This is a working paper has some known mathematical errors, formatting errors and some poorly explained assumptions. Someday, this paper will be revised to correct these.

The Challenge of Enforcement in Market-Based Emission Control Programs

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ABSTRACT

Market-based systems for emission control have met with variable success. Of the two approaches taken, historical, theoretical and experimental data suggest that the cap-and-trade approach is more effective than the baseline-credit approach. In either case, much of effectiveness of a program hinges on enforcement design and implementation. Well designed enforcement schemes ensure initial participation or ratification and contribute to market efficiency, while properly implemented enforcement schemes maintain market integrity and efficiency. This paper reviews historical, theoretical, and experimental comparisons of cap-and-trade and baseline-credit programs and presents a game theoretical model of enforcement alternatives.

Introduction

There are two market-based approaches to emissions control: credit trading and allowance trading. Credit trading assigns emitters a baseline emission level, and credit for reductions in emissions below that level are tradable. This is called the *baseline-and-credit* approach (BCA). Allowance trading sets an aggregate cap on total emissions, distributes allowance permits to emitters, and allows those who under-emit to trade with those who over-emit. This is called the *cap-and-trade* approach (CTA). In principal, either approach can achieve reductions in overall emissions by reducing either the baseline or cap, respectively. In practice, however, the computation of the baseline, time-inconsistency and transaction costs of credits appear to give CTA a distinct advantage over BCA. Evidence for this will be discussed in subsequent sections.

Enforcement issues, and particularly attempts at self-enforcement, are another matter, however. Enforcement is costlier in CTA, if only because the requirement to certify emission reductions in BCA is, to a degree, self-enforcing. In either approach, however, many of the same issues arise in deciding the level and degree of enforcement. Level of enforcement (local, state, federal government or industry) and degree of enforcement (direct regulatory monitoring versus voluntary monitoring with audits) can become quite complicated when international mechanisms, such as the Kyoto Protocol, are also involved.

Ideally, self-enforcing programs would reduce costs, free-riding and other sources of market inefficiency. Finding the right self-enforcement mechanism is not a well-understood process. This paper will discuss enforcement schemes that have arisen historically, theoretically and experimentally and their degrees of efficacy. Self-enforcement will be discussed in the context of its rare appearance in the literature.

Historical Developments

In their rulebook for the Kyoto Protocol, the UN cites the following programs (Tietenberg *et al*, 1999):

- The **Acid Rain Program** in the United States is the largest and most successful emissions cap and allowance trading program in the world. The program has achieved a strict environmental goal of reducing sulfur dioxide emissions, and results since 1995 shows that compliance costs have been less than half those predicted by the Environmental Protection Agency (EPA), and many times lower than those predicted by industry.
- The **Regional Clean Air Incentives Market (RECLAIM)** establishes an emissions cap covering most stationary sources of nitrogen oxides and sulfur oxides in the Los Angeles area. RECLAIM has achieved significant success in reducing the price of compliance, with annual savings relative to command and control regulation projected at $58 million annually, or 42 per cent.
- **New Zealand Fisheries License Trading** uses a cap and trade system to manage the majority of its commercial fisheries. Since 1986 the government has set total allowable commercial catch limits and individual transferable quotas (ITQs) for each fish species in defined management areas, based on sustainable harvests. The ITQ system has led to heavy trading, and it is estimated that 77 per cent of all ITQs initially allocated have changed ownership. The costs of monitoring, administration and enforcement are similar to those of other fisheries management

programs. There are high penalties for noncompliance, including fines and forfeiture of vessels.

- **Emissions credit trading** programs in the United States have been established for major pollutants since 1977. These programs allow firms to demonstrate emissions reductions that are either below the firm's permitted levels or below previous levels, whichever is lower. The credit trading systems in the United States have generally performed poorly, principally because of their high transaction costs and the uncertainty and risk involved in obtaining government approval for credit trades. Although there have been thousands of trades over the decades, the extent of trading has been less than expected, and sometimes much less. More importantly, the programs have uncertain environmental impacts, and they have not achieved significant economic benefits or introduced flexibility into a fairly rigid regulatory system. Finally, since credit trades are project-specific, continued oversight is needed to ensure that the Parties perform as promised. The history of credit trading in the United States demonstrates the tension between the need for high levels of government oversight to ensure credit trades are legitimate, and the high transaction costs such oversight entails.
- **The lead phasedown program** established by EPA in the United States in 1982 was expanded in 1985 to greatly reduce

lead levels in gasoline. The lead phasedown program performed successfully as the first free and open trading market. Lead credits were briskly traded, and trading is believed to have so significantly reduced the cost to producers that it facilitated major additional lead reductions in 1985.

- **A pilot program for activities implemented jointly** that reduce or sequester greenhouse gases was established under article 4.2(a) of the Framework Convention on Climate Change at the first Conference of the Parties in 1995. While not strictly comparable to other credit trading programs as investors gained no formal crediting for the tons purchased, experience with this program is useful in indicating procedures for determining the "additionality" of emissions reductions, which is also required for trades under articles 6 and 12 of the Convention. Results from this program indicate that a greenhouse gas credit trading program which requires a showing of additionality can involve even higher transaction costs and uncertainty than has been the case with other credit trading programs.

Theoretical Developments

A thorough theoretical comparison of taxation, CAT and BCA has been done by Fischer (2001). There are two key findings regarding BCA schemes as typically implemented: **increased inefficiency** and high **administrative costs**.

Most BCA programs index the baseline on output (typically in the form of market share), which amounts to a subsidy on output. This, in turn, prevents BCA programs for reducing aggregate emission levels or, in some cases, effectively controlling emission levels at all. Thus, according to Fischer, there is emphasis on emission rate reduction increasing total output, resulting in higher marginal costs of control and subsequent welfare loss. From this, Fischer concludes that the greater the elasticity of demand, the greater the incentive to respond by increasing emission control levels in order to increase output

Verification of emissions for taxation and CAT programs (and setting CAT caps), is simply a matter of monitoring emissions. Establishing baselines for a BCA scheme requires assessing considerable historical emission, emission byproduct, and output data to establish the appropriate equilibrium levels for both emissions and output. Then, because BCA programs amount to rebates on the cost of reducing emissions, they are usually only realized *after* some period of documented emission reduction. That is, the administrative costs are high, and present value is lost to delayed credit payments.

Experimental Developments

Buckley et al (2005) report on a laboratory experiment designed to test their prediction that under fixed emission rates and variable output capacity, BCA will result in higher levels of output and emissions than CAT. In a computer simulation, subjects representing firms chose output capacities under fixed emission technology and participated in a market for emission rights and output under simulated demand. They point out that importance of design in emission-trading programs in terms of minimizing transaction costs as well as reducing uncertainty.

Their evidence supports the notion that aggregate output and emissions are inefficiently high under a BCA compared to a corresponding CTA. Additionally, they found that BCA resulted in high levels of inventories in permits – the permit market failed to clear. They attributed this partly to the more complex instructions for buying and selling credits, but point out that this is consistent with real BCA markets.

An Extensive-form Emissions Control Game

Consider the decisions facing a planner seeking to design and implement an emissions control program that will maximize social benefit. The overall problem is presented as an extensive-form game in Figure 1.

Key assumptions:

- The amount of emissions reduced (increased) is linear with the amount spent (saved) to accomplish it.
- The buying price equals the selling price for emission credits within a specific program.
- The transaction cost for buying credits is identical to the transaction cost for selling credits within a specific program
- The cost of enforcement is identical for all programs
- The transaction costs include program administrative costs, opportunity costs, and lost revenue (BCA program).

Additional definitions for this model:

P = the polluter
S = society
T = taxaction policy
C = cap-and-trade policy
B = baseline-and-credict policy
$p_<$ = probability that P will reduce emissions
$p_>$ = probability that P will increase emissions
$\Delta_<$ = the amount the polluter would spend to reduce emissions
$\Delta_>$ = the amount the polluter would save by increasing emissions
e = efficiency: the ratio of dollars to emissions
$e\Delta_<$ = the amount emissions are reduced by spending $\Delta_<$
$e\Delta_>$ = the amount emissions are increased to save $\Delta_>$
T = an emissions taxation policy
C = a cap-and-trade policy (CAT)
π_C = the CAT price for $e\Delta$ in emissions
π_B = the BCA price for $e\Delta$ in emissions
t_C = the cost of a CAT transaction
t_B = the cost of a BCA transaction
f_0 = the fine under a taxation program for status quo emissions
$f_>$ = the fine under a taxation program for an $e\Delta_>$ increase in emissions ($f_> > f_0$)
C_E = enforcement cost

The polluter, **P** has some propensity to increase emissions, decrease emissions, or maintain the *status quo*. Society, **S**, doesn't know of which kind of polluter is **P** (hence the information set **S**) when deciding which type of emission control plan to introduce. **S**'s choices are taxation (**T**), a CAT (**C**) program, or a BCA program (**B**).

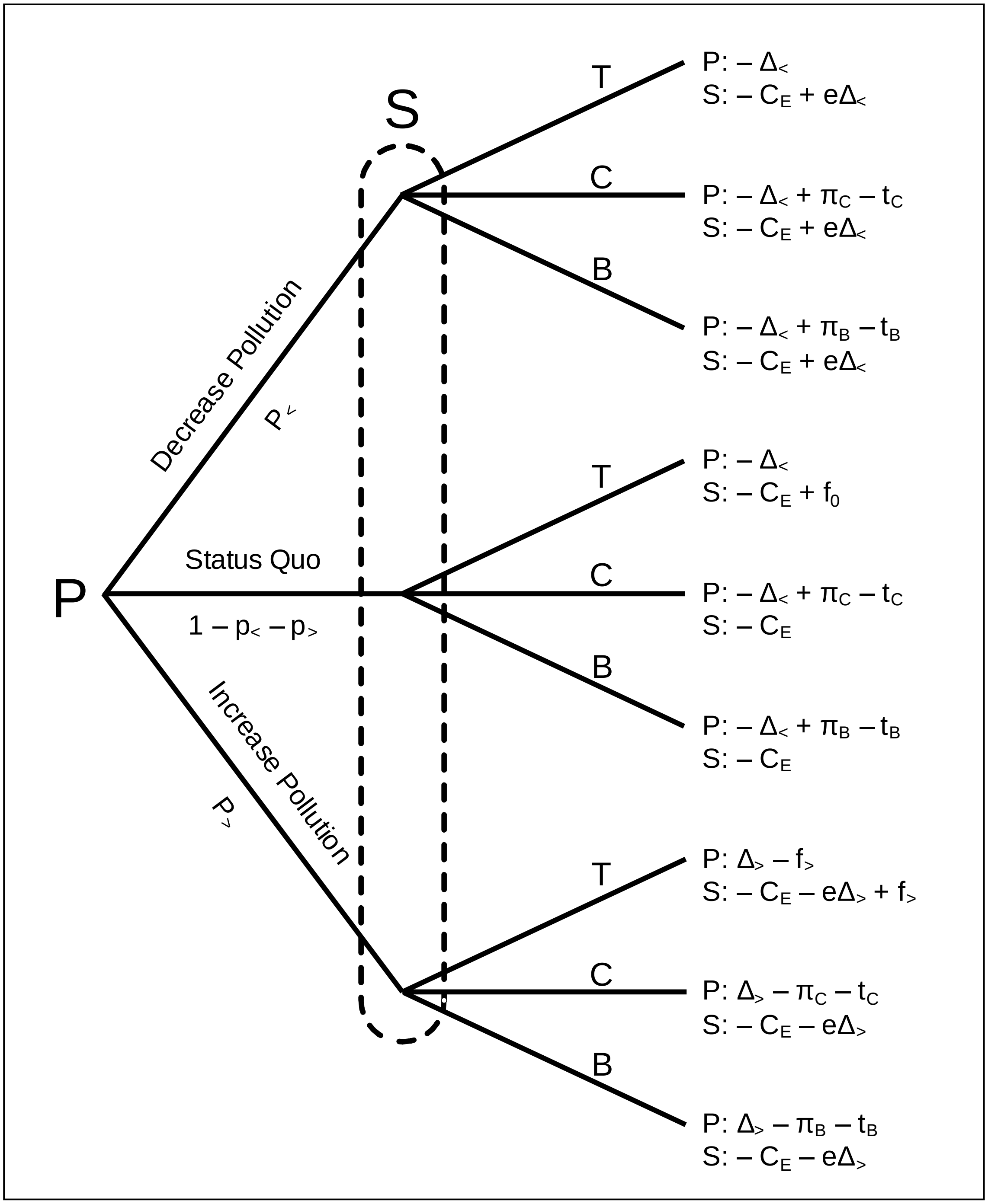

Figure 1 – Extensive-form game for selecting optimum pollution reduction approach.

The payoffs (which are more likely to be negative than not) are also shown in Figure 1. **P** bears the cost in all reduction scenarios, and enjoys the cost savings in all increase scenarios. **P** will benefit from the sale of credits (less transaction cost) in the reduction scenarios, and will have to buy credits (plus transaction cost) in the increase scenarios. The taxation scenario is intended to reduce current emissions, so **P** pays a fine for maintaining the *status quo*, and an even greater fine for increasing emissions.

In all cases, **S** bears the cost of enforcement. **S** enjoys the increased social benefit when emissions are reduced, and suffers reduced social benefit when they are increased. **S** also benefits from any fines levied.

The expected payoff to **P** under the taxation plan is

$$\begin{aligned} E\pi_P^T &= -p_<\Delta_< - (1 - p_< - p_>)\, f_0 + p_>(\Delta_> - f_>) \\ &= p_<(f_0 - \Delta_<) + p_>(\Delta_> + f_0 - f_>) - f_0 \end{aligned} \tag{1}$$

The expected payoff to **P** under the CAT plan is

$$\begin{aligned} E\pi_P^C &= p_<(\pi_C - t_C - \Delta_<) + p_>(\Delta_> - \pi_C - t_C) \\ &= \pi_C(p_< - p_>) - t_C(p_< + p_>) + p_>\Delta_> - p_<\Delta_< \end{aligned} \tag{2}$$

The expected payoff to **P** under the BCA plan is

$$\begin{aligned} E\pi_P^B &= p_<(\pi_B - t_B - \Delta_<) + p_>(\Delta_> - \pi_B - t_B) \\ &= \pi_B(p_< - p_>) - t_B(p_< + p_>) + p_>\Delta_> - p_<\Delta_< \end{aligned} \tag{3}$$

So far, $E\pi_P^C$ and $E\pi_P^B$ are quite similar. This will change when the BCA baselines (and, therefore, price of credits) are a function of output. But even in this formulation, their equivalence is worth examining.

For **P** to be indifferent to which trading program is instituted,

$$\begin{aligned} \pi_C\left(p_< - p_>\right) - t_C\left(p_< + p_>\right) &= \pi_B\left(p_< - p_>\right) - t_B\left(p_< + p_>\right) \\ \pi_C\left(\frac{p_< - p_>}{p_< + p_>}\right) - t_C &= \pi_B\left(\frac{p_< - p_>}{p_< + p_>}\right) - t_B \\ t_C &= t_B + \left(\pi_C - \pi_B\right)\left(\frac{p_< - p_>}{p_< + p_>}\right) \end{aligned} \tag{4}$$

If $\pi_C = \pi_B$ or $p_< = p_>$, **P** is only indifferent if $t_C = t_B$. Otherwise, **P** will prefer the program with the lowest transaction cost. If $t_C = t_B$, then **P** is indifferent if either $\pi_C = \pi_B$ or $p_< = p_>$, or both, as before. In any case, indifference between CAT and BCA gives no information about likely probabilities to reduce or increase emissions. This is to be expected given their similarity.

For **P** to be indifferent between taxation and a trading program (assuming indifference between CAT and BCA for the time being),

$$\begin{aligned} p_<\left(f_0 - \Delta_<\right) + p_>\left(\Delta_> + f_0 - f_>\right) - f_0 &= \pi_C\left(p_< - p_>\right) - t_C\left(p_< + p_>\right) + p_>\Delta_> - p_<\Delta_< \\ p_<\left(f_0 - \cancel{\Delta}_< - \pi_C + t_C + \cancel{\Delta}_<\right) &= f_0 + p_>\left(\cancel{\Delta}_> - \pi_C - t_C - f_0 - \cancel{\Delta}_> + f_>\right) \\ f_0\left(1 - p_< - p_>\right) &= p_>\left(\pi_C + t_C\right) - p_<\left(\pi_C - t_C\right) - p_> f_> \end{aligned} \tag{5}$$

Note that the left-hand side of (5) is just the expected value of the fine in the *status quo* taxation scenario. If it is less than the right-hand side, P will prefer taxation over a trading scheme, irrespective of the inefficiencies of taxes.

Rearranging (5),

$$f_0 = \frac{p_>\left(\pi_C + t_C\right) - p_<\left(\pi_C - t_C\right) - p_> f_>}{1 - p_< - p_>} \tag{6}$$

For $f_0 > 0$

$$\begin{aligned} p_> f_> &< p_>(\pi_C + t_C) - p_<(\pi_C - t_C) \\ f_> &< \pi_C + t_C - \frac{p_<}{p_>}(\pi_C - t_C) \end{aligned} \tag{7}$$

and for $f_> > 0$

$$\begin{aligned} \pi_C + t_C &> \frac{p_<}{p_>}(\pi_C - t_C) \\ \frac{p_<}{p_>} &< \frac{\pi_C + t_C}{\pi_C - t_C} \end{aligned} \tag{8}$$

With the approximation, for $t_C = \pi_C$,

$$\frac{1+\dfrac{t_C}{\pi_C}}{1-\dfrac{t_C}{\pi_C}} \cong \left(1+\frac{t_C}{\pi_C}\right)\left(1+\frac{t_C}{\pi_C}\right) \cong 1+2\frac{t_C}{\pi_C} \tag{9}$$

now (8) becomes

$$\begin{aligned} p_< &< p_>\left(1+2\frac{t_C}{\pi_C}\right) \\ p_< - p_> &< \frac{2p_> t_C}{\pi_C} \end{aligned} \tag{10}$$

By the assumption $t_C = \pi_C$, the right-hand side of (10) is very small. Thus, to be indifferent between taxation and credit-trading, the propensity to reduce emissions can range from zero ($p_< = 0$) to slightly greater than the propensity to increase them ($p_< \square\ p_>$).

For $p_< = 0$, equation (10) implies that

$$\pi_C < 2t_C \tag{11}$$

which is prohibited by the assumption that $t_C = \pi_C$. If, however, $p_< = \delta p_>$, where $0 < \delta < 1$, then as $\delta \square\ 1$ (which is identical to $p_< \square\ p_>$)

$$f_{>} < 2t_C \tag{12}$$

while, as $\delta \square\ 0$

$$f_{>} < \pi_C + t_C \tag{13}$$

For **P** with a very low probability of reducing emissions ($p_{<} \square\ 0$)

$$\begin{aligned} f_0 &> \frac{p_{>}\left(\pi_C + t_C\right) - p_{<}\left(\pi_C - t_C\right) - p_{>}\left(\pi_C + t_C\right)}{1 - p_{<} - p_{>}} \\ &> -\frac{p_{<}\left(\pi_C - t_C\right)}{1 - p_{<} - p_{>}} \end{aligned} \tag{14}$$

which just means that $f_0 > 0$

For **P** as likely to reduce emissions as increase them ($p_{<} \square\ p_{>}$)

$$\begin{aligned} f_0 &> \frac{p_{>}\left[2t_C - p_{>} 2t_C\right]}{1 - 2p_{>}} \\ &> p_{>} 2t_C \frac{1 - p_{>}}{1 - 2p_{>}} \end{aligned} \tag{15}$$

Since this is the condition for $f_0 > 0$,

$$\begin{aligned} 1 - 2p_{>} &> 0 \\ p_{>} &< \frac{1}{2} \end{aligned} \tag{16}$$

which is already implied by the assumption $p_{<} \square\ p_{>}$. If $p_{>} \square\ \frac{1}{2}$, then

$$f_0 > \frac{1}{3} t_C \tag{17}$$

By Error: Reference source not found, and the assumption that $f_{>} > f_0$,

$$\frac{1}{3} t_C < f_0 < 2t_C \tag{18}$$

is the condition for indifference when $p_{<} \square\ p_{>}$.

Thus, for with equal likelihood to reduce emissions as increase them, (18)and (16) give the limits on the fines for which the producer is indifferent to taxation versus credits. If the fines are lower, taxation is preferred, and if they are higher, credit trading is preferred.

Additional study will explore conditions on the other variables imposed by indifference. Positively, these can help a policy-maker determine the program most likely to succeed given a distribution of the probabilities $p_<$ and $p_>$. Normatively, these can help find policies that increase $p_<$ and reduce $p_>$. Also to follow will be an examination of the expected payoffs for society and the policy implications.

Conclusion

Theoretical, empirical and experimental results provide some evidence that cap-and-trade (CAT) programs are more effective than the balance-credit approach (BCA). The model presented here shows that if transaction costs are high, as studies have indicated, this alone is sufficient for CAT to be preferred over BCA. The model also shows that there is a range of fines over which polluters with a non-zero probability of reducing emissions will be indifferent between taxation and a credits program

Future studies will explore the implications of output-proportional BCA plans, the implications for taxation when polluters have no propensity to reduce emissions, and the expected payoffs to society under various regimes.

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