

Multi-agent approach to simulation of the greenhouse gases emission permits market

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Classical market behavior analysis

- Static optimization model;
- Game-theoretic approach.

Agent-based analysis

- Parties are represented by intelligent programming agents;
- Agents negotiate and trade the goods;
- Trade is done according to given market rules and the information available to the agents

Proposed market model assumptions

- No ideal market assumption;
- Neither equilibrium prices, nor the dynamic trading without taking prices into account;

Dynamic market model

- Price negotiation;
- Influence of real prices on the agent behavior;
- The number of transactions is not known in advance;
- Only transactions profitable for both participants are accepted during simulations;
- Profitable transactions moves market toward equilibrium.

General market model

- N parties trading the emission permits;
- Each party has pre-allocated K_n permits – “the Kyoto targets”;
- At the compliance time the party must not emit more than the number of permits it possess;
- Party may freely sell or buy permits to achieve the target;

Centralized market model (with the central planner)

$$\min F(\mathbf{K}) = \sum_{n=1}^N c_n(K_n), \quad \mathbf{K} = (K_1, \dots, K_N) \quad (1)$$

subject to

$$\sum_{n=1}^N K_n = K_0 \quad (2)$$

Marginal costs (using the Lagrange method)

$$\lambda = -c'_n(K_n), \quad n = 1, \dots, N \quad ; \quad \sum_{n=1}^N K_n = K_0 \quad (3)$$

Solution for every party – minimize the total cost

$$\min f_n(x_n, y_n) = c_n(x_n) + \lambda y_n \quad (4)$$

subject to

$$x_n \leq K_n + y_n \quad (5)$$

Problem – Solution

Problem – limited knowledge

- The central planner does not know cost functions $c_n(x_n)$;
- Dynamic trade process;
- Parties don't know the optimal price level λ .

Solution – dynamic bilateral trading

- Two parties meet randomly and exchange the permits;
- The exchange occurs if it is feasible for both parties;
- Any feasible transaction increases the value of the common cost function, at least for small enough number of traded permits.

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Alternatives for agent to find a good partner

- Choose a partner randomly – bilateral trade;
- Tender;

Tools for analysis

- Specialized, multi-criteria evolutionary algorithm;
- Multiagent platform for multicommodity exchange.

Multi-agent system

Multi-agent system definition

- System composed of two or more autonomous software agents;
- Agents communicate with each other and striving for their own purposes;
- Multi-agent system should achieve some overarching objectives;
- The multi-agent system does not implement these objectives directly, but through individual objectives of each of the agents and their interactions;

Agent in multi-agent system

- Each agent represents single party, guided by its own interests;
- Agent comes to interact with others;
- Its motivation is the desire to achieve certain gains from the exchange of permits;

Evolutionary algorithm (EA)

Evolutionary algorithm description

- EA are based on the phenomenon of natural evolution;
- Like in the nature, they operate on a population of individuals;
- Individuals are reproduced, modified and evaluated;
- The best of them are selected in a sequence of generations.
- Individuals are encoded solutions of the solved problem;
- They are modified by evolutionary operators:
 - random changes (mutation);
 - recombination of parent genes (crossover);
 - the best ones are selected as members of the next generation (selection).

Specialized version of the evolutionary algorithm

Agent-based evolutionary algorithm

- Individuals contain information to be used in simulation;
- The information needed to describe all actions of population is encoded in genome structure.

Genome structure

- the marginal cost associated with a give number of permits possessed by the country (shadow price);
- the real current price of a permit for sale/purchase;
- the real current value of a permit for sale/purchase;
- current number of units for sale/purchase;
- the net number of units sold/purchased ;
- current emissions level;
- previous emissions level (before the present transaction);
- present and previous value of the objective function.

Implementation

Evolutionary algorithm – genetic operators applied

- Bilateral trade;
- Tender.

Multi-agent platform – roles and behaviors of agents applied

- Roles of negotiating agent and the Morris Column agent;
- Bilateral trade and the tender behaviors implemented.

Preliminaries

- Five parties: USA, EU, Japan, CANZ (Canada, Australia, New Zealand) and EEFSU (East European and Former Soviet Union);
- Each party n knows:
 - CO2 emission limits (Kyoto limits) – K_n ;
 - Business as usual emissions (BAU) – $x_{0,n}$
 - Functions of cost reduction c_n ;

Cost function

$$c_n = \begin{cases} a_n(x_{0,n} - x_n)^2 & \text{for } x_n < x_{0,n} \\ 0 & \text{for } x_n \geq x_{0,n} \end{cases}$$

Shadow price

$$p_n = \begin{cases} 2a_n(x_{0,n} - x_n) & \text{for } x_n < x_{0,n} \\ \min & \text{for } x_n \geq x_{0,n} \end{cases}$$

- The variable x_n stands for the current emission;
- The min means the minimum price value (introduced for more realistic prices calculation);

Party	BAU emission $x_{0,n}$ [MtC/y]	Cost function parameter a_n [MUSD/(MtC/y) ²]	Kyoto limit K_n [MtC/y]
USA	1 820.3	0.2755	1251
EU	1 038.0	0.9065	860
Japan	350.0	2.4665	258
CANZ	312.7	1.1080	215
EEFSU	898.6	0.7845	1314

Table: Data for the case study [1]



[1] Horabik J. (2005) On the costs of reducing GHG emissions and its underlying uncertainties in the context of carbon trading. Report no. RB/34/2005, IBS PAN

Party	Final emission	Last transaction price	Corresponding marginal price (shadow price)	No. of traded permissions	Permission cost	Reduction cost
	[MtC/y]	[USD/tC]	[USD/tC]	[MtC/y]	[MUSD/y]	[MUSD/y]
USA	1 556.7	143.58	145.24	305.7	48 472.41	19 147.46
EU	960.2	129.52	141.05	100.2	14 025.68	5 487.95
Japan	321.2	123.81	142.07	63.2	10 539.82	2 049.17
CANZ	249.0	142.30	141.16	34.0	2 001.36	4 497.47
EEFNS	811.9	141.68	137.60	-503.1	-75 039.30	6 040.79

Table: Results of simulation using evolutionary method, **bilateral contracts**

Party	Final emission	Last transaction price	Corresponding marginal price (shadow price)	No. of traded permissions	Permission cost	Reduction cost
	[MtC/y]	[USD/tC]	[USD/tC]	[MtC/y]	[MUSD/y]	[MUSD/y]
USA	1 559.83	142.09	143.52	308.83	59 794.97	18 692.00
EU	959.45	142.47	142.41	99.45	20 837.18	5 593.85
Japan	321.62	138.89	140.00	63.62	13 736.11	1 987.87
CANZ	248.44	141.91	142.40	33.44	3 768.45	4 575.90
EEFNS	808.66	141.72	141.12	-505.34	-98 136.71	6 346.66

Table: Results of simulation using multi-agent system, **bilateral contracts**

Party	Final emission	Last transaction price	Final price (shadow price)	No. of traded permissions	Permission cost	Reduction cost
	[MtC/y]	[USD/tC]	[USD/tC]	[MtC/y]	[MUSD/y]	[MUSD/y]
USA	1 561.3	124.70	142.71	310.3	34 901.88	18 480.87
EU	959.1	125.34	143.05	99.1	11 074.84	5 643.23
Japan	321.1	137.41	142.56	63.1	7 169.71	2 060.27
CANZ	248.1	139.74	143.15	33.1	3 588.01	4 623.96
EEFNS	808.4	138.61	141.52	-505.6	-56 733.70	6 382.91

Table: Results of simulation using evolutionary method, **tender**

Party	Final emission	Last transaction price	Corresponding marginal price (shadow price)	No. of traded permissions	Permission cost	Reduction cost
	[MtC/y]	[USD/tC]	[USD/tC]	[MtC/y]	[MUSD/y]	[MUSD/y]
USA	1 559.87	143.50	140.61	308.87	67 843.58	18 686.02
EU	959.92	141.56	142.74	99.92	21 316.12	5 527.12
Japan	321.36	141.28	141.20	63.36	15 904.28	2 023.62
CANZ	248.57	142.11	142.00	33.57	2 359.59	4 558.17
EEFNS	808.28	141.71	141.52	-505.72	-107 423.57	6 400.43

Table: Results of simulation using multi-agent system, **tender**

Party	Final emission	Last transaction price	Final price (shadow price)	No. of traded permissions	Permission cost	Reduction cost
	[MtC/y]	[USD/tC]	[USD/tC]	[MtC/y]	[MUSD/y]	[MUSD/y]
USA	0.20%	1.05%	1.20%	1.01%	94.56%	2.46%
EU	0.08%	9.05%	0.95%	0.75%	43.14%	1.92%
Japan	0.13%	10.54%	1.45%	0.67%	10.66%	2.96%
CANZ	0.23%	0.27%	0.87%	1.70%	10.99%	1.69%
EEFNS	0.40%	0.03%	2.46%	0.44%	31.28%	4.75%

Table: Comparison of the multi-agent and evolutionary methods – **bilateral contracts**

Party	Final emission	Last transaction price	Corresponding marginal price (shadow price)	No. of traded permissions	Permission cost	Reduction cost
	[MtC/y]	[USD/tC]	[USD/tC]	[MtC/y]	[MUSD/y]	[MUSD/y]
USA	0.09%	13.14%	1.47%	0.46%	275.10%	1.11%
EU	0.09%	11.34%	0.22%	0.82%	64.86%	2.11%
Japan	0.08%	2.71%	0.95%	0.41%	29.13%	1.77%
CANZ	0.19%	1.66%	0.80%	1.42%	7.64%	1.42%
EEFNS	0.01%	2.17%	0.00%	0.02%	68.66%	0.27%

Table: Comparison of the multi-agent and evolutionary methods – **tender**

Analysis of the results

- Multi-agent system and evolutionary approaches and the bilateral trade and tender results are quite similar.
- Almost identical values (the difference of a few percent):
 - Final emissions;
 - Numbers of traded permissions;
 - Final shadow prices;
 - Reduction costs;
- Bigger differences can be seen in values of permission costs.
- It is probably caused by different mechanisms of reaching contracts in two considered methods.
- The multi-agent platform is in general closer to real market, thus this results can be more realistic.

Similarity of results

The results obtained using **multi-agent system** and **evolutionary approach** are very similar to the results obtained for the **centralized market**;

Conclusions

Multi-agent / evolutionary methods

- Are often applied in market simulations;
- Are able to deal with complicated systems with many interactions between their elements and participants;
- Economic systems can be quite easily modeled, simulated and controlled using these kind of artificial intelligence (AI) systems;
- This approaches seem to be a suitable tool for analyzing economic phenomena – especially for dynamic market models with elements of uncertainty in prices (negotiated prices, tenders).

Further work

- This paper concentrates on presenting possibility of using some AI tools for simulating the trade;
- Simulation results presented in this paper are preliminary ones;
- More elaborated results will be presented in following publications.