CO_2 TAXES AND TRADABLE QUOTAS, EXPERIMENTAL EVIDENCE OF BIASED DECISIONS

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ABSTRACT

Developed countries should find cost-effective ways to decrease Green House Gas (GHG) emissions to comply with their Kyoto Protocol targets by year 2012. The target can be achieved either by domestic emission reduction or by buying quotas in international markets. Policy makers have to choose between these policy options and decide to what extend and when to use them. In democratic countries these choices may be constrained by limited information and misperception among voters and politicians. Biases in decisions may occur because the choice of policy is complicated by dynamics and uncertainty. To explore the possibility of misperceptions we perform a laboratory experiment where subjects are asked to make these difficult policy decisions during the 12 years preceding 2012. Biases were found.

Key Words: Taxes, misperception, dynamics, climate policy, laboratory experiment

1. INTRODUCTION

Developed countries should find cost-effective ways to decrease Green House Gas (GHG) emissions to comply with their Kyoto Protocol[3] targets by year 2012. The target can be achieved either by domestic emission reduction or by buying quotas in international markets. Policy makers have to choose between these policy options and decide to what extend and when to use them. In democratic countries these choices may be constrained by limited information and misperception among voters and politicians. Biases in decisions may occur because the choice of policy is complicated by dynamics and uncertainty, raising the questions: will nations meet their targest and at what costs? To explore the possibility of misperceptions we perform a laboratory experiment where subjects are asked to make these difficult policy decisions during the 12 years preceding 2012.

[3] The Kyoto Protocol is a convention where 156 countries have committed to reduce green-house gas emissions of at least 5% from 1990 levels by the year 2012. More information is available at: www.unfccc.int

The greatest challenge is to deal with the task of replacement of existing capital. Replacements take place at long intervals of time, thus introducing delays. It will also take time to reduce emissions through retrofits. Appropriate policies must take account of these delays. Few of the existing papers deal with these dynamics, when discussing policies for emission reductions[4]. The most relevant paper seems to be Lecocq *et al* (1998). They studied the impact over time of CO_2 emission abatement policies. They use an energy model with two sectors (flexible: housing and rigid: transport). They conclude that there is a need of early actions to reduce emissions in sectors that need time to replace old equipment. This is a rare, however, key insight for the problem we pose in this study.

It seems unlikely that subjects get much guidance from the ongoing debate where the dynamics of replacement are hardly ever mentioned. From past works like Funke (1991), Moxnes (1998, 2004) and Sterman (1998a) there is evidence of misperception of dynamics, for instance misperceptions of delays (Brehmer, 1989, Sterman, 1998b) and inability to respond properly to feedbacks (Sweeney and Sterman, 2000). People misconceive and mismanage complex problems and the policies to address those problems (Meadows, 1999). Besides, there are some experimental studies that support the hypothesis that people do not have a complete understanding of taxes. Eriksen and Fallan (1996) study the influence of tax knowledge on attitudes towards taxations. They found that knowledge accounts for improved perception of fairness of the system. Bartolome (1995) also found that people misperceive the difference between marginal and average tax. This evidence and the lack of common information on the dynamics, make us suspect the existence of learning problems. Hence, we hypothesize biases and misperceptions when people address the problem of reducing GHG's.

Using laboratory experiments we investigate the existence of biases when people have to decide about emission policies (emission taxes and international emission trading) to comply with an emission target. If we reveal misperceptions this should motivate a next step to formulate policies to correct biases.

The laboratory experiment is designed as follows. Information about abatement cost is given to the subjects in terms of a curve showing the long term costs of emission reductions. We consider two treatments. In treatment 1 subjects are asked to reduce emissions for a country by imposing a tax from 2000 until 2012 to reach a given emission target. Trade in quotas is not allowed. Starting from the same design, we add in treatment 2 a market for emission quota trading between countries (subjects). Each market has five players with the same conditions (symmetric). Since the game is symmetric, proper actions to reach the target emissions require the same tax policy as in treatment 1. In both treatments the discount rate is the same and players are punished if

[4] Some studies focus on estimating curves of marginal abatement costs based on aggregate macroeconomic models or engineering approaches (Ellerman and Decaux, 1998; Criqui *et al*., 2002). Other studies analyze and compare different climate policies using cost-effective and cost-benefit analysis (Yohe and Wallece, 1996; Nordahus, 1994; Kolstad, 1996). This is namely research regarding emission trading for instance, laboratory experiments have been used to study market efficiency (Bohm and Carlén, 1999), however, these experiments do not include much dynamics. The majority of these studies are focused on the discussion of what decision-makers should do and providing simple heuristics among for makers and politicians.

they do not comply with the target at the end of the period. They get paid according to how well they perform.

The main question pertains to the participants' understanding of the dynamics of the system. Do people increase taxes early enough to reach the emission target? Do people understand the delays in reducing emissions? Will trade of emission quotas among countries influence how people set taxes? Interesting observations result. We find that people tend to set too low taxes to reach the emission target. Market prices for quotas become significantly higher than taxes, and differences in tax levels motivate quota trade.

This paper is organized as follows: In section two we describe the method. In section three we show the results. Discussions are presented in section 4. Conclusions are given in section 5.

2. THE METHOD

We use a laboratory experiment which allows players to make yearly decisions, and which simulates the consequences for emissions and for the quota market from year to year. In line with our hypothesis about misperceptions of the delays involved, it is particularly important that the simulator captures the dynamics of the emission reductions. The dynamics we capture here arise from the capital stock turnover and from retrofits. Furthermore, the model represents the market for quota trading between countries. To simplify the experiment, the model is highly aggregated.

2.1 MODEL

In order to reach the emission targets the decision makers have two possibilities; they can either reduce emissions in their own country (domestic reductions) or buy emission rights in the international quota market (paying for reductions abroad). Reductions in domestic emissions can be obtained either by replacing worn out capital equipment by more efficient equipment or by improving the existing equipment (retrofits). The first measure is called replacement, it is relatively cheap, its potential is limited by the yearly discard rate, and the emission reductions do not have a lasting effect (an automobile replaced in 2000 may have to be replaced again in 2011). Retrofit, the second measure, is more expensive but can be executed in less time than replacement (is independent of the discard rate) and we assume it has a lasting effect (irreversible within our time horizon, for instance extra insulation).

2.1.1 Replacement

In general GHG's from human activities are produced by energy consumption and by agricultural and industrial processes[5], which are influenced by the level of economic

[5] Carbon dioxide is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned. Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock. Nitrous oxide is emitted during agricultural and industrial activities, as well as during

activity. To simplify, we set economic activity (gross domestic product, GDP) constant. This is a conservative design since it makes it easier to reach the target and the task is simplified, i.e. it should reduce the tendency towards misperceptions. The rate of production in a country depends on the existing capital stock and so does the GHG emissions. The coflow structure[6] in the stock and flow[7] diagram in figure 1 illustrates the dynamics of replacements.

Although models of GHG emissions are often very detailed, they do not include the dynamics described in Figure 1 (Lecocq, 1998). Lecocq's STARTS model is an exception. Although the Lecocq model is built for a different purpose than ours, we choose a similar design.

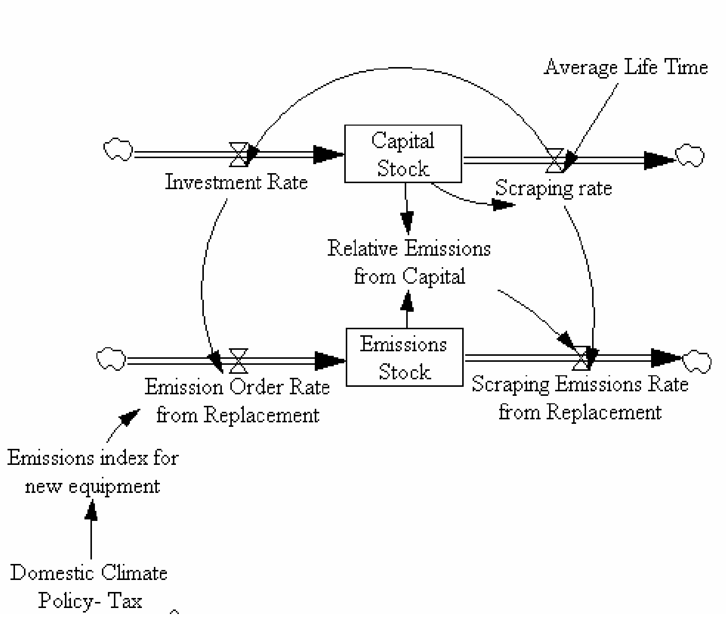

Figure 1 Replacement Dynamics

In figure 1 the Capital is accumulated in a stock (upper rectangular box) which increases by investments and decreases by the scraping rate (pipe with valve). Scrapping equals the capital divided by the average life time. When the investment rate (inflow) is equal to the scraping rate (outflow) the stock is in equilibrium, meaning that no changes take place in the capital stock. People are investing exactly what is discarded.

Each sector of the economy that constitutes the capital stock, like transport, industry, commerce, housing and energy, emits CO_2 and other green house gases. Therefore, a flow of the capital equipment is a flow of emission capacity as well. While capital is going in and out of the stock, emission capacity has the same behavior as the capital. The lower component of figure 1 illustrated that dynamics.

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combustion of solid waste and fossil fuels. Very powerful greenhouse gases that are not naturally occurring include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), which are generated in a variety of industrial processes.

[6] Coflow structures are used to keep track of the attributes of various items as they travel through the stock and flow structure of a system. (Sterman, 2000)

[7] Diagram introduced by Forrester (1961)

The investment rate (SIR) times an emission index for new equipment (EINE) defines the inflow to the stock of emissions (ES). Each unit, leaving the stock of capital, also leads to a removal from the stock of emissions. The emission index for what is removed is given by the relative emissions from capital (RER) (average emission intensity of the existing production capital) times the scrapping of capital, which in a no growth economy equals the investment rate (SIR). This structure is very useful because it keeps track of the emission changes due to every new investment and every scrapping.

The differential equation to describe the stock-and-flow diagram is the following

$$\frac{dES}{dt} = (SIR * EINE) - (SIR * RER) \quad (1)$$

EINE is determined by the climate policy applied, in this case the carbon tax level. Thus, emitters are assumed to choose more efficient equipment as the tax increases. If the tax is set equal to zero, the inflow and the outflow of the emissions stock are the same and the stock stays constant.

A weakness of the above model is that implicit lifetimes of equipment will be widely distributed. To get lifetimes that are more narrowly distributed we split up the stocks into six cohorts. The average life time is set equal to 20 years.

2.1.2 Retrofit

Besides waiting for the capital to be discarded and replaced, existing equipment can be improved by retrofits. This will be an option for equipment with long remaining lifetimes and prohibitive costs of early retirement. Retrofits are modeled as follows. The tax policy and the costs of retrofits define a desired level of retrofits. Since it takes time to decide, plan and carry out retrofits a actual retrofits follow desired retrofits by a delay. Retrofits are assumed to be irreversible within the time frame of the experiment. Thus, if taxes are reduced, all retrofits that have already taken place, will stay in place.

2.1.3 Emission Trading Structure in the Model

The market is modeled as a symmetric network game with five players or countries. Each player decides on a bid-offer curve each year. These curves are such that at high hypothetical prices, subjects sell and at low hypothetical prices they buy. A computer routine ensures that the market equilibrates each year. This routine is like giving reservation prices to a broker who operates in a perfect market. Once the equilibrium price is found, the quotas are assigned according to the bid-offer curves for the individual players.

2.2 EXPERIMENT DESIGN

2.2.1 Task

The experiment starts in year 2000 with initial emissions of 4000 Mtons of CO_2 equivalents for each player. The goal for the participants is to reach a target of 3000[8] Mton of CO_2 equivalents by 2012 with as low costs as possible. A punishment of 200 $/ton has to be paid if the target is not reach by year 2012. Two treatments are considered.

Figure 2 shows the player interface for treatment 1. The upper box displays the current year. The players enter their tax rates in the second box. After the tax rate has been entered, the subject asks the simulator to advance on year, new decisions are made and so forth and so on. The third box gives information about the current emissions, and relates this to the target. The fourth box gives information regarding the total cost achieved by the participant and the payoff. The payoff depends on the total costs, and information in the fourth box is only shown at the end of the game (2012).

Figure 3 shows the interface for treatment 2. It is similar to the interface for treatment 1, with the following exceptions. In the information box there is also information about the players holding of emission quotas. If a player has bought quotas, the need for reductions in 2012 is reduced. A negative holding of quotas implies that the need for reductions increases. A graph is added in the upper left box. By using the mouse the players are able to move the line and create a bid-offer curve, for instance to buy at low prices and sell at high.

Subjects were randomly seated in cubicles. In treatment 2 they did not know who they were competing with. They were paid privately one by one. The appendix shows the exact instructions given to and read aloud for the participants. Note that the instructions did not quantify or mention delays. The participants were, however, told that the underlying computer program was highly realistic with the exceptions mentioned. They were asked to fill in data for the current year in a handout table to keep a record of the history, and as a backup of the data.

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[8] The GHG emission reduction constrains used for this study are base on the estimations of the marginal abatement cost curve done by Ellerman *et al* (1998) in the EPPA model. The region selected to be reproduced by the model is the European Union (EC-12), must reduce emissions in 2012 to 92% of the quantity they were emitting in 1990 (reference year). According with EPPA the target for EC-12 reductions is 2773 M ton CO_2. In EPPA the projected emissions for 2012 are 3901 M ton CO_2, therefore EC-12 should reduce 1128 M ton by year 2012. In the experiment we used approximations to this numbers in order to simplify the calculations for the participants.

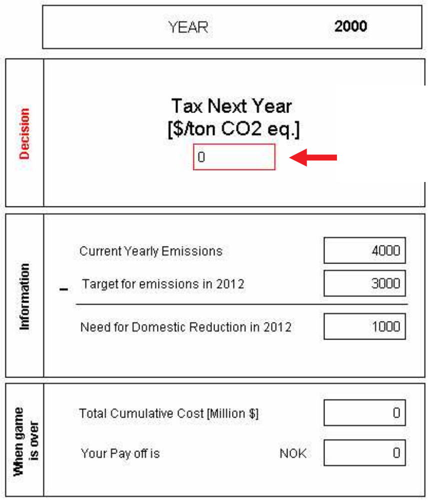

Figure 2. Treatment 1 interface

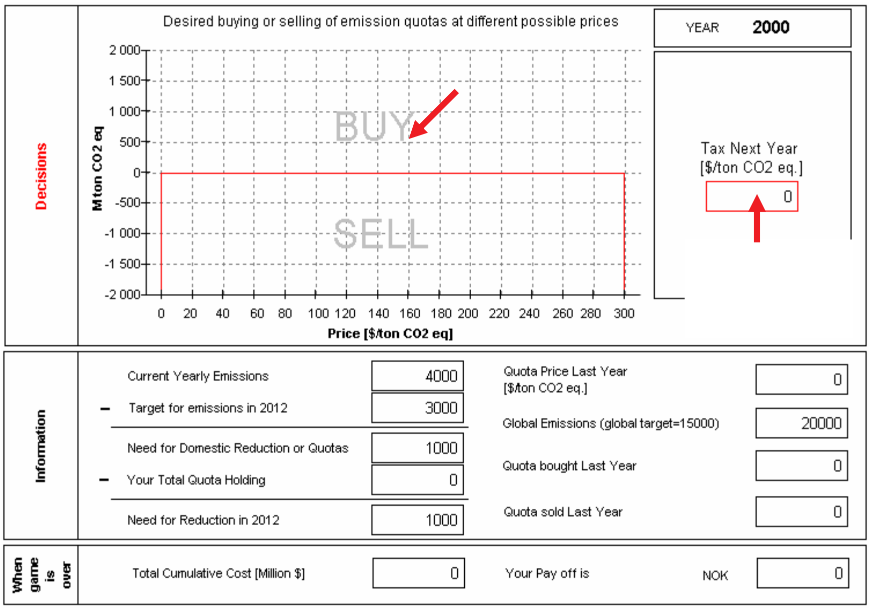

Figure 3. Treatment 2 interface

2.2.2 Optimal Tax and a Feasible Feedback Strategy

To identify the optimal sequence of taxes, subjects have to solve a complex dynamic optimization problem with limited information about the model constraints. We start by assuming full information and use Powersim Solver to find the optimal sequence of taxes and quota price. Figure 4 shows the results. There is a small difference between the two prices because they represent different "quality products". The emission quota maintain its face value until 2012. The tax will lead to some “unnecessary” reductions in that a few early replacements will have to be repeated before 2012. The optimal path also reflects an interest rate of 4 percent p.a. on the “loans” needed to finance the emission reductions.

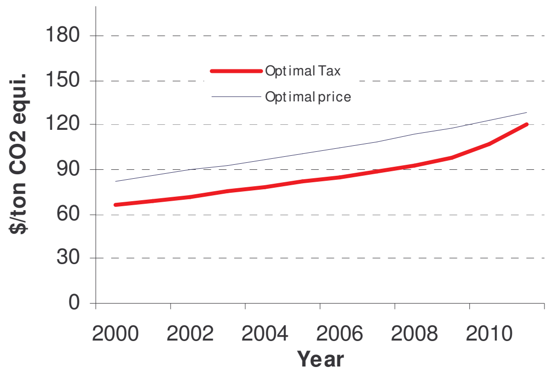

Figure 4. Optimal tax and quota price

In the experiment players do not have the time, tools and most likely not the abilities to optimize. However, we will show that a simple feedback strategy can be used to get very close to the optimal tax sequence and total costs. The feedback strategy, however, requires a minimum understanding of the delays involved.

Step No. 1. Set the initial tax
We start by 40$/ton CO_2 equivalent, which is quite a bit lower than the optimal tax, and on the low side given the cost curve in the introduction.

Step No. 2 Three years fixed tax
The initial tax is kept for three years. The reductions for the first year are 140 Mtons, for the second year are 89 Mtons and 62 Mtons for the third year. The effect drops as retrofits approach their desired level, given by the initial tax rate. The reduction in the last year denotes a maximum yearly reduction per year in the remaining 9 years if the initial tax rate is maintained. Assuming an average reduction of 50 Mtons per year and multiplying with 9 years, we get an expected future reduction of 450 Mtons. Together with the reduction during the first three years, 291 Mtons, we project a total reduction of 741 Mtons in 2012. This is not enough, and the tax rate must be increased. A linear approach suggests a tax increase of around 25 percent to reach the target. Since the cost curve is curving upwards (convex), the tax rate should be increased more than that.

Step No. 3 Repeat
Go back and repeat step 2 with a new tax rate and get data for three new years. Repeat until 2012 has been reached.

This quite simple procedure leads to a result close to the optimal cost level.

2.2.3 Subjects

The experiment was carried out at the University of Bergen (UiB), Norway, and Universidad Nacional Sede Medellin, Colombia, with bachelor and master students from the economics departments.

Thirty subjects from Norway and forty three from Colombia completed the experiment. Treatment 1 was accomplished by 28 subjects and treatment 2 by 45 subjects. To avoid learning effects, no subjects participated more than once.

2.2.4 Hypothesis

In the experiment three hypotheses were tested regarding the tax, the quota prices and the effect of the market on the tax.

H1. Average tax equals optimal tax

The alternative hypothesis is a downward bias due to ignorance of delays. There could also be a downward bias if people dislike taxes or tax increases.

H2. Tax in T1 equals tax in T2

This hypothesis holds that the existence of an emission quota market will not influence taxes. In T2 all players face the same increasing abatement costs (symmetric game). Hence, there is no reason to trade, and the tax rates should not be influenced by the trade option.

We do not state a clear alternative hypothesis. On the one hand, if the market produces an unbiased quota price, this should serve to bring up a tax rate that would otherwise be biased downwards. Subjects should react to a large difference between the two "prices" for emission reductions. On the other hand, the existence of a quota market could be seen as a safety valve, or as an option to avoid having to use taxes or having to deal with an option with uncertain outcomes. Quotas have precise numerical values.

H3. Difference between quota price and tax equals difference between optimal quota price and tax

According to economic theory there should not be different prices for one product. Taxes and quota prices should differ somewhat according to our optimization. The null hypothesis says that there is no difference.

The alternative hypothesis is that there is a difference.

3. RESULTS

We present pooled data for the two places where the experiments were carried out. One outlier in T2 is removed because decisions suggest that the subject have misunderstood the instructions. Therefore the other four subjects in the same market has to be removed as well.

Only Tax Policy

Figure 5 shows the median tax for the subjects in T1 together with the optimal tax (dotted line). We see that the median tax is lower than the optimal tax in all periods except for the last three. Figure 6 shows the p-value for each year when testing if the median is significantly different from the optimal tax (sign test). The tax in T1 is significantly different from the optimal tax from 2000 until 2008. Hence we reject H1 for the early years of T1.

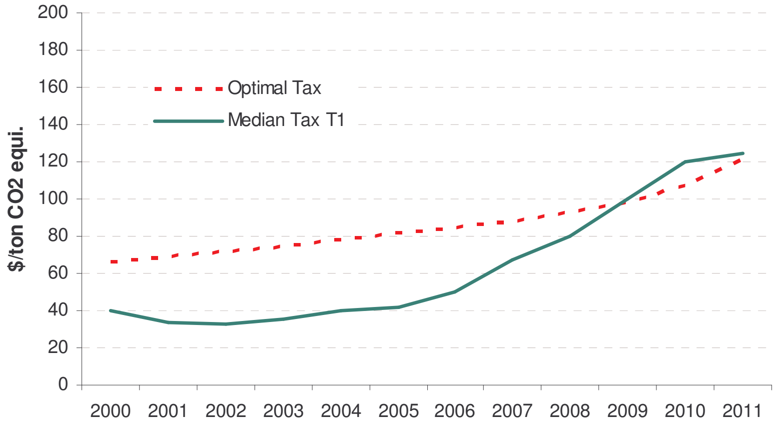

Figure 5. Median tax T1 (no quota market)

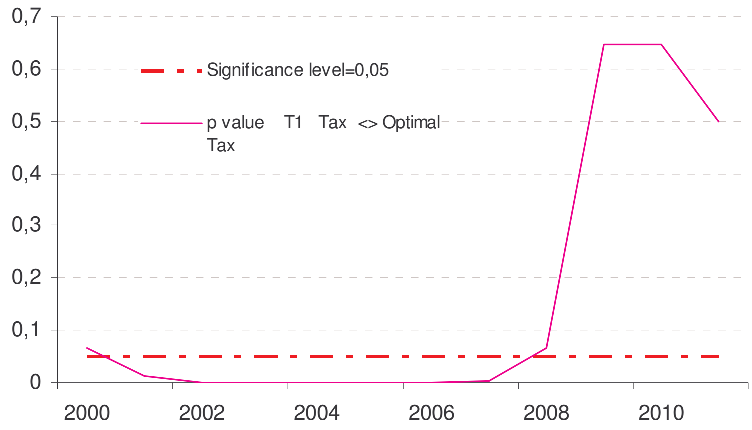

Figure 6. P-value median tax T1 vs. optimal tax

Tax with trade option

Figure 7 shows the median tax for the subjects in the treatment with quota market T2 compared to the optimal tax (dotted line). The median tax is lower than the optimal tax in all periods. Figure 8 shows the p-values. The tax in T2 is significantly different from the optimal tax during the whole period, except for the last year. Hence, H1 is reject for nearly the entire period when a trade option exists.

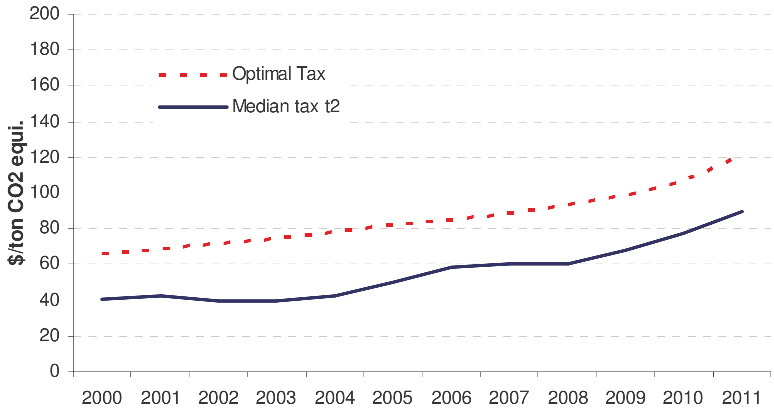

Figure 7. Median tax T2 (with quota market option)

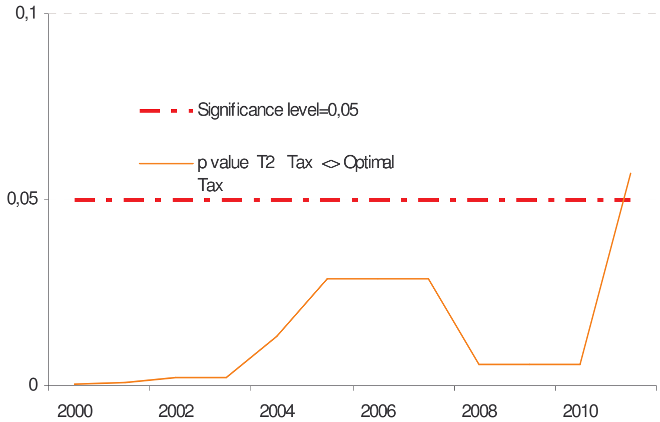

Figure 8. P-value median tax T2 vs. optimal tax

Tax with and without trade option

Figure 9 shows taxes from T1 and T2. The main difference is that with a trade option, taxes do not increase that rapidly towards the end of the period. P-values shows that the difference is significant after 2008. Hence we cannot reject H2 before 2008. After 2007 we reject H2, the trade option works to reduce domestic taxes.

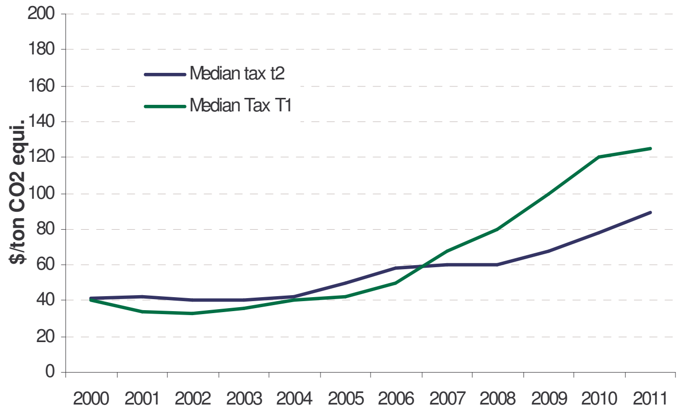

Figure 9. Median tax in T1 and T2

Quota Prices

Figure 10 shows the median quota price over time (thick solid line). During all periods the median price is higher than the optimal quota price (dotted thin line). To test H3 we compare the difference between the median quota price and median tax to the same difference based on optimal quota prices and taxes. The p-values in figure 11 shows that the difference is statistically significant except in years 2008 and 2009. Hence we reject H3 with the exception of the two years.

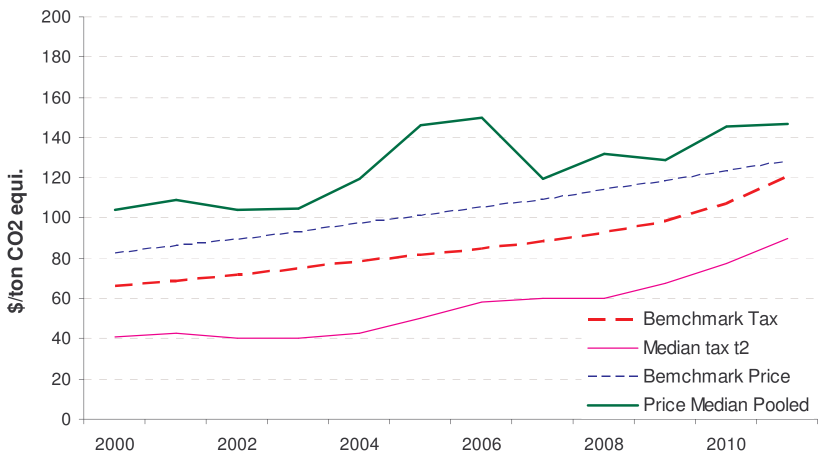

Figure 10. Median tax T2 (with quota market option)

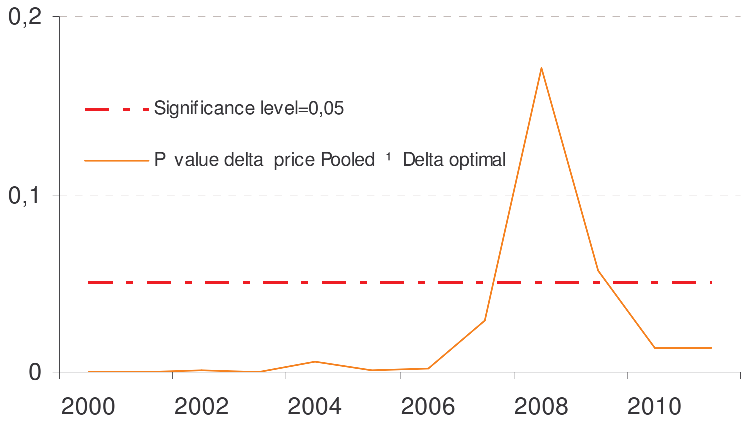

Figure 11. P-value median tax T2 vs. optimal tax

Inefficiencies

Figure 12 shows individual quota holdings in year 2012 (Y axis) as a function of domestic reductions by tax in year 2012 (X axis). The ideal situation is that all individuals reduce domestically by 1000 and engage in no trade. All observations to the left or to the right of this point represent inefficiencies. Given that subjects engage in trade, the second best situation is that they compensate for inoptimal domestic reductions by buying or selling exactly the quota needed to meet the emission reduction target. A line is draw to illustrate the frontier where the target is reached. Those subjects that are under the line do not reach the target and those over the line have excess quotas. While most of the subjects come quite close to the line, there are a few exceptions. Speculation seems to be a dominating reason for these deviations. When quota prices do not rise above previous highs at the end, speculators end up with excess quotas.

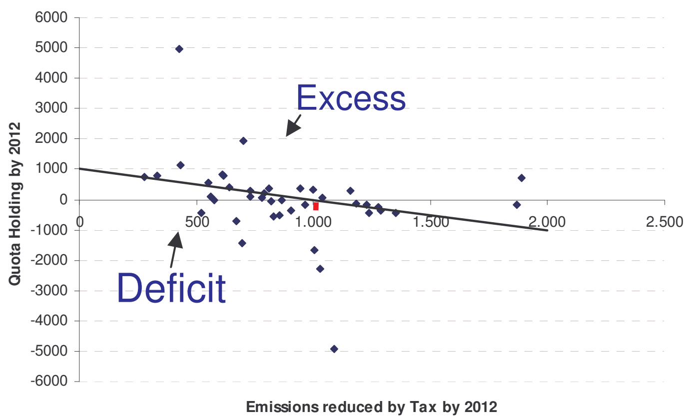

Figure 11. Inefficiencies Aiming the target

Overall Performance

Table 3 summarizes to what extent the subjects reached the target. Average emissions are higher than the target in both treatments (low p-values), and the average is higher when the trade option is present.

	Target Emissions 2012	Average Emission 2012	Lower Emissions	Upper Emissions	p-value target	% Emissions < target	% Emissions > target
T1	3 000	3 090	2 982	3 315	0,017	79 %	21 %
T2	3 000	3 118	2 110	3 723	0,008	48 %	53 %

Table 3. Subjects Performance in Reaching the Target

The average costs over treatments is summarized in Table 4. The most remarkable finding is the much higher costs in T2 than in T1. This is not surprising since all trade serves to reduce overall efficiency in a symmetric game. Cost also increase since the trade option leads to lower taxes in the last years before 2012.

	Optimal Cost	Average Total Cost	Subjects Reaching the Target					
			Average	Lower	Upper	Average	Lower	Upper
T1	44 674	67 568	60 961	31 715	80 277	72 304	59 331	85 278
T2	44 674	236 051	296 522	112 620	485 777	99 626	36 442	162 811

Table 4. Total Costs over Treatments and Subjects

4. DISCUSSION

TAX

Do people increase taxes early enough to reach the emission target?
Do people understand the delays in reducing emissions?

Do people have appropriate mental models to address the problem of reducing emissions to reach the target in time using tax as a domestic policy. Works like Lecocq et al (1998), Schowon *et al* (2004), and Green Paper (2004) provide arguments for early reductions. Emissions should be reduced by steady capital stock renewal rather than by sudden retrofits as the 2012 deadline approaches. It is very costly to reduce emissions rapidly because technologies and specific emissions are imbedded in costly and long lived capital.

Having the correct mental models means that subjects are aware of the time it takes to replace the existing high emission capital equipment by low emissions technology. Hence, subjects should begin to reduce emissions using the tax from the very beginning of the period. All subjects in both treatments set a positive tax the first year. However, the median tax was significantly lower than the optimal tax, except for the last few years.

The fact that subjects set low initial taxes, suggest a lack of correct mental models. Such lack could arise from:

1. **A dislike of taxes**:

The processing of new information depends on the stock of old information, or familiar images, Camerer (1995). If people have mental models saying that emission taxes are not effective, there are reasons to believe that people do not like taxes. There is a common perception of taxes as having a negative effect on economic growth. Emission taxes are criticized because they require firms not only to pay abatement costs, but also taxes their unabated emissions (Vollebergh et al., 1997 as in IPCC, 2005). Recent papers, however, argue that emissions taxes are more cost-effective than direct regulation and may even lead to higher employment (Wellisch, 1995; Hoel, 1998 and IPCC, 2005). The intuition is that with taxes emissions constitute a rent because the firms have to pay for emitting (IPCC, 2005). Besides, some experts criticize emission taxes because they do not guarantee a particular level of emissions. During the Kyoto negotiations there were much discussion around taxes whether they are effective or not. Some countries were very skeptic about the implementation of taxes.

Our subjects, however, are not likely to have very advanced ideas about the economic effect of emission taxes beyond the first and direct effect on costs. In T1 subjects have the tax as the only option to reach the emission target. If they dislike taxes very much they could just play the do-nothing-strategy and pay the punishment. In T1 the subjects did use the tax. Towards the end of the period, the average tax in the sample even exceeds the optimal tax. Hence, at least towards the end the needs seem to dominate an eventual dislike.

In T2 players could use the market as an alternative option. All the strategies in T2 were mixing policies using the tax and the market. There was no player that did not use the tax, however, there was only one player who bought almost all the reductions the first year in the market and fixed the tax at zero for 5 years. This indicates that this person did not realize the potential for profit of the investments (using the tax) in emission reductions for sale. The average price in the market was all the time higher than the average tax. That suggests that players prefer to pay more to avoid the tax, maybe because there is uncertainty about the quantity reduced by taxes. However the fact that subjects in T2 did not set significantly lower taxes than subjects in T1 in the first years make us doubt the importance of their dislike of taxes.

2. **Underestimation of delays**

When people are not aware of delays, they typically expect to see immediate feedback from the decisions made. Sterman (1989b) found that subjects underestimated the time lag between placing and receiving orders in a supply line. In the first weeks subjects failed to allow sufficient orders in the pipeline to achieve their desire inventory level. Subjects increment orders when they realize that the current inventory is not large enough to fulfill the demand. They create an overshoot of the desire inventory because they ignore the supply line.

Although it is not the same problem, the replacement delay in our experiment is like the ignored supply line in Sterman (1989b). Subjects underestimate the time needed to reduce emissions. The low initial tax and the tax panic at the end of T1 accounts for such underestimation. Being unaware of the replacement delays subjects may consider the possibility of postponing the reductions to the last years and save on discounted cost.

3. **Inability to respond properly to outcome feedback over time**

The emission reductions from taxes can not be determined with certainty from the beginning of the experiment. The subjects see the marginal cost curve but they do not have exact information about the delays or the split between replacement and retrofit. Hence, a feedback strategy is needed.

With very low initial taxes, our results do not show clear patterns of increasing tax in order to reach the emission targets. The panic tax in T1 in the last years may indicate learning when the signals are strong enough, however, may also reflect simple time pressure. In T2 there is not such a panic and the tax has a steady growth. The emissions market seems to remove much of the time pressure, and little genuine learning seems to take place.

2. **Punishment is not a salient anchor for taxes**

Interestingly punishment does not seem to be a salient anchor for taxes.

EFFECT OF MARKET OPTION ON TAX

Will trade of emissions quotas among countries influence how people set taxes?

1. Inefficiencies

When subjects have different levels of understanding they opt for different tax levels and trade is motivated. Inefficiency arises when subjects use the trade option to reach the target.

2. Two prices for two nearly identical "products"

Surprisingly, economic students price two quite similar "products" differently. The question arises whether they really understand how taxes work to produce incentives for profitable emission reductions. With a market price higher than the optimal, the optimal tax rate is actually somewhat higher in treatment 2 than the benchmark for no trade. This is because the players could make profits from selling quotas produced by high tax rates. When there is no market and subjects have different cost curves, they should have different taxes and different reductions. But, when there is a market and they have the same cost curve the tax should be the same.

3. Market as a complementary measure

The average tax in both treatments is nearly the same; therefore the market did not have a big influence on the tax. In the last years subjects from T1 are stressed from the possibility of not reaching the target, because they did not set high enough taxes at the beginning, therefore they increase the tax. In T2 there is no strong increase of taxes at the end, even if they did not set high enough taxes at the beginning. The use of both polices show a clear strategy of mixing policies. The market was not a substitute for the tax but a complementary measure.

4. Market Speculation

Smith *et al* (1988) found that speculation in an asset market drives the prices beyond the optimal price, generating a bubble towards the end. The emission quota market can be seeing as an asset market. Works by Moxnes (2003) and Anderson *et al* (2005) show excessively high quota prices due to speculation, indicating that speculation could have played some role for quota prices moving above the optimal market price. However, we cannot know that from this experiment.

Implications of Misperception of Feedback

In the experiment subjects have instant information feedback of what is happening in the system regarding the emission reduction achieved. However, they seem to have problems in finding proper actions to correct the emission path. In real life the time lag between the time measures are implemented and the information about the reductions achieved is very long. Besides, the information is not hundred percent reliable, IPCC methodologies for some GHG's are still in development and the national emissions update has a delay of around one year (or more for some countries). Hence, the policy makers could even have more problems then subjects in the experiment to act properly for correcting the emissions path.

	Target 2012 Mton of CO2	Emission 2002 Mton of CO2	Diference Emission 2002-Target	TAX per ton CO2	TRADIN G SCHEME	Emissions from 2000 to 2002 Mton of CO2	Average annual growth GDP	
							2000	2001
Austria	48	71	22			5	3	1
Belgium	115	146	31		YES	2	4	1
Denmark	45	55	10	13 EUR - 1997	YES	-3	3	1
Finland	53	54	1	16 EUR-1999		3	6	1
France	374	407	33			-4	4	2
Germany	798	838	41			-5	3	1
Ireland	29	45	16			5	12	6
Italy	388	449	60			0	3	2
Luxembourg	8	10	3			1	8	1
Netherlands	199	256	58	ND-2000	YES	7	4	1
Norway	35	46	11	12 EUR - 1999	YES	4	2	1
Portugal	56	67	11			3	4	2
Spain	260	341	81			24	4	3
Sweden	57	55	-2	40 EUR- 1991	YES	0	4	1
Switzerland	41	44	3			-2	3	1
United Kingdom	525	553	28	ND-2002	YES	-3	3	2

Table 3. Current State of CO_2 Emissions European Union (source: www.unfcc.com, www.eia.com , www.worldbank.org, www.oecd.org)

EMISSION REDUCTIONS IN EUROPEAN UNION

- Current State

In the European Union only 5 out of 15 countries are using taxes for reducing emissions (table3). Sweden is an interesting country because it has the highest tax rate, the country is already below the target and has zero emissions growth rate from 2000 to 2002. Countries like Spain, Italy and Germany are far away from the target and are not implementing taxes or trading schemes for reducing emissions. From 2000 to 2002 few countries are achieving reductions at very low rates. Countries like Spain, Portugal, Ireland and Austria are far from the target and are increasing their emissions instead or reducing. The European Union Emission Trading Market which started activities in

February 2005 is reporting prices of 21 EUR /ton of CO_2[9]. This is somewhat higher than the prices obtained in our experiment.

- **Implications**

From the data showed above we have evidence that countries typically are using even lower tax rates and higher market prices than in our experiment. In the experiment subjects fail to understand the dynamics of emission reductions in a simplified environment. In real life the environment is not that simple, adding complexity to the task of reducing emissions and increment the likelihood of bias in the decision making.

[9] www.nordpool.com

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Appendix

The Kyoto treaty experiment

The purpose of the Kyoto treaty is to reduce world emissions of greenhouse gases to limit potential future climate change. According to the Kyoto treaty, the countries that have signed the agreement must reach certain targets for their greenhouse gas emissions by the year 2012. The targets can be reached in two ways:
1. Countries can reduce their domestic emissions, or
2. They can buy emission quotas from other countries, which in turn must reduce their domestic emissions below their agreed targets to make up for the quotas they have sold.

In this laboratory experiment the world is split in 5 identical countries (or regions). You will each be playing the leader in one of these countries, making all decisions for the country by yourself. Your **goal** is to reach the target with the lowest possible cost.

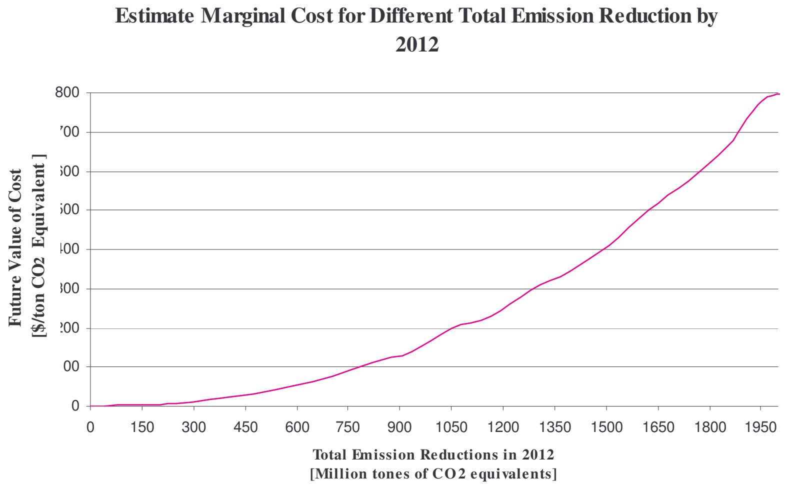
Each year you have **two decisions** to make: You set a tax rate for emissions of greenhouse gases in your own country and you make bids to buy or to sell emission quotas in a market where all 5 countries interact. From one year to the next, the computer calculates how much the domestic emissions have been reduced due to the tax and the amount of quotas you have bought or sold in the market and at what price.

The experiment starts in year 2000 and the emission goal should be reached by 2012. You cannot reach the target without incurring costs. At the end of the game you will receive a payoff that depends on your total costs. The payoff can vary from NOK 70 for very high total costs to NOK 150 for very low total costs.
Your total costs depend on three factors:
1. Domestic emission reductions cost money for those who have to make the reductions. The tax income for the government is of no concern here; just assume that it is returned to the tax payers as reductions in other taxes. It is assumed that all emission-reduction projects that cost less than the tax rate will be implemented each year. Thus, the higher the tax rate, the larger the costs for domestic emission reductions and of course the larger the emission reductions.
2. If you buy emission quotas in the market you generate a cost. If you sell quotas, you decrease your costs.
3. If you do not reach the emission target by domestic reductions or quotas in 2012 you will be punished with an extra cost of 200 $/ton CO2 equivalent for the excessive emissions. Note here that Greenhouse gases are measured in equivalent units of CO_2 (tons of CO_2 equivalents)

Think about the costs as being paid by loans for which you have to pay a 4 percent interest per year. Thus, your total costs in 2012 will include both the direct costs and the interests you have to pay on the loans. Hence, an early reduction in emissions will be more costly than a later and otherwise similar reduction.

To simplify the experiment we assume that there is no economic growth. Furthermore, all emissions reductions must take place with equipment that exists today, there is no technological improvement over time. Your emissions in year 2000 are **4000 million** tons of CO_2 equivalents. Your emission target for year 2012 is **3000 million tons** of CO_2 equivalents. Thus, the needed reduction is **1000 million** tons of CO_2 equivalents.

The experiment is based on studies that have estimated the lowest possible marginal costs of total domestic emission reductions by 2012. The minimum costs require that an optimal sequence of taxes is used. See future values of the minimum marginal costs in the graph below. For your information, a tax of 130 $/ton CO_2 equivalent corresponds to approximately a doubling of current energy prices.



Each year the computer computes the emissions reductions that follow from chosen tax rates. You should assume that the computer program is highly realistic except for the simplifications already mentioned.

How to play

The PC screen is divided in three sections: decisions for the present year, information about the last year, and total costs and payoffs in year 2012. The game progresses in the following sequence: Look at information from last year, make decisions, press the button “Accept Decisions”, the game progresses to the next year, you look at the new information and so on.

DO NOT PRESS “Accept Decisions” BEFORE YOU HAVE CHECKED YOUR DECISIONS - THERE IS NO RETURN ONCE YOU HAVE ADVANCED TO THE NEXT YEAR.

Decisions:

You set the tax rate by entering a number in the Tax box.

You make bids for quotas by clicking on the curve and then dragging it to where you want it. At sufficiently low quota prices (to the left in the diagram) you will probably like to buy quotas - if so, the curve should be in the buy region (higher than zero). At sufficiently high prices you will probably like to sell quotas and the curve should be in the sell region (lower than zero). You have to specify the entire curve, such that the computer program knows how much you want to buy or sell at all possible quota prices. The curve may be flat or declining, it cannot bend upwards at any point (if you do, you get an error message and have to change it). An upward bending curve is like saying that you want more quotas the more expensive they are - that does not make sense.

When all players have entered their curves (and their taxes and have clicked on “Accept Decisions”), the computer program finds the quota price that equilibrates the market, that is, total sales equal total purchases.

Information last year
Current Yearly emissions
Target for emissions in 2012
Need for Domestic Reduction or Quotas
Your total Quota Holding
Need for domestic Reduction by 2012
Quota Price last Year
Global Emissions (Sum of emissions for all five players)
Quotas Bought Last Year
Quotas Sold Last year

Information in year 2012
Total Cumulative Cost
Your Payoff

Thank you and Good luck!!