An Evolutionary Framework for Determining Heterogeneous Strategies in Multi-Agent Marketplaces

Wolf Ketter

Dept of Decision and Information Sciences

RSM Erasmus University

Carlson School of Management - University of Minnesota

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Work done with: Alexander Babanov and Maria Gini.

Overview

- Motivation
- Evolutionary Approach
- Citysim Model
- Analytical Model
- Simulation Results
- Future Work Discussion

Problem Domain

Automated and mixed-initiative multi-agent systems in emerging electronic markets:

- limited resources and competitive environment;
- dynamic with unlimited time frame;
- heterogeneous and complex;
- open environment.

Objective

Study performance of agents' strategies in multiagent systems using an evolutionary framework.

- Find out which agent strategies are good for which market conditions.
- Perform comprehensive testing of electronic market implementations.

Potential Candidate Approaches

- Real market data analysis? Requires real data, which is often either private or inadequate or both. Some emerging electronic markets have no mapping to the real world.
- Analytical analysis? Requires a lot of simplifications contradictory to the domain.
- Competition? Requires strict rules and closing date, disregards non-transitivity, requires fixed market structure on competitors' side.

Evolutionary Approach (1)

General Characteristics:

- Controllable environment and data collection.
- A large range of problems can be studied.
- Testing over a long-time period is possible.
- The type and number of agents change frequently.
- Reputation building is a vital part of any real system.
- Fully specified strategies.

Evolutionary Approach (2)

Generalized setup:

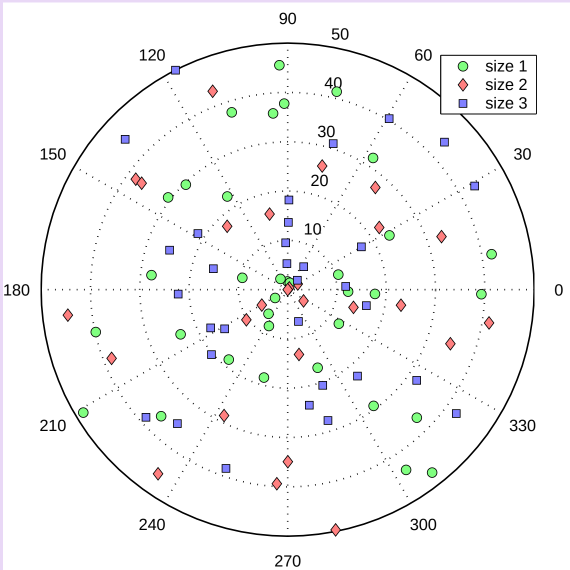
- a dynamic society of many customer and supplier agents
- who enter the market with one of available strategies and initial parameters as determined by a reproduction rule
- and survive in the market according to their accumulated wealth.

Traditional Economics vs Complexity Economics

Some assumptions in economics and game theory may not be valid or useful in building agents for the real world.

- Rational agents vs. bounded rational "satisficing" agents (Simon 2001)?
- Homogeneous agents vs. heterogeneous agents?
- Descriptive agents vs. computational and resource bounded agents?
- Long-run equilibrium vs. path to equilibrium and non-equilibrium processes?

The Citysim Model



- Simulation of a society of suppliers of a service and their customers.
- The agents live and interact in a circular monocentric city.

The simulation is based on a supply and demand model,

- where multiple service providers compete for customers, and
- where profitability is the criterion to stay in business.

Customer Agent (1)

- Anonymous customers come to the market for a single transaction, with a fixed frequency λ^{c}:

$$t^{\mathrm{c}}_{i+1} = t^{\mathrm{c}}_i - \frac{1}{\lambda^{\mathrm{c}}} \log U[0,1]$$

  where $U[x,y]$ is a random variable distributed uniformly on the interval $[x,y]$.

- The location of a new customer in polar coordinates is determined by the following rules:

$$r \sim U[0,R] \qquad \text{and} \qquad \alpha \sim U[0,2\pi)$$

Customer Agent (2)

- Density of customers is inversely proportional to the distance from the city center.
- A customer minimizes its net cost:

$$\text{net cost} = \text{price} + \text{distance} \times c^{\text{mile}} + \text{delay} \times c^{\text{hour}}$$

- Customers do not change their properties during the simulation.

Supplier Agent (1)

- Suppliers are characterized by their pricing strategy, and the number of customers they can serve concurrently (size).

$$\text{agent type} = \langle \text{strategy}; \text{size} \rangle$$

- A type is represented in the market by the corresponding *supplier generator*.
- Each supplier is audited at regular time periods and removed from the market if its profit becomes negative.
- The society of suppliers evolves to meet the demands of the customers.

Supplier Agent (2)

Work costs, $c^{\text{work}}(s)$, and idle costs, $c^{\text{idle}}(s)$, for a supplier decrease with its size, s, to simulate economies of scale:

$$
\begin{aligned}
c^{\text{work}}(s) &= c^{\text{work}}(1) \times (1 - g)^{s-1} \quad \text{for} \quad s \geq 2 \\
c^{\text{idle}}(s) &= c^{\text{idle}}(1) \times (1 - g)^{s-1} \quad \text{for} \quad s \geq 2
\end{aligned}
$$

where $c^{\text{work}}(1)$ and $c^{\text{idle}}(1)$ are constants and g determines a gain due to the supplier's size.

Reproduction of Strategies (1)

Two-layered evolutionary learning:

1. **Auditor:** Evaluates the performance of supplier agents' strategies based on suppliers' average profit over a specified period of simulation time.

2. **Generator:** Maintains a pool of information concerning the history and the current state of its type suppliers.

Reproduction of Strategies (2)

Generalized two-layered reproduction rule:
Auditor (Upper Layer):

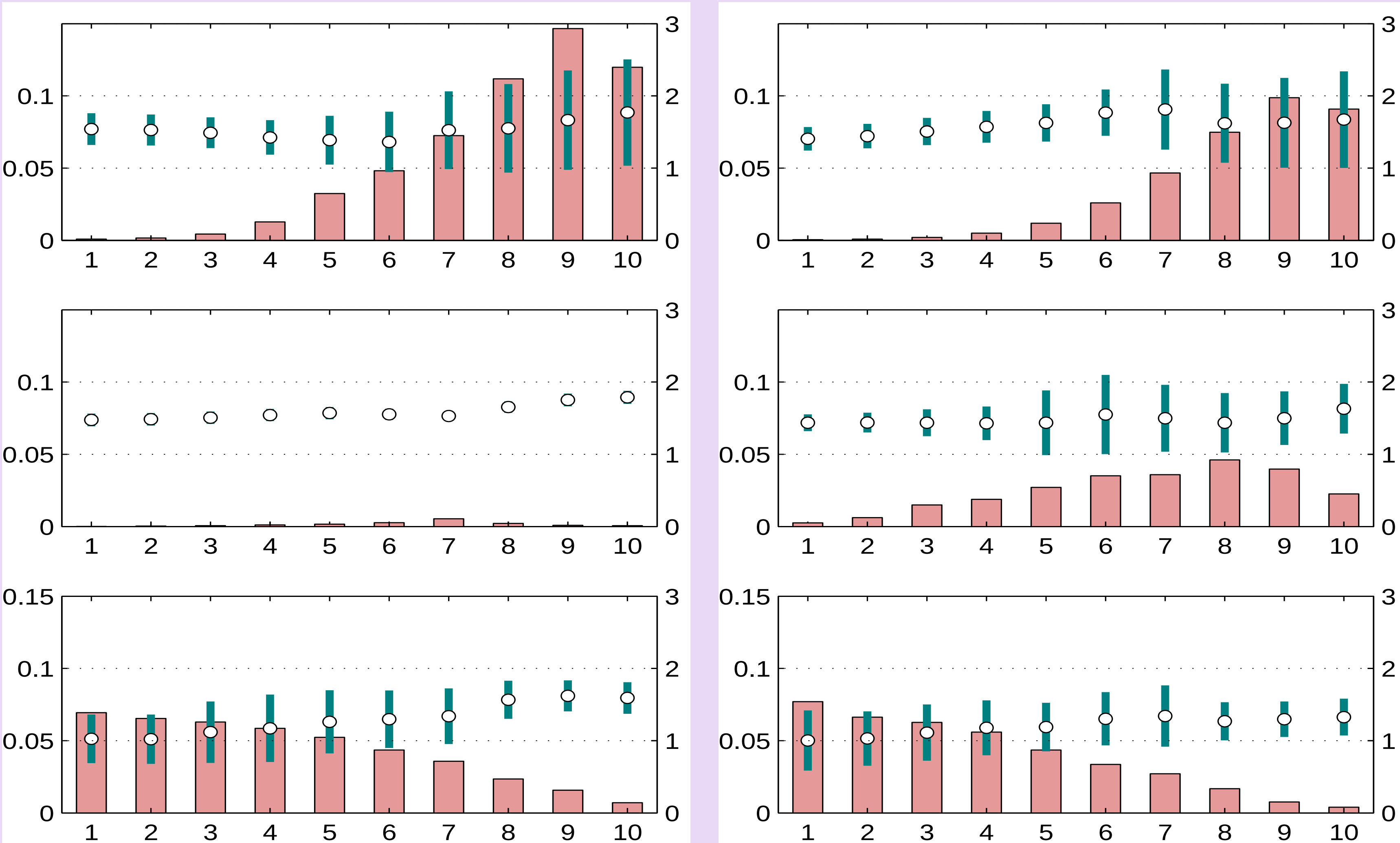
- Agents that make negative profit are removed from the market.
- The probability that a particular type will enter the market next is proportional to the number of its type that are surviving in the market.
- There is a small probability (*noise*) that a new supplier is assigned a type at random.

Reproduction of Strategies (3)

Generalized two-layered reproduction rule:
Generator (Lower Layer):

- General initial parameters based on general demographic information.
- Call a strategy-specific reproduction rule to select the rest of the initial parameters based on the initial parameters of all currently present agents of the same class.

Reproduction of Strategies (4)



Example of pools for a type of supplier.

Sample Simulation with Two Different Strategies:

Market Sampler samples the city in several locations to maximize a potential revenue flow given the state of the market. The price and the number of samples it takes are assumed to be distributed normally.

Price Seeker assumes that the “right” price and density of the suppliers depend solely on the distance from the center of a city.

Why these Two Different Strategies?

- The selected strategies exhibit sufficiently different behavior.
- The strategies were designed, so that neither strategy has a strict advantage over the other.
- Because of that, the strategies can coexist and evolve in the market at the same time.
- The supplier accepts whatever location and price was suggested by its generator and never alters them.
- Only generators are capable of learning and adapting to the market situation.

Analytical Model

Assumptions on the equilibrium state of the market:

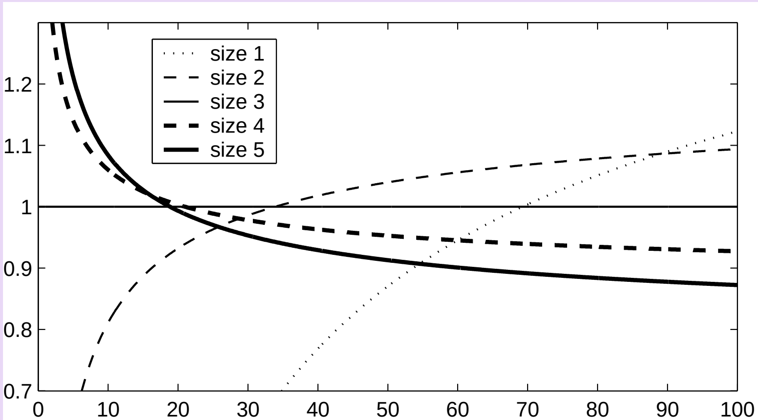
Assumption 1 *Suppliers operate at zero profit without idle periods, and do not discriminate between customers.*

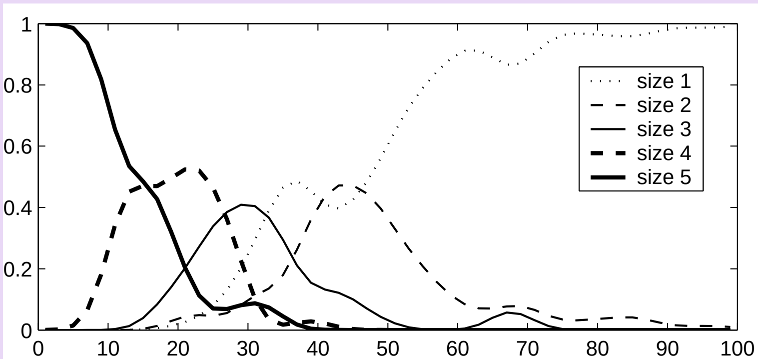
Assumption 2 *The market area of a single supplier is small relative to the size of the whole city,*

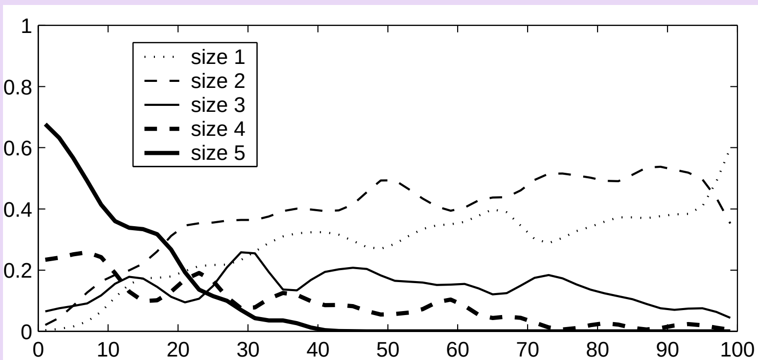
Assumption 3 *Market areas are circular and do not interfere.*

Assumption 4 *Inside each market area customers arrive at regular intervals.*

Reality Check Experiments







Theory:

$\gamma(3, s, \cdot)$ for $s = 1, \ldots, 5$

Practice:

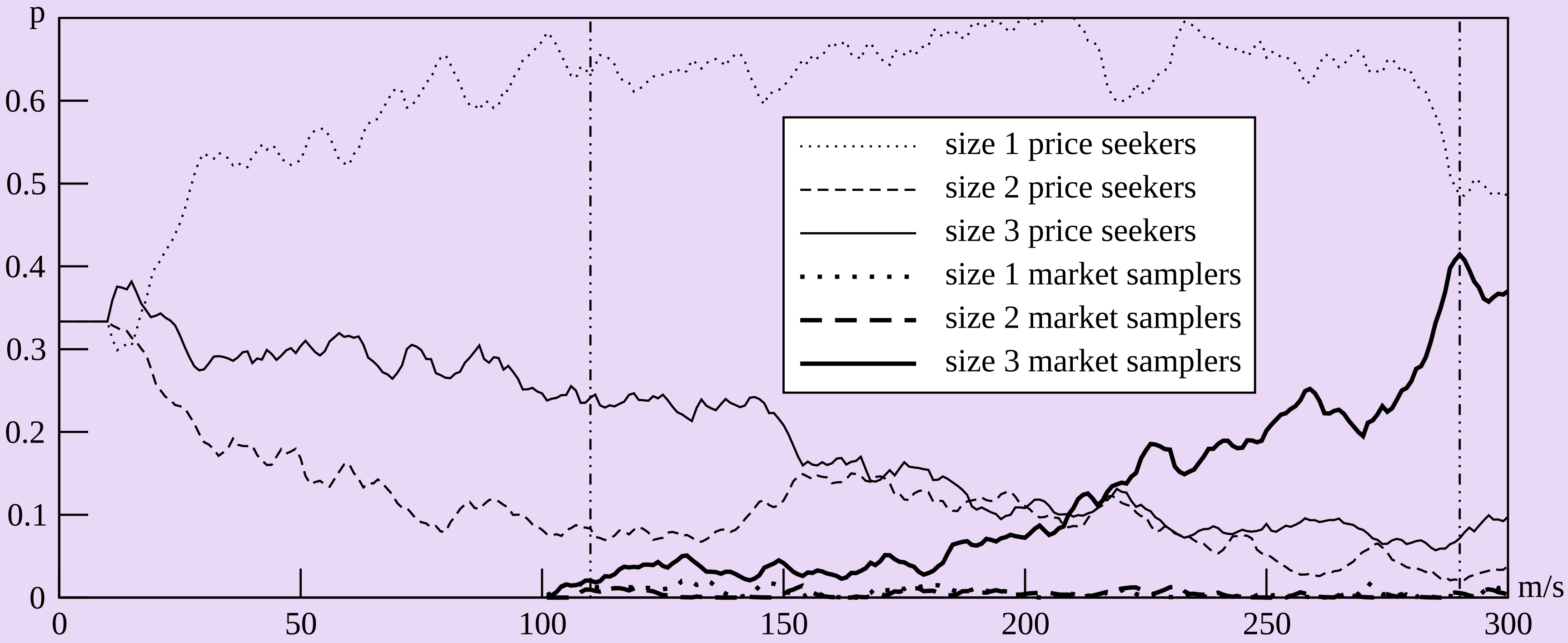
Percentage of capacity provided by suppliers of each size for price seekers

Practice:

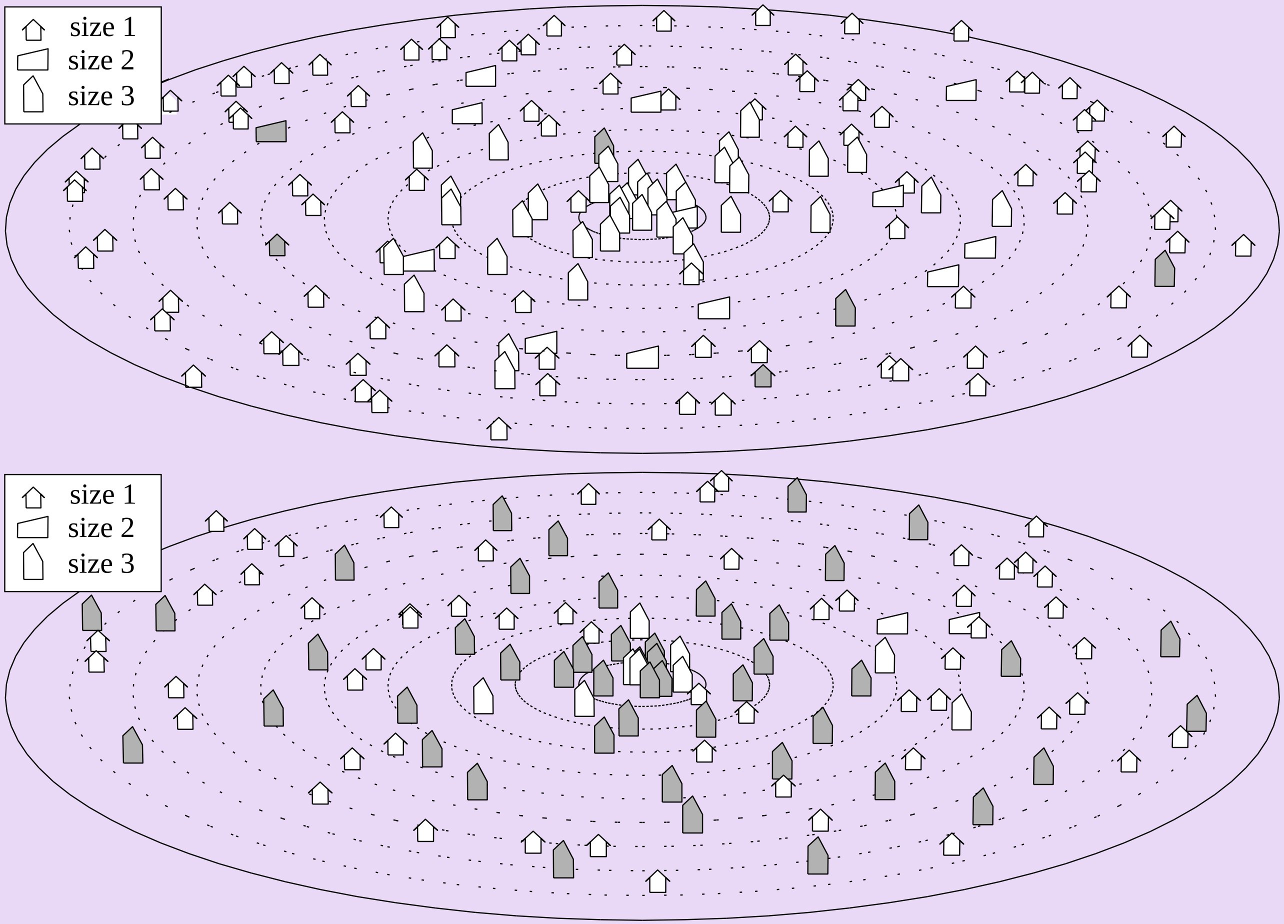
Percentage of capacity provided by suppliers of each size for market samplers

Simulation Time-Line: Supplier Entry Experiment

Probabilities of a new supplier entry for different supplier types as a function of milestone numbers. Market sampler suppliers are introduced at milestone 100.



Results: Structure of the City

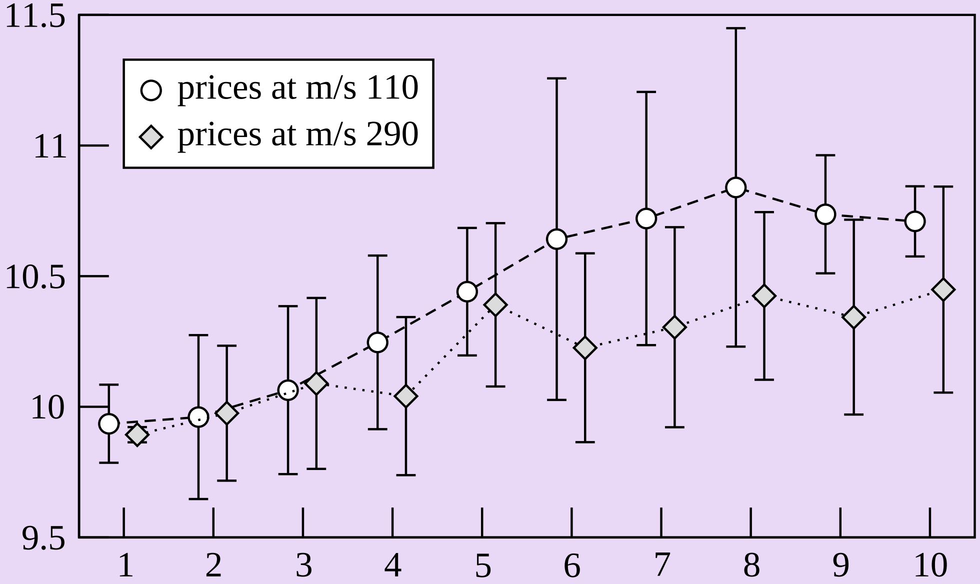


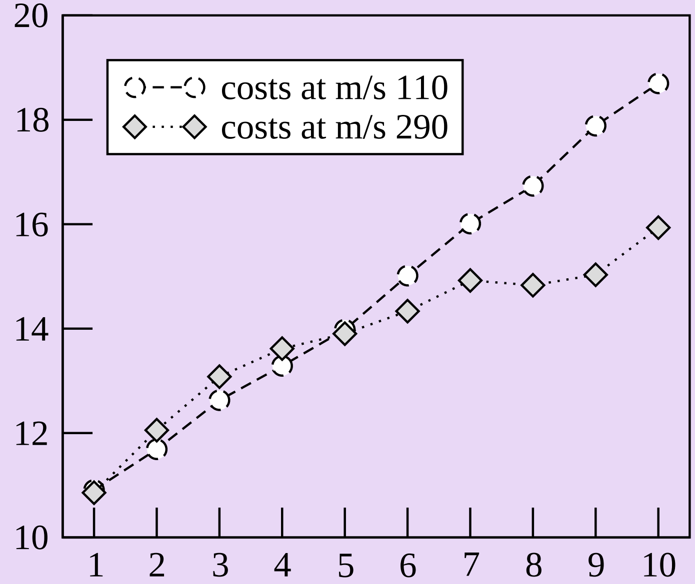
City at milestone 110 (top) and 290 (bottom).

Price seeker suppliers are denoted by white houses, market samplers are gray.

Price Distribution

Average supplier prices with standard deviations (left) and 25 hour half-life decaying averages of customer costs (right) for 10 concentric city zones at milestones 110 and 290.





Why another Evolutionary Framework?

- Heterogeneous strategies can co-exist and evolve. New agents are created by choosing the type and general initial parameters using statistical information on the number of existing agents of the same type.
- Agents with different strategies can enter the market at any time.
- Strategies never disappear. Even when no agents using a specific strategy are left in the market, the probability of creating new agents using that strategy never becomes zero.

Future Work Discussion

- Add rental cost dependant on density of neighbors?
- Add wealth distribution?
- Introduce individual agent learning?
- Bootstrap the model with real data?
- Mixture of strategies?
- ?

Contact:
email: `wketter@rsm.nl`
URL: `http://www.ketter.ws`

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Contact and Description:

email: wketter@rsm.nl
URL: http://www.ketter.ws

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