}$:

$$\mathscr{L}_{\alpha,\beta,\gamma}(S) = \prod_{v \in V} \mathscr{P}^{v}_{(\alpha,\beta,\gamma)}(X, Y, Z)$$

- One can then estimate the determinants of diffusion, *(α, β, γ)*, by maximum likelihood.

Panel Data

- Enrich our dataset with characteristics that can be associated to a state as a source (of the type x_i), as a target (of the type y_j), the relationship between pairs of states (of the type $z_{i,j}$).
  - Economic and Political characteristics : GDP per capita, population density, citizen ideology, partisan control of state government (Berry et al.'s, 1998; Klarner, 2003; Desmarais et al., 2015), **federal government party in charge (eg. Republican/ Democratic);**
  - Contiguity (Bromley-Trujillo et al. 2016);
  - **Environmental variables** : Climate Alliance Membership, Expected economic cost due to global warming (Hsiang et al., 2019), associated amount of CO2 emissions per capita the Genuine Progress Indicator (Fox and Erickson, 2018).

Determinants of Transmission Likelihood

Table on Next Slide

Conclusions and Takeaways (2)

- An epidemic-like model to estimate the network of environmental policies Transmission likelihood across American states + evaluate determinants from adoption data.
  - By doing so, we enhance the understanding of environmental policies diffusion and give policy makers insights to maximize the diffusion of green policies.

- Inefficient Network organization with key states and vice versa (Minnesota, California, Florida vs. South Dakota, South Carolina, Alaska). **Policy —> Targeting leaders to maximize diffusion;**

- **NorthEastern States display highly concentrated diffusion (Regional vs Community approach); Suggests different areas + dynamics of diffusion.**

Conclusions and Takeaways (2))

- **Contiguity**, **GPI :** key determinants of transmission + **Federal gov. color** vs. eg. expected climate change economic losses. **Policy —> Target shared characteristics.**

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Policies collected

Adaptation to climate change: Climate Adaptation Plan, Fire prevention policies, General Hazard Plan, Water Plan, Droughts Plan, Droughts Laws (NCLS), Flood Programs, Adaptation plan, Harvesting Water Program;

Renewables support: Wind Energy Support, Interconnection Standards, Electricity Portfolio Standards, Standards for Electricity Power plants, Solar rebate, Water rebate program (solar heating), Energy Efficiency Loan, Solar/Wind access Policy, Public Funds for RES, Performance Based Incentives, Training Program, Sales Tax Incentives, Loan Program, Personal Tax Credit, Property Tax Exemptions, Pace Program, Grant Program, Green Purchasing Power, Hydrogen, Biogas, Solar/Wind Permitting Standards, Mandatory Net Metering, Renewables Portfolio Standard, Corporate Tax Credit);

Circular economy: Water Efficiency, Composting, Beverage Program Nuclear Waste, Stewardship Recycling, Plastic Bag Recycling Policies, Electronic Recycling Program);

Climate Policies: Carbon pricing, GHGs Regulation, Carbon Capture and Storage, GHGs Emissions Targets, US Climate Action Plan);

Energy Efficiency: Smart Meter Policies, Energy Audits Refrigerator/Cooling, Air Conditioner Policies, Energy Efficiency - Analysis/services, Rebate Program, Energy Efficiency standards and targets, Building Energy Code, Energy Standards for Public Buildings;

Environmental Concerns: GMO Laws, Wildlife Conservation, Bees Keeping Policies, Land conservation, Fracking/Shale gas restrictions, Pollinator Laws, Farmers Markets, Drinking Water Conservation, Forests Management, Environmental Cleanup, Pesticides, Indoor Air Quality;

Transportation (eg. Biofuel Policies, LEV Californian standards, Motor Fuel gas Tax Increase (2013 and so forth), Hydrogen Vehicle, Natural Gas Vehicle, Electric Vehicle Policies, Alternative Fuel Policies, Plug in electric vehicle Policies.

Regions

Description of U.S. Census Bureau - Regions

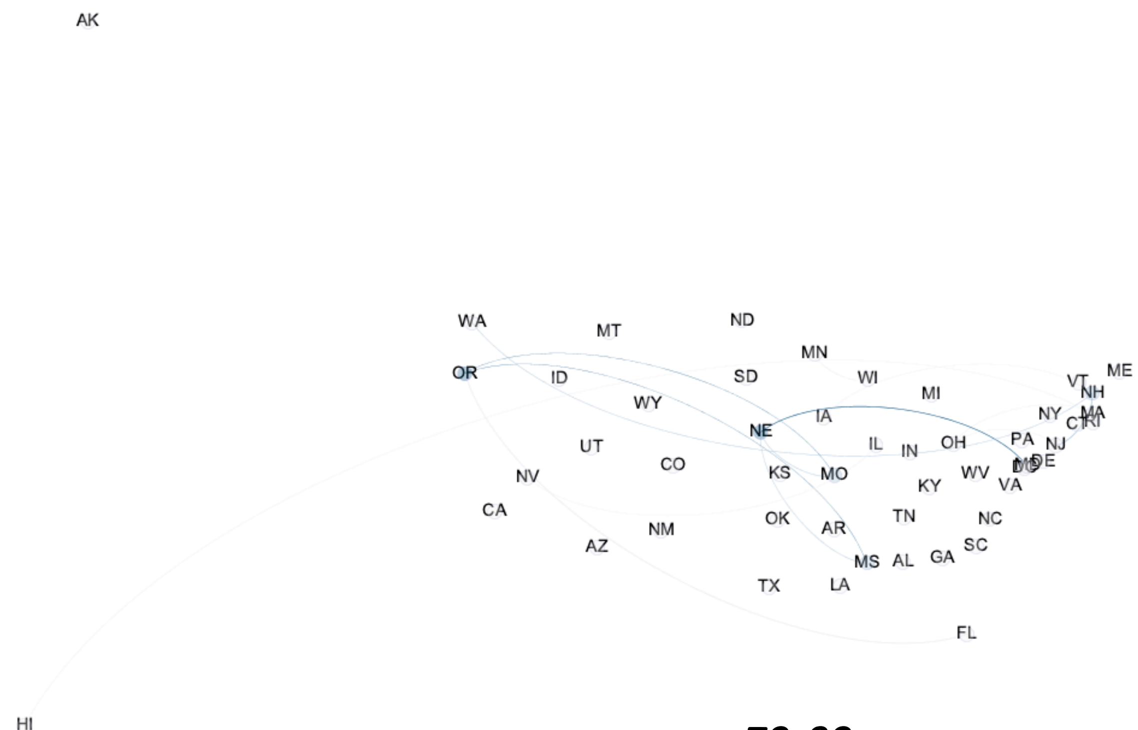
Northeast	**Midwest**	**South**	**West**
Connecticut	Indiana	Delaware	Arizona
Maine	Illinois	District of Columbia	Colorado
Massachusetts	Michigan	Florida	Idaho
New Hampshire	Ohio	Georgia	New Mexico
Rhode-Island	Wisconsin	Maryland	Montana
Vermont	Iowa	North Carolina	Utah
New Jersey	Kansas	South Carolina	Nevada
New York	Minnesota	Virginia	Wyoming
Pennsylvania	Missouri	West Virginia	Alaska
	North Dakota	Alabama	California
	South Dakota	Kentucky	Hawaii
	Nebraska	Mississippi	Oregon
		Tennessee	Washington
		Arkansas	
		Louisiana	
		Oklahoma	
		Texas	

Network formation overtime

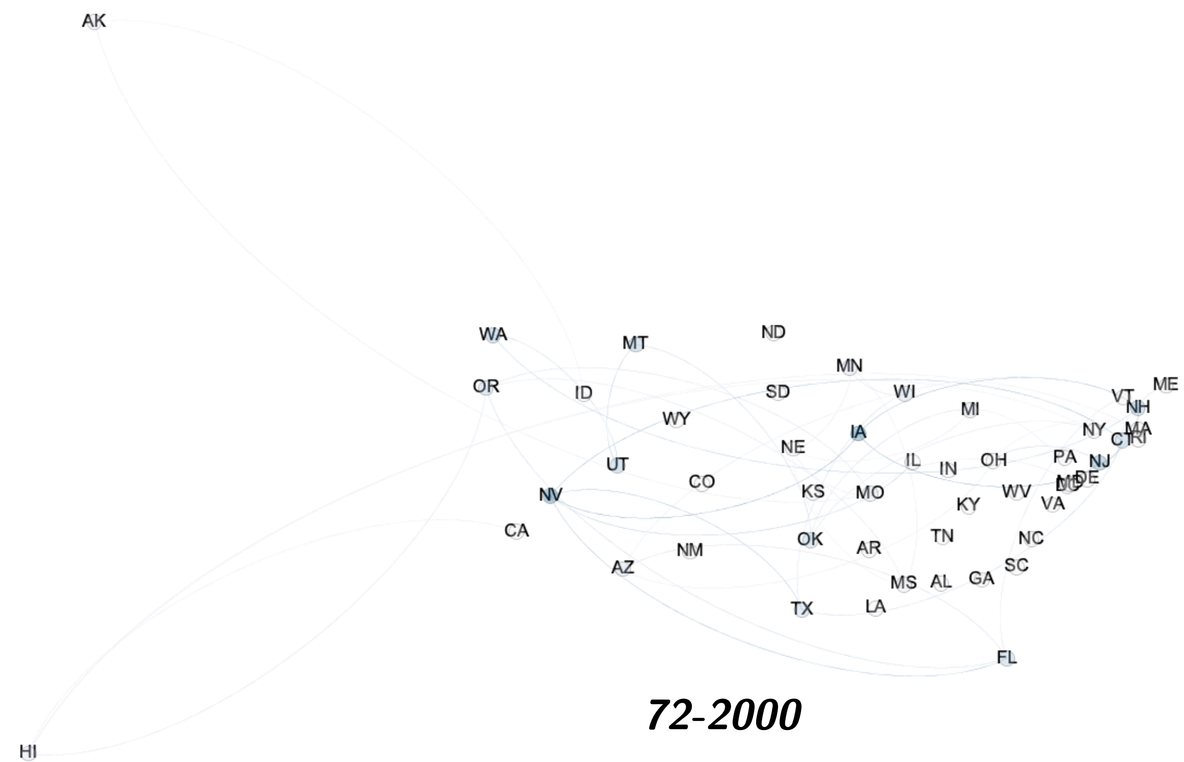
Communities description

1 - Blue	2 - Red	3 - Yellow	4 - Green
Wyoming	Alabama	Arizona	Arkansas
Alaska	Connecticut	Florida	California
Colorado	District of Columbia	Indiana	Idaho
Georgia	Delaware	Iowa	South Dakota
Illinois	Massachusetts	Idaho	
Kansas	Maryland	Minnesota	
Kentucky	Maine	North Carolina	
Louisiana	Missouri	Oregon	
Michigan	Montana	Pennsylvania	
Mississippi	Nebraska	South Carolina	
North Dakota	New Hampshire	Utah	
Nevada	New Jersey		
Ohio	New York		
Oklahoma	Rhodes Island		
Texas	Tennessee		
Virginia	Vermont		
Washington	West Virginia		
Wisconsin			
New Mexico			

Network formation overtime



72-92



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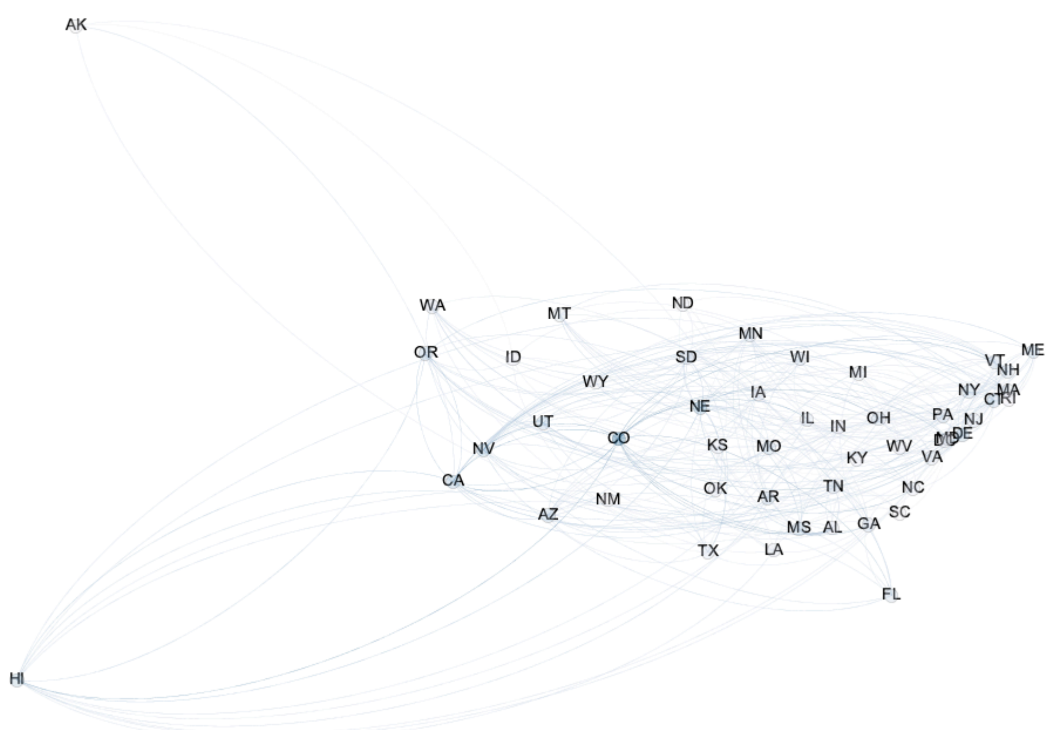

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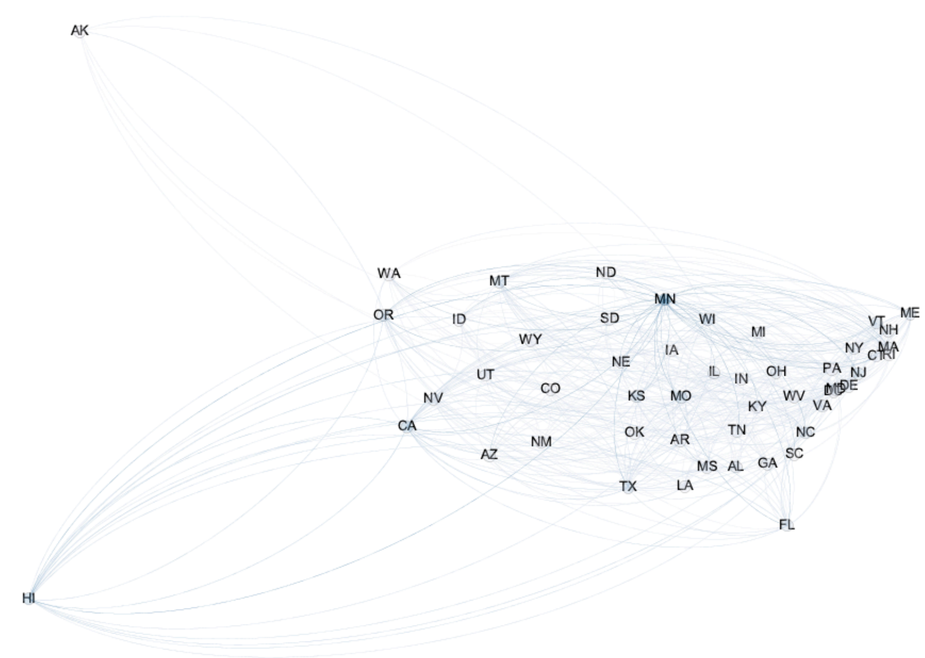
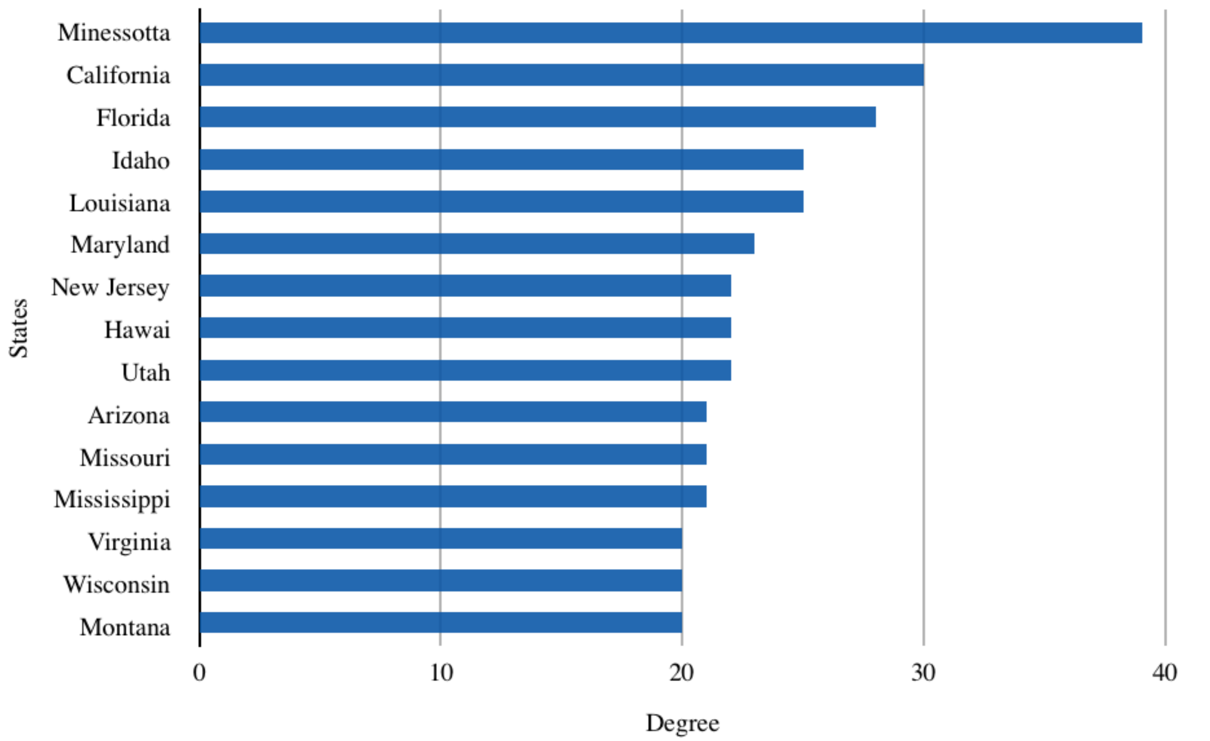
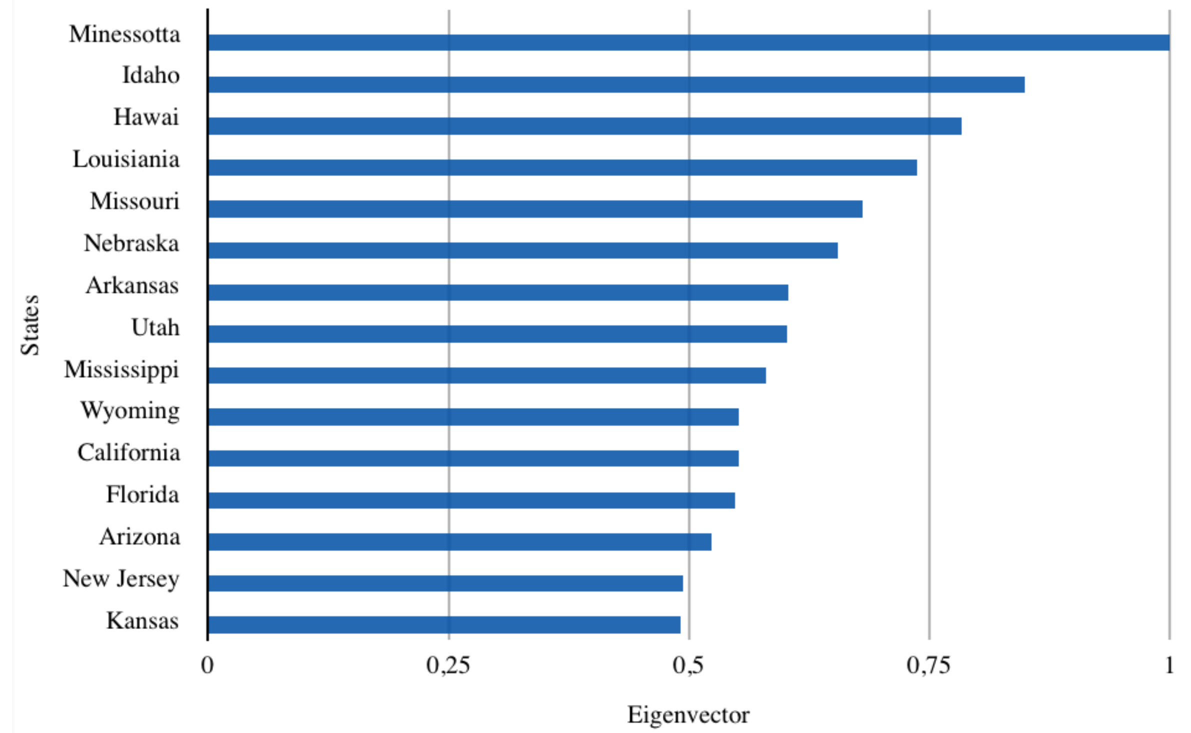
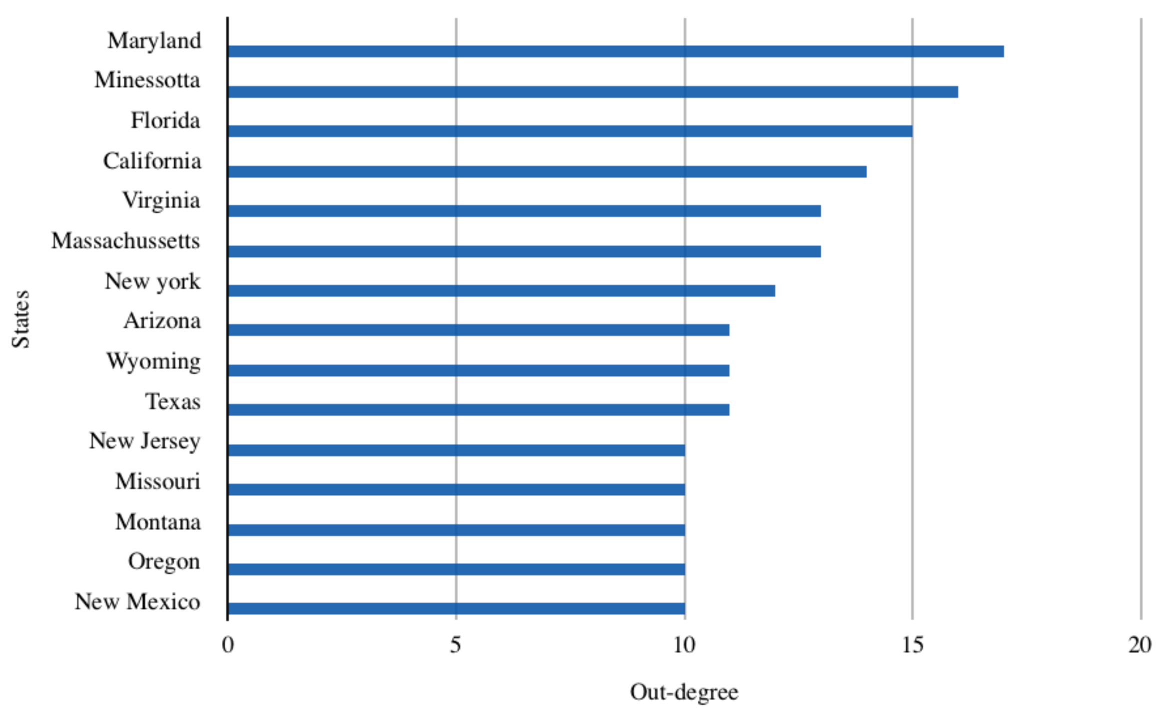


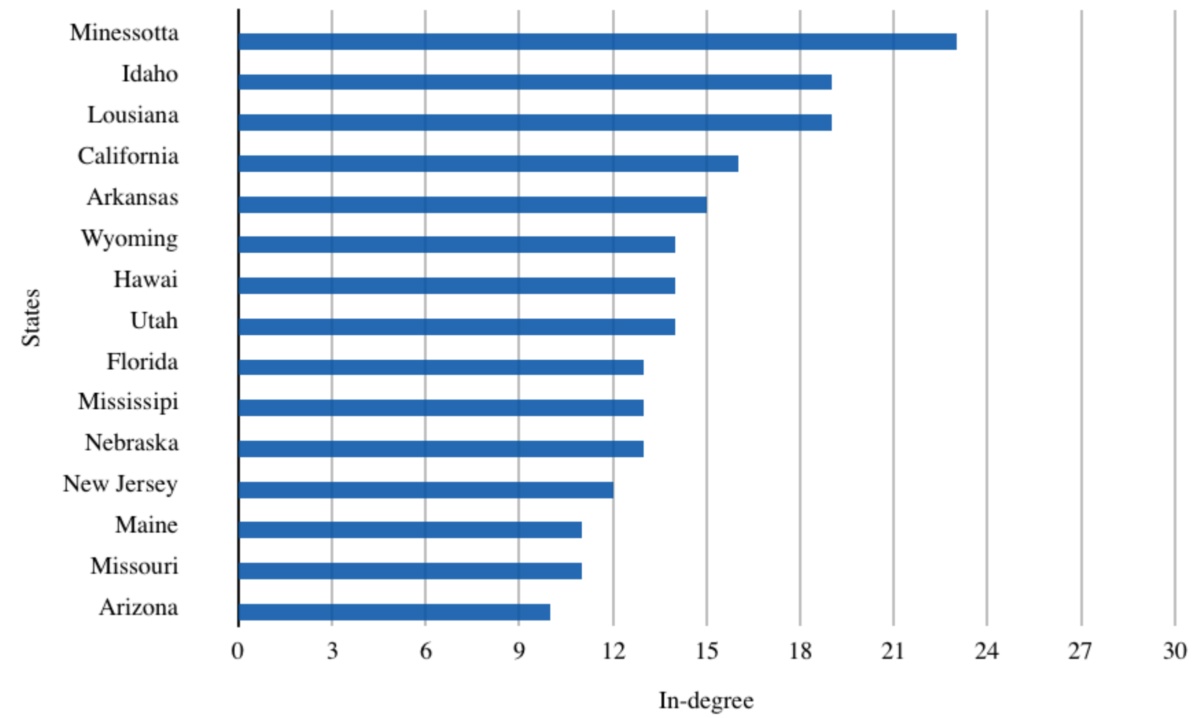
72-2016

Backup - Leaders Centrality Measures

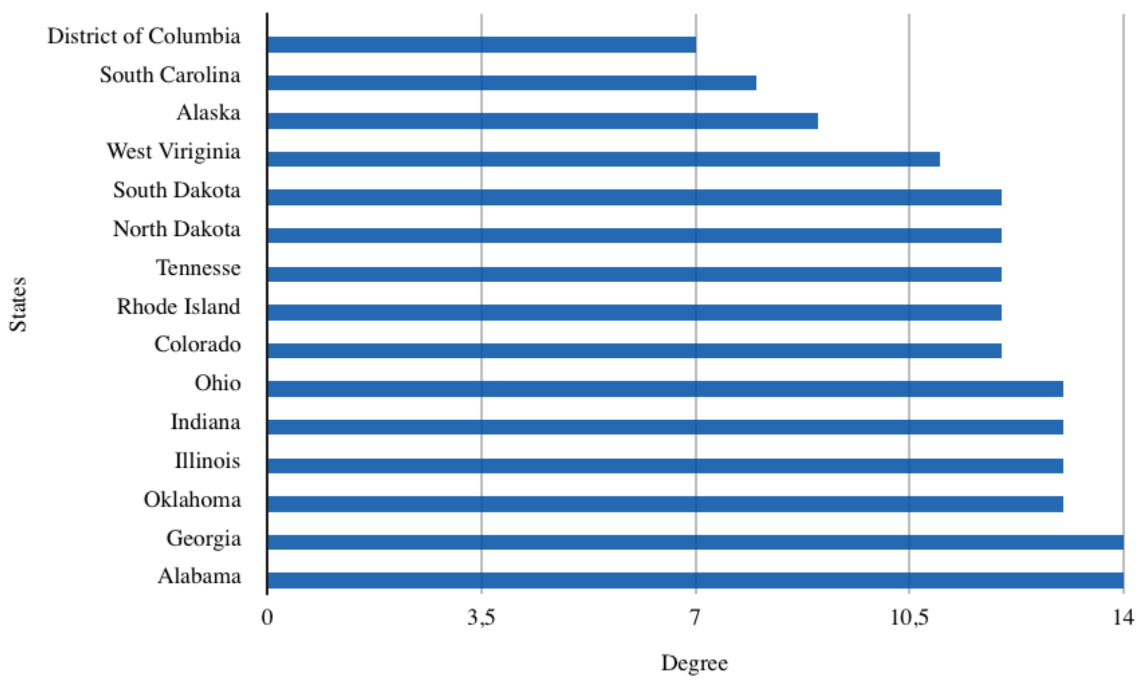


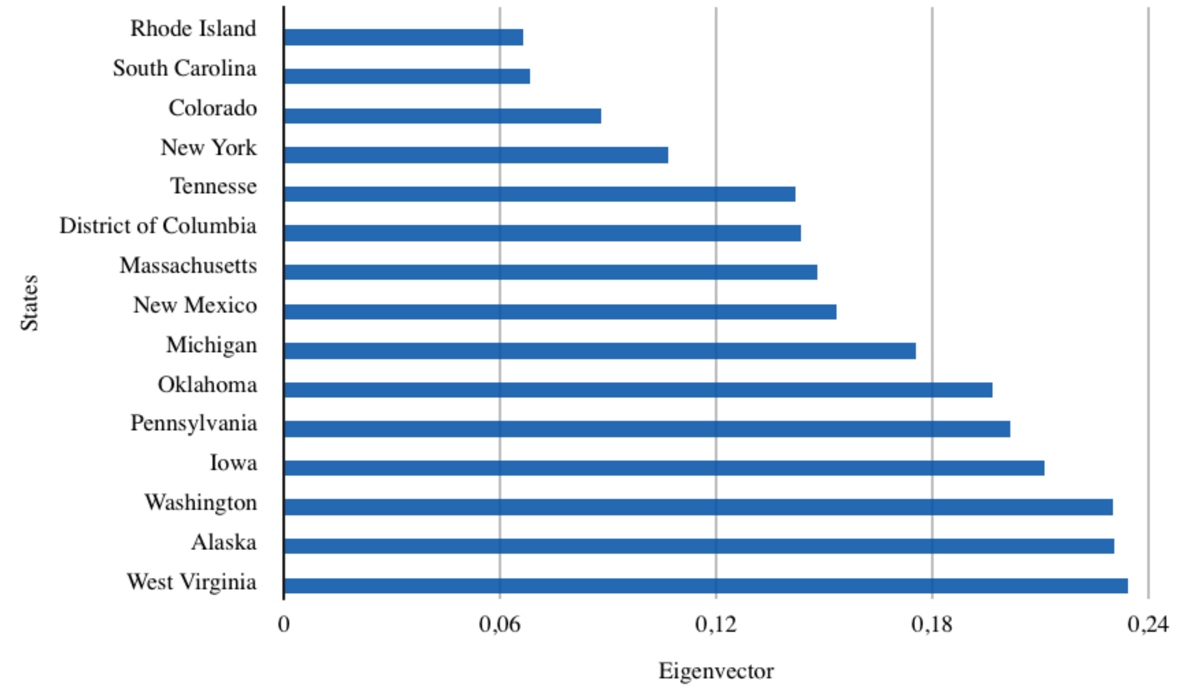


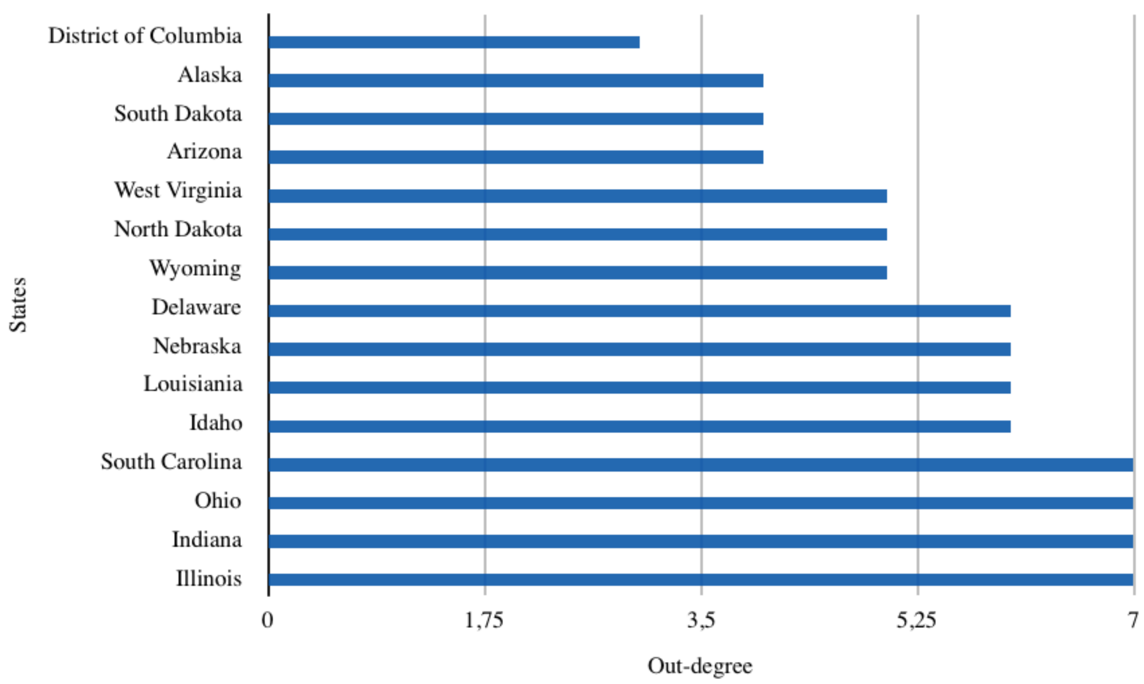


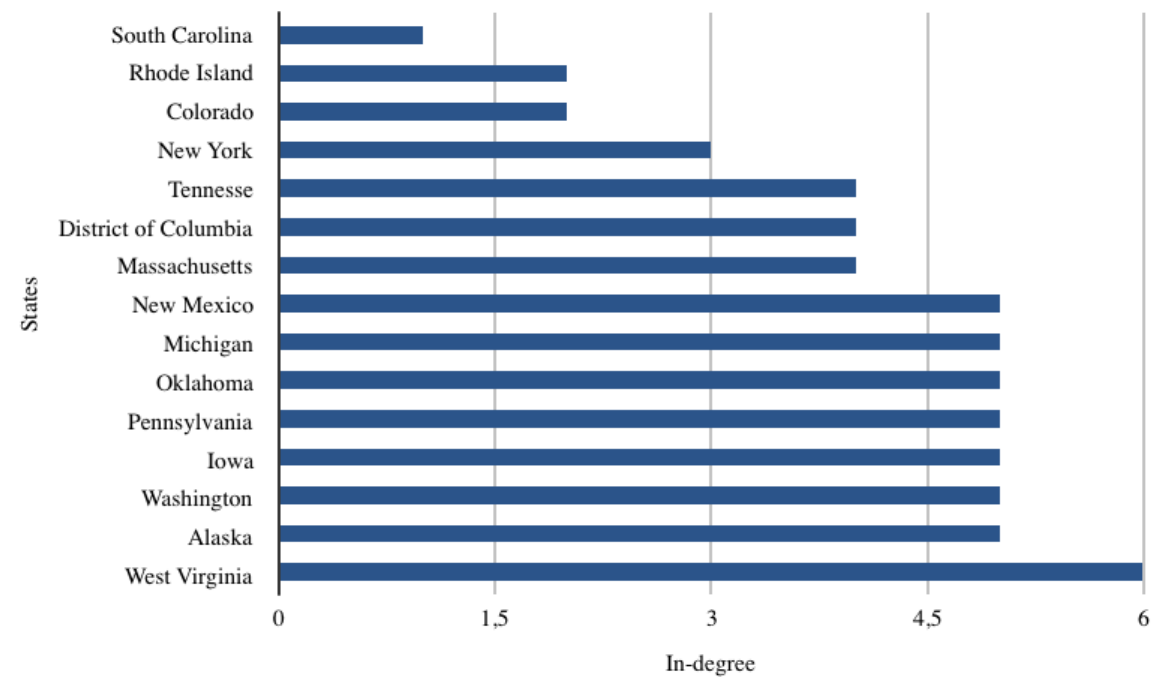


Backup - Followers Centrality Measures



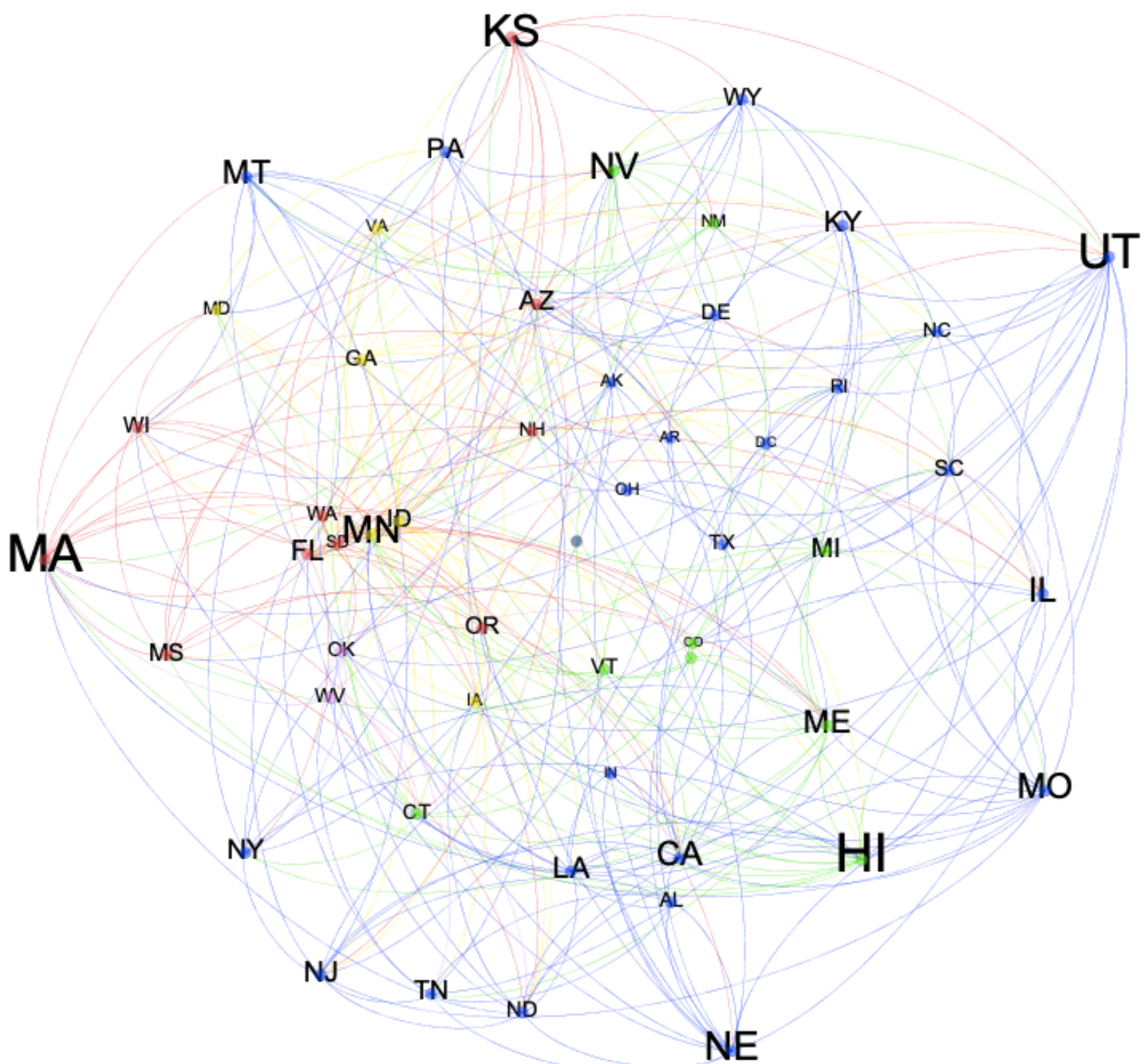




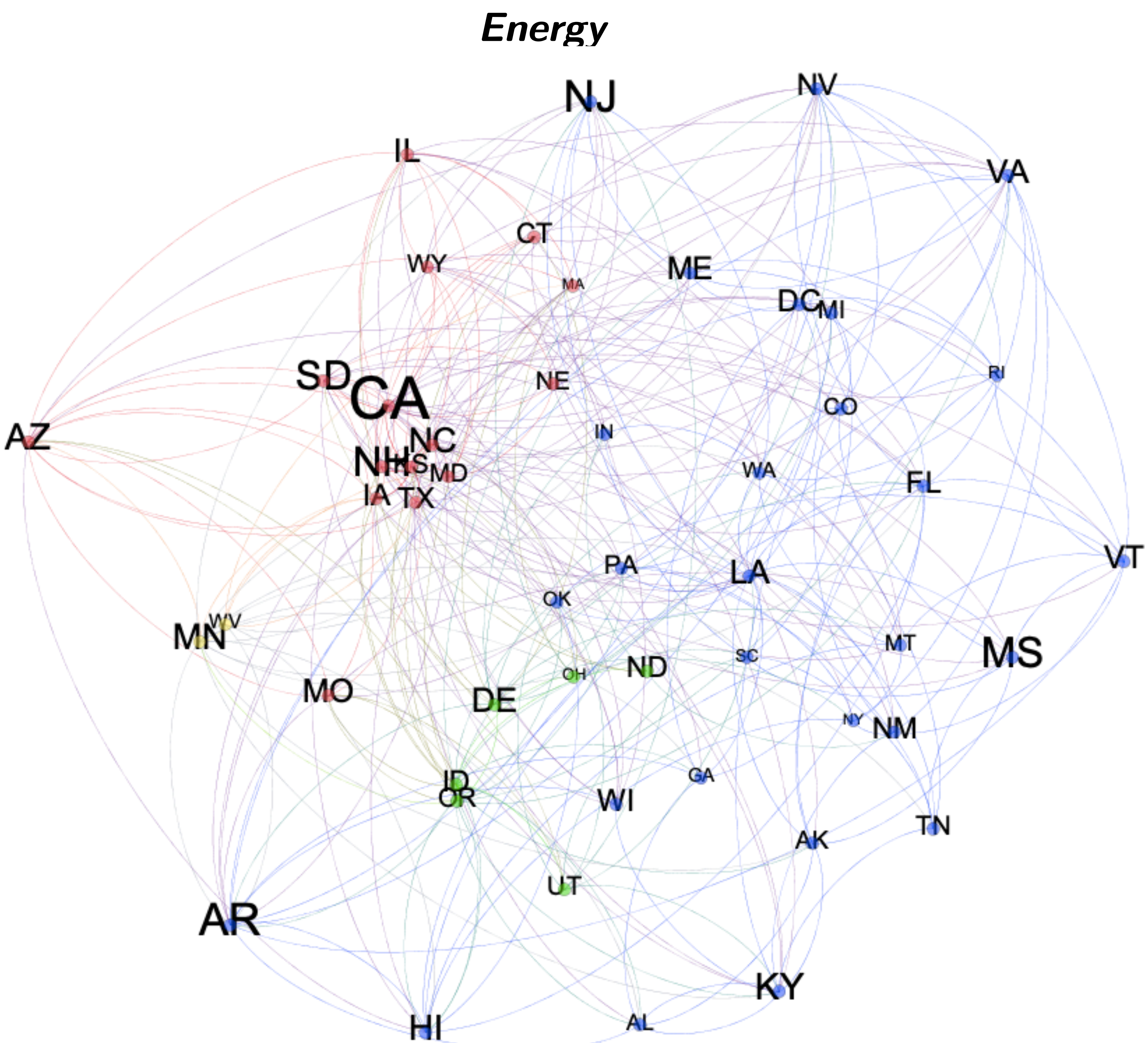


Splitting Networks

Climate and Environmental concerns



Splitting Networks



Econometrics Developments

Methodology (1)

- Given observations of a set of cascades $S=(S_v)_{v \in V}$,V different policies, we can estimate the determinants of bilateral diffusion by maximum likelihood - i.e. determine the coefficients for which the likelihood of the observed diffusion patterns is maximal.
  - Panel data about source countries $X = (x_{i,t})_{i=1 \cdots N,\ t=1 \cdots T}$, target countries $Y = (y_{j,t})_{j=1 \cdots N,\ t=1 \cdots T}$, and relationship characteristics $Z = (z_{(i,j)}, t)_{i=1,\cdots,N,\ j=1 \cdots N,\ t=1 \cdots T}$, one can compute the likelihood of a cascade S_v (see. Halleck Vega et al. (2018)).
  - Given the adoption status in period t, the probability for a non-adopting state *j* to remain non-adopting in period t+1 is :

$$\prod_{\{i|S_v(i,t)=1\}} (1 - P_{(\alpha,\beta,\gamma)}(x_i^t, y_j^t, z_{i,j}^t))$$

  - while the probability that it adopts is :

$$1 - \prod_{\{i|S_v(i,t)=1\}} (1 - P_{(\alpha,\beta,\gamma)}(x_i^t, y_j^t, z_{i,j}^t))$$

Methodology (2)

- Thus the probability of the transition from the adoption vector $S_v(\cdot,t)$ to the adoption vector $S_v(\cdot,t+1)$ is given by:

$$\prod_{\{j|S_v(j,t+1)=0\}} \prod_{\{i|S_v(i,t)=1\}} (1 - P_{(\alpha,\beta,\gamma)}(x_i^t, y_j^t, z_{i,j}^t))$$
$$\times \prod_{\{j|S_v(j,t+1)=1\}} (1 - \prod_{\{i|S_v(i,t)=1\}} (1 - P_{(\alpha,\beta,\gamma)}(x_i^t, y_j^t, z_{i,j}^t)))$$

- Therefrom, using the assumption that the diffusion process is Markovian, one deduces the likelihood of cascade S_v as:

$$\mathscr{P}^v_{(\alpha,\beta,\gamma)}(X, Y, Z) = \prod_{t=0}^{T-1} \prod_{\{j|S_v(j,t+1)=0\}} \prod_{\{i|S_v(i,t)=1\}} (1 - P_{(\alpha,\beta,\gamma)}(x_i^t, y_j^t, z_{i,j}^t))$$
$$\times \prod_{t=0}^{T-1} \prod_{\{j|S_v(j,t+1)=1\}} (1 - \prod_{\{i|S_v(i,t)=1\}} (1 - P_{(\alpha,\beta,\gamma)}(x_i^t, y_j^t, z_{i,j}^t)))$$

Chapter 3

Context (1) - Green Deal / Imported Emissions

Photograph: François Lenoir/Reuters

- Green Deal for Europe (2019):
  - 2030 : jump from 40 % to 50% GHGs emission reduction objective; Net Zero by 2050.

Euractiv', Sept. 2020.

- Efficient plan if emissions are not outsourced ! (i.e. carbon leakage)
  - Resurgent ambition : tackling the issue of imported emissions.

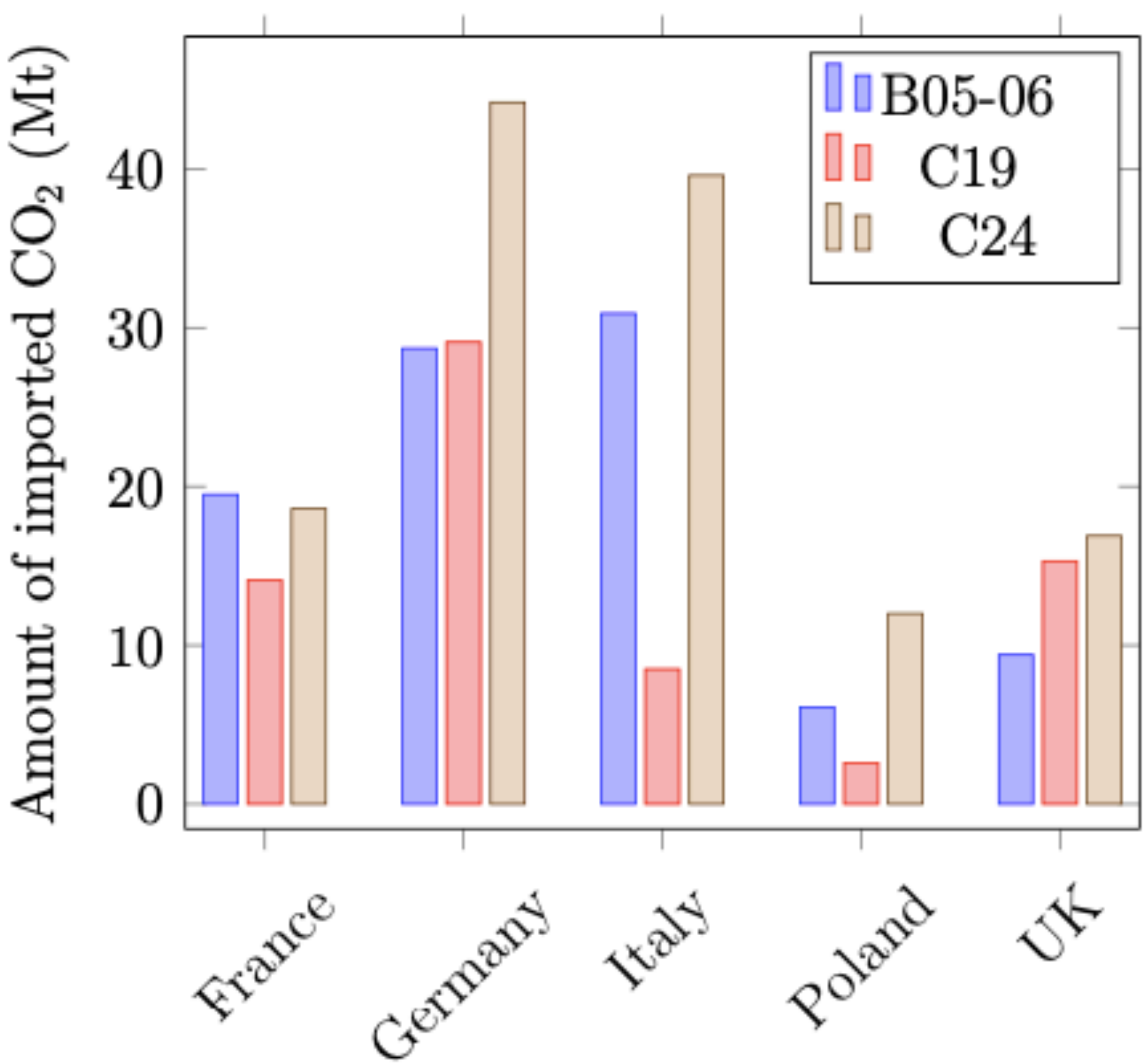
Context (2) - Gap in Emissions

- **Disconnection between territorial and consumption based emissions in the E.U.**

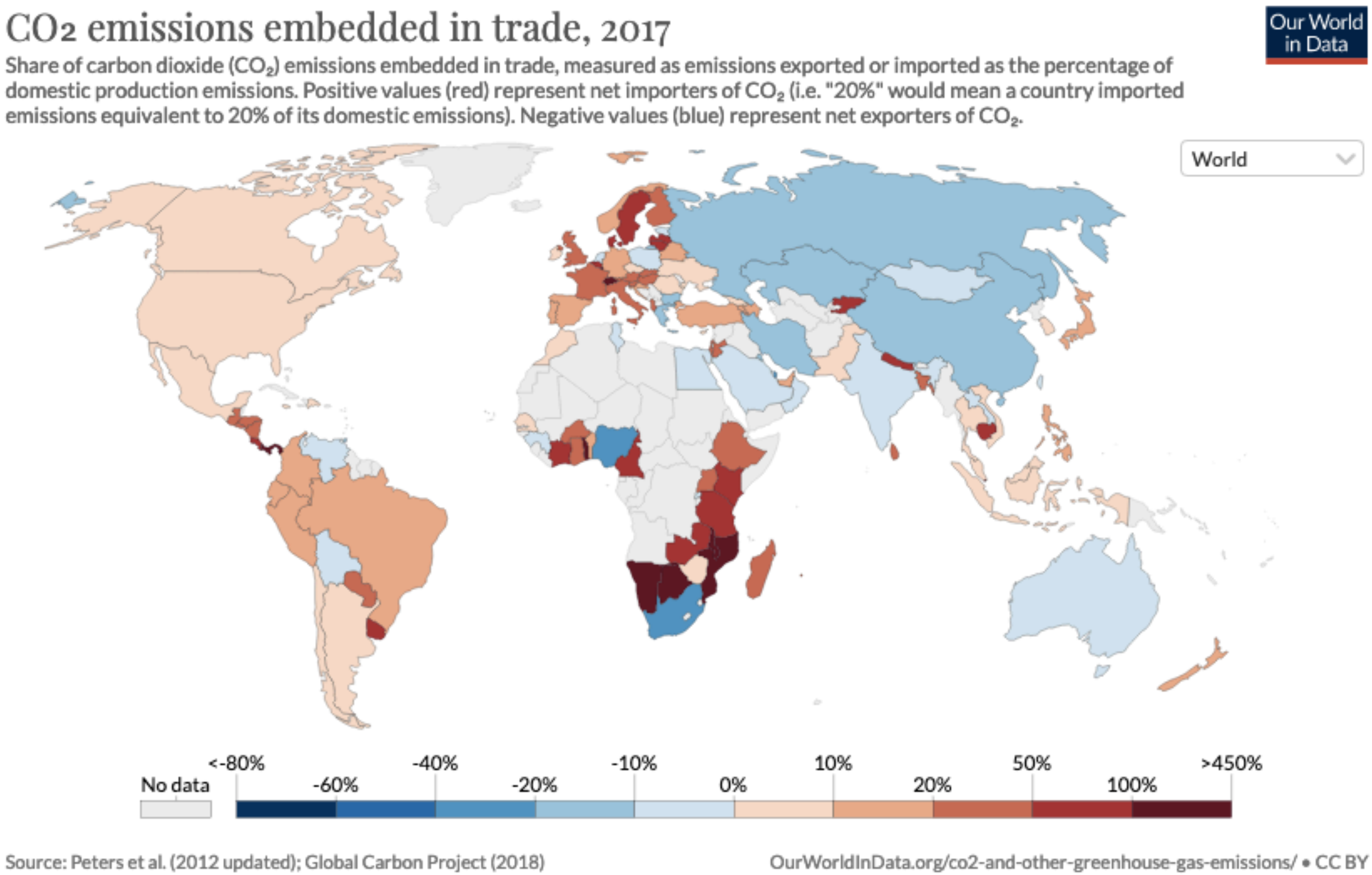
  - 2014, United Kingdom (Office of National Statistics, 2019) :
    - Territorial emissions = 402 Mt of CO_2
    - Consumption emissions = 656 Mt of CO_2
  - 2018, France (Haut Conseil pour le Climat, 2020) :
    - Territorial emissions = 445 Mt of CO_2
    - Consumption emissions = 749 Mt of CO_2

Context (3) EU Focus - Distribution of industrial imported emissions

*Year 2015 : Distribution of imported CO_2 emissions across top industrial sectors : **mining (B05-06)**, **coke/refined petroleum products (C19)** and b**asic metals (C24)**, OECD.*



Context (4) - Least Developed Countries/Developed Countries



Imported Emissions : Int. Trade, Legislative issues and Economic mechanisms (1)

- Main strands of literature - Key insights :
  - **Amount of emissions embedded in international trade** (*Peters et al., 2011; Kanemoto al., 2014; Kim et al., 2019; Simola, 2020*)
    - Russia and China are huge exporters of CO2 emissions : massive exports of energy and carbon intensive final demand goods (*Yang, 2012; Boitier, 2012*);
  - **Legislative design of economic instruments** (*Tamioti, 2011; Holzer, 2014; Mehling et al., 2019*)

Imported Emissions : Int. Trade, Legislative issues and Economic mechanisms (2)

- **Non-discrimination principle in WTO law** (equal treatment of trading partner (Art. I GATT) **but** **Exemptions possible under specific circumstances** (e.g. Art XX (b) GATT : *measures « necessary » to protect human, animal and plant life or health*);

  - BCAs should avoid differentiating between trade partners based on country-specific characteristics (such as policies) & account for their climate efforts;
  - BCAs should demonstrate a sufficient environmental nexus;
  - BCAs to exempt exports & BCAs coupled with free allocation are legally riskier.

Imported Emissions : Int. Trade, Legislative issues and Economic mechanisms (3)

- Economic instruments/impacts (*Monjon and Quirion, 2011; Droge et al., 2019*)
    - BCA mechanisms reduce carbon leakage (*Böhringer et al., 2012; Fischer and Fox, 2012*);
    - Import-BCA = dynamic incentives for stronger carbon pricing in other regions (to capture the additional tax revenue) (*Helm, Hepburn and Ruta, 2012*);
    - *Zachmann and McWilliams* (*2020*) : EU analysis - Unclear effects on carbon leakage + potential negative impacts (trading partners).

Imported Emissions : Int. Trade, Legislative issues and Economic mechanisms (3)

- Energy intensive sectors (e.g. cement and steel) and carbon pricing : **Limited impacts on both competitiveness & carbon leakage** (*Martin, Muûls and Wagner, 2016*; *Dechezleprêtre and Sato, 2017*; *Dechezleprêtre et al., 2020*);

- **BCAs difficult to implement (WTO) + effectiveness largely driven by the design of the instrument (e.g. carbon content measurement, tariffs).**

Systemic perspective : How could we capture intensity of demand/supply of imported products ? of Imported Emissions ?

Source : Godin et al. (2019).

Missing answers ?

- What about the ***dynamics of demand and supply of dirty imports*** within an economy ***?***
- And ***the specific role of economic sectors in reducing such patterns ?***

- Objectives/Contributions are :
  - Identify the sector most likely to create imported emission reductions/provide an estimation of potential amounts of emissions that could be reduced (i.e. <u>interactions across sectors</u>);

Missing answers (2) and Data

- Study emission reduction cascades down from top industrial sectors to the rest of the economy;
- Provide an short-term estimate of the impact of a *carbon-related* tax on imported emissions from basic metals sectors;
  - France, Germany, Italy, Poland, United Kingdom;
  - OECD data (2015).

Methodology for
Emission Reduction Coefficients
and ***Cascades of Emissions***

Approach (1) : Input OutputTables

Figure 1. A stylized Input-Output Table (Cahen-Fourot et al., 2019).

Inter-Industry matrix (Z)		**Intermediate uses**		**Final uses (f)**			**Total use (TU)**
		Sector A	Sector B	Cons.	Inv.	Exp.	
Production	Sector A	Products of A used as inputs by A	Products of A used as inputs by B	Final use of products by A			Total use of products of A
	Sector B	Products of B used as inputs by A	Products of B used as inputs by B	Final use of products by B			Total use of products of B
Total		Total intermediate inputs		Total final uses			Total uses
Value added (v)	Comp. of employees	Total value added					
	Cons. of fixed capital						
	Operating surplus						
Output		Total domestic output					
Imports		Total imports					
Total supply (TS)		Total supply					

Approach (1) : From IOTs to Imports

- Measuring use of imports in IOTs is a hard task ! (e.g. granularity of data);
- **Input similarity : Proxy measurement form of imports sub-allocation**
  - Within product categories of input-output tables, mixes of imports and country-made products are the same and therefore have the same destinations (*U.S. National Research Council of the National Academies* (*2006*));
    - If mining imports 90% of its total supply, we assume this amount to be uniformly distributed across downstream sectors.

Approach (2) : Ghosh Model Output

- **$\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z}$,** Matrix of output allocation coefficients;
  - Each element $b_{i,j}$ quantifies the share of industry i's output that is used by industry j.

- **Ghosh Matrix defined as : $\mathbf{G} = (\mathbf{I}\text{-}\mathbf{B})^{-1}$**
  - Each $g_{i,j}$ of G^T: the change in output x in sector i that would result from a unitary change of primary inputs flowing into sector j —> ***Captures short-term effects !***
  - A decrease of one monetary unit of primary inputs contributing to production in sector i will decrease the output of sector j by an amount equals to $g_{i,j}$.

Approach (3) : Emission Reduction Coef.

- **We define $\mathbf{E}_i = e_i/M_i^d$ as the imported emission intensity of sector i, where M^d represents the domestic output of the sector.**
  - Multiplying the diagonalised form of the vector of emission intensities by the Ghosh matrix, we find the matrix **S** of *emission reduction coefficients* : $\mathbf{S} = \hat{\mathbf{E}}\mathbf{G}^T$
- **Now, elements $s_{i,j}$ of matrix S : the change in imported emissions in sector i generated by a unitary change of primary inputs ($M) used by sector j.**

Approach (4) : From Emission Reduction Coef. to Networks of Emission Cascades

- We can treat the S matrix as an adjacency matrix to a directed **network :**
  - We select top activities (those exhibiting largest total $s_{i,\ j}$) to be the origin of the cascading contraction of emissions;
  - We identify sectors affected by top q percentile of outward edges and place them on the first layer;
  - We repeat the procedure to the sectors in the first/ second/... and so on **to capture the diffusion of emission contraction within the whole industrial system**.

Approach (3) : Productive sectors

Table 3. Breakdown of examined NACE Sectors.

Sector	**Code**	**Sector description**
A	1	Agriculture, forestry and fishing
B05-06	2	Mining and extraction of energy producing products
B07-08	3	Mining and quarrying of non-energy producing products
B09	4	Mining support service activities
C10-12	5	Food products, beverages and tobacco
C13-15	6	Textiles, wearing apparel, leather and related products
C16	7	Wood and of products of wood and cork (except furniture)
C17-18	8	Paper products and printing
C19	9	Coke and refined petroleum products
C20-21	10	Chemicals and pharmaceutical products
C22	11	Rubber and plastics products
C23	12	Other non-metallic mineral products
C24	13	Manufacture of basic metals
C25	14	Fabricated metal products, except machinery and equipment
C26	15	Computer, electronic and optical products
C27	16	Electrical equipment
C28	17	Machinery and equipment n.e.c.
C29	18	Motor vehicles, trailers and semi-trailers
C30	19	Other transport equipment
C31-33	20	Other manufacturing, repair and installation of machinery and equipment
D-E	21	Electricity, gas, water supply, sewerage, waste and remediation services
F	22	Construction

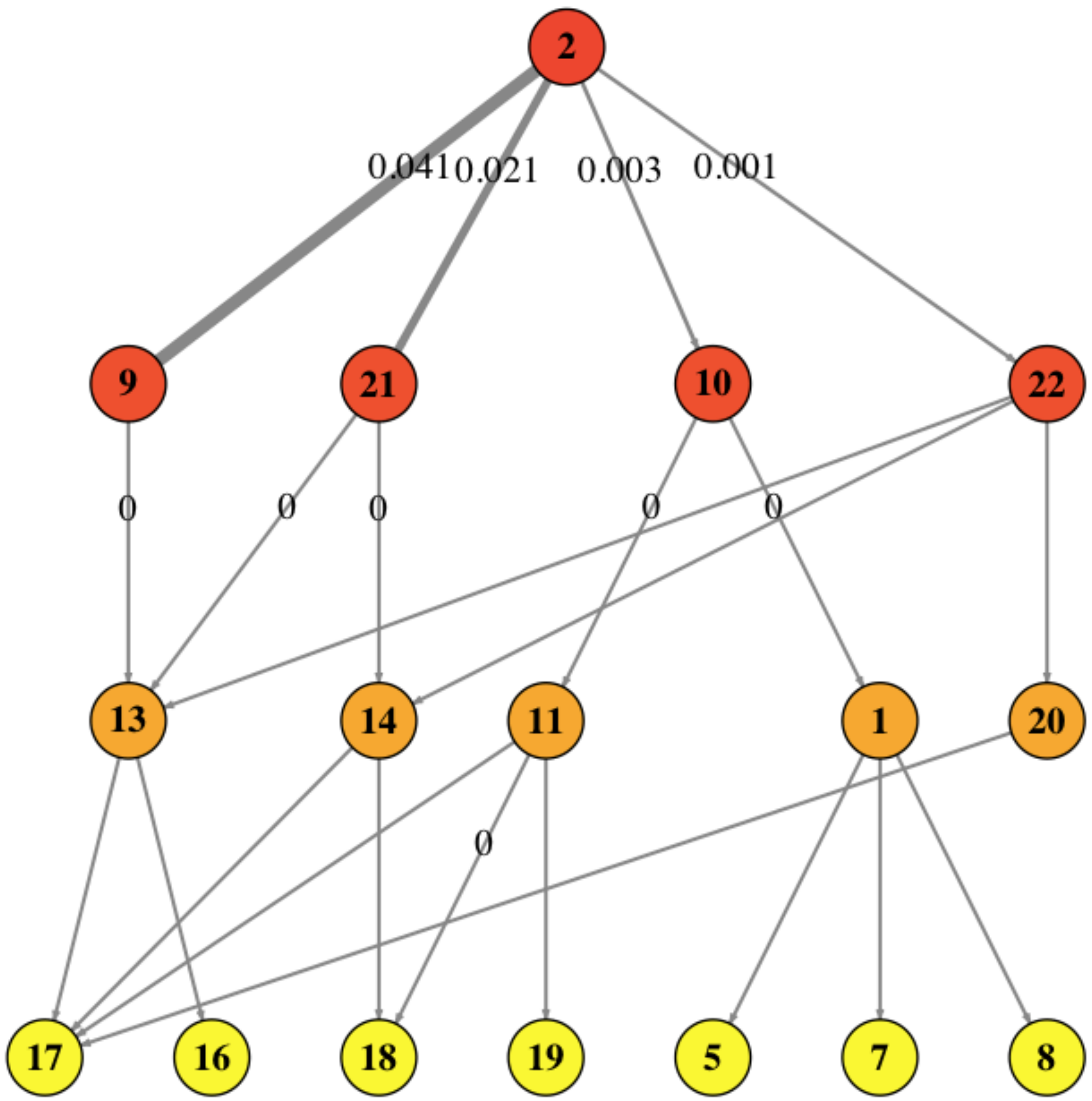
Emission Reduction Coefficients

Emission Reduction Coefficients

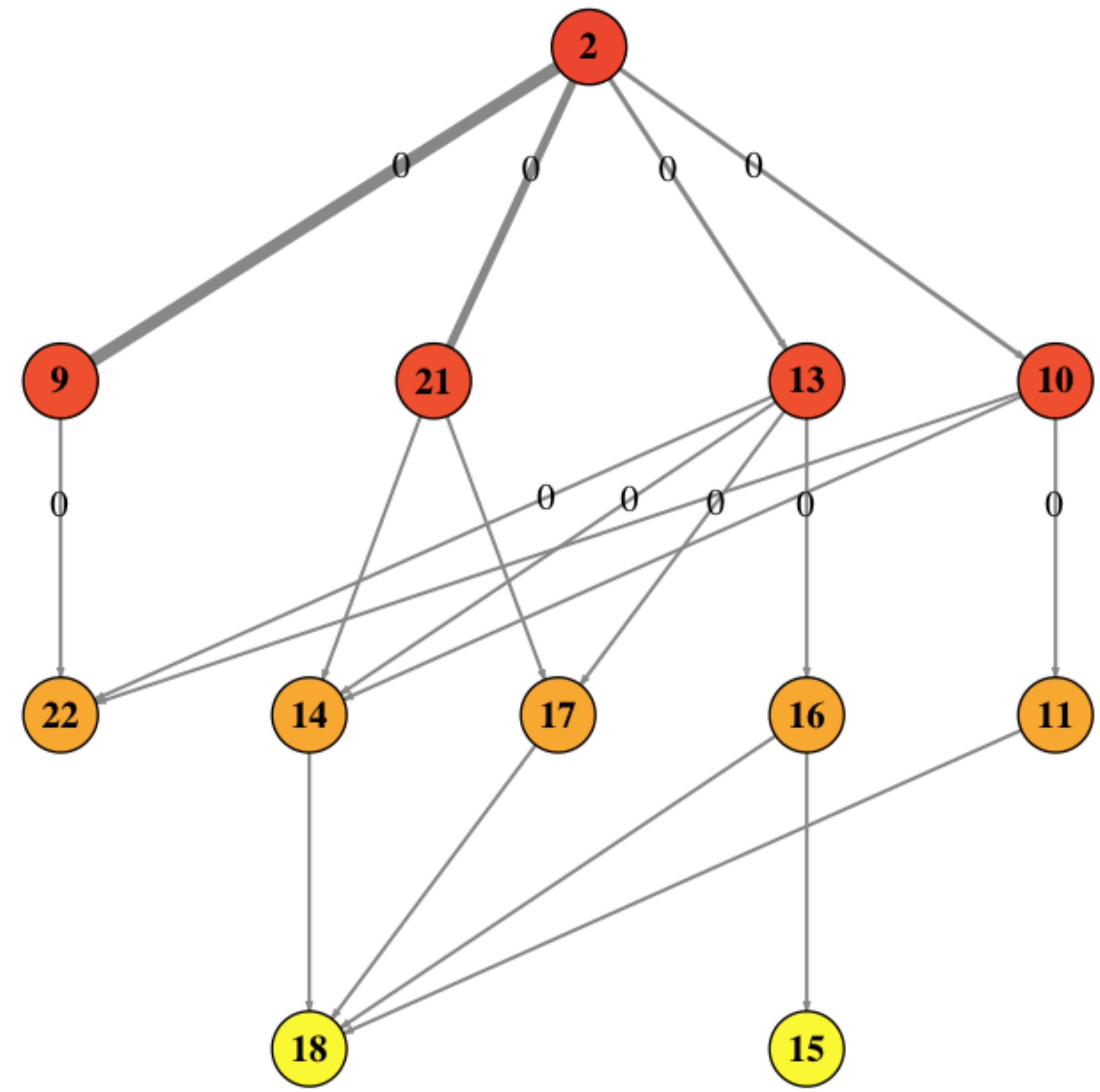
France	Germany	Italy	Poland	U.K.
External Emission Reduction Multipliers (2)				
Mining A (0.0689)	Mining A (0.0089)	Mining B (0.0081)	Mining A (0.0012)	Mining A (0.0004)
Mining C (0.0034)	Mining B (0.0018)	Mining A (0.0024)	Basic metals (0.0005)	Mining B (0.0004)
Mining B (0.0002)	Mining C (0.0008)	Mining C (0.0008)	Mining B (0.0004)	Basic metals (0.0003)
Basic metals (0.0001)	Basic metals (0.0001)	Basic metals (0.0002)	Chemicals (0.0003)	Electrical eq. (0.0003)
Electrical eq. (0.0001)	Coke-refined petrol. (0.0001)	Chemicals (0.0001)	Machinery & eq. (0.0003)	Computer-electronics (0.0002)
Exposure to Emission Reduction Multipliers (3)				
Coke & refined petrol. (0.0420)	Coke & refined petrol. (0.0053)	Basic metals (0.0068)	Basic metals (0.0009)	Other manufacturing (0.0004)
Electricity & gas (0.0222)	Basic metals (0.0026)	Coke-refined petrol. (0.0010)	Electricity-gas (0.0006)	Basic metals (0.0004)
Chemicals (0.0027)	Chemicals (0.0011)	Mining A (0.0009)	Electrical eq. (0.0003)	Coke-refined petrol. (0.0003)
Construct. (0.0026)	Electricity & gas (0.0009)	Chemicals (0.0008)	Machinery-eq. (0.0003)	Other transport eq. (0.0002)
Basic metals (0.0011)	Mining A (0.0007)	Other non-met. min. (0.0007)	Coke-refined petrol. (0.0003)	Electrical eq. (0.0002)

- « **Raw** » **results** - a drop in imported emissions within the whole industrial system generated by a unitary decrease of primary inputs ($M) used by sector *j*.

Cascades (e.g. France and Germany)



France



Germany

Propagation : Takeaways (1)

- Different pathways - largest immediate emission reduction :
  - **Coke and Refined Petroleum Products (C19)** (France, Germany, Poland, U.K.);
  - **Chemicals and Pharmaceutical Products (C20-21)** (France, Germany, U.K.);
  - **Basic metals (C24)** - well connected ! (Germany, Italy, Poland);
  - **Electricity and Gas (D-E)** (France, Germany, Poland, U.K.)
- From coke, the reduction cascades often continue affecting :
  - Basic metals, other non metallic mineral products, chemicals and pharmaceutical products

Propagation : Takeaways (2)

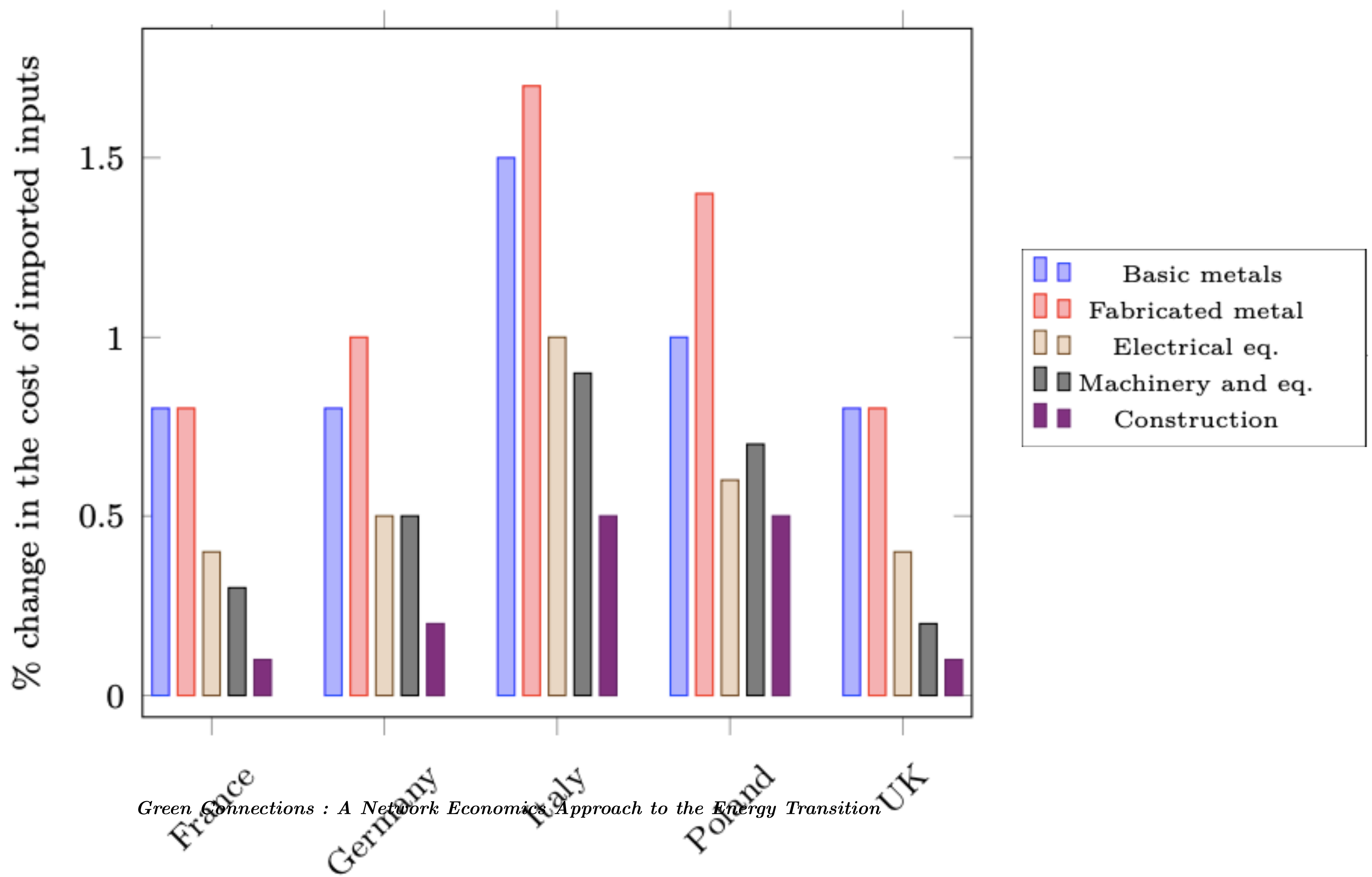
- From chemicals the reduction cascades often continues affecting :
  - Plastics and rubber products, textiles
- From basic metals the reduction cascades often continues affecting :
  - Fabricated metal products, machinery and equipment, electrical equipment, motor vehicles and other transport equipment
- From elec/gas the reduction cascades often continues affecting :
  - Other non-metallic mineral products and chemicals and pharmaceutical products

Taxing Basic Metals Imports

Taxing Basic Metals (1)

- We investigate the potential **short-term impacts of a $25 carbon price** on imported emissions from basic metals across sectors **(a proxy measurement).**

Bar chart 6. % increase cost of sectoral domestic imported inputs, top sectors.



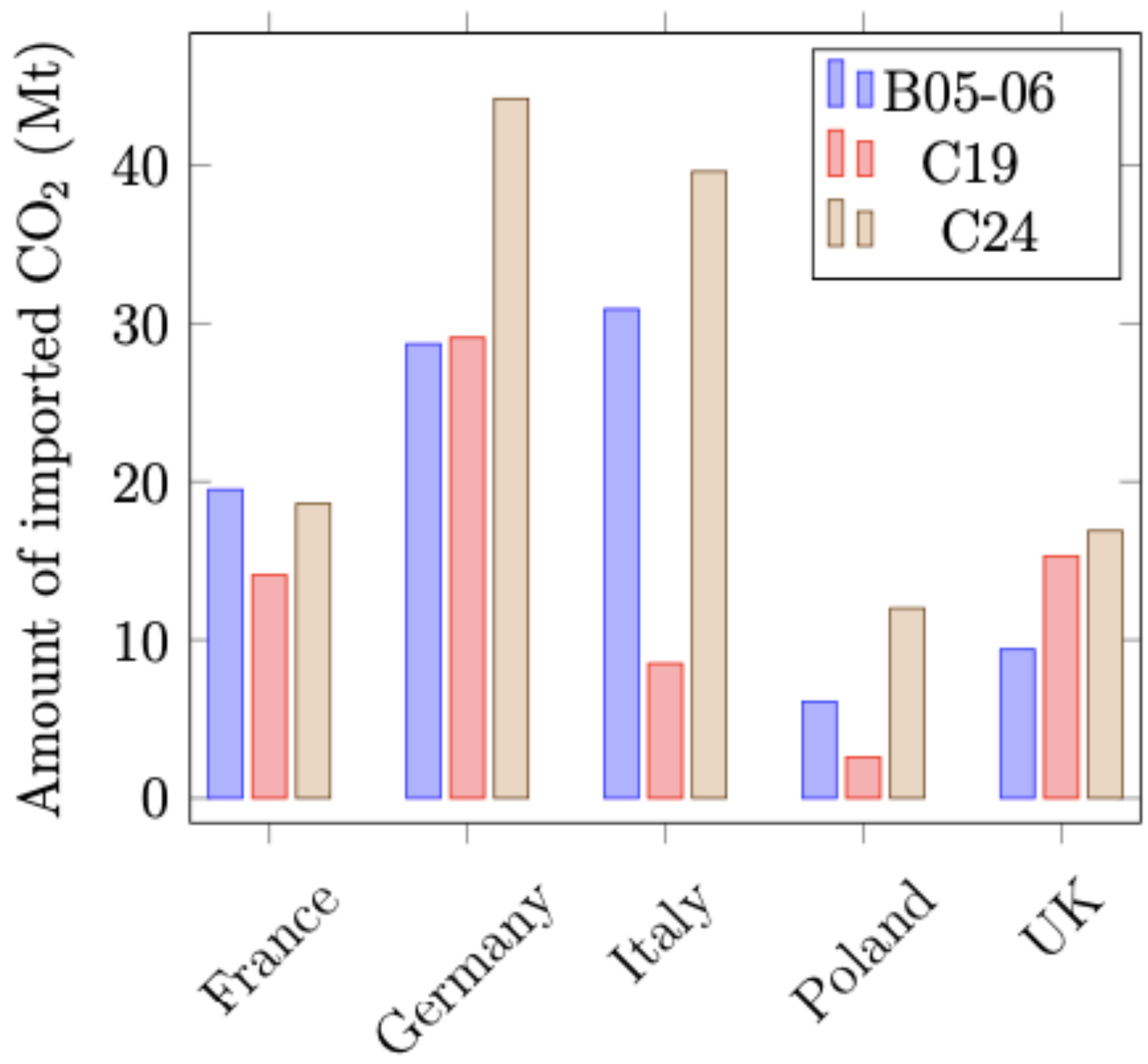
Conclusion

- Mining displays the highest emission reduction coefficients;
- We can identify particularly **relevant cascade patterns** - but **differences across E.U. countries** !
- *Transition away from fossil fuel likely to have a systemic impacts on imports consumed as inputs —> **Greening exposed industrial processes**;*
- **Basic Metals is a huge supplier for other industrial sectors** (e.g. Germany);
- Taxing imported carbon from basic metals —> heavy impacts on fabricated metal products / disparities across countries — > **compensation/exposure** ?

Appendices

Appendix (1) - Imported Emissions by products

Distribution of imported CO_2 emissions across mining (B05-06), coke/ refined petroleum products (C19) and basic metals (C24)



Appendix (2) - Nace Sectors

Table 2. NACE Sectors

Sector code	Sector description
A	Agriculture, forestry and fishing
B	Mining and Quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning
E	Water supply; sewerage; waste management and remediation services
F	Constructions and construction works
G	Wholesale retail trade; repair of motor vehicles and motorcycles
H	Transportation and storage
I	Accommodation and food services activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence: compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other services activities

Annexe - Emission per sector (imports)

Table 4. a. CO_2 emissions (Mt) in gross imports by sectors (A-F), year 2015.

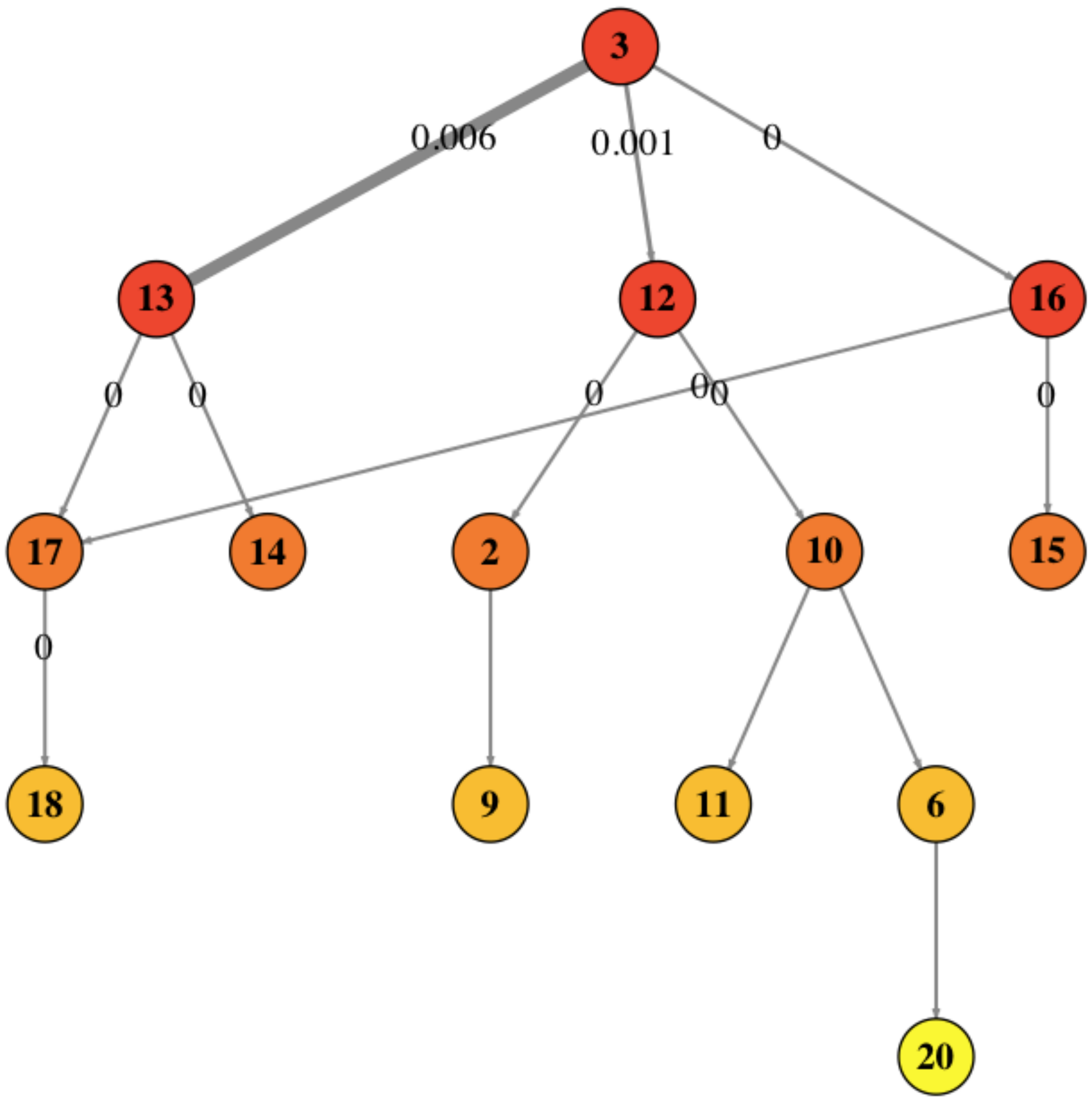
Sector	France	Germany	Italy	Poland	U.K.
Agriculture, forestry and fishing	3,4	9,1	3,9	1,2	3,9
Mining and extraction of energy producing products	19,5	28,7	30,9	6,1	9,4
Mining and quarrying of non-energy producing products	1,1	4,1	1,5	0,8	1,5
Mining support service activities	0,3	0,1	0	0	0,1
Food products, beverages and tobacco	7,8	12,2	6	2,2	9,8
Textiles, wearing apparel, leather and related products	9,6	13,4	9	3,2	16,6
Wood and of products of wood and cork (except furniture)	1,1	2,1	1	0,4	1,8
Paper products and printing	2,9	4,9	2,3	1,5	3,4
Coke and refined petroleum products	14,1	29,1	8,5	2,6	15,3
Chemicals and pharmaceutical products	19,8	28,8	15,4	7,6	19,5
Rubber and plastics products	8,7	11,8	5,8	3,7	8,8
Other non-metallic mineral products	7	10,3	4,3	2,5	7,9
Manufacture of basic metals	18,6	44,2	39,6	12	16,9
Fabricated metal products, except machinery and equipment	7	12,2	4,7	3,2	7,9
Computer, electronic and optical products	12,6	22,7	6,1	5,4	14,5
Electrical equipment	12,8	18,9	8,3	5,4	12,8
Machinery and equipment n.e.c.	12,1	18,9	9,6	5,4	11,2
Motor vehicles, trailers and semi-trailers	11,2	20,5	8,5	3,8	15,2
Other transport equipment	10,8	5,5	3,6	2,7	20
Other manufacturing; repair and installation of machinery and equipment	11,6	13,3	5,5	2,1	18,6
Electricity, gas, water supply, sewerage, waste and remediation services	3,3	7,7	2,4	6,1	2,6
Construction	0,3	0,4	0,1	0,1	0,2

Annexe - Total imported emissions from productive sectors

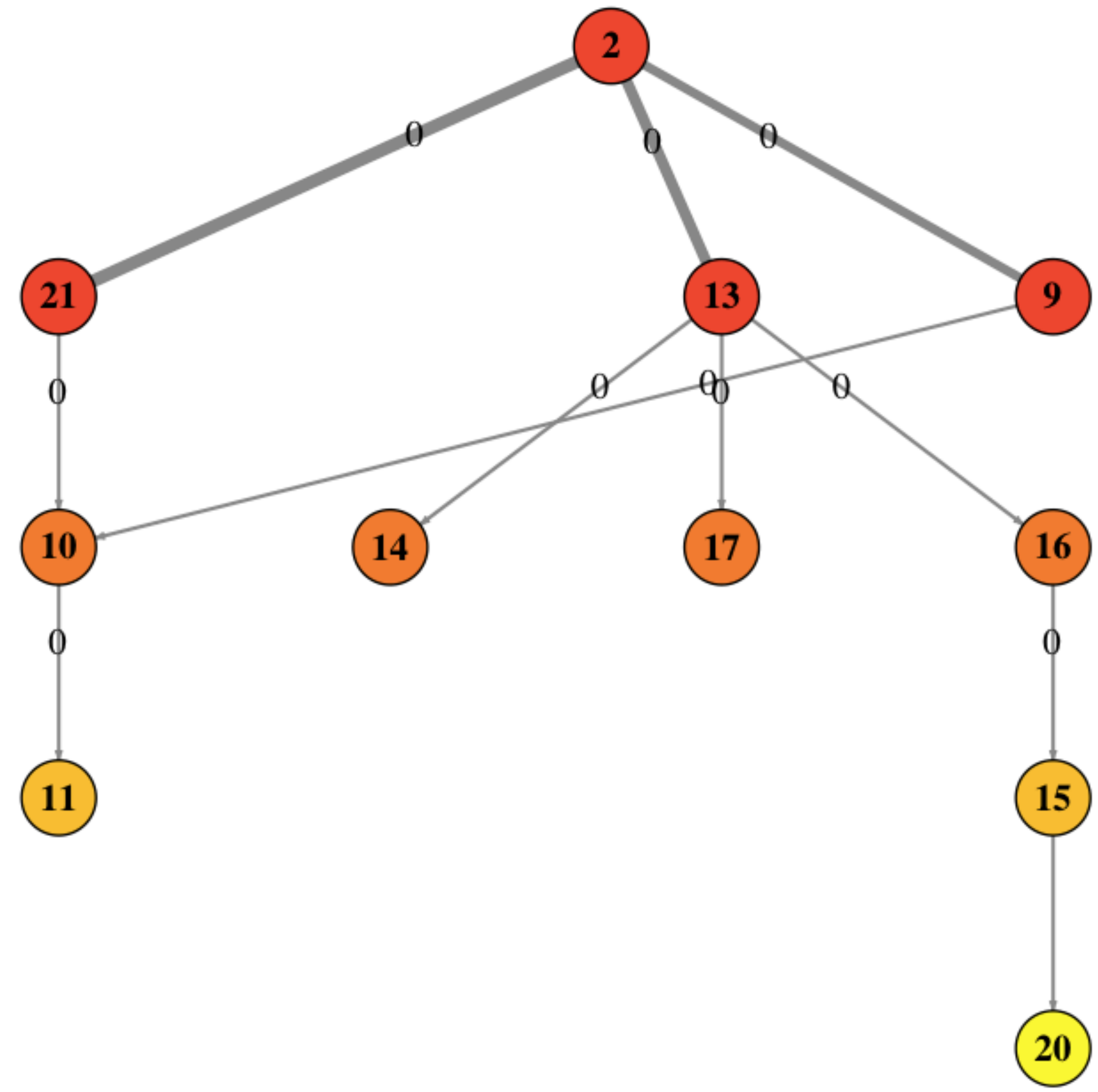
Table 4. b. CO_2 emissions in gross imports, year 2015.

Country	**CO_2 emissions (Mt)**
France	195 600
Germany	318 900
Italy	177 000
Poland	78 000
United Kingdom	217 900

Cascades : Italy and Poland

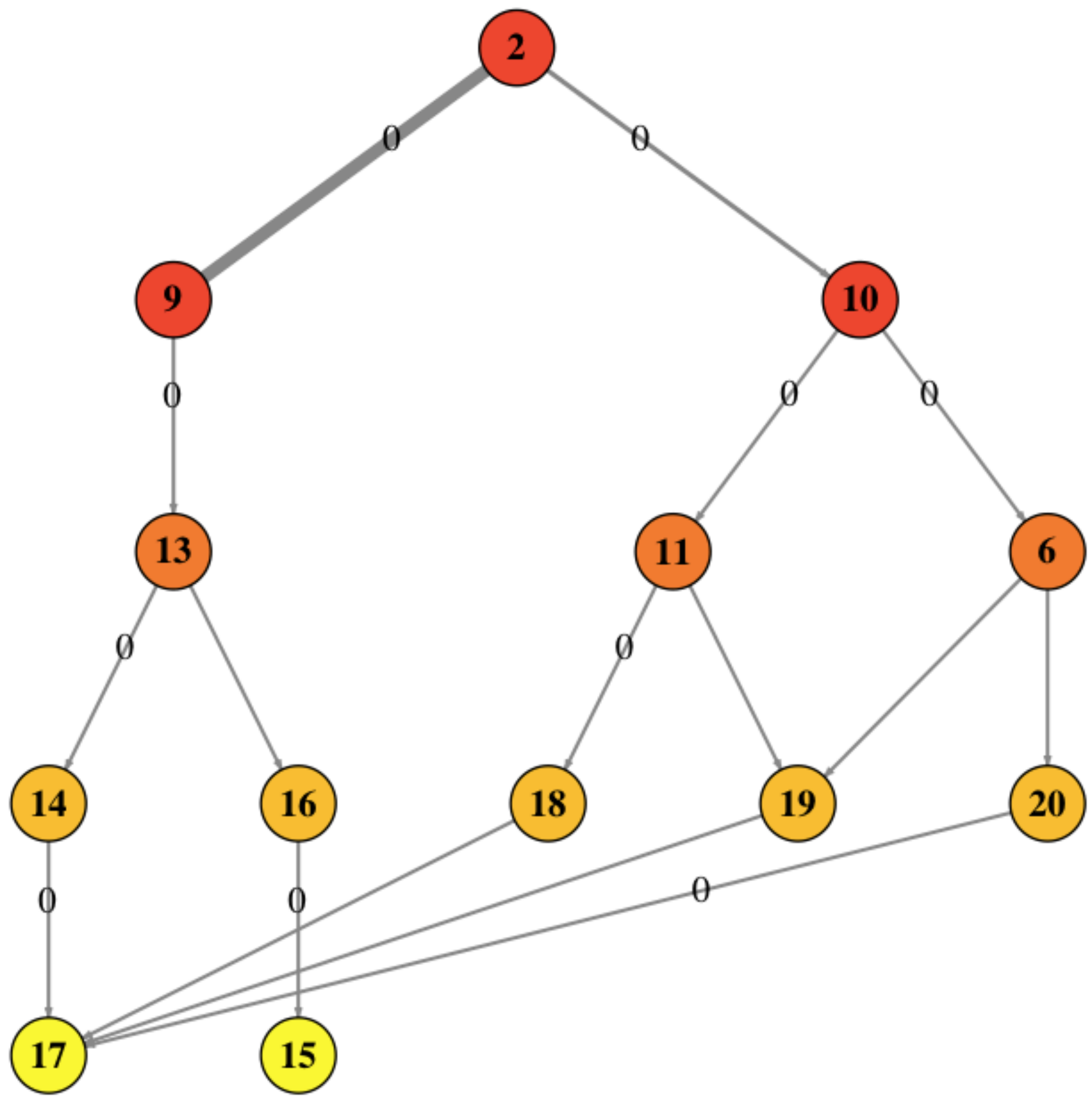


Italy



Poland

Cascades : United Kingdom



United Kingdom

051	05	Hard coal	Houille
052	05	Lignite	Lignite
061	06	Crude petroleum	Pétrole brut
062	06	Natural gas, liquefied or in gaseous state	Gaz naturel, liquéfié ou gazeux
071	07	Iron ores	Minerais de fer
072	07	Non-ferrous metal ores	Minerais de métaux non ferreux
081	08	Stone, sand and clay	Pierres, sables et argiles
089	08	Mining and quarrying products n.e.c.	Produits des industries extractives n.c.a.
091	09	Support services to petroleum and natural gas extracti	Services de soutien à l'extraction d'hydrocarbures
099	09	Support services to other mining and quarrying	Services de soutien aux autres industries extractives
101	10	Preserved meat and meat products	Viande et produits à base de viande
102	10	Processed and preserved fish, crustaceans and mollusc	Préparations et conserves à base de poisson et de produit
103	10	Processed and preserved fruit and vegetables	Produits à base de fruits et légumes
104	10	Vegetable and animal oils and fats	Huiles et graisses végétales et animales
105	10	Dairy products	Produits laitiers
106	10	Grain mill products, starches and starch products	Produits du travail des grains et produits amylacés
107	10	Bakery and farinaceous products	Produits de boulangerie-pâtisserie et pâtes alimentaires
108	10	Other food products	Autres produits alimentaires
109	10	Prepared animal feeds	Aliments pour animaux
110	11	Beverages	Boissons
120	12	Tobacco products	Produits à base de tabac
131	13	Textile yarn and thread	Fils et filés
132	13	Woven textiles	Tissus
133	13	Textile finishing services	Ennoblissement textile
139	13	Other textiles	Autres textiles
141	14	Wearing apparel, except fur apparel	Articles d'habillement, à l'exclusion des fourrures
142	14	Articles of fur	Articles en fourrure
143	14	Knitted and crocheted apparel	Articles à mailles
151	15	Tanned and dressed leather; luggage, handbags, saddle	Cuirs et peaux tannés et apprêtés; articles de voyage et de
152	15	Footwear	Chaussures
161	16	Wood, sawn and planed	Bois, sciés et rabotés
162	16	Products of wood, cork, straw and plaiting materials	Articles en bois, liège, vannerie et sparterie
171	17	Pulp, paper and paperboard	Pâte à papier, papier et carton
172	17	Articles of paper and paperboard	Articles en papier ou en carton
181	18	Printing services and services related to printing	Travaux d'impression et services connexes
182	18	Reproduction services of recorded media	Reproduction d'enregistrements

191	19	Coke oven products	Produits de la cokéfaction
192	19	Refined petroleum products	Produits du raffinage du pétrole
201	20	Basic chemicals, fertilisers and nitrogen compounds, p	Produits chimiques de base, engrais et produits azotés, n
202	20	Pesticides and other agrochemical products	Pesticides et autres produits agrochimiques
203	20	Paints, varnishes and similar coatings, printing ink and	Peintures, vernis et revêtements similaires, encres d'impr
204	20	Soap and detergents, cleaning and polishing preparatic	Savons, produits d'entretien et parfums
205	20	Other chemical products	Autres produits chimiques
206	20	Man-made fibres	Fibres artificielles ou synthétiques
211	21	Basic pharmaceutical products	Produits pharmaceutiques de base
212	21	Pharmaceutical preparations	Préparations pharmaceutiques
221	22	Rubber products	Produits en caoutchouc
222	22	Plastic products	Produits en plastique
231	23	Glass and glass products	Verre et articles en verre
232	23	Refractory products	Produits réfractaires
233	23	Clay building materials	Matériaux de construction en terre cuite
234	23	Other porcelain and ceramic products	Autres produits en porcelaine et céramique
235	23	Cement, lime and plaster	Ciment, chaux et plâtre
236	23	Articles of concrete, cement and plaster	Ouvrages en béton, en ciment ou en plâtre
237	23	Cut, shaped and finished stone	Pierre taillée, façonnée et finie
239	23	Other non-metallic mineral products	Autres produits minéraux non métalliques
241	24	Basic iron and steel and ferro-alloys	Produits sidérurgiques de base et ferroalliages
242	24	Tubes, pipes, hollow profiles and related fittings, of ste	Tubes, tuyaux, profilés creux et accessoires correspondan
243	24	Other products of the first processing of steel	Autres produits de première transformation de l'acier
244	24	Basic precious and other non-ferrous metals	Métaux précieux et autres métaux non ferreux communs
245	24	Casting services of metals	Travaux de fonderie
251	25	Structural metal products	Éléments en métal pour la construction
252	25	Tanks, reservoirs and containers of metal	Réservoirs, citernes et conteneurs métalliques
253	25	Steam generators, except central heating hot water bo	Générateurs de vapeur, à l'exclusion des chaudières pour
254	25	Weapons and ammunition	Armes et munitions
255	25	Forging, pressing, stamping and roll-forming services o	Produits de la forge, de l'emboutissage, de l'estampage et
256	25	Treatment and coating services of metals; machining	Traitement et revêtement des métaux; usinage
257	25	Cutlery, tools and general hardware	Coutellerie, outillage et quincaillerie
259	25	Other fabricated metal products	Autres ouvrages en métaux
261	26	Electronic components and boards	Composants et cartes électroniques
262	26	Computers and peripheral equipment	Ordinateurs et équipements périphériques
263	26	Communication equipment	Équipements de communication
264	26	Consumer electronics	Produits électroniques grand public
265	26	Measuring, testing and navigating equipment; watches	Instruments et appareils de mesure, d'essai et de navigati
266	26	Irradiation, electromedical and electrotherapeutic equ	Équipements d'irradiation médicale, électromédicaux et
267	26	Optical instruments and photographic equipment	Matériel optique et photographique
268	26	Magnetic and optical media	Supports magnétiques et optiques
271	27	Electric motors, generators, transformers and electrici	Moteurs, génératrices et transformateurs électriques et r

3	289	28	Other special-purpose machinery	Autres machines d'usage spécifique
3	291	29	Motor vehicles	Véhicules automobiles
3	292	29	Bodies (coachwork) for motor vehicles; trailers and ser	Carrosseries automobiles; remorques et semi-remorques
3	293	29	Parts and accessories for motor vehicles	Équipements automobiles
3	301	30	Ships and boats	Navires et bateaux
3	302	30	Railway locomotives and rolling stock	Locomotives et autre matériel ferroviaire roulant
3	303	30	Air and spacecraft and related machinery	Aéronefs et engins spatiaux
3	304	30	Military fighting vehicles	Véhicules militaires de combat
3	309	30	Transport equipment n.e.c.	Matériels de transport n.c.a.
3	310	31	Furniture	Meubles
3	321	32	Jewellery, bijouterie and related articles	Articles de joaillerie et bijouterie et articles similaires
3	322	32	Musical instruments	Instruments de musique
3	323	32	Sports goods	Articles de sport
3	324	32	Games and toys	Jeux et jouets
3	325	32	Medical and dental instruments and supplies	Instruments et fournitures à usage médical et dentaire
3	329	32	Manufactured goods n.e.c.	Produits manufacturés n.c.a.
3	331	33	Repair services of fabricated metal products, machiner	Réparation d'ouvrages en métaux, de machines et d'équipements
3	332	33	Installation services of industrial machinery and equip	Installation de machines et d'équipements industriels
3	351	35	Electricity, transmission and distribution services	Électricité, transport et distribution d'électricité
3	352	35	Manufactured gas; distribution services of gaseous fuel	Gaz manufacturé; distribution de combustibles gazeux par conduites
3	353	35	Steam and air conditioning supply services	Production et distribution de vapeur et d'air conditionné
3	360	36	Natural water; water treatment and supply services	Eau naturelle; traitement et distribution d'eau
3	370	37	Sewerage services; sewage sludge	Collecte et traitement des eaux usées; boues d'épuration
3	381	38	Waste; waste collection services	Déchets; collecte des déchets
3	382	38	Waste treatment and disposal services	Traitement et élimination des déchets
3	383	38	Materials recovery services; secondary raw materials	Récupération de matériaux; matières premières secondaires
3	390	39	Remediation services and other waste management ser	Dépollution et autres services de gestion des déchets
3	410	41	Buildings and building construction works	Bâtiments et travaux de construction de bâtiments
3	421	42	Roads and railways; construction works for roads and r	Routes et voies ferrées; travaux de construction relatifs aux routes et voies ferrées
3	422	42	Constructions and construction works for utility proje	Ouvrages et travaux de construction relatifs aux réseaux
3	429	42	Constructions and construction works for other civil e	Ouvrages et travaux de construction relatifs à d'autres projets de génie civil
3	431	43	Demolition and site preparation works	Travaux de démolition et de préparation de sites
3	432	43	Electrical, plumbing and other construction installatic	Travaux d'installation électrique, plomberie et autres travaux d'installation
3	433	43	Building completion and finishing works	Travaux de finition
3	439	43	Other specialised construction works	Autres travaux de construction spécialisés

Germany reluctant to BTA

BERLIN (Reuters) - Germany's powerful BDI industry association on Wednesday criticized a Franco-German proposal to consider a European carbon border tax to protect firms investing in green technology from emission-intensive competition abroad.

The industry group has close links to German Chancellor Angela Merkel's center-right conservatives and has the power to torpedo efforts to introduce a European-wide carbon adjustment tax trough aggressive lobbying in Brussels and Berlin.

France and Germany last week issued a joint statement in which both countries said that the introduction of such a levy should be an option in European efforts to fight climate change.

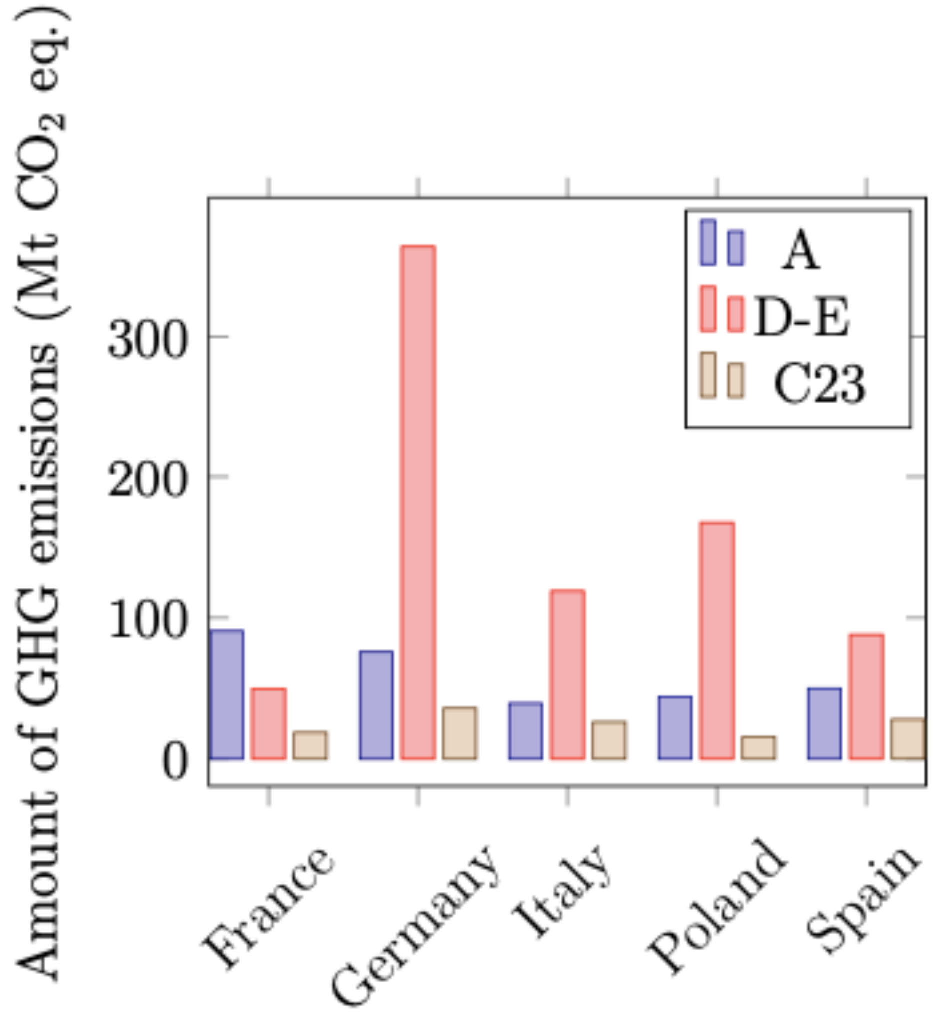
It was the first time Germany has shown a willingness to consider a carbon border tax, pushed for by French President Emmanuel Macron, despite concerns that such a move could increase trade tensions with the United States.

Speaking to reporters in Berlin on Wednesday, BDI President Dieter Kempf said implementing a carbon adjustment tax for imports from countries with less rigorous climate protection schemes was technically difficult, especially for sectors with a high degree of cross-border division of labor.

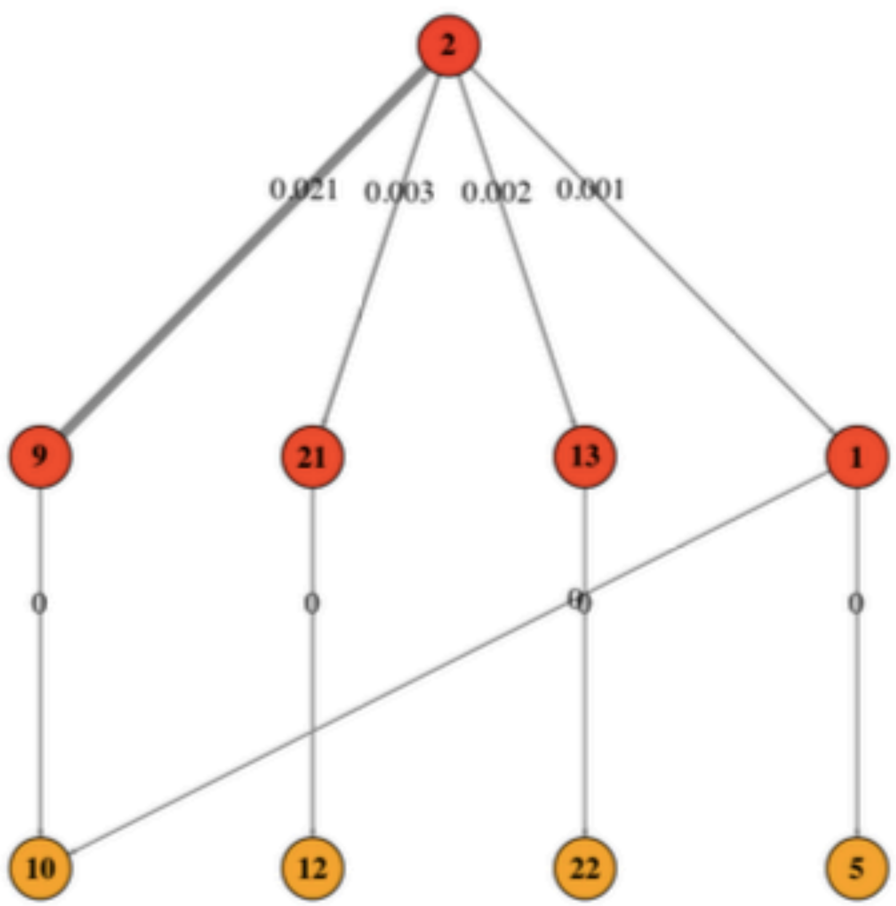
Kempf also warned that such a levy could trigger retaliatory trade measures from other countries which could hit Germany's export-dependent, open economy particularly hard.

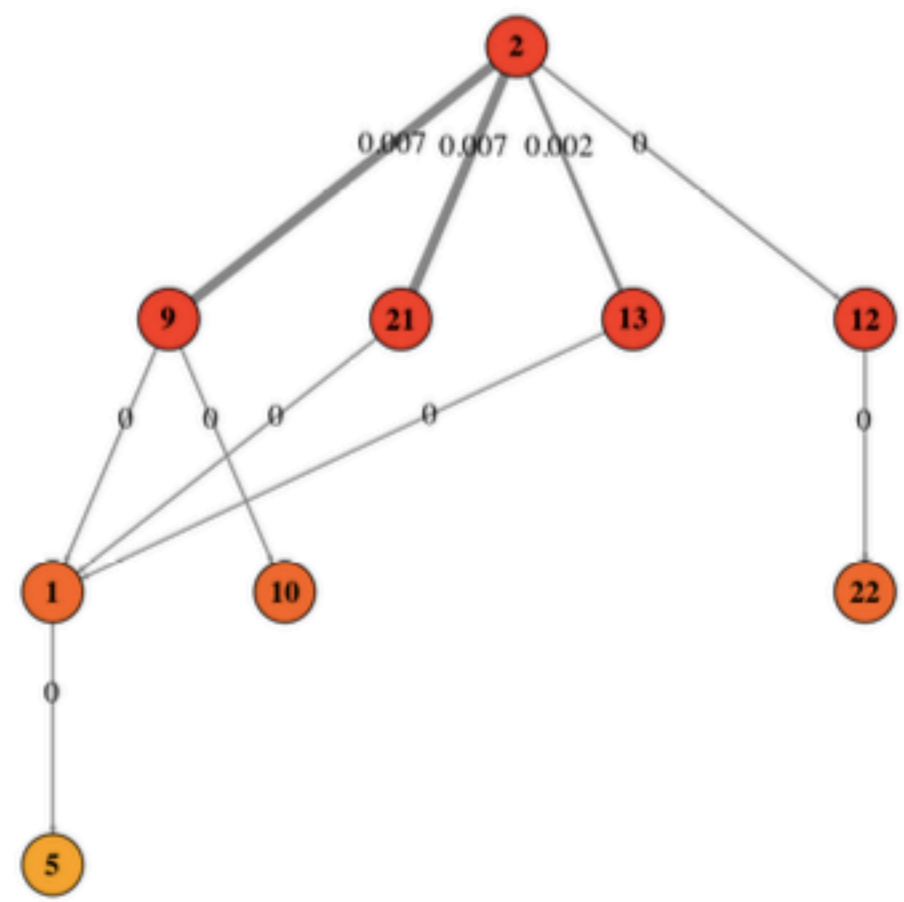
Chapter 4

Figure 4.2: Distribution of total GHG emissions (CO_2 eq.) across Agriculture (A), Electricity and Gas (D-E) and Other Non-metallic mineral products (C23).

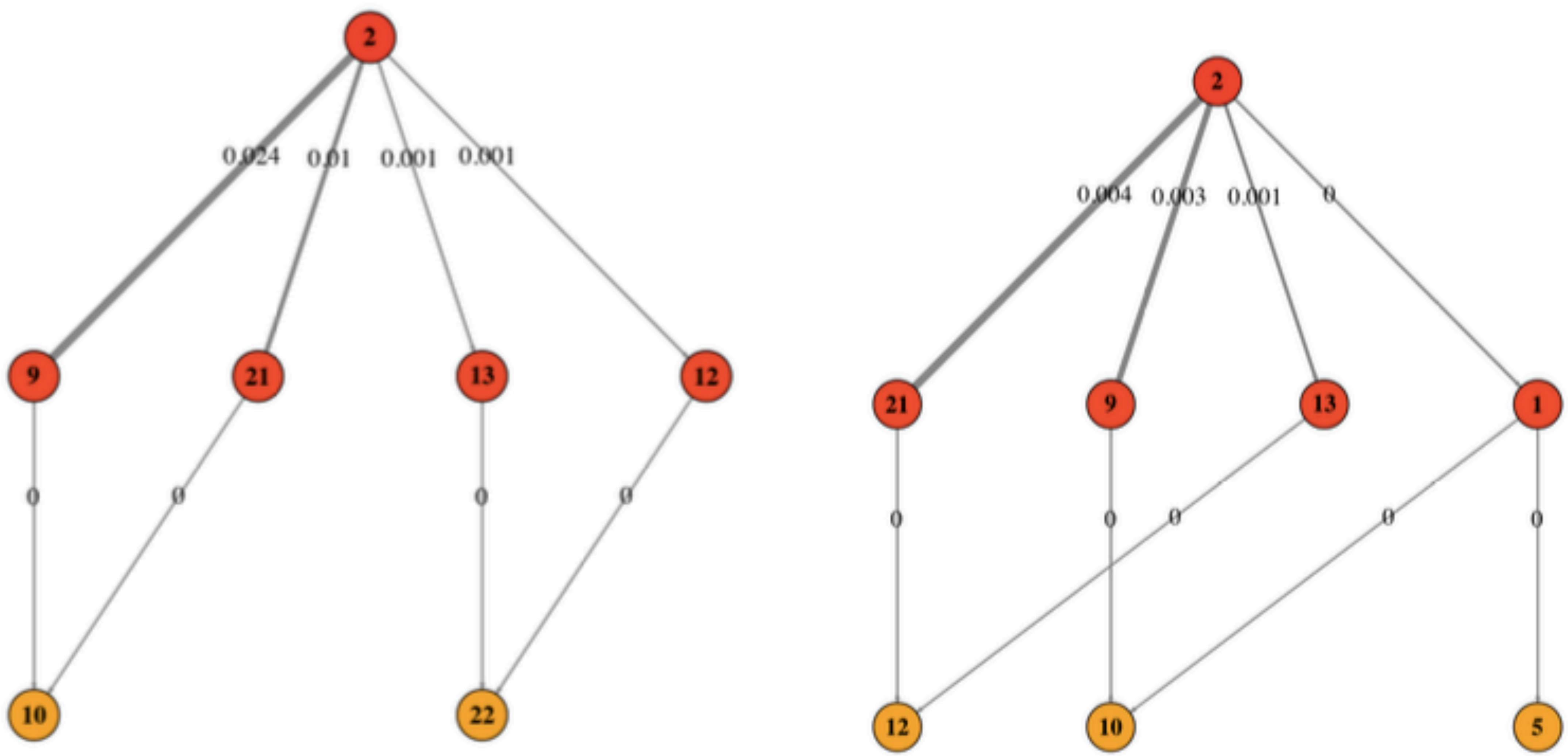


Figures 3 a, b, c, d, e : Hierarchical networks of emission cascades across economic sectors in France, Germany, Italy, Poland and Spain.

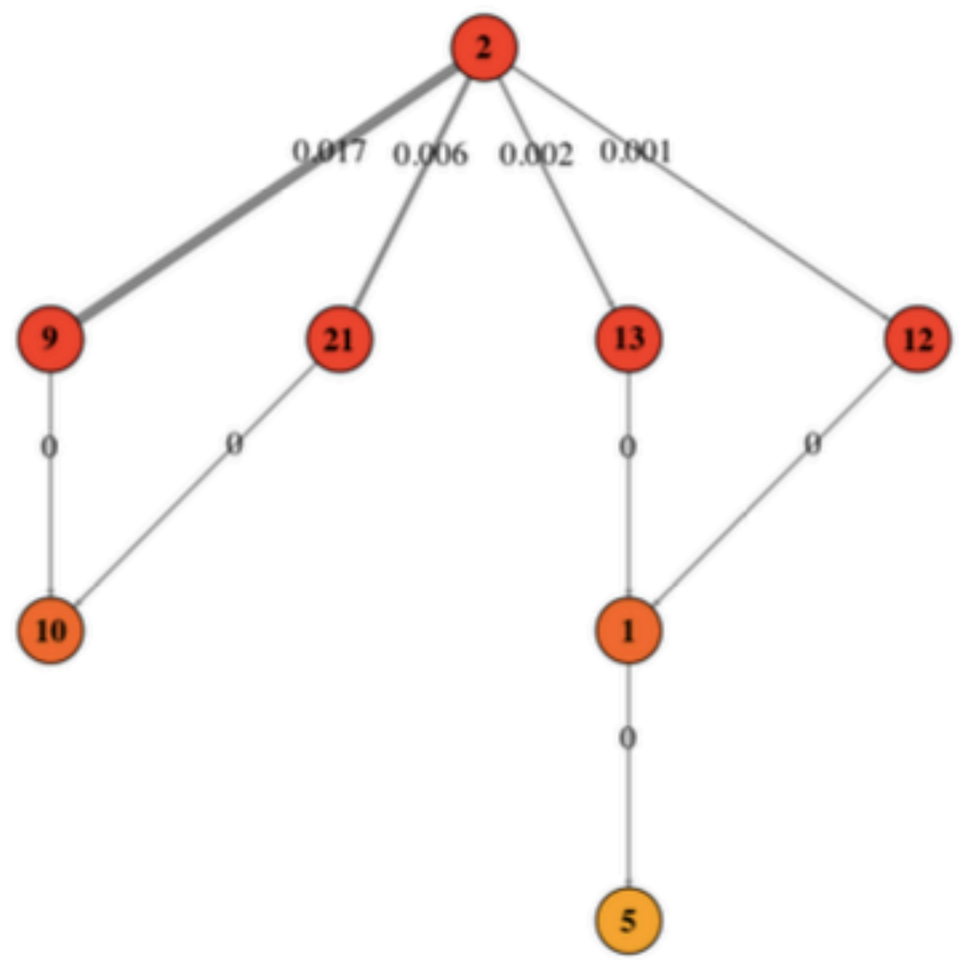




a,b, France (left) and Germany (right)



c,d, Italy (left) and Poland (right)



e, Spain

4 : COVID-19 Recovery Packages and Industrial Emission Rebounds : Mind the Gap

- Strongest immediate emission reductions :
  - From mining to energy intensive manufacturing sectors (coke and petroleum products, steel, iron, chemicals) and power generation (e.g. electricity & gas), further affecting industrial sub-sectors (e.g. construction, rubber and plastics products).
  - Common characteristics across countries = opportunity to design recovery packages sharing common patterns ! (aiming at limiting emission rebounds in sectors identified (e.g. mining (B), coke and refined petroleum products (C19), chemicals (C20-21) and electricity and gas (D-E)).