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Properly designed emissions trading schemes do work!

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Properly designed emissions trading schemes do work!

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Emissions trading markets have been touted as the most efficient mechanism to achieve environmental goals at least cost. Whether in the form of voluntary markets or in a mandatory framework like in the first phase of the European Union (EU) Emission Trading Scheme (ETS), the regulator sets a cap on the emissions which can occur without penalty, and provides emissions allowances accordingly. The recipients are free to use these emission certificates to cover their emissions, or to sell them to the firms which are expected to emit more than what they can cover with their original allocations.

As observed in most existing programs, cap-and-trade systems can fail to reach their emission targets as too generous an allocation of pollution permits serves as a disincentive for emissions reductions and deflates pollution prices. Moreover, the implementation of the first phase of the EU-ETS has been widely criticized on one more sensitive account: providing significant (some went as far as calling them obscene) windfall profits for power producers.

Here we weight on this debate with the results of a rigorous quantitative modeling undertaking, providing insight into what went wrong in the first phase of the EU-ETS, and proposing alternative reduction schemes with provable advantages. Using market equilibrium models and numerical tools, we demonstrate that properly designed market-based pollution reduction mechanisms can reach pre-assigned emissions targets at low reduction cost and windfall profits, while being flexible enough to promote clean technologies. In the present article, we illustrate our claims with the results of a hypothetical cap-and-trade scheme for the Japanese electricity market.

environmental finance | emission markets | cap-and-trade scheme

To protect the environment and reduce industrial pollution, market-based mechanisms (cap-and-trade systems, emission trading schemes) are considered as one of the most promising tools. The most prominent examples of existing cap and trade systems are the EU ETS, the US REgional CLean Air Incentives Market (RECLAIM) program and now, Regional Greenhouse Gas Initiative (RGGI). In such systems, a central authority sets a limit (cap) on the total amount of pollutant that can be emitted within a pre-determined period. To ensure that this target is complied with, a certain number of credits are allocated to appropriate installations, and a penalty is applied as a charge per unit of pollutant emitted outside the limits. Firms may reduce their own pollution or purchase emission credits from a third party, in order to avoid accruing penalties. The transfer of allowances by trading is considered to be the core principle leading to the minimization of the costs caused by regulation: companies that can easily reduce emissions will do so, while those for which it is harder buy credits.

Ideally climate policies seek compliance with a given emission target at the lowest possible consumer and producer costs, and aim for a change in the production portfolio towards cleaner technologies. Though after the first phase of EU ETS it has been questioned whether today's emission trading schemes can reach any of these goals at all. Using an hypothetical emission trading scheme for the Japanese electricity sector, our theoretical and quantitative analyses confirm the shortcomings of the first phase of the EU ETS: with a poor implementation, pollution reduction targets can be missed, and consumers can get the brunt of the operation while producers enjoy excessive profits, the so-called windfall profits which can exceed actual abatement costs by several orders of magnitude. More often than not, the main weapon suggested to combat windfall profits is auctioning of allowances. In this article we show that auctioning is not an appropriate measure to eliminate windfall profits

The main thrust of the present contribution is to demonstrate that most of the above problems can be solved by properly designing the cap-and-trade scheme. We propose a simple relative allocation mechanism in which besides a free upfront allocation, allowances are allocated proportionally to the instantaneous (as opposed to historical) production of goods (the proportionality factor being fixed at the start of the compliance period). In particular we show that this allocation scheme can reach the same emission target while reducing average windfall profits to zero and keeping abatement costs nearly at the same level as standard cap-and-trade schemes. Our tests are performed on a one compliance period prototype modeled after the first phase of EU ETS, hence not allowing for banking or borrowing of allowances. However, it is clear that the conclusions drawn from our comparative statics do remain the same in the more realistic setting of multi period models.

To illustrate the benefits of this mechanism we compare it to tax-based abatement policies, generic cap-and-trade schemes (such as those implemented in the first phase of the EU ETS), and cap-and-trade schemes with a 100% auctioning of allowances. In this article, we illustrate the theoretical outcomes from [1] and provide policy makers and regulators with analytic and quantitative tools to design and implement cap-and-trade schemes capable of a) controlling the incentives to promote changes in the production portfolio towards cleaner technologies and b) reaching reasonable pollution targets at low reduction costs and windfall profits.

Theoretical Analysis of Cap-and-Trade Schemes

For the sake of completeness, we recall some stylized facts about the first phase of the EU ETS that we use in our analysis. At the inception of program the regulator

- controls the **initial distribution** of **allowances**;
- sets the level of the **penalty** for each emission unit not offset by an allowance certificate at end of the compliance period.

Then, risk neutral firms compete for the production of goods (e.g. electricity), whose production causes emissions, while their demand and their production costs (e.g. coal and gas

Abbreviations: GHG, greenhouse gas; EU, European Union; ETS, Emission Trading Scheme; RECLAIM, REgional CLean Air Incentives Market; RGGI, Regional Greenhouse Gas Initiative; BAU, Business As Usual

costs) change randomly over time. During the compliance period (typically 3-5 years), each firm dynamically adjusts its production (and consequently its emissions) and its trading in emission credits to maximize its own terminal wealth.

Equilibrium Models. The analysis of cap-and-trade schemes can be conducted in the framework provided by the mathematical theory of equilibrium economic models. In [1], we provide a rigorous mathematical analysis of an equilibrium model for a finite set of risk neutral agents/firms facing a random inelastic demand and random production costs. Here we use the computer programs developed for [1] to illustrate the pros and cons of different cap-and-trade schemes. We study an Emission Trading Scheme covering the Japanese electricity sector as the basis for our conclusions and recommendations.

For each market design, the program provides

- Monte Carlo scenarios for equilibrium production policies, prices of goods and pollution permits;
- For each scenario, computations of pollution levels, reduction costs, producers windfall profits, and end-consumers costs.

Our mathematical analysis shows that in equilibrium (when prices are such that demand and supply match), prices of the goods are given by production costs and allowance prices as follows: for each specific good (say electricity), and at any given time t, we introduce the notion of effective production cost $\tilde{C}_t^j$ when technology j is used in the presence of regulation. This effective cost is defined by the formula

$$\tilde{C}_t^j = C_t^j + e^j A_t \qquad [1]$$

where C_t^j denotes the cost without regulation, A_t is the allowance price at time t, and e^j is the emission per unit of produced good when using technology j. The price for the good at time t is then given by the classical merit-order relation: it is equal to the effective production costs of the most expensive technology needed to meet the demand. On this account, one sees that the allowance price enters additively in the effective production costs, though nonlinearly in the equilibrium prices in the presence of a cap-and-trade scheme. This formula has two clear consequences. On the one hand, the additive term $e^j A_t$ can change the merit order of technologies. Indeed, if allowances are expensive, then a pollution-intensive technology can appear costly and be scheduled last for production. This effect creates cleaner overall production. On the other hand, the costs $e^j A_t$ offer to the producers the opportunity to sell allowances on the market instead of using technology j, creating opportunity costs. For consumers, this means that the allowance price enters the price of the good at any time t with a factor e^j representing the specific emission of the production technology which is marginal at time t. In other words, the cost of pollution $e^j A_t$ can be viewed as the cost of an extra fuel needed for the production of the goods. At this point, we clearly see the difference between consumer's burden and true costs of pollution reduction. The reduction costs come from switching to cleaner, hence more expensive production technologies, and are driven by a change in the merit order. This is, however, not the only extra cost passed along to the consumer. In the presence of regulation, consumer's costs increase by $e^j A_t$ for each unit produced at time t. This gives rise to huge windfall profits which we define precisely in the short appendix at the end of the paper.

Can a Standard Cap-and-Trade Scheme Meet Emissions Targets?. As observed in the SOx and NOx RECLAIM program and after the first phase of the EU ETS, cap-and-trade systems can fail to reach their emission targets as too generous an allocation of pollution permits serve as a disincentive for emissions reductions and deflate pollution prices. However the same is also true for a regulation with too low a penalty in case of non compliance. This effect is illustrated in Figure , which depicts the histograms of the total emissions computed for each of the equilibrium Monte Carlo scenarios generated for the purpose of our case study. For the sake of definiteness, we consider the standard cap-and-trade scheme with different penalties, and with an initial allocation of $300Mt$ which corresponds, in the case of Japan's electricity market, to a 20% reduction target. See details given below.

The case with zero penalty corresponds to *Business As Usual* (BAU): obviously, it misses the reduction target by far. When the penalty is set at 20$ per ton, the emission target

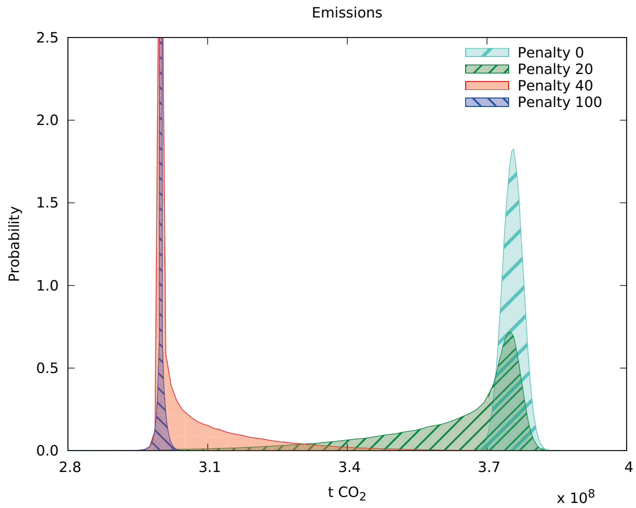

Fig. 1. Effect of the level of the penalty on the statistical distribution of the actual emissions at the end of a period of implementation of a standard cap-and-trade scheme.

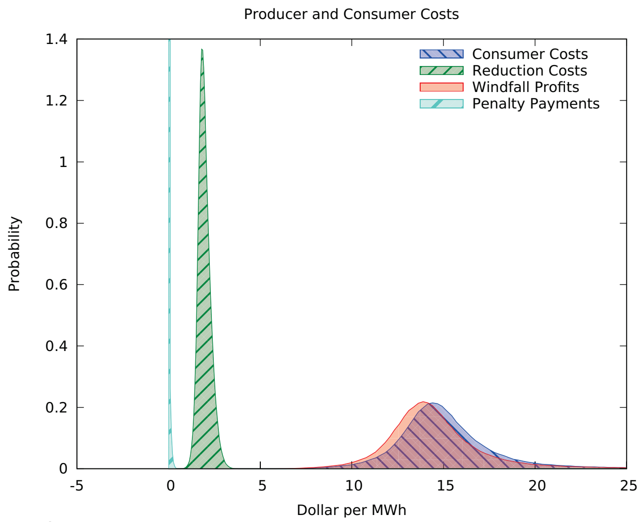

Fig. 2. Histograms of the differences between the consumer costs, reduction costs, windfall profits and penalty payments of an standard cap-and-trade scheme and the corresponding quantities for BAU. Here, the cap-and-trade scheme is calibrated to reach the emissions target with 95% probability.

is missed by the same amount with a very large probability. With a 40$ penalty, there is a significant probability to meet the target, but the distribution of the emissions has a long tail overshooting the target. On the other hand in the case of a 100$ penalty, the probability to reach the reduction target is 95%. This shows that the probability for a cap-and-trade scheme to reach a given emission target depends not only significantly on the initial allocation of allowances, but also on the penalty applied in case of non compliance, though the importance of the penalty is often underestimated. The main thrust of this article is to demonstrate that cap-and-trade schemes work as long as parameters are properly calibrated. An example of a rigorous calibration of these parameters is presented in [1].

Costs of a Standard Cap-and-Trade Scheme. While the specific distribution of the initial allocation of emission allowances among the various participants (installations covered by the scheme) does not influence the overall emissions reduction, it plays other important roles which we now investigate. One of the goals of climate policy is to promote a change of the production portfolio towards cleaner technologies. We argue in [1] that this goal is not reached automatically by introducing emission trading schemes. However such objectives can be reached by benchmarking the initial allocation, e.g. by distributing the initial allowances (as in part of EU ETS or RGGI) depending upon the type of power plant, or even as a reward for building clean plants. Note that, since allowances have a financial value, this can be seen as a direct subsidy financed by the other market participants.

However whether or not a cap-and-trade scheme can be considered a success also depends upon the overall costs incurred to reach the emission target, as well as the part of these costs that are passed on to the end consumer. To illustrate the relative importance of the different costs associated with a standard cap-and-trade scheme, Figure compares reduction costs, penalty payments, end consumer costs and windfall profits in the case of our model of the Japan electricity markets. For these computations, we use a 100$ penalty and an initial allocation of $300Mt$.

It turns out that consumers' costs (in average 15.13$ per MWh) exceed by far the overall reduction costs (in average 1.96$ per MWh), which as it was the case in the first phase of EU ETS, gives rise to huge windfall profits for the producers. Obviously, costs of production are higher in the presence of a cap-and-trade scheme. This is because, due to the emission constraints, producers switch to cleaner and more expensive technologies to avoid paying the penalty. However for a 20% reduction target, average abatement costs are only 1.96$ per MWh of produced electricity! Though as observed in EU ETS consumers costs exceed the overall reduction costs by far (a factor of 8 in the present case). This is one of the main reasons for the huge windfall profits which have been the core of the main criticism of cap-and-trade schemes by consumer advocates.

It is commonly believed that an initial auctioning of allowances, even partial, will reduce windfall profits. However, we show below that even auctioning of the total initial allocation of a standard cap-and-trade scheme may not reduce windfall profits to a reasonable level. Moreover full auctioning of the allowances does take away a major regulatory mechanism to control the incentives. This leads us to consider proportional allocation schemes, which can reduce windfall profits to zero (at least in average) and *preserve* enough initial allocation to still allow the regulator to set incentives with this tool.

Alternative Cap-and-Trade Schemes

In light of the shortcomings of the first phase of EU ETS which were documented in the public press and illustrated earlier, it is important to understand if the implementation in question is to blame, or if cap-and-trade schemes are doomed to fail. Several alternative reduction mechanisms are proposed and studied in [1]. They include a form of emissions tax, and several random allocation schemes. Here we highlight one proportional scheme (which we call *relative scheme* from now on) as an alternative to the standard EU ETS - which we call *standard scheme* for the sake of definiteness. We compare our relative scheme to the standard scheme with and without auctioning or emission tax.

A Proportional Allocation Scheme. In this new scheme, the upfront allocation is only part of the overall emission target, a big part being distributed over time, proportionally to the production of goods (in electricity markets nothing should be allocated to nuclear production). Since allowances have a financial value, allocating allowances proportionally to the production reduces the marginal costs of production and hence the price of goods and windfall profits.

In the case of random demand, the lack of certainty may worry some environmentalists concerned about the fuzziness surrounding the emissions target. But because historical data are readily available, econometric models can be brought to bear, and the statistics of the future demand for goods can be estimated with great accuracy. In this way, the regulator can calibrate the proportionality coefficient of the distribution of pollution certificate in order to meet emissions targets with any given statistical degree of certitude, using for example percentile measures in the spirit of Value-at-Risk as in the previous section when we discussed the standard scheme. Notice that even in a standard cap-and-trade scheme with deterministic emission target the probability for emissions to exceed a given emission target is not negligible (see e.g. [1] and [2]). The reason is the randomness of electricity demand. Our quantitative analysis confirms that applying standard econometric methods, emissions targets can be reached with any given statistical measure of risk, both for the proportional and for the standard cap-and-trade scheme.

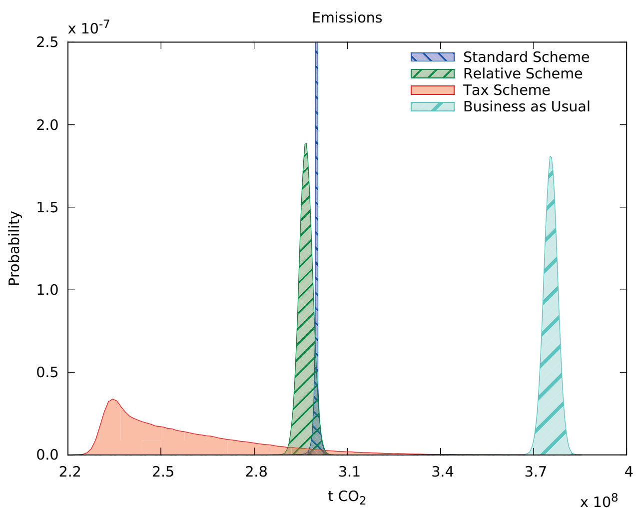

Fig. 3. Yearly emissions from electricity production for the Standard Scheme, the Relative Scheme, a Tax Scheme and BAU.

Auction. The most frequently advanced approach to reduce windfall profits is to replace free allocation of allowances (which was common practice in the first phase of EU ETS) by an auction-like procurement. With auctioning, producers pay for allowances and the regulator can return revenues to consumers or invest these revenues in other emission reduction projects. However, auctions are not sufficient to efficiently reduce windfall profits. Indeed, by selling allowances, one is able to collect an amount which is essentially equal to the total number of allowances times the allowance price. This money will, in general not match the overall consumer burden, since the latter is related not to the number of allowances, but instead to the number of product units consumed within one compliance period. In the following case study, we assume that prices are not changed by the auction and the price settled in the auction corresponds to the equilibrium price settled at the beginning of the trading period under free allocation.

Taxes. The last type of pollution reduction mechanism we consider is a static tax that is paid for the emission of each ton of CO_2 – equivalent. In the case of the electricity markets where demand can be considered to be inelastic, the tax has to make coal more expensive than gas (which emits less CO_2) to trigger any emission reduction. However, since both coal and gas prices are stochastic, the emission reductions are nearly impossible to control with a tax. This is illustrated in Figure below.

Comparison of the Various Cap-and-Trade Schemes

We illustrate our claims by comparing the three alternative reduction schemes discussed above in a case study of the Japanese electricity market with data extracted from Japanese official projections for 2012.

Case Study: the Japanese Electricity Market. At the core of our analysis is the main abatement mechanism in electricity production: the fuel switch from coal to gas. This was the main abatement mechanism in EU ETS [3]. As explained in a recent governmental task force report [4], this is also the abatement mechanism with the largest abatement potential in the Japanese electricity sector.

The Japanese electricity market is divided into an Eastern and a Western part, with only 1 Giga Watt interconnection capacity. Hence, for the purpose of this case study, we assume that we are dealing with two separate electricity markets sharing a joint emission cap. We use the production capacities given in Table 1.

Assuming further that the Japanese electricity market is totally deregulated we can use a straight-forward generalization of the results of [1] to this situation. The numerical results reported below are based on the following assumptions:

The **goal of the regulator** is to reduce emissions by 20% of what the emissions level would have been at the end of 2012 under the Business-As-Usual (BAU) scenario. This implies an emission target of less than or equal to 300 Mega-ton of carbon dioxide. Since we are working in a non-deterministic framework, this target must be interpreted accordingly. We consider reduction schemes with a compliance period covering the year 2012 and with

(*) total emission less than or equal to the cap of 300 Mega-ton of CO_2 with probability of 95%

Controls available to the regulator:

i) Standard scheme: size of the penalty, and total number of allocated allowances.

ii) Relative scheme: size of the penalty, total number of allowances allocated upfront, and factor of proportional allocation.

iii) Tax scheme: tax levied to discourage dirty production

Calibration. In order for our comparison of the various schemes to be meaningful and fair, we choose the parameters in the following way. For the standard scheme, the initial allocation is set to 300 Mega-ton of carbon dioxide. Setting the penalty at 100 USD, numerical calculations confirm that (*) is satisfied. To make schemes comparable, we need to adjust the other parameters of the different schemes. For the relative scheme, we also set the penalty to 100 USD, the upfront allocation to 63Mt CO_2 (this is equivalent to 20% of the cap in the standard scheme) and the proportionality factor to 0.45 to fulfill (*). For the tax scheme, (*) is met with coal taxation at $39.5\$/t_{CO_2}$. Details of the calibration procedure needed to fine tune the *right* coefficient of proportionality are given in [1].

Yearly Emissions. Figure gives the plots of the statistical distributions of the yearly emissions for the various production schemes considered in this study. As explained above, these schemes were calibrated to the yearly emissions target (cap) of 300Mt CO_2, so that only 5% of the scenarios would give a yearly emissions level above target. Obviously, this does not apply to BAU scenarios. They ignore the cap and miss the target because of the lack of penalty. For standard and relative cap-and-trade schemes, producers' emissions are tightly concentrated just below the cap, showing that in both cases producers emit as much as possible while remaining under the cap. Because of the randomness inherent in the relative scheme, producers end up emitting less.

But the striking fact illustrated by this figure is the width of the histogram of the yearly emissions under an emission tax. Guaranteeing that the yearly emissions will not be greater than the cap more than 5% of the time can only be done at the cost of widely fluctuating yearly emissions due to the stochasticity of abatement costs (fuel switching). Since these fluctuations remain below the cap, they could be viewed as a sign that properly calibrated, the tax scheme is better than the cap-and-trade schemes for emissions reduction. However, clearly the shape of the histogram shows a lack of efficiency

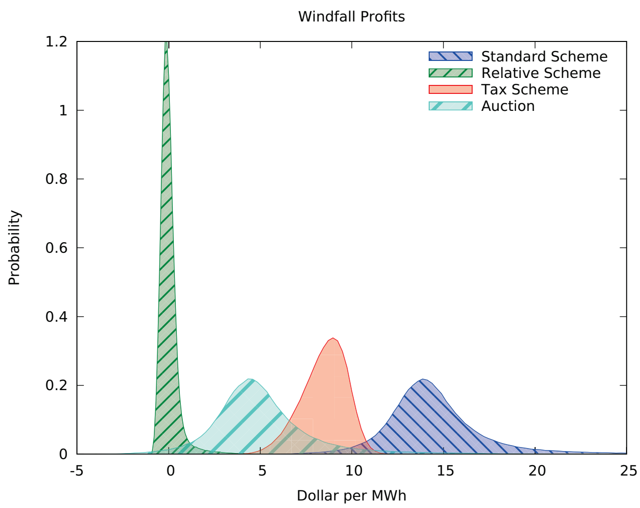

Fig. 4. Histograms of the yearly distibution of windfall profits for the four schemes considered in our case study. Note that the only scheme with close to zero windfall profits is the Relative Scheme.

Consumer Burden

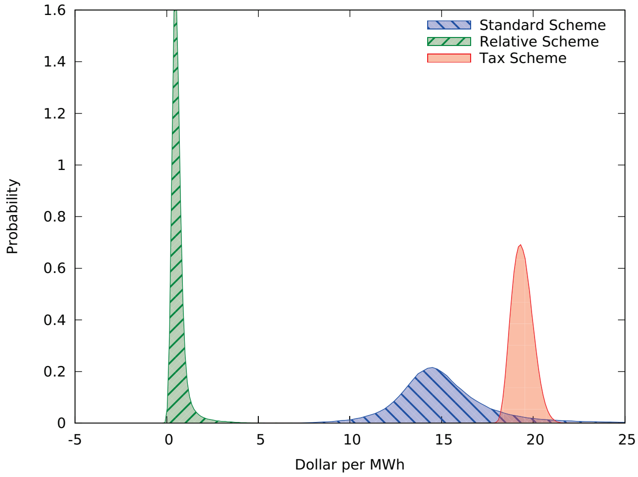

Fig. 5. Histogram of the yearly distribution of consumer costs for the Standard Scheme, a Relative Scheme and a Tax Scheme. Notice that the Standard Scheme with Auction possesses the same consumer costs as the Standard Scheme without auction, so the corresponding histogram is not plotted.

in the abatement, and as we are about to see, this abatement happens at a much higher cost.

Windfall Profits. Windfall profits are defined in the appendix. Figure shows the statistical distributions of the windfall profits. Neither the tax scheme nor the standard scheme with full initial auctioning of the allowances are able to reduce the windfall profits to a satisfactory level. The reason is that due to increased electricity prices, profits are made in all cases with electricity produced from nuclear power plants while at the same time, neither the auctions nor the tax can reduce the earnings of the nuclear plants. The only scheme with close to zero windfall profits is the relative scheme. As explained above, the proportional allocation reduces electricity prices and therefore combats windfall profits at their origin.

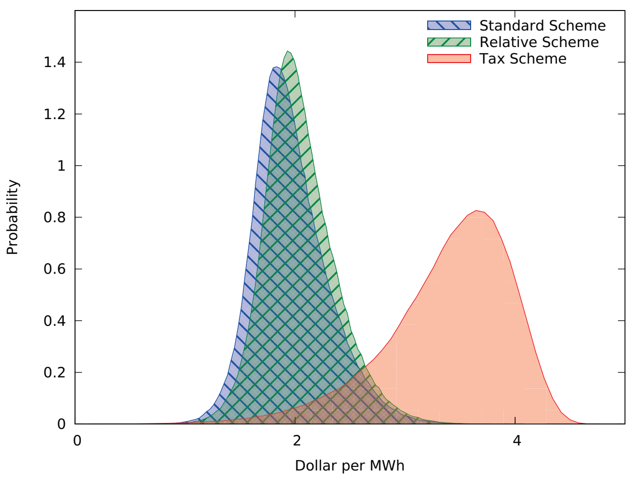

Fig. 6. Yearly abatement costs for the Standard Scheme, the Relative Scheme and a Tax Scheme.

Consumer Burden. As explained in the appendix, the consumer burden, whose histograms are displayed in Figure 2 for the different schemes, captures the difference in total consumer's costs with and without regulation. The high consumer burden for the standard scheme is in line with its high windfall profits. For the tax scheme the histogram indicates that in average, electricity prices would increase by approximately 20$ per MWh! However the regulator could give back part of this amount to the end consumer, e.g. by reducing other taxes. Because the average auction revenue corresponds to $9,5\$/MWh$ consumer costs exceed by far the revenue from the auction. This amount can only cover about tow thirds of the consumer costs. Hence the commonly believed argument that auction revenues can be used to cover costs of endconsumers is wrong and there is still significant wealth transfer from consumer to producer. On the other hand in the case of a relative scheme, the consumer burden is tightly concentrated around zero. This means that even for a reduction target of 20%, electricity costs are nearly the same as in BAU!

Abatement Costs. Figure 2 illustrates the fact that the reduction costs of the relative cap-and-trade scheme are insignificantly higher than the reduction costs of the standard cap-and-trade scheme. Further both schemes are more economical and emissions control and reduction are easier than with an emission tax. We see that the cost of emissions reduction is nearly twice as high than in the case of the tax than for the cap-and-trade schemes. Again this illustrates the shortcomings of a tax scheme.

Conclusions

The main goal of climate policies is to incentivize the use of cleaner technologies. Deciding which public policy tools to use in order to curb Green House Gas (GHG) emissions is paramount. In this research article, we approached the problem from three different points of view: social, consumer's and producer's. Our optimal solutions take into account the randomness of the outcomes of the reduction schemes. Although market mechanisms alone cannot solve all the pollution problems, we proved that properly designed cap-and-trade schemes **can work** if

- they are given the right emission targets and penalty;
- the appropriate tools are used to allocate emissions credits.

Despite the fact that they are easy to explain and implement, **taxes** (see for example [5] for a discussion in the context of pollution abatment) are the least efficient of the schemes considered in this study. Because of the uncertainties in the demand for goods and the costs of productions they are less efficient and more costly than cap-and-trade schemes. In particular, we demonstrate in this study that, when it comes to reaching emissions targets they do not perform as well as properly designed cap-and-trade schemes. Moreover, taxes are unpopular and in most countries, synonymous of *political suicide* for policy makers. So it seems that taxation will very unlikely be considered as an alternative to cap-and-trade mechanisms.

Auctioning is very popular among the supporters of cap-and-trade schemes puzzled by the magnitude of the windfall profits of the first phase of EU ETS. We show that auctions cannot lower windfall profits to a reasonable level. They merely help the re-distribution of these costs. Indeed, even if one uses the figures advanced in the discussions of the most optimistic scenarios for the planned US regulations, the revenues of the auctions (expected to be in the range of 9,5 $

per MWh) remain orders of magnitude smaller than the consumer costs, covering only approximately two thirds of the latter. Hence the commonly believed argument that auction revenues can be used to cover costs of end consumer costs needs to be substantiated as there is significant wealth transfer from consumer to producer.

The main contribution of this paper is to demonstrate the merits of new cap-and-trade schemes and for that, we study the costs and benefits of what we call a **relative allocation scheme** in which allowances are distributed proportionally to the production of goods at the source of emissions. This design is reminiscent in spirit of some of the features of the California Low Emissions Fuel initiative [6]. We show that such a proportional allocation scheme

- Can reach emissions targets;
- Offers a perfect control of the windfall profits;
- Minimizes the consumer costs.

The theoretical and quantitative analyzes of cap-and-trade schemes for the purpose of emissions reduction are still in their infancy. However, we hope that this contribution will convince regulators and policy makers of the importance of the insight which could be gained from using the tools developed for the purpose of this study.

Appendix

If for a given demand D_t on day t, we denote by S_t^* the equilibrium price of electricity under a cap-and-trade regulation, and similarly by S_t^{BAU*} the equilibrium price of electricity in BAU (i.e. in the absence of a penalty and a market for emissions) then the **Consumer Burden** due to the regulation is defined as

$$CB = \sum_t (S_t^* - S_t^{BAU*}) D_t.$$

Note that we would sum this quantity over all the goods if we included more than electricity in our case study. See for example [1]. On the other end, the producers' burden is defined as the quantity

$$RC = \sum_t \sum_{i,j} (\xi_t^{i,j*} - \xi_t^{BAU,i,j*}) C_t^{i,j}.$$

which we call **Reduction Costs** or **Abatement Costs**. Here we denote by $C_t^{i,j}$ the cost to producer i of producing on day t, one MegaWatt hour of electricity with technology j, and $\xi_t^{i,j*}$ is the optimal amount that producer i will output in equilibrium on day t with technology j. Clearly, $\xi_t^{BAU,i,j*}$ is the analog quantity in the BAU scenario. With these two definitions in mind, it is natural to define the **Excess Profit** as the difference between he Consumer Burden and the Reduction Costs to which we add the possible Penalty Payments. However, this natural notion of Excess Profit is different from what we define as **Windfall Profits**. Indeed the later are defined (see [1]) as another way to understand the extra profits made by the producers. If ξ^* is an optimal production strategy in equilibrium, we define the electricity target price $\hat{S}_t$ as:

$$\hat{S}_t := \max_{i,j} C_t^{i,j} \mathbf{1}_{\{\xi_t^{*i,j} > 0\}}. \qquad [2]$$

This price is the marginal cost under the optimal production schedule without taking into account the cost of pollution. We then define the overall windfall profits as

$$WP = \sum_t (S_t^* - \hat{S}_t) D_t - M\,A_0. \qquad [3]$$

These windfall profits measure the profits for the production of goods in excess over what the profits would have been, had the same dispatching schedule been used, and the target prices (e.g. the marginal fuel costs) be charged to the end consumers without the cost of pollution. The quantity M appearing in formula (3) is the number of allowances auctioned at time $t =$. Note that we have $M = 0$ when the scheme does not include an initial auction.

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1. R. Carmona, M. Fehr, J. Hinz and A. Porchet (2008):Market design for emission trading schemes. SIAM Review (to appear)
2. Tendances Carbone: The Monthly Bulletin of the European Carbon Market.
3. J.Reinaud: CO_2 Allowance & Electricity Price Interaction, International Energy Agency, February 2007.
4. Japan's 6% Reduction Citizen's Proposal, November 2000.
5. W. D. Nordhaus (2007): To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming. Review of Environmental Economics and Policy, 1(1), 26?44.
6. S. P. Holland, C. R. Knittel and J. E. Hughes: Greenhouse Gas Reductions under Low Carbon Fuel Standards? Center for the Study of Energy Markets, U.C. Berkeley, Working Paper, May 2007.
7. Interim Report (Executive Summary) of the Advisory Committee on Emissions Trading Schemes, Japanese Ministry of the Environment, May 2008.

Table 1. Production capacity in the two Japanese electricity markets

Production Capacity in GW		
Type	East	West
Nuclear	27	26
Coal	31	11
LNG	35	33
Oil	27	14