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Emission trading model CO_2 with the buying prices

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Abstract. In the paper we consider buying/selling prices of CO_2 emission permits in the trading model with uncertainty. We assume that the commonly omitted factor, in standard models, can have a significant influence on trading market. Thus, we want to construct a more realistic trade model and compare it with standard one. To accomplish this goal, we introduced several important changes to the standard model, especially a new optimized quality function and transactions with of price negotiations between regions. Additionally, we used a new method of simulating such market based on a specialized evolutionary algorithm method (EA).

Keywords: emissions trading, Kyoto Protocol, inventory uncertainty, evolutionary algorithm

Introduction

It is generally claimed that implementation of tradable emission permit system can be an efficient strategy for achieving environmental goals. In permit systems a regulatory agency distributes emission permits to polluters in accordance with the environmental goal. The permits are allowed to be transferable among polluters, resulting (in terms of commonly used simple trade models) in an equalization of marginal abatement costs between pollution sources.

Winiwarter [11] points out that emission reduction as proposed by the signatories of the Kyoto protocol are far too small to decrease increasing GHG concentrations. Therefore, new targets for future emissions should be settled. Due to possible underreporting, a periodic review of the emission reduction targets should consider inventory uncertainty. The problem of uncertainty was extensively discussed at the workshop on Uncertainty in Greenhouse Gas Inventories.

According to [10] uncertainty can be defined as "an imperfection in knowledge of the true value of a particular parameter or its real variability in an individual or a group". It can be represented by a range of values calculated by various models or by qualitative measures. The IPCC provided general guidance for uncertainty management in greenhouse gas emissions [7]. They underline that the IPCC Tier-1 methodology relies on three points: (1) all individual emission sources are independent from each other; (2) the emissions shows normal (Gaussian) distributions and (3) uncertainties for greenhouse gases are smaller than 60%. Many uncertainty estimates are ultimately based on expert judgment and are very subjective. The calculated uncertainty in the total CO2 emissions trends for years 1990-2002 in Netherlands is $\pm 3\%$.

To be fully informed, how the obligations of greenhouse gas emissions will influence into world economy and which rules will be present on the market, researchers from different countries want to build model of such market and find optimum solutions, which enables to forecasts emissions allowances process and the cost of emission reduction for different countries [4]. Important problem is to build a transaction model and to solve many other problems associated with emission level reports credibility and uncertainty [5], [8], [9].

The standard model of emission permits trading for CO_2 does not show transaction prices. Although theoretical prices are calculated by the model, they are not practically applied. The goal function has to find the equilibrium price point and ensuing from it emission reduction costs and permits prices. In the considered previous model no negotiation of prices is applied, nor any additional transaction costs. In that model we assume obligation to conduct relevant transactions by theoretical prices and optimal solution is in the equilibrium prices [4].

Proposed method of problem solving is slightly different from the real market situation. Therefore more elaborated market model was considered, in which the additional elements were added, like the possibility of price negotiation and influence of real prices on the solutions.

New market model

The idea of emission permits trading is based on the assumption, that some countries have surplus of not used emission permits. Therefore they are able to sell them to those countries who would like to emit more than Kyoto Protocol obligations.

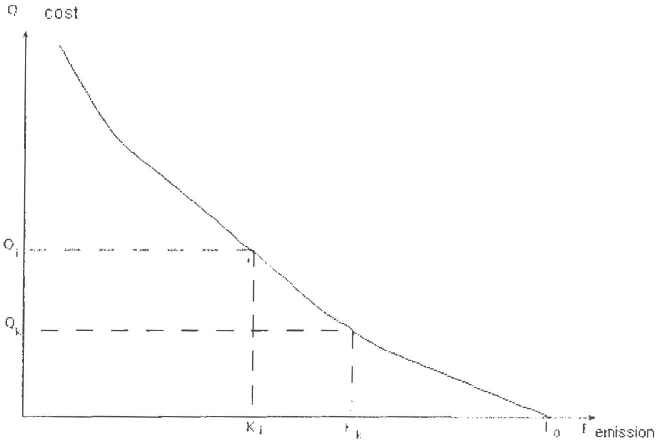

Figure 1. CO_2 emission reduction cost: without trade (Q_i), and with trade (Q_k) for buying country, K_i – Kyoto limit, F_k – emission after trade, F_0 – initial emission.

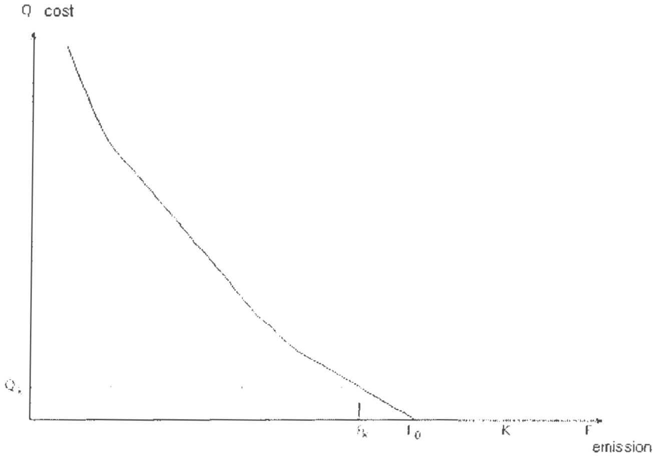

Figure 2. Emission reduction cost of CO_2 without trade are zero, and with trade for selling country (Q_k), K_i – Kyoto limit, F_k – emission after trade, F_0 – initial emission.

Trading is beneficial only when the price of permits will be lower than the cost of emission reduction. The country can reduce emissions more than its obligation and sell the permits surplus to another country (see figure 1 and 2).

In the base model the total cost of holding emissions in region i down to x_i, is denoted by $C_i(x_i)$, these are abatement cost function. We assume that cost functions $C_i(x_i)$ are positive, decreasing and continuously differentiable for each region. Kyoto target for each region i is indicated by K_i. A number of emission permits acquired by source is expressed by y_i (y_i is negative if region i is a net supplier of permits).

$$E = \min_{x_i} \sum_{i=1}^{n} c_i(x_i) \tag{1}$$

With the constraints:

$$x_i \leq K_i + y_i \tag{2}$$

$$\sum_{i=1}^{n} y_i = 0 \tag{3}$$

where:

E – quality function of the base model;

$c_i(x_i)$ –the costs of holding emissions at region i down to x_i;

y_i – the number of emissions permits acquired by region i;

K_i – Kyoto target for region i;

n – number of regions;

x_i – current emission.

The goal is to minimize the reduction cost to cut emissions to required level, to comply with the Kyoto target.

Normally prices (shadow price) are defined as the costs derivatives in a given point. In the real word reduction cost and cost reduction function are not precisely known. Moreover, assuming they were known, they could not be applied, as they are not the only component of emission permits. More factors are influencing permit price. Therefore, in described solution we assume that transaction is finalized only when permit prices which was negotiated, is lower than the average cost of reduction for the buyer, and higher than the average cost of the seller. It is obvious that each party wants to maximize its profit and this assumption is a base for our new quality function.

In a presented model we conduct some important changes in relation to the previous models. The most important change is different goal function (4).

In the new model the goal function is given by the following formula:

$$G = \max_{s_{ji},\pi_{ji}} \sum_{i=1}^{n} \sum_{j=1}^{T} \left(c_{j-1,i}(x_{j-1,i}) - \left(c_{j,i}(x_{j-1,i}) - s_{ji} * \pi_{ji} \right) \right) \tag{4}$$

With the constraints:

$$x_{ji} \leq K_i + y_{ji} \tag{5}$$

$$\sum_{i=1}^{n} y_i = 0 \tag{6}$$

where:

G – quality function of our new model;

T – number of transactions of permits;

$c_{ji}(x_{ji})$ – the costs of holding emissions at region i x_{ji} after j transactions;

y_{ji} – the number of emissions permits acquired by source;

K_i – Kyoto target for country i;

n – number of regions;

x_{ji} – current emission;

s_{ji} – the number of emissions permits acquired by source i;

π_{ji} – price of permits bought/sold.

In the other words, we maximize the difference between cost with no emission reduction and the sum of the cost in trade scenario plus permits expenditures. It enables us to include also buying and selling permit price, which considerably influences transaction profitability and decision to buy/sell permits, or if it is better to reduce emissions rather than to buy permits.

Thanks to new function we want to find solution, which will maximize the difference between the cost without trade and the cost with permits, in other words the profit from emission trading. In the previous goal function we minimize the cost of emission reduction without including any buying prices and expenditures for this goal, and the cost of buying can be considerable, in comparison to expenditures for CO_2 reduction if there is no trade. We assume also a bit different methods of permit price setting. The authority or market must set the minimal price, below which price permit cannot decrease. It is to protect to such a case when country, which reports emission below the Kyoto level has zero marginal cost of abatement (fig. 2). Therefore marginal cost (e.g. shadow price) is not derivative of abatement cost, but derivative with minimal value. The real price of permit and permit number is not known, before computer simulation of market activity, Therefore in computer simulations, presented in this paper, the number of sold permits is randomly chosen from some interval. In similar way permits price is chosen from interval between maximal price (shadow price) of the buyer and minimal price (modified shadow price) of the seller.

The second important change is introducing of transactions to the model. Transactions are conducted iteratively until no one can be reached. Prices and amounts of transferred permits are negotiated. Thus, our market model is dynamic, contrary to static base one.

Evolutionary algorithm method in computer simulations

Standard evolutionary algorithm works in the manner as it is shown in the Algorithm1, but this simple scheme requires many problem specific improvements to work efficiently.

The adjustment of the genetic algorithm to the solved problem requires a proper encoding of solutions, an invention of specialized genetic operators for that problem and accepted data structure and a fitness function to be optimized by the algorithm.

1. Random initialization of the population of solutions.
2. Reproduction and modification of solutions using genetic operators.
3. Valuation of the obtained solutions.
4. Selection of individuals for the next generation.
5. If a stop condition not satisfied, go to 2.

Algorithm 1. The evolutionary algorithm.

Thus, we use specialized evolutionary algorithm to solve the problem. One agent contains information about all the countries participating in the market, so it is a complete solution of our problem. Another method may be also applied when each country is one agent [1], [2], but in that case we receive only one solution, and the population of solutions in evolutionary algorithm is limited to the number of countries participating in the trade, which in considered case (5 countries) is too small for evolutionary algorithm to work efficiently. Therefore it was not used.

The whole population of agent contains such number solutions like the number of agents, but solutions have not to be different. Information needed to describe one country is following:

- Theoretical price of own permits (shadow price);
- The Real price of current sold/bought permit;
- The value of current sold/bought permits;
- Number of currently sold/bought permits;
- The total sum of sold/bought permits;
- Current emission;

- Previous emission (before present transaction);
- Value of present and previous goal function

To modify solution, the following genetic operators were used:

- competition – the chosen country set some numbers of permits for sale, and the other set offers to buy, and the best option is chosen, and the solution is modified;
- sale – the chosen countries conduct transactions

transaction process, and number of permits are randomly chosen. For the number of permits is value from interval {1,..,5}, and permit price is as a value between buying offer and sale offer.

Computer simulations results

Computer simulations were conducted on data set, similarly to other authors' papers, mainly: [3], [6] and [8]. We consider following countries groups: USA, EU, Japan, CANZ (Canada, Australia, New Zealand), Former Soviet Union (FSU) and Eastern Europe. We assume that cost depends on emission reduction in the following way (quadratic cost function) [6],[3].

$$C = \begin{cases} a*(F_0 - F)^2 & \text{for} \quad F < F_0 \\ 0 \quad \text{for} \quad F \geq F_0 \end{cases} \tag{7}$$

where:

a – cost function parameter;

F_0 – initial emission;

F – final emission.

Below in table 1 we describe cost function abatement coefficients, which have special interpretation of .

Table 1. The data applied for calculations for various regions.

Country	Initial emission (F_0) MtC/y	Cost function parameter (a) MUSD/(MtC/y)^2	Limit Kyoto (K_i) MtC/y
USA	1820.3	0.2755	1251
EU	1038.0	0.9065	860
Japan	350.0	2.4665	258
CANZ	312.7	1.1080	215
FSU	898.6	0.7845	1314

In a traditional method (perfect market assumption) we obtain results are presented in the table 2.

Table 2. Results in scenario assuming perfect permit market model.

Region/country	Final Emission MtC/y	Final price USD/tC	Number of imported permits Mt/y	Permits expenditures MUSD/y	Emission reduction cost MUSD/y
USA	1562	143	310	11974.3	18523.7
EU	959	143	100	15790.6	5515.1
Japan	321	143	63	29987.6	2074.3
CANZ	248	143	33	16077.6	4638.2
FSU	808	143	-506	-73830.3	6439.5
Total					

In a case of new model application the results are presented in table 3.

Table 3. The results of simulation from the new model without uncertainty.

Region/country	Final Emission MtC/y	Final price USD/tC	Number of imported permits Mt/y	Permits expenditures MUSD/y	Emission reduction cost MUSD/y
USA	1480.0	187.5	229	4290.6	31904.0
EU	959.0	143.2	99	1183.6	5657.5
Japan	335.0	74.0	77	2337.2	555.0
CANZ	268.0	99.1	53	381.2	2213.9
FSU	856.0	66.8	-458	-8192.5	1423.7
Total					

Table 4. Results obtained using the described new model with different values of risk parameter α.

Region	Reported emissions (MtC/y)	Final price USD/tC	Permits traded (Mt/y)	Cost of traded permits MUSD/y	Cost of emission reduction MUSD/y
Risk parameter α=0.5					
USA	1465.0	195.8	214	12800.3	34778.6
OECDE	970.0	123.3	110	6117.1	4191.7
Japan	335.0	74.0	77	5045.4	555.0
CANZ	258.0	121.2	43	1798.5	3315.2
FSU	841.0	44.9	-444	-25761.3	641.7
α=0.3					
USA	1448.0	216.7	197	12375.5	42611.8
OECDE	953.0	174.4	93	5607.3	8390.5
Japan	331.0	118.1	73	4702.1	1412.7
CANZ	253.0	143.8	38	1587.5	4668.1
FSU	913.0	52.9	-401	-24272.4	892.6
α=0.1					
USA	1403.0	253.1	152	10438.5	58109.4
OECDE	956.0	189.3	96	5711.4	9883.3
Japan	327.0	162.1	69	5098.9	2663.9
CANZ	256.0	148.7	41	2020.4	4991.0
FSU	956.0	61.0	-358	-23269.2	1184.9
α=0.0					
USA	1395.0	263.2	144	10133.6	62882.8
OECDE	952.0	206.7	92	6011.1	11785.0
Japan	319.0	213.7	61	5000.9	4630.8
CANZ	252.0	163.4	37	1988.2	6021.6
FSU	980.0	61.1	-334	-23133.7	1188.9

Conclusions

Contrary to the previous model described for instance in [3], our permits market model is dynamic. The results show that including perfect permits prices is more cost-effective, but also more expensive solution. Therefore, less permits are imported (4 column in tables 2 and 3) the structure of buying countries is changed, and more beneficial is to reduce emissions than to buy permits in case of US (6 column in table 2 i 3). Surprisingly, Japan and Canada reduce emissions less and purchase more emissions. Obviously, the total cost of emission reduction in the second method (41754 MUSD/y) is higher than in first method (37190.8 MUSD/y), what can be explained by higher cost of expenditures for permits, and higher necessary reduction. Results obtained using new model with different values of risk parameter α show that in a case with full uncertainty, less permits are purchased and more emission is reduced, what is more expensive. Practically we can expect that, applying dynamic model requires additional agreements among regions. While such activities are difficult to implement, our analysis can show they are environmentally friendly, since they require emission reduction.

Literature

[1] F. Alkemade, H. La Poutre, H. M. Amman: *Robust Evolutionary Algorithm Design for Socio-economic Simulation*, Computational Economics (2006) 28, pp 355-470.

[2] C. Clemens, T. Riechmann: *Evolutionary Dynamics in Public Good Games*, Computational Economics (2006) 28, pp 399-420.

[3] P. Bartoszczuk, J. Horabik: *Tradable Permit Systems: Considering Uncertainty in Emission Estimates*, Water Air Soil Pollution: Focus (2007) 7: 573-579, Springer Verlag, 2007.

[4] Y. Ermoliev, M. Michalevich, A. Nentjes: *Markets for Tradable Emission and Ambient Permits: A dynamic approach*, Environmental and Resource Economics 15, 2000, pp 39-56.

[5] O. Godal: *Simulating the Carbon Permit Market with Imperfect Observations of Emissions: Approaching Equilibrium through Sequential Bilateral Trade*, Interim Report IR-00-060, IIASA, Laxenburg, Austria, 2000.

[6] J. Horabik: On the costs of reducing GHG emissions and its underlying uncertainties in the context of carbon trading, Raport Badawczy RB/34/2005, IBS PAN, 2005.

[7] IPCC (2000), Good Practice Guidance and Uncertainty Managment in National Greenhouse Gas Inventories, IPCC-TSU NGGIP, Japan.

[8] G. Klaasen, A. Nentjes, M. Smith: *Testing the dynamic theory of emissions trading: Experimenatl evidence for global carbon trading*, Interim Report IR-01-063, IIASA, Laxenburg, Austria, 2001.

[9] Z. Nahorski, J. Horabik, M. Jonas, Compliance and emissions trading under the Kyoto protocol; Rules for uncertain inventories, 2007.

[10] Nillsson S., Shvidenko A., Jonas M., (2004), Uncertainties of the regional terrestial biota Full Carbon Account: A systems analysis, in: International Workshop on Uncertainty in Greenhouse Gas Inventories: Verification, Compliance & Trading, 1-12

[11] Winiwarter W., National greenhouse gas inventories: Understanding uncertainties vs. potential for improving reliability, in: International Workshop on Uncertainty in Greenhouse Gas Inventories: Verification, Compliance& Trading, 2004