[center]

School of Mathematics
FACULTY OF MATHEMATICS AND PHYSICAL SCIENCES
UNIVERSITY OF LEEDS

Investigating Energy Efficiency Interventions using a Network-Diffusion Model

Nick McCullen
School of Mathematics
University of Leeds
& everyone on the Energy-Complexity project.

IMA Seminar
22nd November 2011
University of Nottingham

Investigating Energy Efficiency Interventions using a Network-Diffusion Model

Introduction to the Energy-Complexity Project

Network Models

Dynamical Models

Model Results

UNIVERSITY OF LEEDS

Focus of the Pilot Study

- Study interventions related to adoption of new technology or energy use strategies,
- mediated by social contacts between individuals (as well as through the media).
- This dissemination of technology or ideas can be studied using models of diffusion on networks,
- Theoretical/computational results can then be put into the context of energy technology/use,
  - particular schemes may be considered by public or private bodies.

UNIVERSITY OF LEEDS

Schemes Under Consideration

1. Green Deal provider covers upfront costs of EE tech, paid back from the savings in energy bills;
2. Subsidy for installing EE out of LA budget;
   - word-of-mouth about savings achieved,
   - incentives such as "recommend a friend discounts".
3. Smart meter installation;
   - effects of seeing own use compared to neighbours'.

UNIVERSITY OF LEEDS

Interventions to Consider

Comparisons can be made between various strategies, e.g.:

1. street-by street targeting for installation;
2. focusing on communities to induce a "critical mass",
   - may then propagate outwards on the network;
3. 'random' installation,
   - e.g. via advertising campaign;
4. 'word-of-mouth' propagated installation,
   - e.g. incentive to "recommend to a friend".
5. strengthening network ties to improve communication.

Network Models

- Individuals, organisations, households, . . ., considered as *nodes* on a network.
  - Properties of nodes are associated with variables (states), e.g.:
    - ability to buy (income + subsidy),
    - willingness to buy (personal and social utility).
- *Links* ('edges') are drawn between connected individuals.
  - Information/influence passed along (weighted) edges.
- This is a *complex system* of interacting individuals.
- Dynamics of variables governed by equations (rules) based on own and neighbours' state.

Types of Model Network

- Various theoretical network models exist,
  - give qualitatively different networks, exhibiting different real-world phenomena.

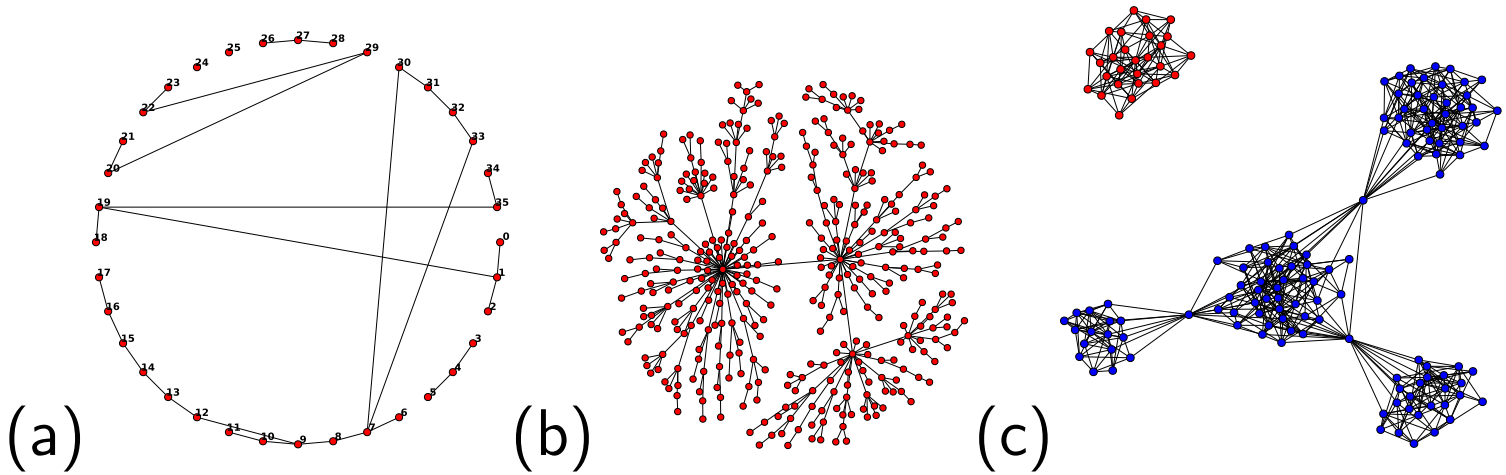


Figure: (a): A *small world* network with 20% rewiring of a regular lattice. (b): A preferential attachment graph which has a *scale-free* degree distribution. (c): A simple model of weakly-connected communities.

Real-World Social Networks

- Different types of social connection exist; these include:
  - geographical neighbours, distant friendships, family trees & communities.

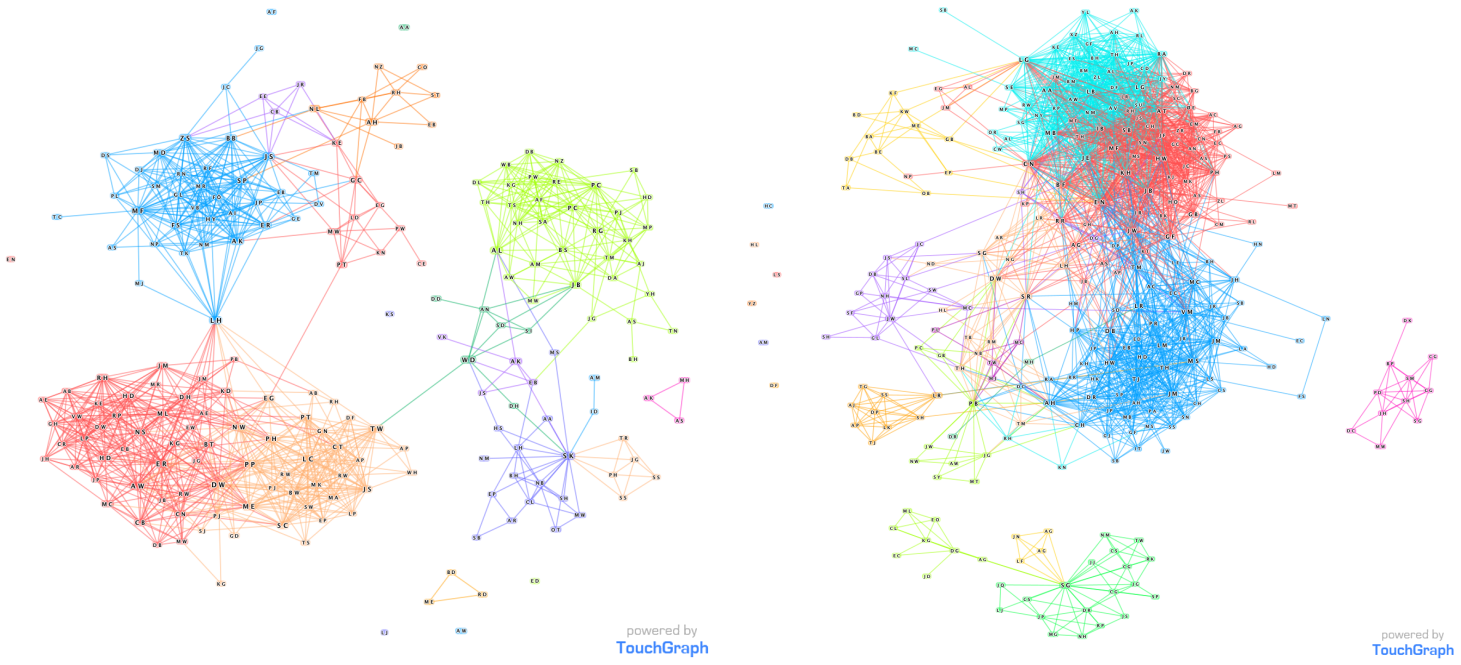


Figure: Inter-friend contacts on the *Facebook* website.

The Leeds City Model

UNIVERSITY OF LEEDS

Diffusion Models

Behaviour of individuals could be influenced by many factors:

- Analysis of benefits and costs:
  - Decision made when total benefit crosses some threshold.
- Would likely have multiple parameters.
- Includes social benefit from friends/contacts.
- We are interested in diffusion models:
  - individuals use the technology if a certain number or proportion of the neighbours are using it.
- Can quantify system "effectiveness" counting either:
  - number of individuals who have technology,
  - average opinion of technology.

Models of Social Influences

Models exist weighting individual's own opinion relative to social contacts [1]:

- *Utility* (benefit) of product to individual i:

$$U_i = (1 - \beta_i)p_i + \beta_i s_i$$

p_i: personal utility: value of product to individual,
s_i: social utility: fraction of other individuals with technology,
β_i: relative weighting of social to personal value.

Social Utility

Data suggests individuals assign different relative value to personal contacts and society [2].

UNIVERSITY OF LEEDS

Model Specifications

1. The individual households are nodes on the network.
2. Their weighted "opinion" of an EE product is bundled into a *utility* variable:
   - $U_i = \alpha p_i + \beta_i s_i + \gamma m$

   p: personal value to individual,
   s_i: average "opinion" if individual's social contacts,
   m: society average "opinion" (via media etc.),
   α, β, γ: relative weighting of factors (based on personality).
3. When U_i is greater than threshold (financial and personal costs minus any incentives) then a purchase is considered.

UNIVERSITY OF LEEDS

Simulation Results

For a particular network and choice of model parameters:

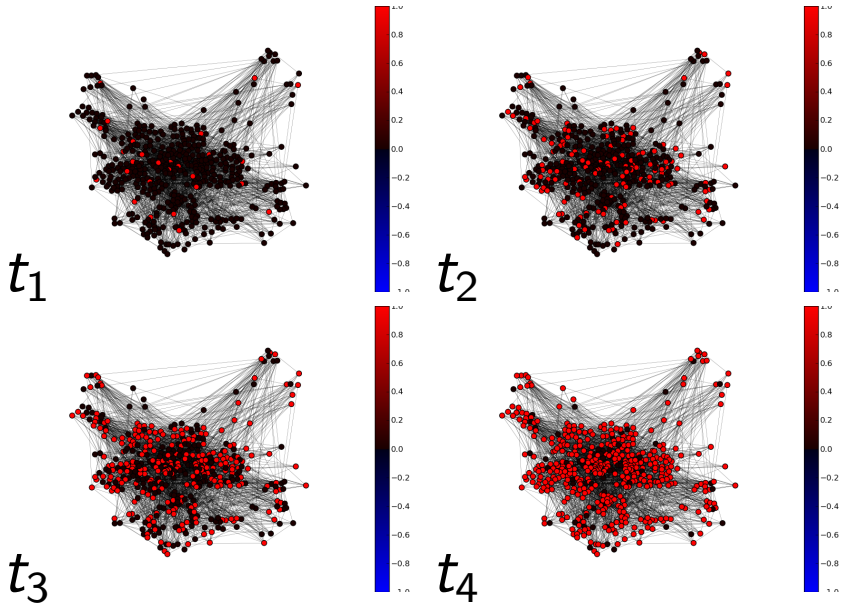
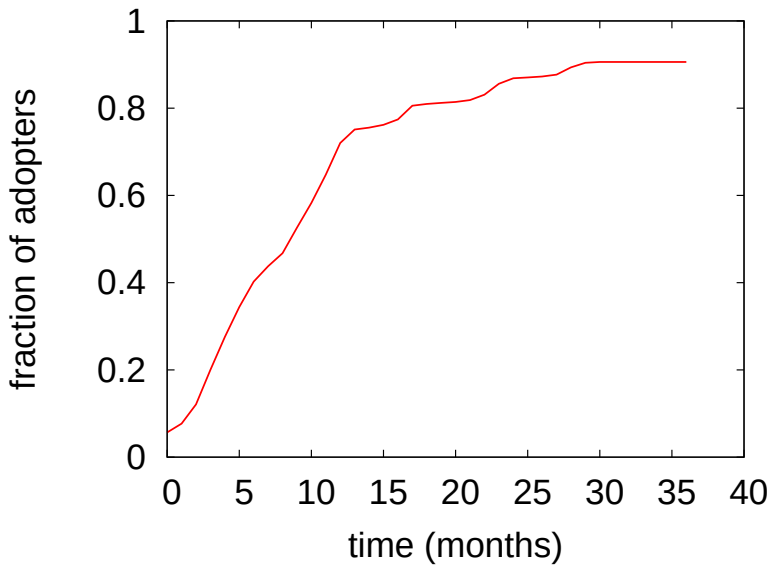


Figure: t_1=0, t_2=4, t_3=9, t_4=27

"Successful" uptake:



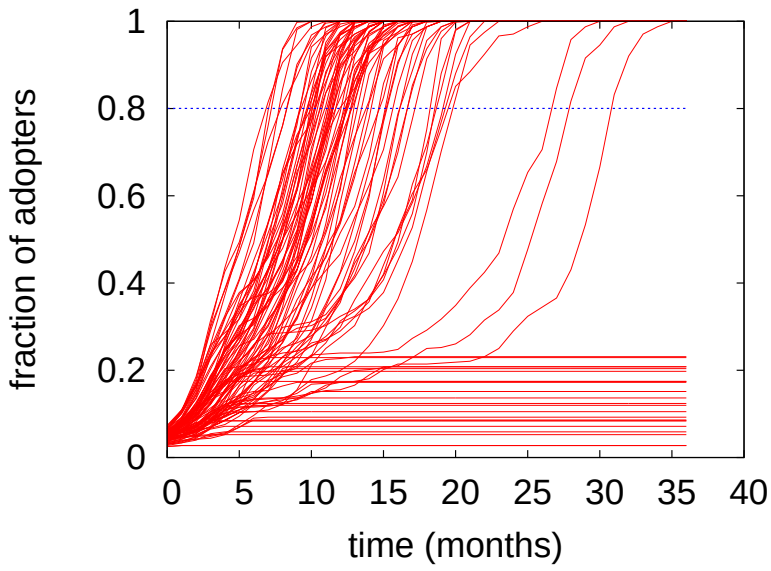
UNIVERSITY OF LEEDS

Sensitivity to Initial Conditions

For a particular network and choice of model parameters:

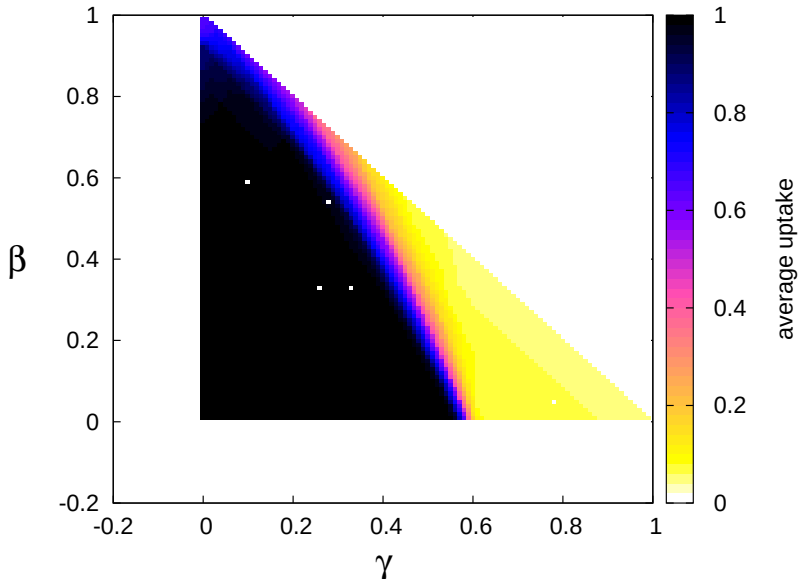
- Same network class can give wildly different results.
- Sensitive to details of network and initial uptake (targeting strategy).
- Find common factors in multiple runs to gain deeper insight
- Need to study *ensemble averages*.

100 realisations:

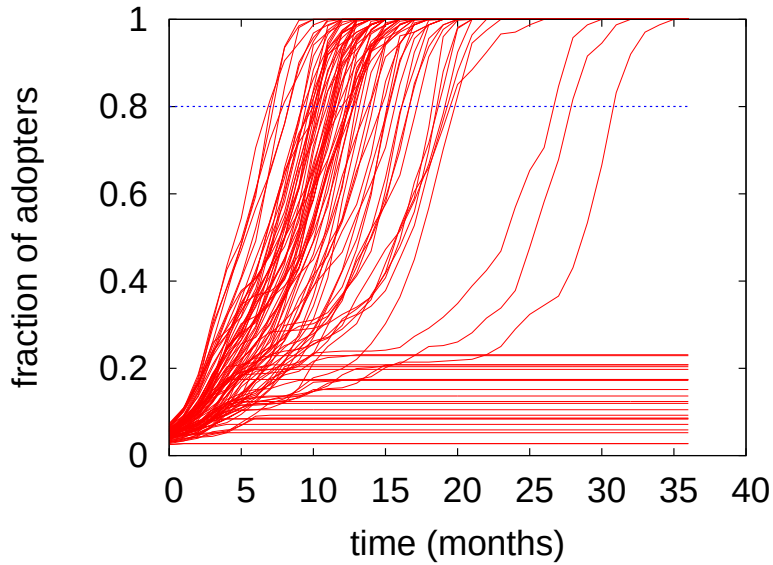


Sensitivity to Model Parameters

For a particular network:



$\alpha = 0.05, \beta = 0.8, \gamma = 0.15$:



UNIVERSITY OF LEEDS

Comparing Network Properties

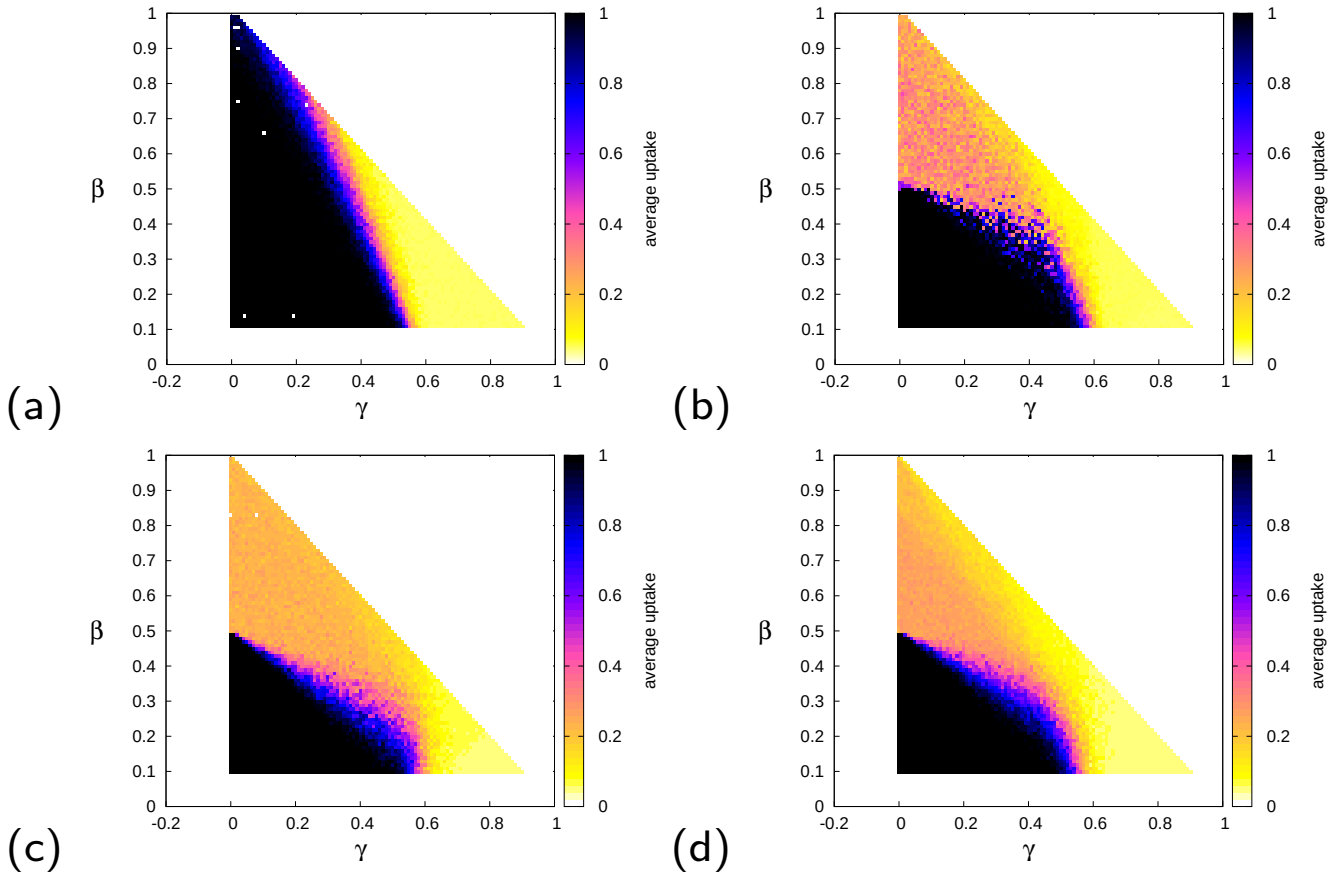


Figure: **(a)**: "Leeds Model". **(b)**: No long-distance (work) links. **(c)**: Random locations, fewer nodes. **(d)**: Half number of links.

UNIVERSITY OF LEEDS

Modelling Interventions

1. Measure effect of different interaction network:
   - can test for sensitivity to and correctness of model network,
   - investigate enhancing network contacts.
2. Measure diffusion with and without a given intervention.
3. Compare possible interventions:
   - reduce costs by providing incentives,
   - targeting communities and opinion leaders,
   - encourage communication using "recommend a friend" schemes.

Potential Recommendations

- Increase network ties for swift transition:
  - incentivise people to spread the word, e.g. by:
    - money back for recommending a friend,
    - money off for groups investing together.
- Make energy more visible to consumers, e.g.:
  - smart meters, showing neighbourhood averages, time-averaged individual (monthly/weekly) spend,
  - potential savings from EE measures,

UNIVERSITY OF LEEDS

S.A. Delre, W. Jager, T.H.A. Bijmolt, and M.A. Janssen.
Will it spread or not? The effects of social influences and network topology on innovation diffusion.
Journal of Product Innovation Management, 27(2):267–282, 2010.

T.W. Valente.
Social network thresholds in the diffusion of innovations.
Social Networks, 18(1):69–89, 1996.