Tradable emission permits as efficient strategy for achieving environmental goals

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Abstract

We start with explaining the idea of emission trading and then we describe marginal abatement curve, which are the starting point for determining the demand and supply for emission permits. In the absence of any trading the region would abate to achieve its "Kyoto target", and the corresponding price would be "autarkic" marginal costs. If emission trading were a possibility, the region would purchase or sell permits. We distinguished six regions and attempted to calculate how much each region will reduce emissions or buy permits. We consider different level of uncertainty coefficient in emission reporting and simulate costs of abatement.

1 Introduction

It is commonly 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 an equalization of marginal abatement costs between pollution sources.

In general, the literature provides strong support for the use of that kind of markets in environmental policy [1,3,4,6,7]. Market based instruments have also become increasingly popular among environmental policy makers during the last decade. Tradable emission permit systems are, together with taxes, the most commonly suggested market based instrument for achieving environmental goals.

In emission permit trading system, a new type of property right is introduced. This property right allows to emit some amount of pollutants. Each permit entitles its holder to emit one unit (for example one tone of pollutant). If an emitter posses 100 permits it would be allowed to emit 100 units of pollutants. Thus, total number of permits held by all sources puts a limit on the total quantity of emissions. These permits can be sold to anyone participating in the permit market. First, system is initialised by central decision on the number of permits which are to be put into circulation. Because the total number of permits is usually lower than current total emissions, some emitter will receive less permits than their current emissions. The countries listed in Annex B of Kyoto Protocol have agreed to decrease their emissions for about 5% of the 1990 emission level in the period 2008-2012 [4]. We follow definition of Annex B countries as in the EPPA model, see [1] and [6]. The parties of the Protocol have not decided yet about the rules of emissions trading. Some parties are for restrictions on the number of permits. Conversely, other are for free trade.

We applied model described by [1] and calculated total cost of abatement together with final emissions from each country, and number of emission permits traded by each region or country from Annex B. Emissions of greenhouse gases cannot be observed perfectly, therefore regions can underreport emissions because of uncertainty. If we consider uncertainty in the data, the reported emissions plus the possible unreported emission must be below the Kyoto target for the region. Therefore, the emission reduction should overshoot the level of uncertainty or at least its fraction, if we agree to bear some risk. We consider three scenarios: when the risk parameter $\alpha = 0$, 0.33 and 0.5.

2 Marginal abatement curve

The marginal abatement costs curve MAC plots the shadow prices corresponding to constraints of increasing severity at time T against the quantity abated [1]. One point on the curve thus is marginal cost for region R of abating an additional unit of carbon emissions at quantity q in time T. The integral under the curve is simply the total abatement cost for region R of carbon emission reduction q at time T (Fig. 1).

Any emission reduction can be represented as a point on its marginal abatement curve. By abating more, lower cost regions can sell emissions permits [1]. The difference in the marginal costs associated with each region's commitment in the absence of trade creates a potential gain to be shared between the two regions. We can reach aggregate emission reduction at the least cost when the regions trade until their marginal costs are given by equations (1) and (2). We

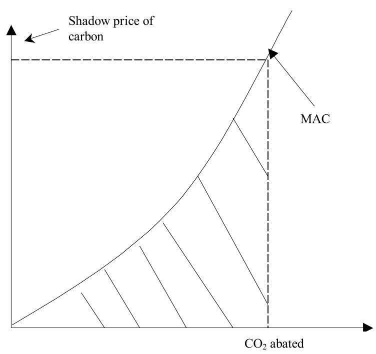

Figure 1: Marginal abatement cost concept

present the gains from trading for regions R_1 and R_2 (Fig. 2). The trade is constrained: C must be abated to the level q for the region R_1 and t for the region R_2. If there is trade between two sources: R_1 and R_2, then marginal costs of two regions are equal market price (eq. 1 and 2).

$$p' = p_1'(q) = p_2'(t) \tag{1}$$

and

$$r - q = t - s \tag{2}$$

Abatement cost is given by the area below the curve. The area of the field COr is abatement total cost in the region R_1 and the $F0t$ is abatement cost in the region R_2. Region R_1 buys $r - q$ permit and region R_2 sells $t - s$ permits. R_1 pays $p'(r - q)$, the area of $(ABqr)$ to R_2; from the other hand R_2 receives $p'(t - s)$, the area of field $(DFst)$ from R_1. Total cost for the region R_1 is area of $(A0q) + (ABqr)$, which is less than the area (COq) and the total cost for region R_2 is area $(0Ft) - (DFst) < (0Es)$. The savings from trading are equal for region R_1: area (ABC) and for region R_2, area (DEF).

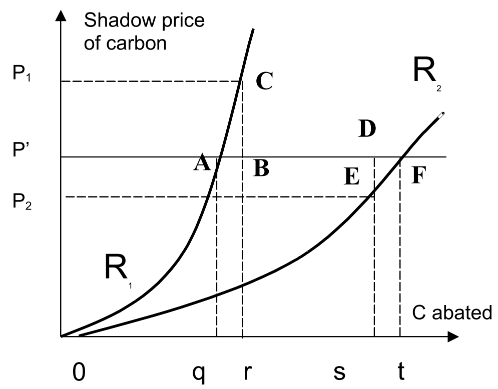

Figure 2: Emission trading gain illustration

Marginal abatement curves are the basis for determining how many permits are needed. In the absence of any trading the region would abate what is on the intersection of the amount of abatement required for the region to meet Kyoto target with MAC curve, and the corresponding price would be the "autarkic" marginal price. If emission trading were a possibility, the region would purchase or sell permits according to the relation of the market price to its autarkic marginal cost.

We can distinguish following cases:

1. market permit price lower than autarkic MAC; therefore region wants to buy permits corresponding to difference between the autarkic emission reduction and the domestic abatement it would undertake at the market price

2. market price is higher than its autarkic marginal cost, it would abate more and sell permits to other region

3. if autarkic MAC is zero, than those regions would be only suppliers of permits

3 The data

We employ data on the costs of emissions reduction estimated from the EPPA model and consider ANNEX B countries: USA, Japan (JPN), European Union 12 countries as in 1992 (EEC), Other OECD (OOE), Eastern Europe (EET), and Former Soviet Union (FSU) countries [1]. The carbon emission reduction constraints used for this study are based on the commitments made by countries to the Kyoto Protocol. We present in Figure 3 the emissions in base year, the reduction and emission target [1].

	USA	JPN	EEC	OOE	EET	FSU
Emission 1990 year, Mton C	1362	298	822	318	266	891
Emission 2010 year	1838	424	1064	472	395	763
Necessary reduction/ref 1990	7%	6%	8%	6%	-4%	2%
Kyoto Target 2010 year	1267	280	756	301	277	873
Reduction/Ref 2010	571	144	308	171	118	-110

Figure 3: Emission in 1990, anticipated emissions in 2010, Kyoto target in 2010 year and necessary reduction

4 The methodology

First, we define the necessary set of variables:
$i = 1...6$ are regions from Annex B countries in Kyoto Protocol,
$\alpha =$ the risk of not satisfying the Kyoto target due to uncertainty of the report,
$c_i =$ the costs of holding emissions at region i down to x_i,
$d_i =$ relative uncertainty of the source i,
$f_i(y) =$ function of the least cost for region i,
$k_i =$ Kyoto target for region i,
$n_i =$ initial emissions at source i in Mton,
$x_i =$ the reported emissions at source i in Mton,
$y_i =$ the number of emission permits acquired by source i (y_i is negative if region i is a net supplier of permits)

Our problem is to define the least cost for regions to comply with Kyoto protocol for a given amount of permits, y_i through the minimization of total emission reduction costs (eq. 3). In solution of this problem we adopt some concepts from [5] and [2].

$$f_i(y) = \min_{x_i} \sum_{i=1}^{6} c_i(x_i) \tag{3}$$

$$st. \qquad x_i + (1 - 2\alpha)d_i n_i \leq K_i + y_i \tag{4}$$

Each country i can either reduce its emission to the required Kyoto target, or buy necessary permits y_i, (see eq. 4). Moreover, if region i emissions are below it's Kyoto target, it can sell permits. It can also reduce emissions and simultaneously sell permits. The total sum of permits bought and sold equals 0. Regional marginal costs must equalize in such a way that the total amount of carbon abated is the same as in the no-trading case. We also assume that final emissions of each region cannot be higher than its initial emissions. Also, in similar way as e.g. [5] we add risk that real, unknown emissions actually exceed reported level due to inventory uncertainties (see eq. 4). The equation of shadow price of carbon is of the form: $P = aQ^2 + bQ$, where Q is abated amount in million metric tons of carbon and P is the marginal cost, or shadow price, of carbon in 1985 US dollars. By integration, the total abatement costs of carbon are calculated as $c = 0.33aQ^3 + 0.5bQ^2$. The coefficents a and b of those functions were given in [1].

5 Results

Initially, before trade, the highest shadow price is for Japan, 584 $/ton, and is higher than for EEC, which is 273$/ton. For the OOE countries the shadow price equals 233$/ton and for USA it is 186$/ton, as can be calculated from the marginal abatement curves [1]. The total cost for the analysed countries is $119 billion. We assume the regions begin to trade and calculate market price of emissions permits. We will present calculations for three scenarios: when parameter α equals 0.5, 1 and 0.33.

In the first scenario, the coefficient α equals 0.5, and therefore uncertainty involved overshoot fraction $1 - 2\alpha$ is 0. The market shadow price of permits equals $128/ton (Fig. 4). It is below the autarkic marginal costs for countries: EEC, JPN, OOE and USA, but above those for the EET, and FSU. Therefore, JPN, EEC, OOE and USA want to purchase permits equivalent to 346 Mton to avoid an expensive abatement, while such regions like EET and FSU conduct additional abatement and sell permits (4). In this way, trading brings some gain for regions. The total savings for the Annex B regions is $66 billions. EEC and USA imports the most, 106 and 103 Mton i.e. 34% and 18% of the reduction required by its Kyoto commitment, accordingly. Both regions spend $14 and $13 billions for permits. Japan spends $12 billions for buying permits. While EEC benefits $7 from emission trading in relation to the no trading case, USA gains only $3 billions. The countries of EET have practically no gain from selling permits. Former Soviet Union is the principal exporter of permits, it sells 345 permits and other regions pay for them $44 billions. About a third of its permits consist of 'hot air', with a cost 0, because FSU reduces its emissions only for 235 Mtons. The cost of such reduction ($10 billions) is lower than gain from emission trading. Overall, FSU benefits most from trading: $34 billions. Japan draws the second largest benefit from emissions trading in this market scenario ($19 billions). The OOE countries benefit $3 billions (buy 43 permits). In the second scenario, coefficient $\alpha = 0$, therefore we add full uncertainty in emission reporting, which are handled as an increased Kyoto reduction. The total cost of abatement for the analysed countries without trading is $378 billions (Fig. 5). In the second scenario cost of emission reduction after trading is higher than in the first scenario: $260 billions and Annex B countries save from trading: $126

		USA	JPN	EEC	OOE	EET	FSU	SUM
1 Reduction in 2010 year	(Mton)*	571	144	308	171	124	\	1318
2 Marginal costs	($/ton)*	186	582	274	233	116	\	\
3 Cost of abatement	($bill.)*	**37**	**34**	**30**	**13**	**5**	**0**	**119**
4 Reduction with trading	(Mton)	468	49	202	129	123	235	1207
5 Market price of permits	($/ton)	*128*	*128*	*128*	*128*	*128*	*128*	*128*
6 Cost of abatement	($bill.)	21	3	10	5	5	10	54
7 Permits exp(-)/imp(+)	(Mton.)	103	94	106	43	-1	-345	0
8 Commitment import	[7:1]	18%	65%	34%	25%	\	\	\
9 Permits exp(-)/imp(+)	($bill.)	13	12	14	5	0	-44	0
10 Total cost [6+9]	($ bill.)	**34**	**15**	**23**	**10**	**5**	**-34**	**54**
11 Gain from trade [3-9]	($bill.)	3	19	7	3	0	34	66

**no trading*

Figure 4: Cost of abatement in first scenario $\alpha = 0.5$

billions, what is more than in the first scenario. The market price of permits is 360 $/ton, which is much more than in the first scenario. It is below the autarkic marginal costs for EEC, EET, JAPAN, OOE and those countries are importers of permits - they purchase permits equivalent to 332 Mtons. Regions: EEC, EET, JPN and OEE spend $59, $1, $37, $40 billions for permits and gain: $27, $10, $ 32 and $3 billions on trading, accordingly.

Conversely, FSU and USA sell permits. Though USA sells 52 permits and obtains $19 billions for them, it gains only $1 billion from trade. Its marginal autarkic abatement cost is very close to permit price. US settles its emission reduction on 807 Mtons. Overall, there is less permits issued than in the first scenario. FSU sells 277 permits for $53 billions. It benefits $54 billions from trade.

		USA	JPN	EEC	OOE	EET	FSU	SUM
1 Reduction in 2010 year	(Mton)*	755	207	521	252	237	119	2090
2 Marginal costs	($/ton)*	315	1044	729	514	455	33	\
3 Cost of abatement	($bill.)*	**82**	**85**	**132**	**42**	**36**	**1**	**378**
4 Reduction with trading	(Mton)	810	105	358	212	211	395	2090
5 Market price of permits	($/ton)	***360***	***360***	***360***	***360***	***360***	***360***	\
6 Cost of abatement	($bill.)	101	16	46	25	25	47	260
7 Permits exp(-)/imp(+)	(Mton.)	-55	103	163	40	26	-277	0
8 Commitment import	[7:1]	\	50%	31%	16%	\	\	\
9 Permits exp(-)/imp(+)	($bill.)	-19	37	59	14	1	-100	-8
10 Total cost [6+9]	($ bill.)	**82**	**53**	**105**	**39**	**26**	**-53**	**252**
11 Gain from trade [3-9]	($bill.)	0	32	27	3	10	54	126

**no trading*

Figure 5: Cost of abatement in second scenario $\alpha = 0$

In the third scenario, coefficient $\alpha = 0,33$. The total cost for all regions is $99 billions. In the third scenario most countries gain from trading, more than in first scenario, $84 billions, but less than in second scenario (Fig. 6). We assume the regions begin to trade and we calculated market price of emissions permits as \$190/ton, which is more than in first scenario and less than in second scenario. US reduces emissions most: 580 Mtons with the costs of \$38 billions. It imports 52 permits and pays for them \$10 billions. It's marginal abatement costs are much higher than market price of permits. Overall, US gains from trading only 1 billion. Japan reduces only 67 Mtons of carbon, i.e. 40 % of its commitment, what costs \$6 billions. It buys 98 permits with the cost of \$18 billions. After trading Japan saves \$24 billions.

Both EEC and OOE purchase 167 permits and gain from trade: \$12 and \$3 billions. They reduce emissions considerably for 253 and 156 Mton. EET buy 9 permits and gain from trade only 1 billion. FSU is the only exporter in this scenario (322 permits), and receives from other regions \$61 billions. It reduces emissions for 288 Mton, which costs \$18 billions. FSU exports 322 permits, but reduces only 288 Mton, therefore it sells 'hot air' - 30 Mtons. It gains after trading \$43 billions.

		USA	JPN	EEC	OOE	EET	FSU	SUM
1 Reduction in 2010 year	(Mton)*	632	165	378	198	157	\	1530
2 Marginal costs	($/ton)*	225	721	400	314	204	\	\
3 Cost of abatement	($bill.)*	**50**	**48**	**54**	**20**	**11**	**0**	**183**
4 Reduction with trading	(Mton)	580	67	253	156	153	288	1496
5 Market price of permits	($/ton)	*190*	*190*	*190*	*190*	*190*	*190*	*190*
6 Cost of abatement	($bill.)	39	6	18	9	9	18	99
7 Permits exp(-)/imp(+)	(Mton.)	52	98	125	42	5	-322	0
8 Commitment import	[7:1]	8%	60%	33%	21%	3%	\	\
9 Permits exp(-)/imp(+)	($bill.)	10	18	24	8	1	-61	
10 Total cost [6+9]	($ bill.)	**49**	**24**	**42**	**17**	**10**	**-43**	**99**
11 Gain from trade [3-9]	($bill.)	1	24	12	3	1	43	84

**no trading*

Figure 6: Cost of abatement in third scenario $\alpha = 0.33$

6 Conclusion

The paper shows how important is emission trading in pollution abatement. When emission trading is possible, there are cheaper abatement options available. MAC's abatement curves applied here are not empirically estimated but derived from complex models, as it is presented in [1]. In this paper the parameter estimates of cost were adapted from [1], which allowed us to conduct simulations.

From presented three scenarios it is clear that the highest abatement (2090 Mtons) is necessary in second scenario, ie. when the uncertainty is fully accounted for ($\alpha = 0$). In this case, regions derive not only highest cost of abatement (\$260 billions), but also highest gains from trading system (\$126) billions. Variation in neccesary emission reduction, due to r uncertainty leads to lower supply of permits, and thus higher market shadow prices.

The benefits from emissions trading is not evenly distributed. The effect of trading is always to reduce costs. In trading schemes participating parties derive some benefits. As it was stated in [1], regions whose autarkic marginal cost is further from the trading equilibrium will benefit more than those regions whose autarkic marginal cost is closer to the trading equilibrium. The greatest benefits obtains FSU, who is the biggest exporter of permits, and Japan that imports more than 60% of its Kyoto commitment.

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