Evolutionary Agent - Based Economics: Two applications

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Evolutionary Agent-Based Economics

- Boundedly rational agents (decision makers)
- The role of interaction
- We study economic problems where many of these boundedly rational agents interact.
Evolutionary Algorithms

- Heterogeneous agents
- Competition of alternative strategies
- Selection of strategies that perform better, and
- The possibility of creating new rules
Intermediaries in an electronic trade network

Can intermediaries continue to exist in electronic markets?
Simulation model

![Simulation model diagram]

The diagram illustrates a simulation model with the following components:

- **Producers (P1, P2, P3)**
- **Intermediaries (I1, I2)**
- **Consumers (C1, C2, Cn)**

The model includes trade network connections and strategy base for each type of intermediary and consumer.
Flow of Information

1. Request for price quotes from Intermediary to Producer
2. Price quotes from Producers to Intermediary
3. Request for price quotes from Consumers to Sellers (Producers and Intermediaries)
4. Price quotes from Sellers (Producers and Intermediaries) to Consumers
5. Consumer purchases good directly from Producer, or
   a. Consumer purchases good through intermediary who
   b. instantly purchases the good from the Producer
Consumers

Each trade period consumers take the following steps:

Step 1. Decide which links to form to sellers

Step 2. Choose preferred seller:

- With probability $1 - \epsilon$ (where $\epsilon$ is small)
  
  Preferred seller is the linked seller offering the lowest price

- Or, with probability $\epsilon$

  Preferred seller is a randomly selected linked seller

Step 3. Buy the good from the preferred seller

Step 4. Calculate utility: $- (\text{price} + \text{total search cost})$

Step 5. Update link strategy
Producers

Scenario 1: Producers using a downward sloping demand curve

Step 1 Calculate expected demand, using: $Demand^{exp}(t) = Demand(t - 1)$

Step 2 Determine Price $P$, using $P = a - (b \times Demand^{exp}(t))$

Step 3 Sell the good to buyers

Step 4 Calculate actual demand ($Demand(t)$)
Producers

Scenario 2: Producers using the derivative follower algorithm

**Step 1** If the profits in the previous period are smaller than profits in the previous period

Then reverse direction of price adjustment ($dpa$)

**Step 2** Determine Price $P$,

using: $P = P_{old} \times (1 + (dpa \times \text{stepsize}))$

**Step 3** Sell the good to buyers

**Step 4** Calculate actual profit
Intermediaries

Each trade period intermediaries take the following steps:

Step 1  Decide which links to form to sellers

Step 2  Determine Price,
using: \[ P = Acquisition\ Price \times (1 + \text{markup}), \]

Acquisition Price is the price from the linked seller offering the lowest price

Step 3  Calculate profit (number of units sold \times \text{markup} - \text{costs})

Step 4  Update link strategy
Market dynamics

1. Producers choose their prices
2. Intermediaries form links to producers
3. Intermediaries choose their prices
4. Consumers form links to sellers
5. Consumers buy 1 unit of the good from their preferred linked seller
6. Consumers calculate their utility
7. Consumer search strategies are updated
8. Intermediaries calculate their profits
9. Intermediary search strategies are updated
10. Producers calculate their profits
11. Producers update their prices for the next period
<table>
<thead>
<tr>
<th>Economic model parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Producers</td>
<td>10</td>
</tr>
<tr>
<td>Downward sloping demand</td>
<td>$P = a - b \times \text{Demand}^{\text{exp}}$</td>
</tr>
<tr>
<td>Derivative follower</td>
<td>$P = P \times (1 + (\text{dir} \times \text{step size}))$</td>
</tr>
<tr>
<td>Number of Consumers</td>
<td>40</td>
</tr>
<tr>
<td>Number of Consumer Types</td>
<td>10</td>
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<tr>
<td>Link costs</td>
<td>1</td>
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<tr>
<td>Initial network density cons.</td>
<td>0.2</td>
</tr>
<tr>
<td>Number of Intermediaries</td>
<td>1</td>
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<tr>
<td>Initial network density int.</td>
<td>0.2...1.0</td>
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<tr>
<td>Intermediary markup</td>
<td>5%</td>
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<tr>
<td>EA parameters</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>EA</td>
<td>Simple GA</td>
</tr>
<tr>
<td>Mutation rate</td>
<td>0.02 per bit</td>
</tr>
<tr>
<td>Crossover rate</td>
<td>1.0</td>
</tr>
<tr>
<td>Size of strategy base/population size</td>
<td>20</td>
</tr>
</tbody>
</table>
Simulation environment

Figure 1: Screenshot of the simulation environment.
Scenario 1

Average utility per consumer per generation (25 runs).
Producers use a downward sloping price demand curve

Utility

Generation

- no intermediaries
- intermediary expertise level 0.2
- intermediary expertise level 0.4
- intermediary expertise level 0.6
- intermediary expertise level 0.8
- intermediary expertise level 1.0
Scenario 1

Average fraction of total sales that were made by the intermediary (25 runs)

- Intermediary expertise level 0.2
- Intermediary expertise level 0.4
- Intermediary expertise level 0.6
- Intermediary expertise level 0.8
- Intermediary expertise level 1.0
Scenario 1

Average fraction of sales made by the intermediary (20 runs) when initially all consumers have a link to the intermediary (decreasing demand producers)

Graph showing the fraction of sales through the intermediary over generations for different levels of intermediary expertise.
Scenario 2

Average utility per consumer per generation (25 runs).
Producers use a derivative follower pricing strategy.
Scenario 2

Average fraction sales made by the intermediary (25 runs).
Producers use a derivative follower pricing strategy

Fraction of sales through intermediary

Generation

intermediary expertise level 0.2
intermediary expertise level 0.4
intermediary expertise level 0.6
intermediary expertise level 0.8
intermediary expertise level 1.0
## Scenario 2

<table>
<thead>
<tr>
<th>Expert level Intermediary</th>
<th>Fraction of Intermediated Sales</th>
<th>Average Consumer Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>no intermediary</td>
<td>0</td>
<td>0.89 (0.05)</td>
</tr>
<tr>
<td>0.2</td>
<td>0.03 (0.04)</td>
<td>0.89 (0.05)</td>
</tr>
<tr>
<td>0.4</td>
<td>0.09 (0.03)</td>
<td>0.89 (0.05)</td>
</tr>
<tr>
<td>0.6</td>
<td>0.10 (0.06)</td>
<td>0.89 (0.04)</td>
</tr>
<tr>
<td>0.8</td>
<td>0.19 (0.08)</td>
<td>0.89 (0.05)</td>
</tr>
<tr>
<td>1.0</td>
<td>0.25 (0.10)</td>
<td>0.89 (0.04)</td>
</tr>
</tbody>
</table>

Averages over 25 runs of 40 generations when producers use a derivative follower pricing strategy.
Scenario 2

Average fraction of sales made by the intermediary (20 runs) when initially all consumers have a link to the intermediary (derivative follower producers).
Random production

Average fraction of sales made by the intermediary (20 runs)

Random production

Fraction of sales made by intermediary

Generation

intermediary expertise level 0.2
intermediary expertise level 0.4
intermediary expertise level 0.6
intermediary expertise level 0.8
intermediary expertise level 1.0
Learning to become an expert

Intermediaries learn faster than consumers.

\[
\text{Fraction of sales through intermediary}
\]

Generation (of the intermediary)

IPA herfstdagen 2004 – p.23
Two runs where the intermediary gains substantial market share

- Dotted line: Intermediary expertise level 0.2
- Solid line: Intermediary expertise level 1.0

Graph showing the fraction of sales through the intermediary over generations.
Conclusions

- Intermediaries that are search experts can still make a profit in an electronic market if market dynamics are sufficiently complex.
- Intermediaries can learn to become such search experts and make a profit.
Advertising on a social network

- We consider a firm that has to choose an advertising strategy to introduce a new product.
- Consumers base their purchase decision on the behaviour of other consumers around them.
- Question: Can firms learn about social network structure and consumer characteristics when only limited information is available in order to develop good advertising strategies?
Social Networks

A: Regular Network  B: Small World Network  C: Random Network

The rewiring constant $r_c$ determines the percentage of 'rewired' links in the small world network.
Influence of network topology

A: Star Network
B: Regular Network
Simulation Model
Consumers

Each trade period consumers take the following steps:

1. *Consumers* who have already adopted the innovation talk about the product to their neighbors.

2. A *Consumer* decides to adopt the product if:
   - Word of mouth it receives from its neighbors exceeds its Exposure Threshold.
   - and (in case of negative externalities) Word of mouth it receives from its neighbors does **not** exceed its Over-Exposure Threshold.
Firms take the following steps:

1. Select an advertising strategy
2. Calculate fitness of the strategy:
   \[ \text{Fitness} = \text{Sales} - \text{Advertising costs} \]
3. Update Strategies:
   Update strategy base using a GA
4. Go to 1.
The genetic algorithm

We use a simple genetic algorithm with adapted crossover and mutation operators to model fixed advertising budgets.

Parent 1: 1 0 1 0 1 0

One-preserving Crossover

Parent 2: 0 0 0 1 1 1

C_{cross} = 1

Offspring 1: 1 0 0 0 1 1

Offspring 2: 0 0 1 1 1 0

Parent: 1 0 0 0 1 1

One-preserving Mutation

Offspring: 1 1 0 0 0 1
Diffusion dynamics

Each cycle:

1. *Firms* choose an advertising strategy (from their strategy base)
2. *Consumers* who have already bought the product talk about the product to their neighbors
3. *Consumers* decide whether to (still) adopt the product
   Go to 2. (Repeat for a given number of timesteps)
4. Firms calculate their profits
5. Firms update their strategies for the next period
## Parameter values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of consumers</td>
<td>1000</td>
</tr>
<tr>
<td>Degree</td>
<td>1-20</td>
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<tr>
<td>Rewiring constant ((rc)) (Small World network)</td>
<td>0.05</td>
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<tr>
<td>Exposure Threshold</td>
<td>0.0-0.5</td>
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<tr>
<td>Number of initially targeted consumers</td>
<td>10</td>
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<tr>
<td>Diffusion time (during learning)</td>
<td>10-50</td>
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<tr>
<td>Generations</td>
<td>20</td>
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<tr>
<td>number of strategies</td>
<td>50</td>
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<tr>
<td>Pone-mut</td>
<td>0.1</td>
</tr>
<tr>
<td>Pone-cross</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Homogeneous Consumers

Informational Cascades – Directed versus Random Advertising

(Average) Degree of the Network

Critical Exposure Threshold

- Regular Networks
- Small World Networks
- Random Networks

Learned Strategies
Random Advertising
Heterogeneous Consumers

Directed versus Random Advertising:
Size of the diffusion as a function of the degree of the network

Number of Consumers that have adopted the product after 1000 steps

(Average) Degree of the network

Learned Strategies
- Random Advertising
Diffusion Times

Diffusion as a function of time

- Regular network
  - Connectivity 5
- Small World network
  - Connectivity 5
- Random network
  - Connectivity 5

- Regular network
  - Connectivity 20
- Small World network
  - Connectivity 20
- Random network
  - Connectivity 20

Legend:
- Learned strategy
- Random Advertising
Evolved strategies

- Firms target consumers with a high exposure threshold
- Firms target well-connected consumers
- Firms target isolated consumers
Summary

Firms can learn a directed advertising strategy based on aggregate information. These learned strategies take into account both the topology of the social consumer network and the characteristics of the individual consumers.