Modelling the effect of social networks on the spread of energy innovations

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CASA, UCL, 6th February 2012

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Future Energy Decision Making for Cities:
Can Complexity Science Rise to the Challenge?

With: Catherine Bale, Timothy Foxon, William Gale, Alastair Rucklidge. (Leeds)

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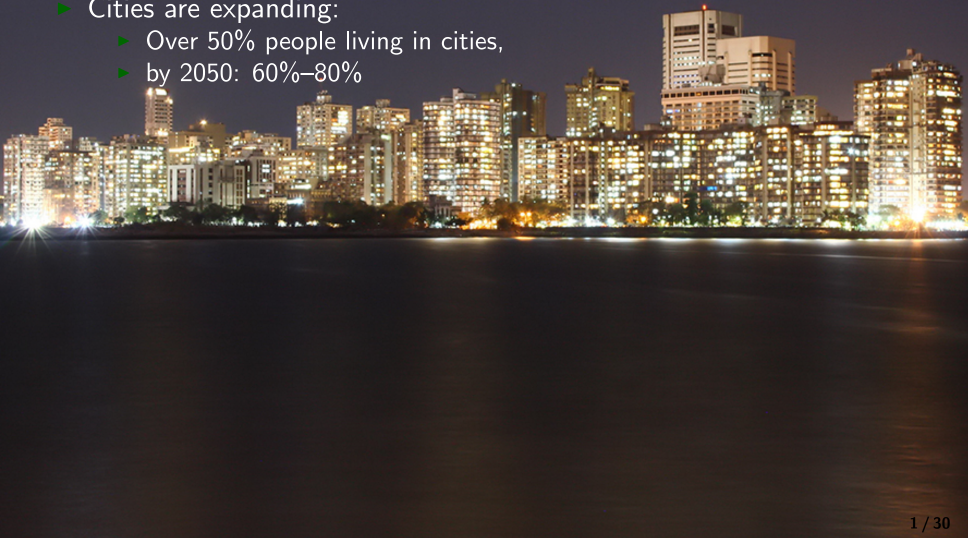
  - by 2050: 60%–80%



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- Buildings consume 20%–40% of total energy.
- Local authorities can influence residents/businesses to reduce energy demand.
- Decision-making tools are needed to support their potential contribution to energy and climate change targets‡.

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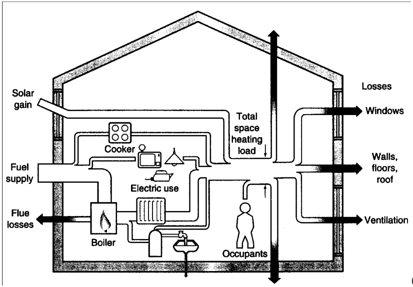
‡: Bale, et al. *"Strategic energy planning within local authorities in the UK: A study of the city of Leeds."* Energy Policy (2012)

- Considering domestic energy use:

- Energy use depends on both technology and behaviour:



Introduction

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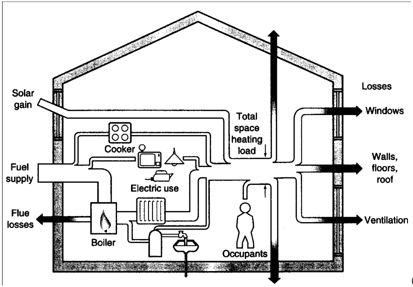
  - use of installed tech & decisions to install.



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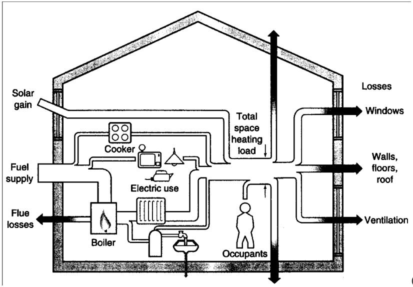

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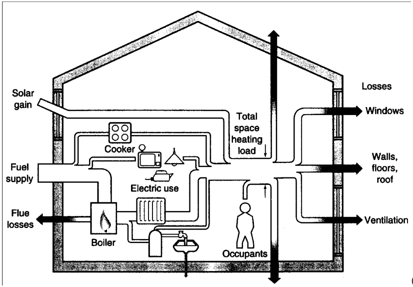

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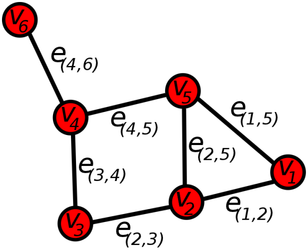
- can we create models of energy innovation uptake?

Diffusion Models

- Individuals are considered as *nodes* on a network.
  - Properties of nodes are associated with variables.

Diffusion Models

- Individuals are considered as *nodes* on a network.
  - Properties of nodes are associated with variables.
- *Links*: interactions where people communicate information with each other about energy.
  - Behaviour *rules* determine dynamics.



Threshold Models

- Current adoption state, $x_i = 0, 1$.
- Uptake based on perceived *"usefulness"* crossing a threshold:

$$\text{future state: } x_i' = \begin{cases} 1 & \text{if } x_i = 1, \\ 1 & \text{if } x_i = 0 \text{ and } u_i > \theta_i, \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

- θ_i: threshold (barriers, costs etc.)

Modelling innovation diffusion

Decisions to adopt can be based on various factors:

a) rational decision-making with regards to the intrinsic value of a product;

b) social spreading of technology or ideas induced by peer-to-peer communication of information;

c) interaction with the "mainstream" via a global feedback:

- e.g. via media, markets etc.

Why is Energy Different?

- Model of uptake of technology.
- E.g. Smart-phones:
  - visible and socially desirable,
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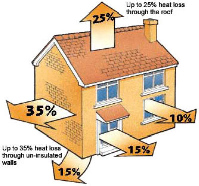
http://www.greendayrenewables.com

Why is Energy Different?

- Model of uptake of technology.
- E.g. Smart-phones:
  - visible and socially desirable,
  - mediated by social contacts between individuals.
- Energy technologies:
  - sometimes visible (solar panels).
  - can be hidden (e.g. loft insulation),
  - decisions based on individual benefit.

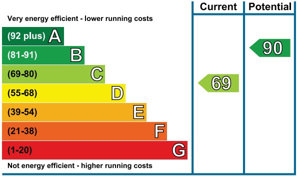
http://www.greendayrenewables.com



http://www.homeinsulationgrants.com

Intrinsic benefit

Energy Efficiency Rating



The graph shows the current energy efficiency of your home.

The higher the rating the lower your fuel bills are likely to be.

The potential rating shows the effect of undertaking the recommendations on page 3.

The average energy efficiency rating for a dwelling in England and Wales is band D (rating 60).

Top actions you can take to save money and make your home more efficient

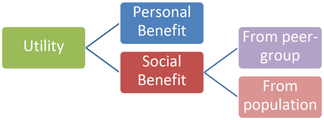
Recommended measures	Indicative cost	Typical savings over 3 years	Available with Green Deal
1 Increase loft insulation to 270 mm	£100 - £350	£87	✓
2 Floor insulation	£800 - £1,200	£123	✓
3 Add additional 80 mm jacket to hot water cylinder	£15 - £30	£69	✓

See page 3 for a full list of recommendations for this property.

To find out more about the recommended measures and other actions you could take today to save money, visit **www.direct.gov.uk/savingenergy** or call **0300 123 1234** (standard national rate). The Green Deal may allow you to make your home warmer and cheaper to run at no up-front cost.

Social aspects of decision-making

- Decision of to adopt based on combination of factors:
  - personal + social benefit[1].



1: Delre et al., *"Will it spread or not? the effects of social influences and network topology on innovation diffusion."* Journal of Product Innovation Management (2010).

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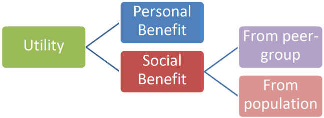

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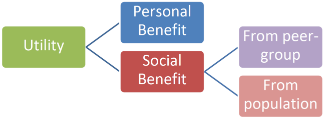
Social aspects of decision-making

- Decision of to adopt based on combination of factors:
    - personal + social benefit[1].
- Intrinsic benefits to individual.
- Social benefit combination of both[2]:
    - personal social network – friends & neighbours,
    - mainstream social norm (society as a whole).



1: Delre et al., *"Will it spread or not? the effects of social influences and network topology on innovation diffusion."* Journal of Product Innovation Management (2010).

2: Valente, *"Social network thresholds in the diffusion of innovations."* Social networks (1996).

Mathematical Model

- Total *utility* to individual[♠]:

$$u_i = \alpha_i p_i + \beta_i s_i + \gamma_i m \qquad (2)$$

- p_i, s_i, m: personal, peer-group and societal influence.
- $\alpha_i, \beta_i, \gamma_i$: relative weightings given to each factor,

♠ McCullen et al., *"Multi-parameter models of innovation diffusion on complex networks"*, SIADS (2013).

Real-world social networks

- Real networks have many features, including:
  - local connections, distant ties, wide spread in degrees, community structure. . .

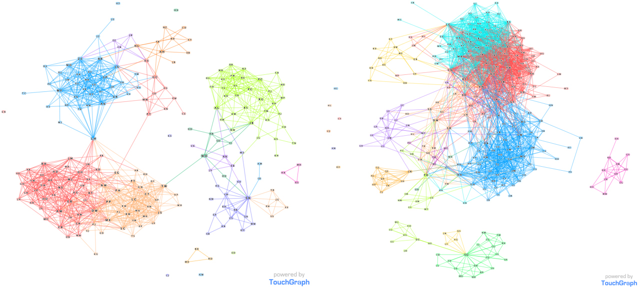
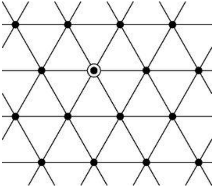


Figure: Inter-friend contacts on the *Facebook* website.

Network models

- Regular lattice:

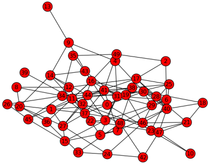


⊕ e.g. city-like geography,

⊕ can have high *clustering*,

⊖ long path-lengths $l \propto d^{1/D}$.

- Random (Erdős Renyí):



⊕ short path lengths $l \propto \frac{\log N}{\log \bar{k}}$,

⊖ no *clustering* $(N \to \infty)$.

"Complex" networks

- Different models reproduce different features.

(a) (b) (c)

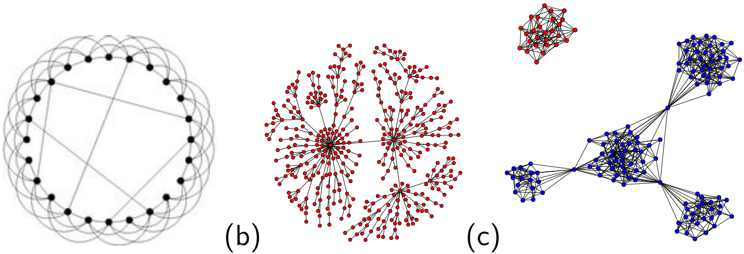
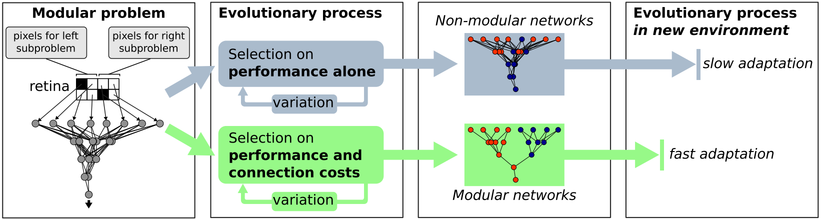


Figure: (a): A *small world* network with random *rewiring* of a regular lattice. (b): A preferential attachment graph which has a *scale-free* degree distribution. (c): A simple model of weakly-connected communities.

Model for Network Modularity

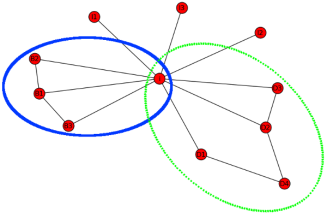
- Selection based on performance and connection costs:



Clune, Mouret and Lipson *"The evolutionary origins of modularity"* Proc. R. Soc. B (2013)

Random Clustered Model*

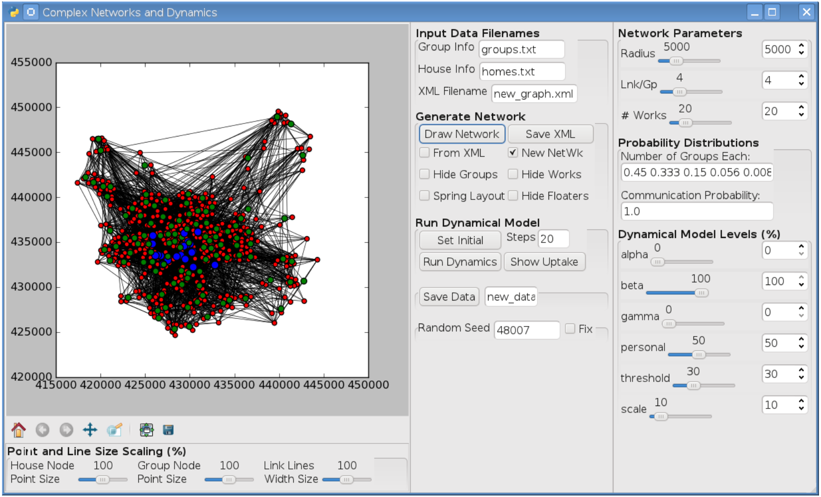
- Each node associated with G *groups*.
- Linked to L others in each group.



- Can also be linked to individuals in wider network.
- Can also impose geography.

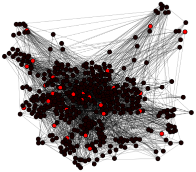
⋆: Newman *"Properties of highly clustered networks."* Physical Review E (2003).

Simulation Demonstration

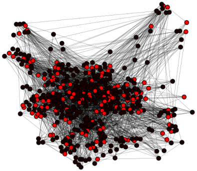


Outcomes — homogeneous case

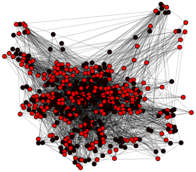
Expected chance of success depends on details:



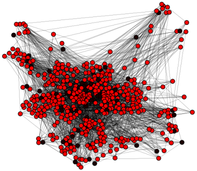
t_1



t_2



t_3



t_4

Outcomes — homogeneous case

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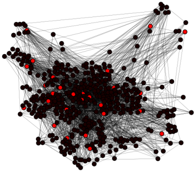
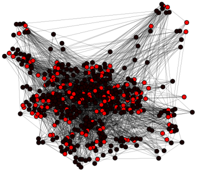
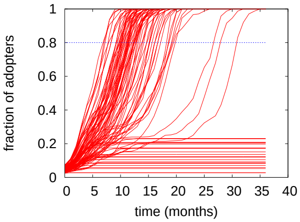
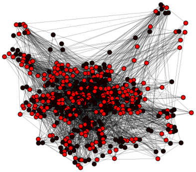


t_1

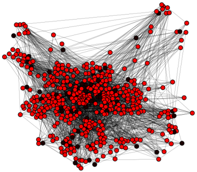


t_2





t_3



t_4

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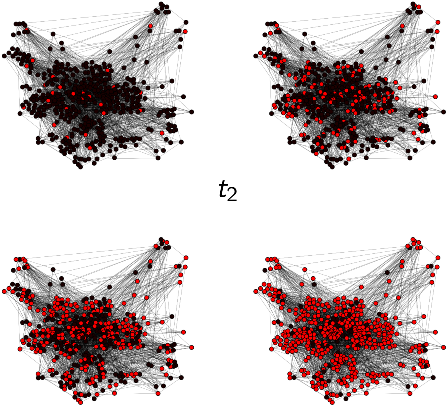
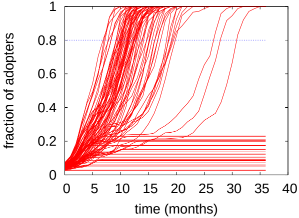
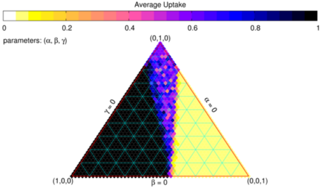


t_1 t_2

t_3 t_4





Analysis of Results

- Given individuals have a certain $\theta, p, \alpha, \beta, \gamma$ and m, require critical fraction of *active* neighbours:

$$s^* = \frac{\theta - \alpha p - \gamma m}{\beta}, \quad (3)$$

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- combining (3) and (4) gives X^* regions of β, γ plots...

Comparison with Watts-Strogatz

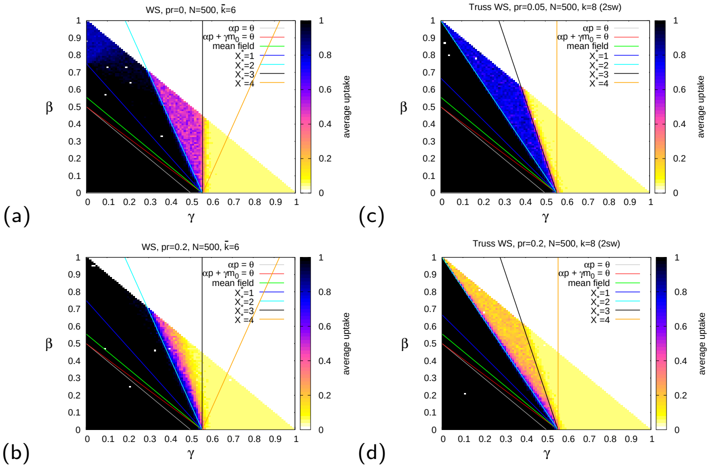

Figure: **(a)** 1D $\bar{k} = 6$, $p_r = 0$, **(b)** 1D $\bar{k} = 6$, $p_r = 0.2$;
(c) truss $k = 8$, $p_r = 0.05$, **(d)** truss $k = 8$, $p_r = 0.2$.

Chance and rate of uptake

- Number of active neighbours can be sufficient by chance with probability†:

$$P(X \geq X^*) = \sum_{n=X^*}^{k} \binom{k}{n} m^n (1-m)^{(k-n)}, \qquad (5)$$

  - $X^* = \lceil k(\theta - \alpha p - \gamma m)/\beta \rceil$.

† assume $k_i = k$ and random network.

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  - $X^* = \lceil k(\theta - \alpha p - \gamma m)/\beta \rceil$.
- This is fraction of remaining $(1-m)$ of individuals to adopt, increasing overall average:

$$\Delta m = (1-m) P(X \geq X^*). \qquad (6)$$

† assume $k_i = k$ and random network.

Effect of initial seed size

$$\Delta m = (1-m)\sum_{n=X_i^*}^{k_i}\binom{k_i}{n} m^n (1-m)^{(k_i-n)},$$

- for small m:

$$\Delta m \sim \binom{k_i}{X_i^*} m^{X^*}. \tag{7}$$

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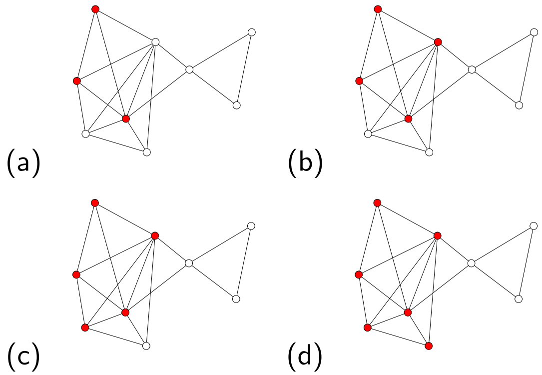
- For $X^* > 1$ disproportionate effect of low initial seed sizes (*"funding"*).
  - E.g. $k = 15$, $X^* = 4$, $\Delta m \sim 1365 m^4$.
    Half initial m_0 takes 8 times as long to reach target.

The Effect of Clustering

Clustering creates non-independent neighbourhoods:



Clustering and Communities

Enhances expected uptake:

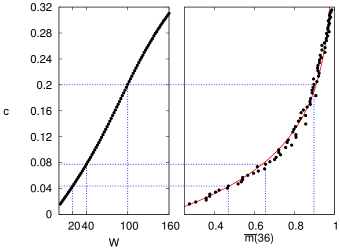


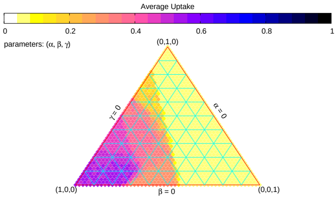
Figure: Expected uptake for clustered random network, with number of *groups* W determining level of clustering c.

- Only one "success" required in network for spreading to occur.

Modelling Inhomogeneity

- Thresholds distributed over three values:

(a)



(b)

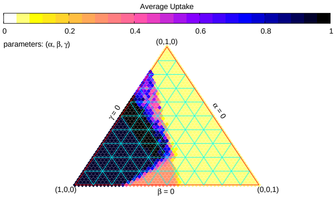


Figure: (a) 28% of $\theta = 0.25$, 17% of $\theta_2 = 0.45$, 5% of $\theta_3 = 0.75$, 50% of $\theta_4 = 1$; (b) 28% of $\theta_1 = 0.25$, 67% of $\theta_2 = 0.45$, 5% of $\theta_3 = 0.75$.

Modelling Inhomogeneous ‘Archetypes’

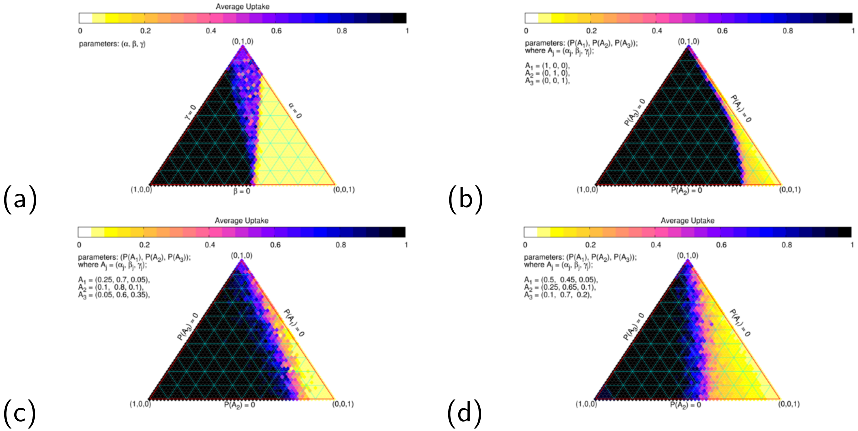


Figure: Other than homogeneous case (a), the population is divided into three archetypes and individual nodes are each assigned to an archetype $A_j = (\alpha_j, \beta_j, \gamma_j)$. (b) $A_1 = (1, 0, 0)$, $A_2 = (0, 1, 0)$, $A_3 = (0, 0, 1)$.
(c) $A_1 = (0.25, 0.7, 0.05)$, $A_2 = (0.1, 0.8, 0.1)$, $A_3 = (0.05, 0.6, 35)$.
(d) Thresholds are also distributed, with: $A_2 = (0.25, 0.65, 0.1)$, $A_3 = (0.1, 0.7, 0.2)$

Inputting real data

- Survey data including info on behaviours.
  - Over 1050 valid responses received from residents of Leeds.
- Data used as a guide rather than definitive source,
  - used to narrow choice of structure and parameter values,
  - also to illustrate potential applications.

Model element	**Parameter**	**Question / Data**
Network	number of active individual / group connections.	Q. on who talks to whom about energy.
Threshold	θ	Q. on house type, tenancy and income.
Node archetypes	α, β, γ	Defra types of pro-enviro. behaviour

Parameterising the Models

Model Feature	**Parameters**	**Data (if used)**
Network structure	N, G, M | W, L	Survey | Assumption
Individual connections	I | L	Survey | Assumption
Group connections	G | L	Survey | Assumption
Archetypes	$A_i = (\alpha_i, \beta_i, \gamma_i)$, $P(A_i)$	Simulation
Threshold	θ | $P\theta$	Survey | Assumption

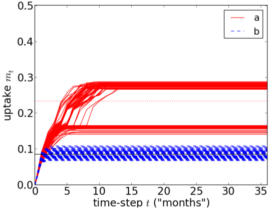
Modelling Scenarios

- Different **scenarios** studied by varying *dynamical model* and *network parameters*.

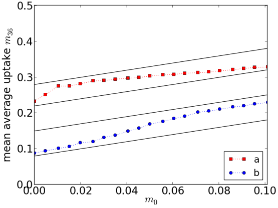
	Baseline	**Seeded**	**Community**	**Incentives**	**Snowball**
Model Param.	Do Nothing	Give efficiency measure to some (random) individuals	Give efficiency measure to whole communities.	Advertise a money off scheme.	Recommend-a-friend discount voucher scheme.
Links	Data based	–	–	–	**Increase**
Threshold	Data based	–	–	**Lower**	**Lower**
Initial Seed	Unforced	**Random**	**Target**	–	–

Comparison of Model Scenarios

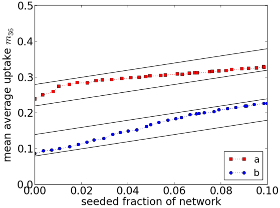
Baseline



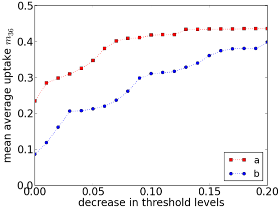
Seeded



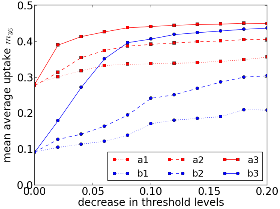
Communities



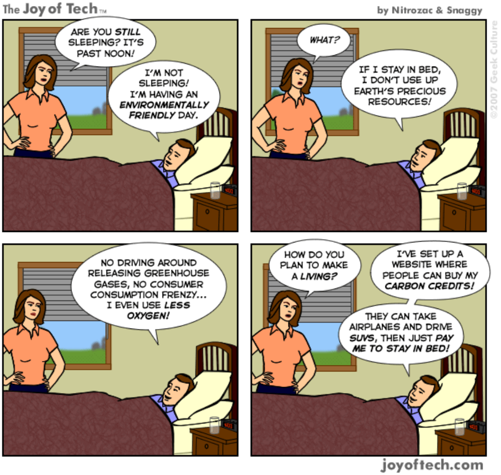
Incentives



Snowball



Other Strategies?



UNIVERSITY OF BATH

FutureBuild 2013

4th – 6th September, 2013
University of Bath, United Kingdom.

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Welcome to FutureBuild 2013

FutureBuild is an international conference and networking event dedicated to the design of the built environment 2030-2050 and beyond. It will investigate what radical and transformative technologies and ideas might be being employed by that date, with a focus on the whole building, energy systems, communities and occupants.

Over the next forty years many of the world's cities are forecast to double in size. There is the expectation that energy systems will largely decarbonize and it is likely that the climate will be markedly different. Buildings built or refurbished at this date and beyond will therefore have very different constraints on them. They will need to be able to provide suitable internal and external climates, use very little energy, integrate fully with a decarbonized and decentralised smart grid and be built in novel ways using novel materials. Such a challenge will require a considerable leap in knowledge in many areas of engineering and architecture, but also urban planning, social science and IT. It will also requirea holistic approach, considering the whole system operation and the lifetime and durability of buildings.

FutureBuild is a platform for the discussion of the challenges, innovative solutions, paradigm shifts, significant step changes, emerging technologies and unconventional ideas needed to create a built environment that is adapted to future needs, while basing these on solid projections and scientific methodologies.

FutureBuild 2013 will mainly concentrate on two of these challenges:**energy demand** and the **adaptation to a future climate**. The unique aspects of the conference are that only the post 2050 world will be considered and that we hope to use the conference as a way of encouraging substantive international research collaborations for future work in this new area.

UNIVERSITY OF BATH

Department of Architecture and Civil Engineering

Research unit for Energy and the Design of Environments (EDEn)

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