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OPTIMAL OPT-IN "CLIMATE" CONTRACTS

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The paper studies the design of a tradeable permit system with voluntarily opt-in possibilities for LDCs in the context of climate change. In setting the optimal opt-in rule, the social planner faces a trade-off between production efficiency (minimization of control costs) and information rent extraction (reduction of excess permits). Results from a simulation exercise based on data from MIT's EPPA model are also provided.

I. Introduction

Current emissions trading proposals in dealing with climate change call for early carbon dioxide (CO_2) restrictions on industrialized countries with voluntarily opt-in possibilities with the rest of the world.[1] By permitting non-affected sources with low control costs to voluntarily opt-in and receive tradeable permits (allowances), the overall cost of compliance falls. Because of information asymmetries however, an "opt-in" provision that is attractive

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[1] See Tietenberg and Victor (1994) and Kyoto Protocol. For a good description of the economics of climate change see Nordhaus (1994) and Schelling (1992).

to some sources is almost certain to involve the allocation of unneeded allowances to at least a few, and those few are more likely to opt in *ceteris paribus*. In this paper we study the welfare implications and implications for instrument design of this particular asymmetric information problem.

There has been proposed two ways under which less developed countries (LDCs) could voluntarily opt-in into a climate change treaty. First, by agreeing to a *Voluntary Commitment* (VCs) that sets a ceiling on the country's CO_2-equivalent emissions. The opt-in LDC would receive allowances equivalent to the ceiling which could be traded in an international CO_2 market. The second alternative is through the *Clean Development Mechanism* (CDM), under which an industrialized country could fund projects in LDCs to reduce CO_2 emissions and obtain the corresponding emission reduction credits. Or alternatively, an LDC could undertake a project and sells the reduction credits to an industrialized country at the "market" price.

Like any other regulatory practice, the optimal design of a phase-in emissions trading program—only a fraction of sources is "mandatorily" affected—with opt-in possibilities for non-affected sources is subject to an asymmetric information problem in that the social planner has imperfect information on individual unrestricted (or baseline) emissions and control costs. The best example illustrating these sorts of issues is the Substitution Provision of the Acid Rain Program. In fact, Montero (1998a) explains that the allocation rule for opt-in sources proved to be too lenient *ex-post*.[2]

As our results indicate, in a world with perfect information and no transaction costs, a planner would issue allowances to opt-in sources equal to their unrestricted emissions in each period. In practice, however, the environmental planner cannot anticipate the level of unrestricted emissions. Yet, she must establish an allowance allocation rule in advance that cannot be changed easily even if new information would suggest so. Sources reducing emissions below their allowance allocation independent of the environmental

[2] It is approximately based on 1987 emissions; 8 years before the program started in 1995.

legislation will receive excess or unneeded allowances. Thus, in deciding how to set the allocation rules for affected and opt-in sources, the planner faces the classical trade-off in regulatory economics between production efficiency (aggregate control cost minimization) and information rent extraction (reduction of excess allowances). For instance, a too restrictive allocation rule for opt-in sources may inefficiently leave too many low-cost sources outside the program.

The planner's problem reduces to that of finding the optimal allowance allocations for affected and opt-in sources that maximizes social welfare under conditions of imperfect information and distributional concerns. We study the optimal instrument design problem of a phase-in emissions trading program with a voluntary opt-in provision, following the literature on the economics of regulation (Laffont and Tirole, 1993), and optimal environmental regulation under imperfect information (Kwerel, 1977; Dasgupta et al., 1980; and Spulber, 1988). Although similar to Kwerel (1977), Dasgupta et al. (1980), and Spulber (1988) in that information asymmetries may not prevent the environmental planner of achieving the social under some circumstances, our work focuses exclusively on emissions trading as regulatory policy. Therefore, by definition we rule out monetary transfers to the firms (subsides/taxes), and restrict the planner's instruments to the allowance allocations to different sources and assume conditions of perfect competition and monitoring in the permits market.

Our results first indicate that if the planner has two instruments—the allowance allocation to originally affected units and to opt-in sources—in the absence of income effects and distributional concerns, she can achieve the first-best outcome. If the planner, however, cannot make "permits transfers" from affected to non-affected sources, so that she has only one instrument—the allowance allocation to opt-in sources—she achieves a second-best outcome in which the allocation to opt-in sources is lower than the first-best allocation to the point where gains from information rent extraction are just offset by the productive efficiency losses of leaving low control cost sources outside the program.

The remainder of the paper is organized as follows. In Section II, we develop the model and explain the trade-off between production efficiency and information rent extraction. In Section III, we derive the social optimum or first-best allowance allocation rules for affected and opt-in sources when the planner lives in a world of complete information and certainty. In Section IV, we derive the optimal design when the planner has incomplete information regarding individual unrestricted emissions and marginal control costs but still has the two instruments (the allowance allocation rule for affected and opt-in sources), and there is no income effects from allowance allocation transfers between affected and opt-in sources. In Section V, we include distributional concerns and restrict the Section VI analysis to the optimal design when the planner has only one instrument, the allowance allocation to opt-in sources. In Section VII, we include a numerical example of an opt-in rule for Chile using data from MIT's EPPA Model (Yang et al., 1996) and Montero and Cifuentes (1998). Concluding remarks are in Section VIII.

II. The Model

There are two periods, $t = 0,1$, and a continuum of polluting sources of mass $1+n$. We do not consider pollution in Period 0, and without loss of generality, we let emissions in Period 0 to be equal across sources and equal to u_0. For Period 1, the total of each source's baseline or unrestricted emissions $u_i \in [u_l, u_h]$ and $E[u_i] = u_0$, where u_l and u_h are low and high unrestricted emissions respectively. In addition, each source can reduce one unit of emissions at a constant marginal cost c_i. The planner implements an emissions trading program to optimally control pollution in Period 1.

The timing of the problem is as follows. (Hereafter we omit the sub-index i). In Period 0, the regulator designates a fraction of mass n of the total of sources to be mandatorily affected (what we call *affected* sources). We discuss neither why only some sources are mandatorily affected in the first place nor the criteria used to select these affected sources. Each affected source receives fully tradeable allowances or permits a_A. Also in Period 0, the regulator observes emissions from the remaining *non-affected* sources, of mass 1, and sets an allowance allocation rule, a_{OP}, for non-affected sources that voluntarily want to opt in (what we call *opt-in* sources). At the beginning of Period 1, each non-affected source observes its unrestricted emissions u and control costs c and decides whether to opt in or not. Affected and opt-in sources trade allowances in a competitive allowance market such that at the end of Period 1 each source has permits equal to its Period 1 emissions, which can be perfectly monitored by the regulator.

For our notation also, let q be the aggregate quantity of emissions reductions, $B(q)$ the total social benefits from emissions reduction, $C_A(q)$ the aggregate control costs from affected sources, and $C_{NA}(q)$ the aggregate control costs from non-affected sources. As usual, we assume that $B'(q) > 0$, $B''(q) < 0$, $C'(q) > 0$, $C''(q) > 0$, $B'(0) > C'(0)$, and $B'(q) < C'(q)$ for q sufficiently large, which hold for both C_A and C_{NA}. The social planner's problem is to find the optimal allowance allocation rule for affected and opt-in sources that maximizes social welfare in Period 1. We are also interested in the case where the planner takes the allowance allocation to affected sources as given and only optimizes welfare on the allocation to opt-in sources.

In setting allowance allocations, the planner faces a trade-off between control cost minimization and information rent extraction. Let us illustrate with an example. In Figure 1, the horizontal axis indicates the amount q by which total emissions are reduced below their unrestricted level. $B'(q)$ represents the marginal social benefit of emissions reduction as a function of the quantity of emissions q that are controlled. $C_A'(q)$ represents the marginal control cost of emissions reduction from affected sources. Due to imperfect information or political constraints, we let q_{TA} be the emissions reduction target chosen by the authority to be imposed over affected sources. Equivalently, total allowances to affected sources is equal to u_A - q_{TA}, where u_A is the sum of unrestricted emissions from affected sources in Period 1 (which are equal to aggregate emissions in Period 0). Aggregate control costs are given by the area under $C_A'(q)$ from 0 to q_{TA}.

In case the environmental planning agency implements the voluntary program and issues allowances to opt-in sources equal to their historic emissions or emissions in Period 0, the new marginal control cost curve shifts downward due to the inclusion of low-marginal-cost opt-in sources. Let $C'_{AOP}(q)$ be the aggregate marginal control costs from affected and opt-in sources. If unrestricted emissions in Period 1 of all opt-in sources are equal to historic emissions and hence to the allowance allocations, the reduction target remains the same and aggregate control costs reduce to the area under $C'_{AOP}(q)$ from 0 to q_{TA}, and savings from the voluntary program are given by *A*(*ABFG*), where $A(\cdot)$ denotes area. In short, there is no adverse selection and not need for information rent extraction.

When some opt-in sources have reduced their unrestricted emissions levels below their historic emissions and in this case below the allowance allocation, the original reduction target q_{TA} reduces to q_{TA} - *EA*, where *EA* are the total excess allowances from opt-in sources. *EA* are used to cover reductions that would have occurred had the voluntary program not been implemented. The adverse selection effect is represented by this shift of the original reduction target to the left. Aggregate control costs are now given by the area under $C'_{AOP}(q)$, from 0 to q_{TA} - *EA*. While savings from lower cost reductions are given by *A*(*ABCJ*), savings from avoided reductions are given by *A*(*ICFH*), where $A(\cdot)$ denotes area. On the other hand, emissions will be larger than otherwise by an amount equal to *EA*. The social cost of additional emissions are given by the area under $B'(q)$ from q_{TA} - *EA* to q_{TA}, which is *A*(*IDEH*).

The total savings or net benefits associated with the voluntary program are given by *A*(*ABCJ*) - *A*(*CDEF*), which can be positive or negative, depending on the slope of the $B'(q)$ and $C'(q)$ curves, how much reduction substitution between affected and opt-in sources is economically available, and where the original reduction target q_{TA} is situated. As we move the reduction target q_{TA} to the right, marginal costs increase while marginal benefits decrease, and so does the negative effect of excess allowances.

For instance, if a new reduction target, q'_{TA}, is located to the far right, the adverse selection effect from excess allowances may have no deleterious welfare effects, but the opposite. For clarity in exposition let us say that in Figure 1, $C'_{AOP}(q)$ is still the aggregate marginal control costs from affected and opt-in sources when q'_{TA} is the original reduction target and the allowance allocation to opt-in sources is, again, equal to historic emissions.[3] By the same arguments proposed before, it is not difficult to see that given the new reduction level q'_{TA} - *EA'*, where *EA'* is the new level of excess allowances, total benefits from the voluntary program are equal to *A*(*ABML*) + *A*(*KMNQ*), which is obviously positive.

In the following sections, we will solve the planner's optimization problem under different conditions. We start here with the case where the regulator lives in a world of complete information and certainty.

III. Optimal design under Complete Information

Here we assume that the planner observes individual unrestricted emissions in Period 1, or equivalently, that they are equal to emissions in Period 0, and has perfect knowledge about the aggregate benefit and aggregate control costs curves for affected and non-affected sources. There is no adverse selection. The objective of a risk-neutral planner is to choose a reduction target (q_T), and actual reductions from affected and non-affected sources (q_A and q_{NA} respectively), by a set of allowance allocations to affected and opt-in sources that maximizes the value

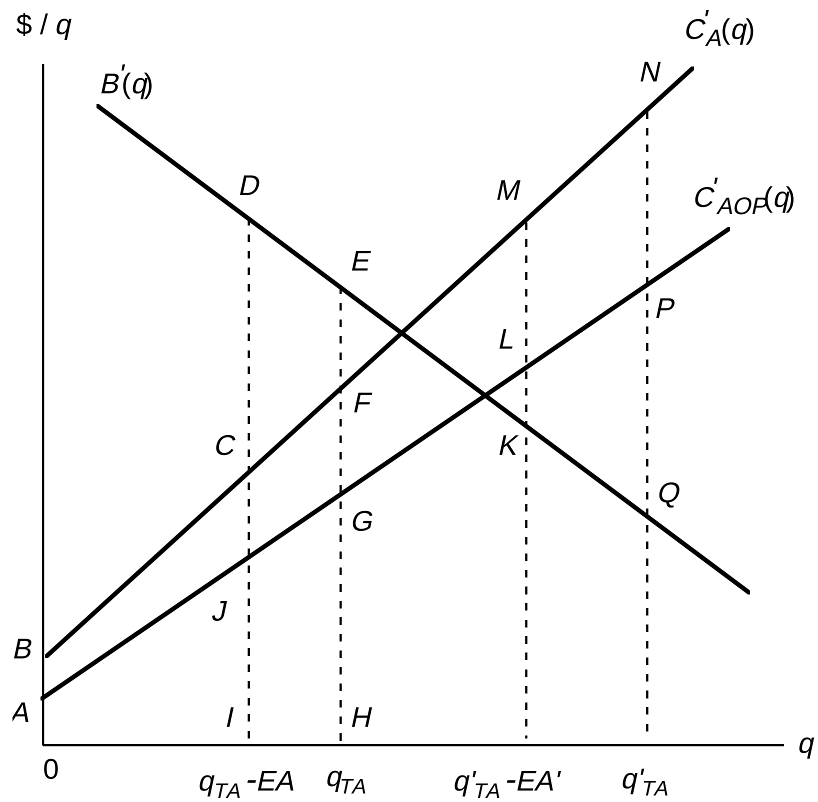
$$W = B(q_T) - C_A(q_A) - CT_{NA}(q_{NA}) \tag{1}$$

such that

$$q_T = q_A + q_{NA} \tag{2}$$

[3] In reality, it shifts downward. Given the higher equilibrium price, low-cots sources that did not opt in before because of high unrestricted emissions may now opt in. This will become more clear in the following sections.

Figure 1. Net Benefits from Voluntary Compliance



Replacing (2) into (1), we obtain the solution q_T* that must satisfy the first-order condition

$$B' (q^*_T = q^*_A + q^*_{NA}) = C'_A (q^*_A) = C'_{NA} (q^*_{NA}) \tag{3}$$

To implement the social optimum, the planner must issue tradeable permits to affected and opt-in sources such that the market price of permits, p, turns out to be equal to $C'_A\,(q^*_A) = C'_{NA}\,(q^*_{NA})$. The allocation rule for opt-in sources must be such that all non-affected sources with marginal costs below or equal to the optimal price, $p^* = C'A\,(q^*_A) = C'_{NA}\,(q^*_{NA})$, voluntarily opt in. In other words, the allocation rule must be such that for a non-affected source with $c \leq p^*$ we have

$$\pi = (a_{OP} - u)p^* + (p^* - c) \geq 0 \tag{4}$$

where π are opting-in profits of a small source reducing one unit of emissions, a_{OP} are allowances issued to it, u are its unrestricted emissions, and c is its marginal control cost assumed constant. An opt-in source obtains profits by having unrestricted emissions below the allowance allocation and producing one permit or allowance at a cost below the market price.

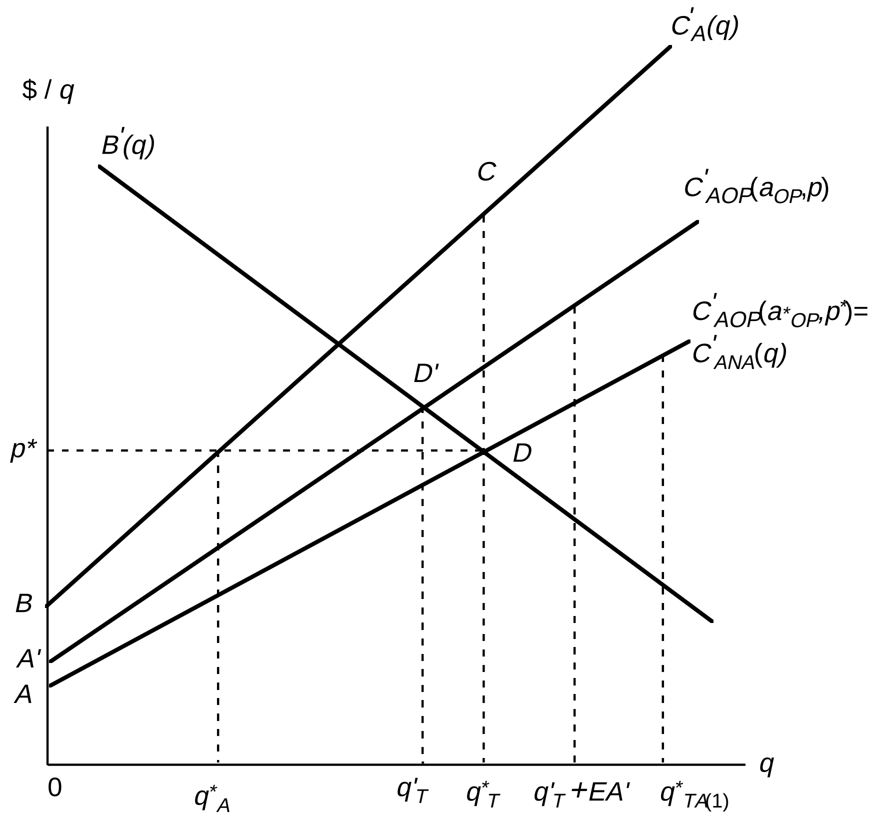
The planner would not want to set allowance allocation $a_{OP} < u$ because that would inefficiently prevent sources with $(1 - (u - a_{OP}))p^* < c < p^*$ from opting-in. Neither would she want to set $a_{OP} > u$, because high-marginal-cost sources might opt in without making any reduction. Although in the latter situation the planner could still achieve the first-best by reducing the allocation of affected units further, she rather sets as the optimal allocation rule $a^*_{OP(O)} = u$, where "(0)" stands for the complete information optimum.

On the other hand, since $a^*_{OP(0)} = u$, $EA = 0$. Therefore, the optimal reduction target imposed over affected sources is $q^*_{TA(O)} = q^*_T$. Finally, allowance allocations to affected sources, a_A, are equal to the difference between their unrestricted emissions and the reduction target $q^*_{TA(O)}$ such that

$$\int_0^{n_A} a^*_{Ai(0)}\,di = \int_0^{n_A} u_i\,di - q^*_T \tag{5}$$

where the allocation "function", $a^*_{A(O)}$, can be chosen arbitrarily. Summarizing:

Figure 2. Optimal Allocations for Affected and Opt-in Sources.



Proposition 1. *In a world of perfect information, the planner allocates permits to opt-in sources equal to their unrestricted emissions. Aggregate allowances to affected sources are set equal to the difference between their aggregate unrestricted emissions and the optimal reduction target* q^*_T. *(Note that in the absence of distributional concerns and income effects the planner can also achieve the social optimum by allocating allowances equal to* $a_{OP} > u$ *for opt-in sources and proportionally lower for affected sources such that* q_T *remains at* q^*_T *.)*

Figure 2 illustrates our first result more generally. $C'_{ANA}(\cdot)$ is the marginal control costs from affected and non-affected sources. Note that $C'_{ANA}(\cdot)$ and $C'_{AOP}(a^*_{OP}, p^*)$ are identical because all low-cost units opt in. First the planner optimally sets $q_T = q^*_T$ by issuing allowance to affected sources in an amount that the reduction imposed is $q^*_{T\,A(O)} = q^*_T$. Then she sets the voluntary allocation rule as $a^*_{OP(O)} = u$. With that allocation rule, all non-affected sources opt in, and since there are no excess allowances, EA = 0, the additional benefits from the voluntary program are equal to *A(ABCD)*. Thus, the planner achieves the social optimum (maximum net benefits). At the social optimum, the market permits price is p^*, so affected units control at $q_A{}^*$ rather than at their original target q^*_T. The difference is covered by emissions reductions from opt-in sources.

IV. Optimal Design under Incomplete Information

Now let us incorporate incomplete information regarding Period 1 unrestricted emissions u and control costs *c*. First, the regulator cannot anticipate u from both affected and opt-in sources. The value of *u* is the firm's private information. As common knowledge, we assume that u parameters can take values in the interval $[u_l, u_h]$, and that are independently identically distributed according to an arbitrary cumulative distribution F(*u*), with density *f(u)* and mean u_0. At the aggregate level, however, the regulator knows that unrestricted emissions are equal to Period 0 aggregate emissions (law of large numbers). While imperfect information regarding affected units does not matter from an efficiency standpoint, since all sources are affected, it does matter regarding non-affected sources, since sources reducing emissions independent of compliance are more likely to receive excess allowances and to opt in.

Although the regulator knows the aggregate marginal cost curves $C'_A\,(q)$

and $C'_{NA}(q)$,[4] he has imperfect information on individual cost values c. For non-affected sources we assume that c is distributed according to the cumulative distribution $G(c)$ in the interval $[c_l, c_h]$, with density $g(c)$. Thus, the regulator knows a priori whether non-affected sources have, on average, lower marginal control costs than affected sources. Note that observing c and not u does not solve the adverse selection problem entirely, as observing only u would.

The planner's problem, again, is to find the optimal allowance allocations to affected and opt-in sources that maximizes the value of (1). For a given reduction target for affected sources q_{TA} (or allocation a_A) and allocation rule a_{OP} for opt-in sources, there will be a final equilibrium price $p = p(a_{OP}, q_{TA})$,[5] which the planner can predict, even though he cannot observe individual marginal costs. Given p and a_{OP}, the likelihood of a non-affected source opting in is illustrated in Figure 3. The horizontal axis depicts the range of possible marginal costs c while the vertical axis depicts the range of possible unrestricted emissions u. A non-affected source represented by (c, u) will opt in as long as it falls in area A_1, A_2 *or* A_3, that is where $\pi \geq 0$ (see eq. (4)). A source falls in area A_1 if it has unrestricted emissions below its allowance allocation ($u \leq a_{OP}$) and is no making any reduction because $c \geq p$. It falls in A_2 if $u \leq a_{OP}$ and is making a unitary reduction because $c \leq p$. Finally, it falls in A_3 if, having $u \geq a_{OP}$ it still makes a reduction because $\pi \geq 0$.

Thus, the total emissions reduction from opt-in sources (q_{OP}), total control costs (C_{OP}), and total excess allowances (EA) would be given by

$$q_{OP} = q_{OP}(a_{OP}, p(a_{OP}, q_{TA})) = \iint_{A_2 A_3} dG\, dF \tag{6}$$

$$C_{OP} = C_{OP}(a_{OP}, p(a_{OP}, q_{TA})) = \iint_{A_2 A_3} c\, dG\, dF \tag{7}$$

[4] Montero (1998b) introduce uncertainty in the knowledge of these curves.

[5] For an interior solution, we assume $c_1 < p < c_h$.

and

$$EA(a_{OP}, p(a_{OP}, q_{TA})) = \iint_{A_1 A_2 A_3} (a_{OP} - u)\, dG\, dF \tag{8}$$

respectively.

If the planner imposes a reduction q_{TA} on affected sources by issuing allowances a_A, and sets an allocation rule for opting units a_{OP}, the actual total reduction turns out to be $q_T = q_{TA} - EA$, and the reduction from affected units $q_A = q_T - q_{OP} = q_{TA} - EA - q_{OP}$. Therefore, the objective of our risk-neutral planner is to find a mechanism, $q_{TA} = q^*_{TA(1)}$ (or $a_A = a^*_{A(1)}$) and $a_{OP} = a^*_{OP(1)}$, that can implement the first-best outcome (sub-index "(1)" stands for first-best). This mechanism maximizes the value

$$W = B(q_{TA} - EA) - C_A(q_{TA} - EA - q_{OP}) - C_{OP}\,. \tag{9}$$

From the envelope theorem, derivatives of W with respect to q_{TA} and a_{OP} take into account only the direct effect of q_{TA} and a_{OP}, and not the indirect effect stemming from adjustments in price p. Thus, the solution $(q^*_{TA(1)}, a^*_{OP(1)})$ must satisfy the two first-order conditions

$$\frac{\partial W}{\partial q_{TA}} = B'(\cdot)\cdot 1 - C'_A(\cdot)\cdot 1 = 0 \tag{10}$$

$$\frac{\partial W}{\partial a_{OP}} = -B'(\cdot)\frac{\partial EA}{\partial a_{OP}} + C'_A(\cdot)\frac{\partial EA}{\partial a_{OP}} + C'_A(\cdot)\frac{\partial q_{OP}}{\partial a_{OP}} - \frac{\partial C_{OP}}{\partial a_{OP}} = 0 \tag{11}$$

where $C'_A(\cdot) = p$, by definition of a perfectly functioning allowance market.

First-order condition (10) indicates that at the optimum marginal benefits and marginal costs are equal, that is $b(q^*_{TA(1)}, a^*_{OP(1)}) = p(q^*_{TA(1)}, a^*_{OP(1)})$, where $b(\cdot) \equiv B'(\cdot)$. Condition (11), on the other hand, indicates that at the optimum, marginal gains from voluntary compliance are equal to marginal losses. The first two terms on the right-hand side represent marginal losses and gains from excess allowances, which cancel out at the optimum since $b = p$. The final two terms represent marginal gains from cheaper reductions from opt-in sources. Using (6) and (7), first-order condition (11) can be rewritten as

$$\frac{\partial}{\partial a_{OP}}\left(\iint_{A_2 A_3}(p-c)\,dG\,dF\right) = 0 \tag{12}$$

Eq. (12) indicates that the optimal allowance allocation $a^*_{OP(1)}$ must be such that no additional gains are due to cheaper reductions from non-affected sources if the allocation is increased a bit. Since $p \geq c$, for all sources making a reduction (i.e., in either area A_2 or A_3), eq. (12) holds in two situations. The first situation is when $a_{OP} < u_l$, where u_l is the "lower" limit for unrestricted emissions. A small increase in a_{OP} does not change things because no source is opting in; obviously, this not optimal. The second case is when $a_{OP} \geq u_h$, where u_h is the "higher" limit for unrestricted emissions. If $u_l \leq a_{OP} < u_h$, the planner can always increase a_{OP} for a given p and obtain additional gains from cheaper reductions ($A_2 + A_3$ increases with a_{OP}). As before, the planner sets $a^*_{OP(1)} = u_h$ so that all sources just opt in. (Note that she may still choose an allocation $a_{OP} > u_h$ but the amount of transfer from affected to opt-in sources would be larger).

Now, with $a^*_{OP(1)} = u_h$, we can obtain $EA_{(1)}$ and hence $q^*_{TA(1)}$ or $a^*_{A(1)}$. Since we have a continuum of mass 1 of sources with $E(u) = u_0$ and every one opts in, $EA_{(1)} = u_h - u_0$. According to eq. (12) and Proposition 1, $q^*_{TA(1)} - EA_{(1)} = q^*_T = q^*_{TA(o)}$, where $q^*_{TA(o)}$ is the optimal reduction target for affected sources under complete information. The planner must increase the reduction target of affected sources from q^*_T to $q^*_{TA(1)} = q^*_T + EA_{(1)}$. Therefore, allowances to affected sources reduce to

$$\int_0^{n_A} a^*_{Ai(1)}\,di = \int_0^{n_A} u_i\,di - q^*_{TA(1)} \tag{13}$$

With the aid of Figure 2, we can explain this result more generally. To achieve the first-best, affected sources are required to reduce $q^*_{TA(1)} = q^*_T + EA_{(1)}$ rather than q^*_T. If the planner sets $a_{OP} < a^*_{OP}(1) = u_h$, $C'_{AOP}(a^*_{OP}, p^*) = C_{ANA}(q)$ is not longer the marginal cost curve of the industry, but $C_{AOP}(a_{OP}, p)$. Because some low-cost units in the upper left corner of Figure 3 would not opt in, $C_{AOP}(a_{OP}, p)$ has shifted upward. Given that, the best the planner can do is to set the reduction target for affected sources equal to $q'_T + EA'$ such that the final equilibrium is D', instead of the first-best D. The welfare loss is $A(AA'D'D)$. Therefore, $a_{OP} < a^*_{OP}(1) = u_h$ cannot be optimal.[6] We can now summarize our findings.

Proposition 2. *Despite information asymmetries, the planner can achieve the first-best outcome when distributional concerns are not important. The planner sets the allowance allocation of opt-in sources high enough so that all non-affected sources opt in. Affected sources receive less allowances than otherwise in an amount equal to total (expected) excess allowances from opt-in sources.*

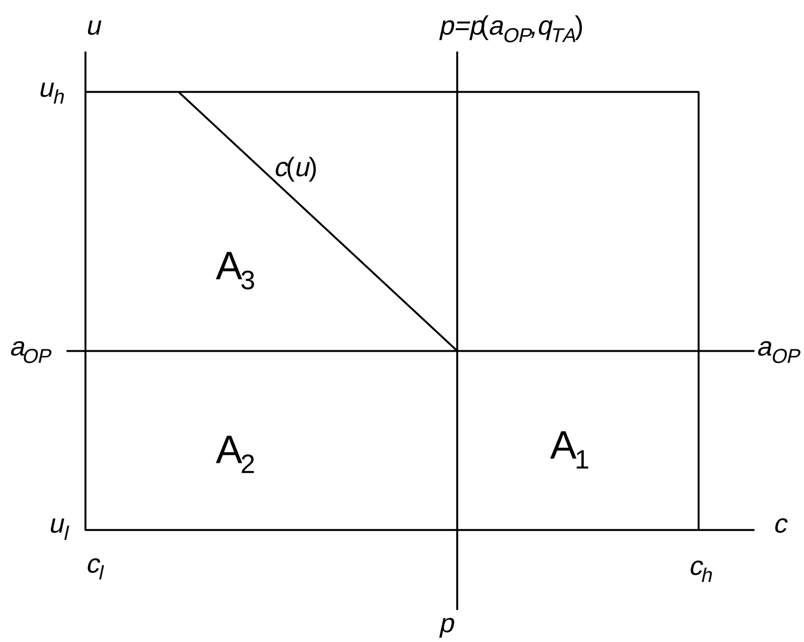
Not surprisingly, our result is similar to Loeb and Magat's (1979) and Spulber (1988) for the case of monopoly and environmental regulation respectively, in that the information asymmetries can have no deleterious welfare effects. Given that the planner has two instruments here, she can optimize for both control cost minimization and information rent extraction. Intuitively, all non-affected sources (the entirety of all four quadrants in Figure 3) become opt-in sources. Excess allowances become the "social cost" of getting all cost-effective abatement possibilities, but that can be completely offset by reducing allowances to originally affected sources.

In practice, however, first-best designs may not be implemented either because of significant distributional effects or simply because the planner's inability to make transfer permits from one group of sources to the other. For

[6] If $p^* > c_h$ we may have a corner solution. A high price may not prevent any source from opting in, even if $a_{OP} < u_h$.

instance, if the number of non-affected sources is too large compared to the number of affected sources ($n_A/n_{NA} << 1$), for u_l - u_0 sufficiently large, affected sources may have to receive "negative" allowances in order for the planner to implement the first- best. If that is the case and we constrain a_A to be non-negative or above a minimum aggregate level, for example, we are in front of a second-best problem. Finally, it is worth noting that cost information did not affect our design beyond defining the location of the optimal target reduction q_T^*. That may change in a second-best design, as we shall see in the next section.

Figure 3. Likelihood of a Non-affected Source Opting-in



V. Optimal Design under Incomplete Information and Limited Transfers

If the process of allocating allowances to affected sources is carried out independently of whether a voluntary program is to be implemented or not, the planner may have only one instrument-the allocation rule of opt-in sources-to deal with the adverse selection problem in case the voluntary program is actually implemented. Under these circumstances, or in the case where aA is constrained to some predetermined value, optimal instrument design turns out to be a second-best problem.

To derive the optimal design, we will start by assuming that affected sources are required to reduce a predetermined amount of emissions q_{TA} , so the aggregate number of allowances issued to these sources is fixed. Thus, to derive the second-best allocation rule, $a^*_{OP(2)}$, of opt-in sources we solve eq. (11), which can be rewritten as

$$\frac{\partial}{\partial a_{OP}}\Big(\iint_{A_2 A_3}(p-c)dGdF\Big)=(b-p)\frac{\partial EA}{\partial a_{OP}}\,. \tag{14}$$

First-order condition (14) implies that at the margin, gains in cheaper reductions are equal to losses from excess allowances. As explained before, for a given p, the term of the left-hand side is non-negative and $\partial EA/\partial_{OP} > 0$, by construction. For eq. (14) to hold, at the second-best optimum we must have $b(a^*_{OP(2)}, \overline{q}_{TA}) \geq p\ (a^*_{OP(2)}, \overline{q}_{TA})$. Two cases are possible, depending on whether the reduction target of affected sources q_{TA} was pre-fixed above or below $q^*_{TA(1)}$. First, if $q_{TA} \geq \overline{q}^*_{TA(1)}$ we return to the first-best case with $a^*_{OP(2)} \geq a^*_{OP(1)}$ and $b(a^*_{OP(2)}, \overline{q}_{TA}) \geq p\ (a^*_{OP(2)}, \overline{q}_{TA})$. This will not likely ever be the case for what appear that to be, in the absence of voluntary compliance, a too large and inefficient reduction imposed on affected sources.

In what follows, we focus on the second case, that is when $\overline{q}_{TA} < q^*_{TA(1)}$. Here, $b > p$, and the right-hand side of (14) is positive, so $u_l \leq a^*_{OP(2)} < u_h$, in order for $a^*_{OP(2)}$ to solve (14). That $a^*_{OP(2)} < a^*_{OP(1)} = u_h$ implies that the planner must give up some cost efficiency by preventing low-cost non-affected sources from opting in to extract some information rents or excess allowances. At $a_{OP} = a^*_{OP(2)}$, both effects exactly offset each other. We then establish:

Proposition 3. *In the presence of incomplete information and limited transfers, the planner implements the second-best outcome by issuing allowances to opt-in sources in an amount* $a^*_{OP(2)} < a^*_{OP(1)}$. *The planner lowers the first-best allowance allocation to the point where cost efficiency losses exactly offset gains in information rent extraction. (In the rare case where the allowance allocation (reduction target) to affected sources was set too low (high), it may be possible to implement the first-best with an allocation* $a^*_{OP(2)} \geq a^*_{OP(1)}$*).*

Total excess allowances will be given by

$$EA_{(2)} = \iint_{A_1 A_2 A_3} (a^*_{OP(2)} - u) dFdG \tag{15}$$

and such that $q^*_{A(2)} + q^*_{OP(2)} + EA_{(2)} = \bar{q}_{TA}$. Note from Figure 3 that for a p high enough, it may exist an optimal allocation rule $a^*_{OP(2)} < u_0$, such that $EA_{(2)} < 0$. If that were the case, total emissions would be lower than otherwise. So we can state:

Proposition 4. *For an equilibrium price p high enough (or c low enough), it may exist an optimal allocation rule* $a^*_{OP(2)} < u_0$, *such that* $EA_{(2)} < 0$.

VI. A Numerical Example: The Case of Chile

In this section we explore the opt-in allocation rule for an individual LDC such as Chile that decide to participate in *Voluntary commitments*. We assume that industrialized countries, so called Annex I countries, comply with the emissions limits established in the Kyoto Protocol by the use of fully tradeable allowances. Each Annex I country receives allowances equal to its "Kyoto emissions limit." We simulate a perfect CO_2 market in year 2010 as representative of the commitment period 2008-2012.[7] Data on

[7] All numbers are in 1985 dollars.

baseline emissions and marginal control costs are obtained from the MIT's EPPA model (Emissions Prediction and Policy Analysis Model).[8] It is a computable general equilibrium model that divides the world in 12 regions: 6 Annex I regions and 6 non-Annex 1 (LDCs).

Data for Chile's baseline emissions and control cost are obtained from Montero and Cifuentes (1998). Since Chile is such as small country, we treat it as the 13th region. Table 1 shows the basic data and cost of compliance for Annex I countries under trading. The clearing price is 132.8 $/ton of carbon ($/tonC) and the total compliance costs are $57.8 billion. The exercise that follows has a very simple setting. We assume that Chile observes its marginal costs and baseline emissions a decides whether to opt-in or not based on the opt-in allocation rule. From the planner perspective we assume that Chile's baseline and control costs can be either high or low with same probability.

If the allocation rule is equal to Chile's expected baseline (24.1 million tonC), there is a 25% chance that Chile would not participate. In fact, if Chile's baseline and control cost turn out to be high, it incurs in a loss of about $60 million. Contrarily, if the baseline and control costs turn out to be low, gains are about $1.6 billion. On the other hand, for this same allocation rule, the planner's expected control cost savings from Chile's participation are approximately US$0.8 billion (Montero and Cifuentes, 1998) and expected excess allowances are equal to 1.53 million tonC.

If the allocation rule is equal to Chile's high baseline (28.9 million tonC), planner's expected control cost savings from Chile's participation are $1.6 billion and expected excess allowances are equal to 4.8 million tonC. If marginal environmental damages are equal to 245 $/tonC, both rules provide same expected net benefits. If marginal damages are lower than that, however, the second rule provides higher net benefits. For example, if marginal damages are equal to the equilibrium price of permits (132.8 $/tonC), it is optimal to set an opt-in allocation rule higher than the expected baseline.

[8] For all details of the model see Yang et al. (1996). I must deeply thank Denny Ellerman and Annelene Decaux for providing me with the data.

Table 1. Data and results from emissions trading among Annex I countries

Annex 1 Regions	Emissions 1990	Projected Baseline 2010	"Kyoto" Allowances 2010	Emissions Reduction	Trading Volume	Compliance Costs
USA	1362.0	1838.3	1266.7	477.2	94.4	35.180
Japan	297.9	424.2	280.0	51.0	93.2	15.426
EEC	822.3	1063.7	756.5	206.0	101.2	23.626
Others OECD	318.2	472.0	300.7	130.9	40.4	10.888
EET	266.1	394.8	247.4	126.6	20.7	8.484
FSU	891.1	762.8	873.3	239.4	-349.9	-35.842
Total	**3957.6**	**4955.8**	**3724.6**	**1231.1**	**350.0**	**57.759**
Market price					**132.8**	

Notes: EEC is 12 countries of the European Economic Community, EET is Eastern economies in transition, FSU is Former Soviet Union. Emissions and allowances are in million ton of carbon. Costs are in billion dollars of 1985. Market price is in $/ton of carbon.

VII. Conclusions and Policy Implications

Current emissions trading proposals in dealing with climate change call for early carbon dioxide (CO_2) restrictions on industrialized countries with voluntarily opt-in possibilities with the rest of the world. In this paper, we have presented a theoretical analysis of the welfare implications and implications for instrument design of such phase-in emissions trading program under conditions of imperfect information and distributional concerns.

We have shown that the planner faces a trade-off between production efficiency (control cost minimization) and information rent extraction (reduction of excess allowances for opt-in sources). A planner having two instruments—the allowance allocation to originally affected units and the allowance allocation to opt-in sources—can, in the absence of income effects and distributional concerns, implement the first-best outcome. If the planner cannot make permits transfers from affected to non-affected sources, so that he has only one instrument—the allowance allocation to opt-in sources—she implements the second-best allocation to opt-in sources, that is lower than the first-best allocation to the point where gains from information rent extraction are just offset by the productive efficiency losses of leaving low-control-cost sources outside the program.

A numerical example of an opt-in allocation rule for Chile is also provided. We showed that it may be optimal from a planner's perspective to set the opt-in allocation rule above the expected baseline.

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