Network Economics and the Environment

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Outline

1. Objectives
2. Motivation
3. Network Economics 101
4. Environmental issues where networks are important
   i. The adoption and diffusion of new technologies
   ii. Common-pool resource management with multiple sources
   iii. International environmental cooperation
5. Conclusions

Aim

- Bridge two disjoint fields: network economics (NE) to environmental and resource economics (ERE)
  - Discuss some potential contributions of NE to ERE

- Identify features of environmental problems which motivate the use of networks
  - Gather insights for both theory and practice

Motivation: Pervasiveness 1

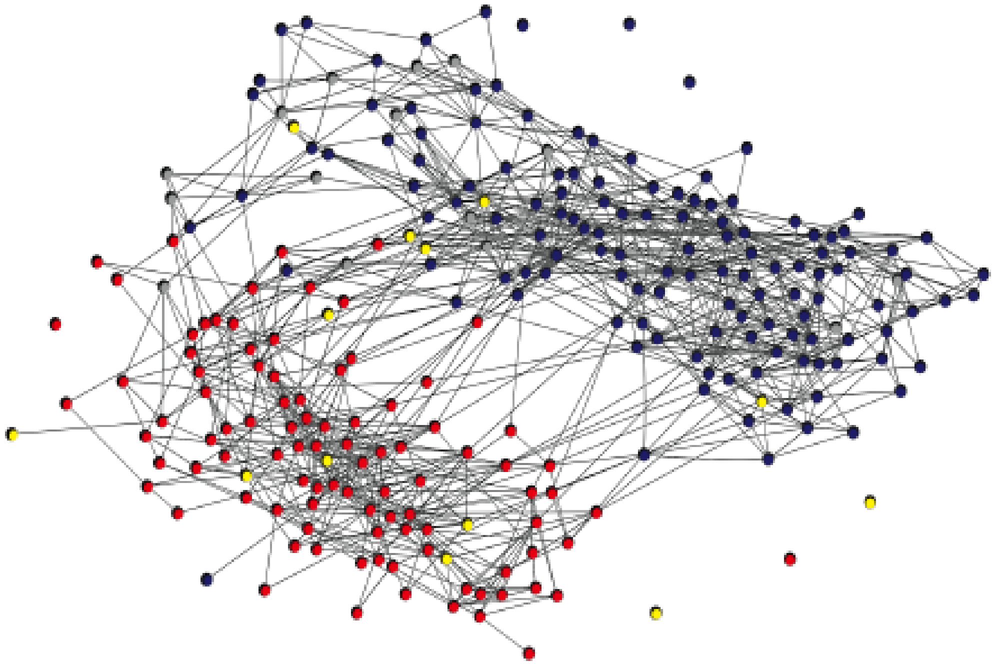
- Explicitly modelling the network structure of social and economic relations can provide significant theoretical insights, and account for previously unexplained empirical evidence

- Relevant areas of application range from labour markets to diffusion of opinions and diseases, trade and financial markets, R&D collaborations, to friendship and peer effects identification

- Networks are particularly suited to analyse problems where social distance affects the nature and extent of economic interactions

Motivation: Pervasiveness 2

- In a network agents interact only with a subset of other agents called the **neighbours**
  - E.g., in labour markets information on job vacancies mainly flows on social ties
  - Likewise, peer effects are observed in friendships and workplace relationships



High School Friendships

Blue=White, Red=Black, Yellow=Hispanic, Grey=Asian

Source: Currarini, S., M.O. Jackson, and P. Pin (2009)

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Motivation: Environmental problems 1

- Local interactions and network structures feature in many environmental problems
- The pattern of adoption and the speed of diffusion of green technologies are likely to depend on the network of social connections
- In international environmental cooperation, multiple issue negotiation may involve non-transitive relations which can be modelled as a network
- Many CPR problems are characterized by a multiplicity of sources and users
  - The strategic decisions of which source to use can be described as link formation, the decision of how much to extract can be modelled as local interaction on the network

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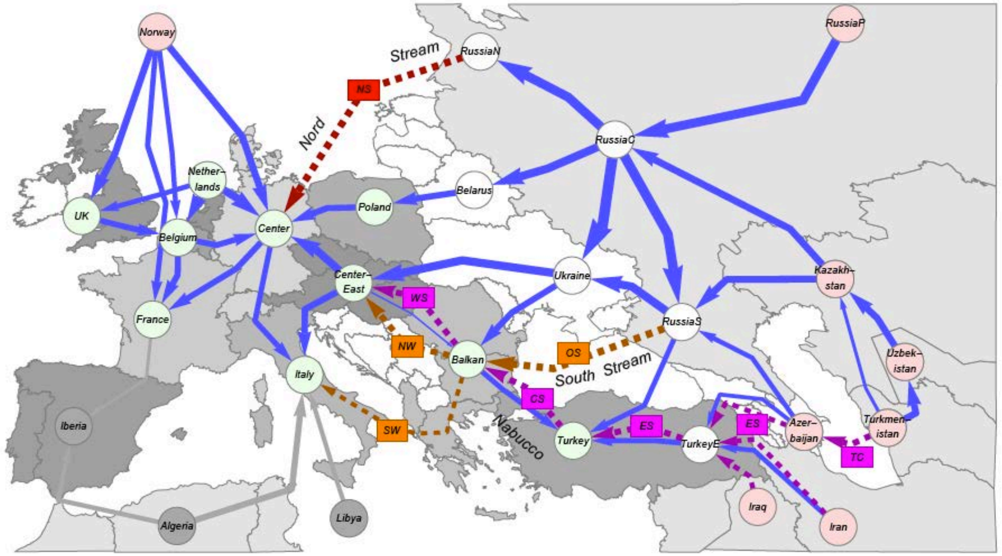
Motivation: Environmental problems 2

- Network characteristics have important empirical implications. When modelling diffusion of a renewable energy technology or a gas pipeline, networks allow one to be specific about the interactions among nodes



Source: Hubert and Cobanli, 2010

Thinking of a node as a country, one can introduce frictions in the transmission due to constraints specific to two neighbouring countries, such as political barriers

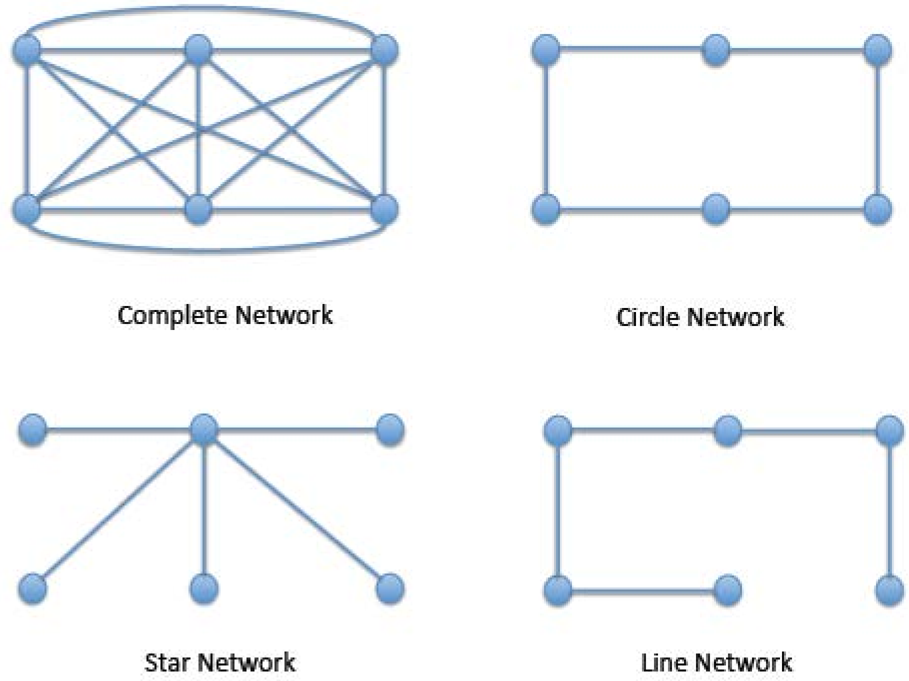
Network Economics 101: Glossary

- A network is defined by a set of **nodes**, and a set of **links** between pairs of nodes
  - So, if nodes i and j are linked in network g, $ij \in g$
- The **neighbours** of node *i* in *g* are all nodes *j* that are linked with *i* in *g*
- The number of neighbours of a node is called the **degree** of that node
- *Indirect connections* within a network: although *i* and *j* are not linked, they have a common neighbour *k*
  - we can go from *i* to *j* through the network following a path of length 2 (i.e., the links *ik* and *kj*)
- We can thus define a **distance** between two nodes in *g* as the shortest way to go from one node to the other through the network

Network Economics 101: Architectures

The complete network is made of all potential links

The star network has one node connecting all the others



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Network Economics 101: Indices 1

Connectivity

1. *Average degree:* measures how many neighbours nodes have on average

2. *Diameter:* maximal distance between any two nodes. If the diameter of g is 6, it means that it takes at most 6 steps to go from any node to any other node in the network

3. *Average distance:* measures how distant nodes are on average

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Network Economics 101: Indices 2

Clustering

Two neighbours of a given node may or may not be themselves neighbours. When they are, they close the triangle of relationships by forming a *cluster*

The degree of clustering may greatly vary across networks, depending on the nature of the relations described by links

- In a hierarchical organization, clustering is very low to maintain the “chain of command“ clear
- In friendships clustering may tend to be quite high, since common friends often feel right to close the triangle

A measure of how clustered a network is to consider the proportion of the potential triangles that are actually closed; in other words, of all agents with a common friend, how many are themselves friends

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Network Economics 101: Indices 3

Centrality

One important aspect of networks is that nodes may have different degrees of importance in connecting other nodes

1. Node's *degree:* its number of neighbours
2. How *close* a node is to all other nodes
3. Degree of *betweenness* of node *i*: the fraction of shortest paths between any two nodes *k* and *j* that go through node *I*
4. *Bonachich Centrality Measure*: node is central if it is connected with many other central nodes

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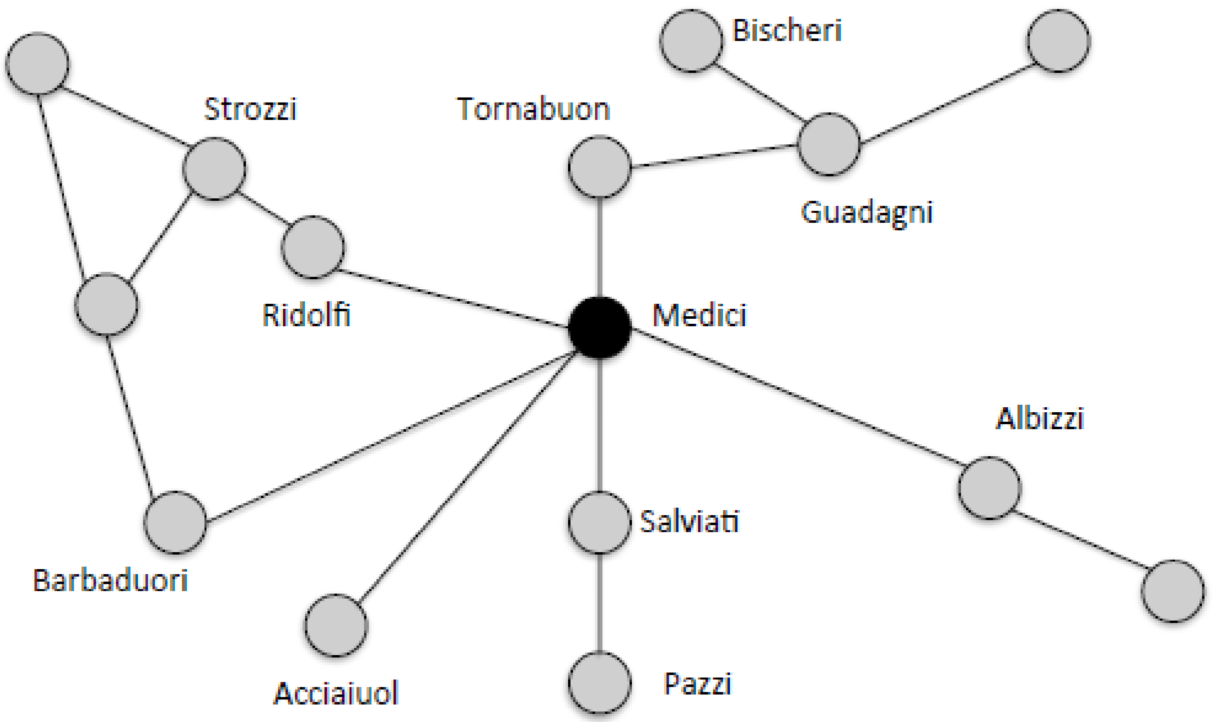
Network of marriages in Renaissance Florence



Source: Padgett and Ansell (1993)

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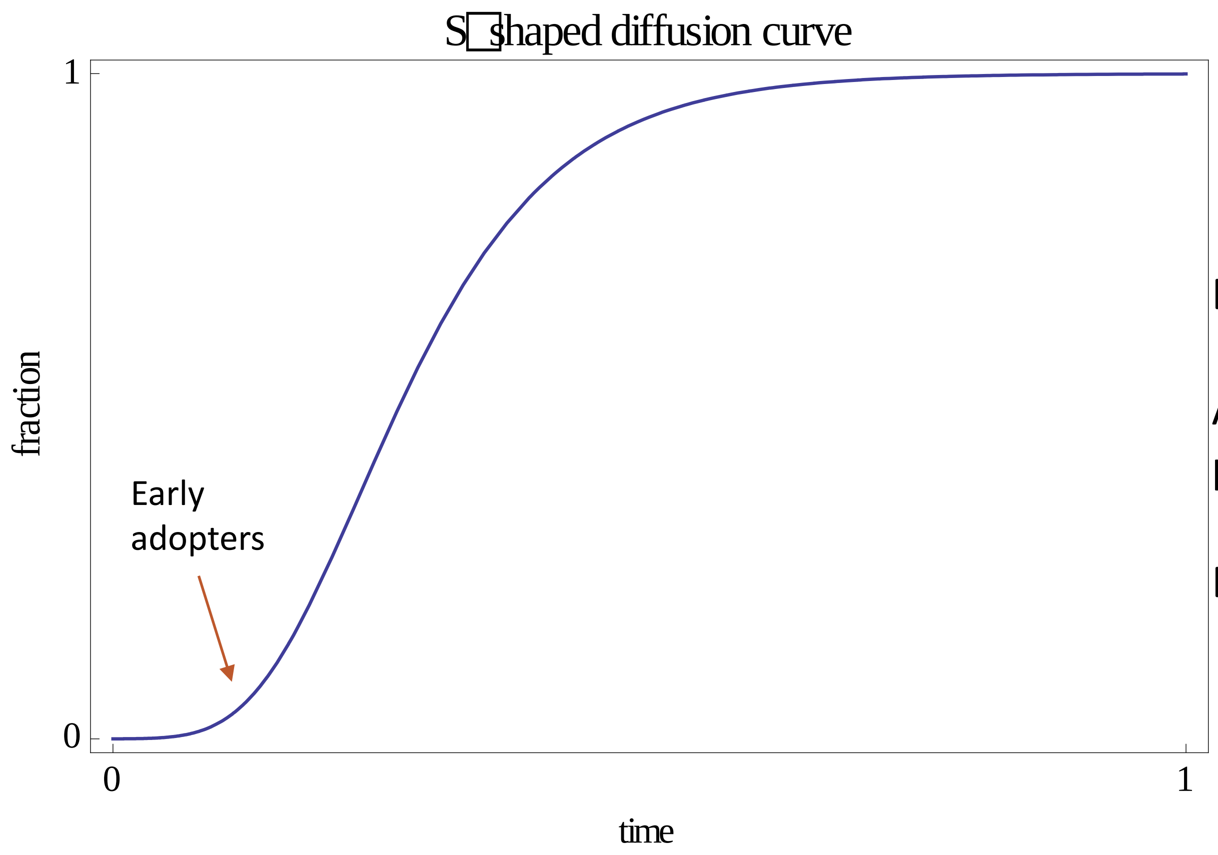
Environmental Issue 1: Adoption and diffusion of technologies & behaviour

- Much like behaviours, technologies diffuse through social interactions, since adoption by one agent increases the likelihood that others will become aware of its existence and potential benefits over the incumbent technology

- Mutually reinforcing choices lead to accelerating diffusion of behaviours or technology once a critical threshold has been reached. This process saturates, once the pool of adopters is so large that there is little scope for imitation

Adoption / diffusion



Bass model (Bass, 1969)

Agents have an adoption threshold that is a positive function of the number of other adopters

Diffusion of an innovation behaves like epidemics

Green technology adoption and tipping

- Heal and Kunreuther (2012) offer illustrative evidence on the role of early adopters in triggering a global shift from damaging pollutants to greener alternatives

EX. 1: **Adoption of unleaded gasoline**

The unilateral adoption by the U.S. reduced adoption costs for others to modifying refinery capacity, since motor industries exporting to the U.S. had to transition to lead-free fuel immediately after the move. Thanks to these reduced costs for the followers, the new technology spread quickly worldwide

Green technology adoption and tipping

EX. 2: **Phasing out chlorofluorocarbons (CFCs)**

The U.S. decision to sign the Montreal Protocol hinged on a technological innovation by Du Pont, the world's largest producer of CFCs, allowing the company to gain from elimination of CFCs. Strategic complementary led most countries to phase-out ozone-depleting chemicals

Further examples:

- Adoption of hybrid corn seeds among Iowa farmers follows S-shape (Ryan and Gross 1943, Griliches 1957)
- Participation in a microfinance program diffuses through social networks in several rural villages in South India (Banerjee et al. 2012)

Green technology adoption and tipping

- While insightful about the non-linearity of diffusion dynamics, the Bass model is silent about the topology of the network
- Heterogeneity among agents can enrich it to capture driving forces behind different adoption rates, e.g. spatially heterogeneous costs of adopting a new technology
- Similarly, behavioural forces may play an important role in determining imitation rules. These need not be proportional to the fraction of the adopters. Peer and neighbourhood effects could drastically change the way innovations diffuse, relative to a mean field interaction model

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Issue 2:
CPR management with multiple sources

- Managing common pool resources requires the consideration of geographic and social distances, and the analysis of how local interactions scale up

- While models tend to assume multiplicity of sources away, most commons are local, but *numerous* (forests, pastures, groundwater)
  - the '06-'07 drought in Spain led the government to consider transferring water from north to south → political/environmental/economic issues

- Network economics allows one to analyse foundational CPR characteristics that ultimately contribute to its (un)successful management

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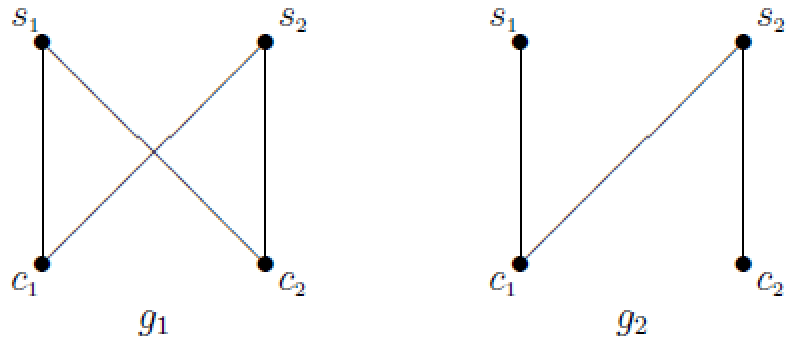
Networks of commons (Ilkilic 2011)

Network comprised of *m cities* $(c_1, \ldots, c_m)$ extracting (at a convex cost) from *n* water sources $(s_1, \ldots, s_n)$, gaining a benefit (which is a concave function of total extraction at the *s*)



Exploitation at each s_i depends on the centrality of the links connecting it to the users

In *g1*, non-cooperative extraction is symmetric*:* both cities take the same amount from each *s* (equivalent to extraction level in case of single big common source)

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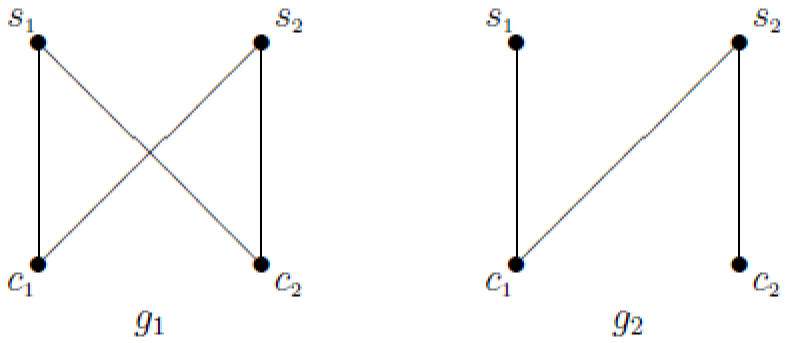
Networks of commons (Ilkilic 2011)

In *g2*, c_2 expoits s_2 more than in the complete network

=> extraction from s_2 becomes more costly, leading c_1 to consume less water from it, and rely more on the exclusive connection with s_1

=> the absent link (1,2) harms both the city where it has been severed (c_2) and indirectly c_1



Externalities diffuse through the paths: a user's extraction at a *s* does not only depend on # of competing users, but also on the # of *s* their neighbours are linked to, etc.

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Networks of commons (Ilkilic 2011): Policy

- Disregarding the structure of the network may be misleading as different structures affect both overall extraction and the distribution of the resource across users and sources

- *g1* leads to higher overall water consumption

- *g2* is such that s_2 is exploited more severely, with governance implications

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Issue 3: International environmental agreements

- A common, yet restrictive assumption in the economic literature of IEAs is that countries are symmetric. When considered, asymmetries are typically modelled as differences in terms of costs and benefits of emission abatement

- However, due to their history of political, economic and cultural interactions, countries may also differ with respect to their relationship and role within the process of building up cooperation.

- In the presence of spillovers, this may have important implications for the incentives to cooperate and the stability of an IEA altogether

International environmental agreements (IEA)

- In a standard setting, it is implicitly assumed that any country defecting from the coalition would form the same expectation on the reaction of the remaining countries
- For instance, the so-called ‘delta assumption’ postulates that all remaining countries would carry on the cooperation; the ‘gamma assumption’ instead postulates that cooperation would break down as a result of the defection
- Our claim is that countries’ expectations may differ depending on their own and others’ role in the negotiation process

IEA: Three-country coalition

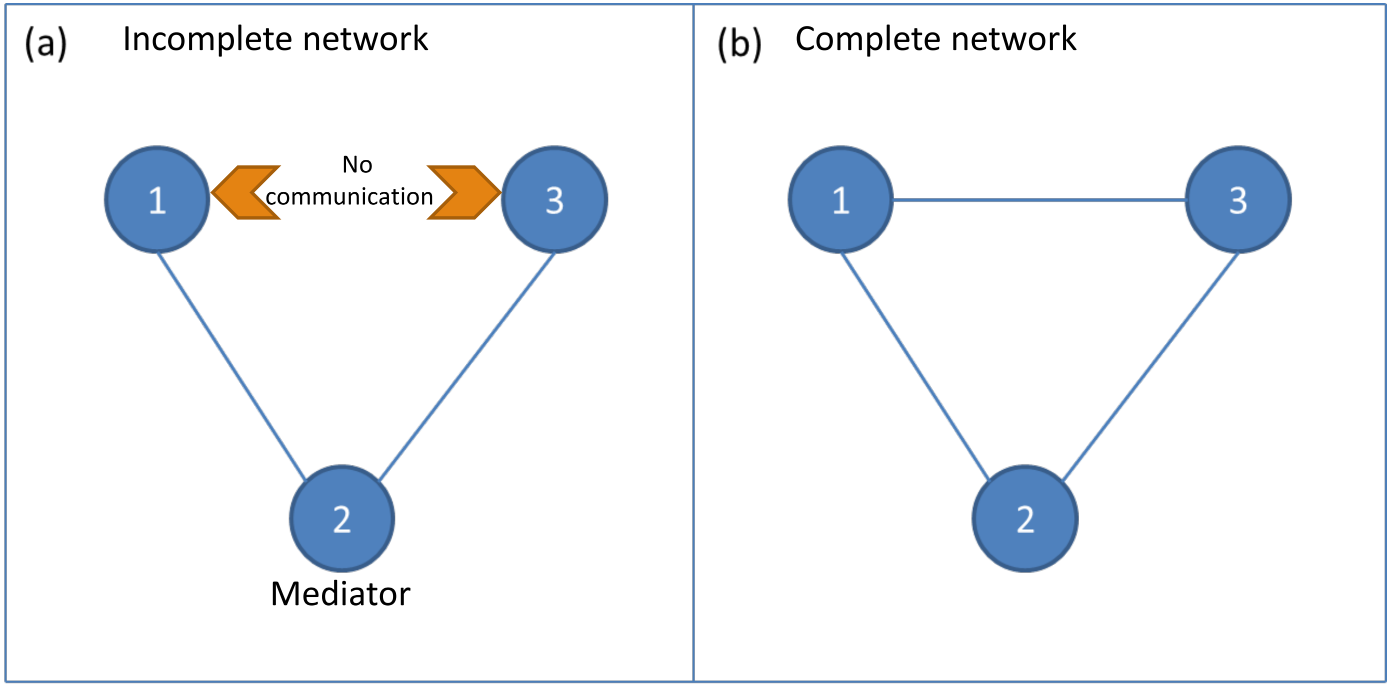

Figure 1: Internal structures of a 3-country coalition

- Internal coalition structure affects players' expectations about consequences of defection
- In (a) player 2's defection would be likely to cause the breakdown of cooperation
- Under positive spillovers on outsiders, player 2 would face lower incentives to defect than 1 & 3
- If outside options affect players' bargaining power, 2's is weaker in the incomplete structure
- Stability depends on structure: while in (a) 1's & 3's claims are the same as in (b), 2's claim is higher in (b)
- Hence total claims are larger in the complete structure. If the gains from cooperation are the same in both, cooperation is more difficult to sustain in (b)
- If incompleteness reduces the gains from cooperation, a tension between efficiency and stability may arise

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IEA: Cooperation on multiple issues

- IEA models typically adopt a partial equilibrium approach when analysing stability of cooperation, focusing on a single issue (e.g. emission abatement)
- Yet, countries often engage in negotiations over multiple issues at the same time, with possibly different sets of participants

- The gains from cooperation and the stability of an agreement on one issue may well depend on whether cooperation is achieved on related matters
- A full understanding of the incentives to cooperate and the stability of cooperation calls for models that explicitly account for such interplay, and its strategic consequences

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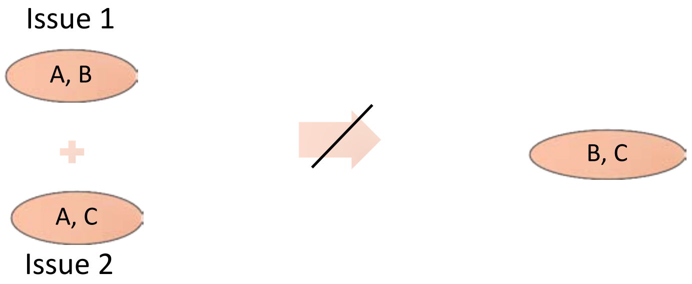
IEA: Cooperation on multiple issues



Cooperation over multiple issues, with overlapping sets of participants, typically implies a lack of transitivity:
B and C need not both cooperate on any issue

- Such situation can be usefully framed in terms of networks
- A notion of stability should account for individual incentives to either expand or restrict the set of issues
- These incentives depend on the entire cooperation structure (which countries cooperate on what)
- If issues are strongly interrelated, one should expect substantial network externalities in the decisions to expand or restrict cooperation, and therefore possible conflicts between individual and social incentives

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Building Environmental Coalitions through Pairwise Contacts

- The process by which environmental coalitions are formed can be varied and multifaceted, and the timing and framing of negotiations is likely to matter for the final success of cooperation
- Large coalitions are likely to be built gradually, with a limited number of very committed members who then adopt various strategies to enlarge the coalition
- Such countries have the task of building up a larger coalition through successive individual contacts with other countries, where degrees of commitment and compensations are negotiated
- The design of such bilateral contacts is a crucial element of the cooperation process, and attains to the timing of such contacts, their degree of centralization and delegation of the process
- Both centralization and delegation have plausible pros and cons
- Delegation may be preferred when diplomatic, geographical and historical relations between countries are heterogeneous

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Building Environmental Coalitions: 3-player example (Currarini and Feri 2007)

i has the task of building up a coalition with *j* and *k*

Benefits from cooperation are captured by a partition function *v*, mapping each partition of the set of players into a vector of payoffs, specifying an aggregate payoff for each coalition in that partition

Let *v(S,π)* denote the value generated by *S* in the partition π. Set:

$$v(\{i\},\{i,j,k\}) = v(\{j\},\{i,j,k\}) = v(\{k\},\{i,j,k\})$$

$$v(\{ij\},\{ij,k\}) = v(\{ik\},\{ik,j\}) = v(\{jk\},\{jk,i\})$$

Assume that the grand coalition *{ijk}* is efficient, i.e. it generates more aggregate payoff than any other partition of the players' set:

$$v(\{123\},\{123\}) \geq \sum_{S\in\pi} v(S,\pi), \forall\pi$$

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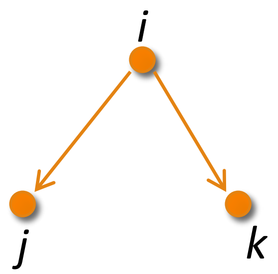
Building Environmental Coalitions: 3-player example (Currarini and Feri 2007)

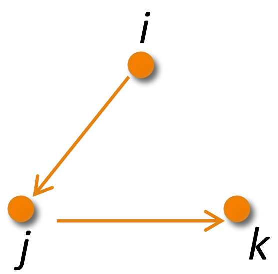
i designs the structure of his contacts with *j* and *k*

Either *i* contacts *j* and *k* simultaneously, proposing to form a coalition of three players, or sequentially, contacting *j* first, proposing him to join the forming coalition, and delegating him the task of enlarging the coalition to *k*

i admits *j* in the coalition, and transfers to *j* the technology to negotiate with *k*. The assumption that *i* can commit not to contact agent *k* when delegating to agent *j* the contracting power is crucial and allows us to get a very sharp intuition

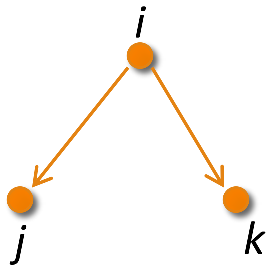


Centralized Contact-Building

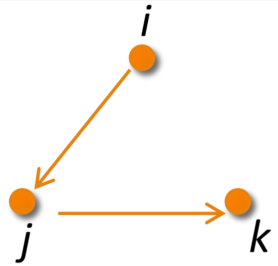


Delegated Contact-Building

Building Environmental Coalitions: 3-player example (Currarini and Feri 2007)



Centralized Contact-Building



Delegated Contact-Building

j and *k* simultaneously receive an offer. For both of them to accept, the offer has to exceed the outside option given that the other has accepted
These outside options are $v(\{j\},\{j,ik\} = v(\{k\},\{k,ij\}$

j needs to receive at least what he would get by rejecting the offer, which is $v(\{j\},\{i,j,k\})$. *k*'s payoff when contacted by *j* would instead be at least $v(\{k\},\{k,ij\}$ = his outside option if rejecting to join the coalition

i needs to give up different slices of the total cake in the two alternative regimes:
By centralizing contacts, *i* gives up $v(\{j\},\{j,ik\} + v(\{k\},\{k,ij\}$; by delegating, he gives up $v(\{j\},\{i,j,k\} + v(\{k\},\{k,ij\}$
Which regime is preferred by *i* depends on whether $v(\{j\},\{ji,k\} \gtrless v(\{j\},\{i,j,k\}$ (coalitional spillovers)
i will prefer centralized contacts when spillovers are negative, and sequential contacts when positive

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Conclusions

- We have explored a range of issues that highlight the potential of network economics to contribute relevant insights for environmental management
- Social and geographical distance are ubiquitous in environmental issues, and neglecting them may aggravate the challenge of understanding coupled socio-ecological systems
- Yet, networks are largely absent in environmental economics, with the exception of empirical efforts mostly concentrated in agricultural economics
- Plenty of room for applied theory building on game theory and network economics!

Thank you!

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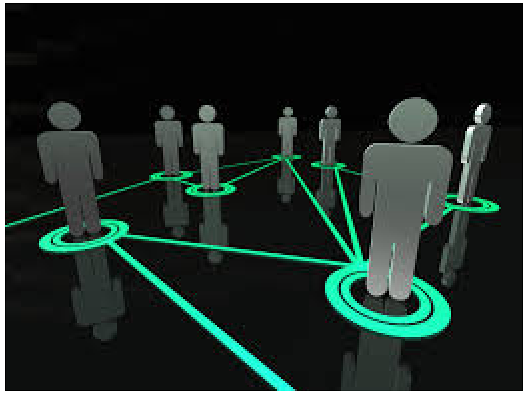
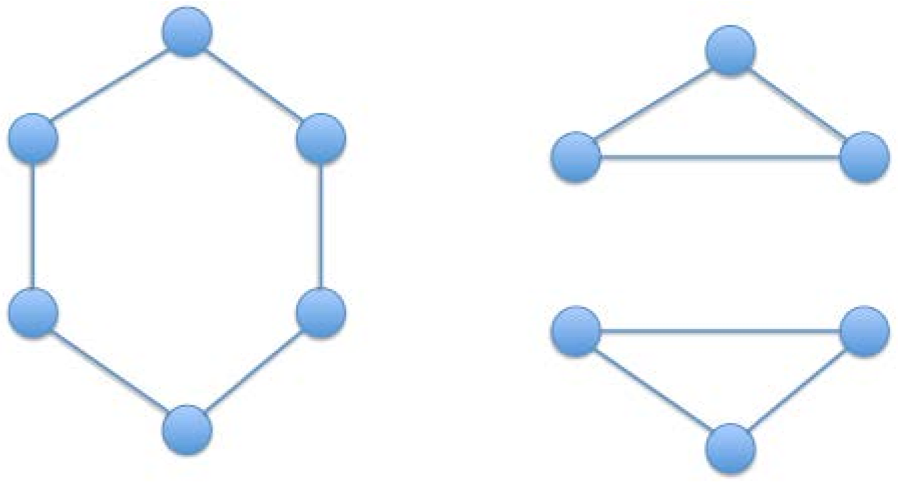


Network Economics 101: Glossary

- A set of nodes is *internally connected* when for each pair of nodes there is a connecting path that only goes through nodes in the set
- An internally connected set of nodes forms a component of g if no node in the set is connected to any node outside the set
- When a node can get back to itself following the network, we say that there is a cycle
- When a network is cycle-free (a tree), then we can interpret the links as hierarchical relations, and select one node as the top of the hierarchy
- **Degree distribution** of a network provides information on what proportion of nodes have what degree
- A **scale-free network** is a network whose degree distribution follows a power law, at least asymptotically

Clustering and degree distribution



Green technology adoption and tipping

- As an example of the complex link between neighbourhood composition and behaviour, Jackson (2008) refers to the choice of software: if one wants it to be compatible with most neighbours, the ensuing interactions must be treated as a coordination game, where adoption by a critical number of neighbours can tip the system to a different technology

- The speed of diffusion is related to the network structure. Scale-free networks and other networks with mean-preserving spreads in degree distribution or large variances are more easily subject to contagion than other random networks. The same tends to happen when the degree density increases

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