Diffusion of innovation within an agent-based model

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Further reading

- P. Przybyła, K. Sznajd-Weron, R. Weron (2013) *Diffusion of innovation within an agent-based model: Spinsons, independence and advertising*, HSC 13/04 (RePEc)
Why diffusion of innovation?

• **Diffusion of innovation** [E. Rogers]
  – process in which an innovation is communicated through certain channels over time among the members of a social system.

• **Innovation**
  – an idea, practice, object that is perceived as new

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Why diffusion of innovation?

- Important, fascinating and highly interdisciplinary – medicine, marketing, sociology, anthropology, etc.
- Simple agents SPINSON = SPIN + PERSON


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Responses to social influence

## How to model conformity?

<table>
<thead>
<tr>
<th>Majority rule</th>
<th>Threshold models</th>
<th>Q-voter</th>
</tr>
</thead>
<tbody>
<tr>
<td>group of influence</td>
<td>all neighbors</td>
<td>group of influence</td>
</tr>
<tr>
<td>absolute majority (or with bias)</td>
<td>majority above threshold</td>
<td>unanimity</td>
</tr>
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</table>

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The general model
How to model social influence?
Opinion dynamics

\[ p(1-f) \quad \text{Independence} \]

\[ (1-p) \quad \text{Conformity} \]

\[ (1-p)(1-h) \quad (1-p)h \quad \text{External field} \]
Why adoption fails?

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Time evolution of adopted

MC simulations, 100x100, p=0.1, h=0.09

The percentage of household penetration for three products in the U.S.


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Let's have a look

You can download *The World According to Spinson (WAS)*, a standalone application for simulating agent-based models, from the IDEAS/RePEc repository: [http://ideas.repec.org/c/wuu/hetcode/zip13001.html](http://ideas.repec.org/c/wuu/hetcode/zip13001.html)
Simulation snapshots

Independence $p=0.01$ and external field $h=0.11$

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Scaling: How many parameters?

- Independence ($p$), flexibility ($f$), external field ($h$)
Adoption on a complete graph

\[ c_{t+1} - c_t = g(c_t) \]
Phase diagram, $f=0.1$
Conclusions

• A simple, „base” model of diffusion of innovation
• Parameters $p, f, h$ as an average in the society
  – Scaling: $\frac{pf}{1-p} = \frac{pf'}{1-p'}$
  – $p$ describes the society and the innovation
• The model reproduces the S-shaped curve
• The innovation
  – Fails for $p<p^*(h), h<h^*(p)$
  – Spreads in the society for $p>p^*(h), h>h^*(p)$
• For the same values $(p, f, h)$ different scenarios
  – The time needed for the ‘take-off’
  – The success of the diffusion
Going green: Agent-based modeling of the diffusion of dynamic electricity tariffs

Anna Kowalska-Pyzalska
16.09.2013
Motivation

- Ambitious goals set by the EU
  - Climate Policy 3x20, Directive 2012/27/EC
- Smart grids
- Energy efficiency of end-users
- Demand Side Management (DSM) /Demand Response (DR) tools
- Diffusion of innovative dynamic electricity tariffs
Goals and contributions of the study

- We focus on the **change of opinions (attitudes)** of electricity consumers
- Using an ABM approach, we show how personal attributes and product features impact opinions of the consumers
Dynamic tariffs

- Price of electricity depends on the balance between supply and demand
  - The role of dynamic tariffs is to flatten the curve and shift demand from on-peak to off-peak hours
  - Role of enabling technologies
Agenda

- Introduction
- Consumers in the electricity market
- Model description
- Results
- Conclusions
Introduction of dynamic pricing, especially when accompanied by enabling technologies, can reduce peak demand up to 44% (Erhard-Martinez et al. 2010; Star et al. 2010)

... and energy consumption can be reduced over 10% (ATKearney 2012; Darby, McKenna 2012)

But...
Low program participation and enrollment rates

- In Illinois, U.S., only 18% of customers were aware that the pilot program was run, only 10% understood the program and only 5% were interested in it; in the end, less than 1% of customers enrolled in the program (Star et al. 2010)

- Only 8% think that energy needs attention and improvement (OFGEM 2010)

- 60-75% of consumers are not willing to shift their consumption to off-peak hours (ATKearney 2012; FORSA 2010; Gerpott, Paukert 2013; Paetz et al. 2012)

- In Italy, 70% of respondents are willing to increase energy savings, only 2% are currently reducing their energy use (Pongilione 2011)
Consumer attitudes towards energy conservation

- Most people are unaware, disengaged and uninterested → indifferent

- Barriers:
  - discomfort of rescheduling, uncertain savings, lack of information, etc.

- Social norms play a significant role in the adoption process

- A great dispersion of customer attitudes towards dynamic tariffs
Agenda

- Introduction
- Consumers in the electricity market
- Model description
- Results
- Conclusions
We consider a set of \( i = 1, \ldots, N \) agents, called spinsons.

Each spinson:

- represents a household
- is characterized by its attitude \( S_i \) toward an innovative dynamic electricity tariff
- If \( S_i = +1 \) the spinson prefers the new dynamic tariff
- If \( S_i = -1 \) the spinson prefers the traditional, uniform tariff
The opinion of each spinson depends on three factors:
- Indifference
- Conformity
- Product features
Indifference

- Lack of importance, insignificance of the topic, care of concern, autonomy of the individuals (Boudon, Bourricaud 2003; Hofstede 2001; Przybyła et al. 2013)

- Reasons for the high level of indifference:
  - Energy is an abstract commodity
    - People are disengaged, uninterested
  - Consumers are confused and unable to evaluate tariffs
    - Lack of information
Conformity – social influence

- ‘Word of mouth’ between a spinson and its neighbors

- If a group of neighbors unanimously shares an opinion, the spinson will also accept it (Asch 1955)

- In energy conservation, social norms have greater impact than other non-normative motivations (Allcott 2011; Ayers et al. 2013; Bollinger, Gilingham 2012; Ozaki 2011; Nolan et al. 2008; Schultz 2007)
The strength of the external field depends on the features of the new dynamic electricity tariff:

- Potential savings
- (Dis)comfort of usage
- Intensity of advertising
Simulation setup

- We run $M$ experiments
- Each experiment consists of $T$ Monte Carlo Steps
- In each MCS, $N$ sub-steps are repeated, where $N$ is the population size
- The outcome of a single MCS is the ratio of convinced spinsons after time $T$
- Average of the ratios of convinced spinsons over $M$ experiments

$$c_m(T) = \frac{\#\{i : S_i(T) = 1\}}{N}$$

$$c(T) = \frac{1}{M} \sum_{m=1}^{M} c_m(T)$$

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\[ p(1 - f) \]

**Indifference**

\[ pf \]

\[ (1 - p) \]

**Conformity**

\[ (1 - p)(1 - h) \]

\[ (1 - p)h \]

**External field**
Agenda

- Introduction
- Consumers in the electricity market
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- Results
- Conclusions
Assumptions

- A square lattice 100x100, $N=10000$ spinsons
- $T = 720$ MCS, $M = 1000$
- Initially all spinsons are down
- Initial values of parameters $p$, $h$ and $f$:
  - High value of indifference ($p > 0.5$)
  - Indifferent agents change opinions with probability $f = 0.5$
  - A weak external field ($h$ close to 0)
Results

Conclusions

- In our model new product adoption is driven by the internal and external influences (Kiesling et al. 2011; Rogers 2003)

- We define immunity of some agents to the social influence as indifference
  - Randomness in the model

- The fact that people are inconsistent in their behavior is modeled by the probability of indifference
  - An agent’s behavior changes in time
Conclusions

- The adoption of dynamic tariffs is virtually impossible due to the high value of indifference in today’s societies.

- If the indifference level of the retail consumers is not reduced, the efforts to smooth the electricity demand via dynamic tariffs will not bring the expected results.
Recommendations

- The indifference level could be decreased by:
  - Education
  - Better advertising of the new dynamic tariffs
    - Offers that are easier to understand
  - Compensating discomfort of rescheduling
  - Higher financial savings
Turning green: Agent-based modeling of the adoption of dynamic electricity tariffs

Katarzyna Maciejowska
18.09.2013
Motivation

- Ambitious goals set by the EU
  - Climate Policy 3x20, Directive 2012/27/EC
- Smart grids
- Energy efficiency of end-users
- Demand Side Management (DSM) /Demand Response (DR) tools
- Diffusion of innovative dynamic electricity tariffs
Dynamic tariffs

- Price of electricity depends on the balance between supply and demand
  - The role of dynamic tariffs is to flatten the curve and shift demand from on-peak to off-peak hours
  - Role of enabling technologies
Introduction of dynamic pricing, especially when accompanied by enabling technologies, can reduce peak demand up to 44% (Erhard-Martinez et al. 2010; Star et al. 2010)

... and energy consumption can be reduced over 10% (ATKearney 2012; Darby, McKenna 2012)

But...
Stylized facts cont.

- Low program participation and enrollment rates:
  - In Illinois, U.S., only 18% of customers were aware that the pilot program was run, only 10% understood the program and only 5% were interested in it; in the end, less than 1% of customers enrolled in the program (Star et al. 2010)

- Discrepancy between attitude and behavior:
  - In Italy, 70% of respondents are willing to increase energy savings, but only 2% are currently reducing their energy use (Pongilione 2011)
Goals and contribution

The goal is to develop an agent-based model, which

- takes into account both social norms and financial incentives
- describes the diffusion of opinions and the adoption process
- explains the intention-behavior gap
- explains low enrollment rates
Agent-based models in electricity markets (demand side):

◦ No distinction between an opinion and a decision (Jackson 2010; Zhang, Nuttall 2011; Zhang et al. 2011)

◦ Modeling only opinions (Kowalska-Pyzalska et al. 2013)

Classical models of innovation diffusion

◦ Model stated-willingness-to-adopt and actual-adoption separately; reasons for the gap – free rider problem, unreliable production (Diaz-Rainey, Tzavara 2012)
Innovation adoption process

1. Knowledge stage – gain knowledge of an innovation
2. Persuasion stage – form an attitude towards it
3. Decision stage – decide to adopt it or reject it
4. Implementation stage – implement it
5. Confirmation stage – confirm the decision
Attitudes and behaviors

1. Principle of aggregation
2. Attitude should correspond closely to the predicted behavior
3. Attitude must be potent
Intention-behavior gap

- Value-action gap, KAP gap, attitude-belief gap
  (Godin et al. 2005; Fennis et al. 2011; Sheeran 2002; Zhang, Nuttall 2011; Ozaki 2011; Blake 1999; Kollmuss, Agyeman 2002; Gadenne et al. 2011; Rogers 2003)

- Possible reasons for intention-behavior gap in electricity markets:
  (Diaz-Rainey, Tzavara 2012)
  - Free rider problem
  - Unstable opinions
    - Consumer confusion, high indifference
  - Lack of sufficient supply
Agenda

- Motivation
- Intention-behavior gap
- Model description
- Results
- Conclusions
Model construction

Opinions

YES  YES  YES  YES

Aggregation

Decision

YES
Model construction

- We consider a set of $i = 1,...,N$ agents, called spinsons
- Each spinson:
  - represents a household
  - at a given time $t$ is characterized by its attitude $S_i(t)$ and decision $D_i(t)$
  - toward an innovative dynamic electricity tariff
Opinions

- Spinson’s opinion may take two values:
  - If $S_i(t) = +1$ the spinson prefers the new dynamic tariff
  - If $S_i(t) = -1$ the spinson prefers the traditional, uniform tariff

- Formulation of the opinion depends on:
  - Social norms and conformity – a spinson shares the opinion of its four neighbors, if they are unanimous (Asch 1955)
  - External field ($h$), which represents product features
  - Indifference ($p, f = 0.5$), which results from
    - An individual’s autonomy
    - Lack of importance of the problem
    - Incomparability of the products
Opinions in the energy market

- External field is weak:
  - Small potential savings
  - Discomfort of usage (change of daily routines)
  - No promotion/advertising

- Indifference is high:
  - Tariffs are difficult to compare
  - Lack of knowledge about consumption patterns
  - Difficulty of quantifying discomfort of adopting
  - Lack of interest
\[ p(1 - f) \quad \leftarrow \quad p(1 - p) \quad \rightarrow \quad pf \]

**Indifference**

**Conformity**

\[ (1 - p)(1 - h) \quad \leftarrow \quad (1 - p)h \quad \rightarrow \quad (1 - p) \]

**External field**
Decisions

- The spinson must possess a **constant opinion** for a certain period of time to make a decision (rule of aggregation)

- Conditional on the past opinions, the spinson:
  - Adopts the innovation, $D_i(t) = +1$, if its opinions are all positive over a decision time
  - Rejects the innovation, $D_i(t) = -1$, if its opinions are all negative over a decision time
  - Does not change its decision, if its opinions fluctuate

- Length of the memory (decision time) is described by parameter $\tau$
Simulation setup

- We run 1000 experiments
- Each experiment consists of $T=720$ Monte Carlo Steps (MCS)
- Square lattice 100x100 of $N=10000$ spinsons is considered
- Results are averaged

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Assumptions

- Examined values of parameters $p$, $h$ and $\tau$:
  - Indifference: $p \in [0,1]$
  - External field: $h \in [0,1]$
  - Decision time: $\tau = 30, 60$

- In an energy market, we should focus on:
  - High values of indifference: $p > 0.5$
  - Low values of field intensity: $h \approx 0$
Agenda

- Motivation
- Intention-behavior gap
- Model description
- Results
- Conclusions
Results for $\tau = 30, 720$ MCS
Results for $\tau = 60, 720$ MCS
Opinions as a function of indifference $p$ and time (measured in MCS) for $h = 0.05$
Decisions, $\tau = 30$

Decisions as a function of indifference $p$ and time (measured in MCS) for $h = 0.05$ and time delay $\tau = 30$
Decisions as a function of indifference $p$ and time (measured in MCS) for $h = 0.05$ and time delay $\tau = 60$
Conclusions – general

- The model has some well known features of diffusion of innovation models:
  - S-shaped curve
  - Existence of the so-called critical mass and valley-of-death, which cannot be obtained within classical theories

- Some minimal levels of indifference and external field are needed for the innovation to be adopted
Conclusions – general

- A simple decision rule is introduced
- For low levels of indifference and a sufficient field:
  - Opinions and decisions are closely related
  - Decisions may exceed opinions (after some time)
- For high values of indifference:
  - There is a gap between opinions and decisions
  - The gap narrows over time, but the process is slow
  - The longer the decision time, the larger the gap
Conclusions – electricity market

- The electricity market is characterized by a high level of indifference and a weak field.
- For indifference level $p = 0.5$ and field $h = 0.05$:
  - The adoption rate is very low, around 10%.
  - More than 50% of spinsons have a positive attitude.
  - There is an intention-behavior gap of around 40%.
- The higher the indifference level or longer the decision time, the lower the adoption rate and larger the gap.
To narrow the gap between opinions and decisions in the electricity market, we should:

- Decrease the indifference level
  - Provide clear and full information to consumers (to reduce the confusion, and to increase the interest)
  - Increase public awareness of the problem
- Shorten the decision time
  - Make it easy to sign a contract (via internet, etc.)
  - Offer consumers easy return to the old contract