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Carbon Markets in Dynamic Perspective:
The Optimal Duration Problem

Jorge Fernández
Sebastián Miller

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Abstract[1]

The effectiveness of carbon markets in the reduction of emissions at minimal cost requires several conditions. In a dynamic context the inter-temporal dimension adds new conditions for the desirable performance of the market, and some tradeoffs. One tradeoff is related to the duration of permits. A long permit allows the private agent to optimize using a longer time horizon, but increases the risk associated with the initial allocation of the permits, for example the risk of generating market power. A short permit generates problems with the private agent's planning horizon but allows the planner to correct initial misallocations, in particular in new markets or those that face important uncertainty. These issues are important in the implementation of these systems, especially in developing countries such as the Latin American ones studied in this paper.

JEL classifications: Q54, D47
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[1] Jorge Fernández is affiliated with Georgetown University, and Sebastián Miller is affiliated with the Inter-American Development Bank.

1. Introduction and Related Literature

Cap-and-trade systems have been used to address different environmental problems as a policy to correct market failures in an efficient manner. For example, this kind of system has been implemented in the European Union by the European Union Emission Trading Scheme (EU ETS) for greenhouse gas emissions. In the United States it has been used for leaded gasoline phase-out, the SO_2 allowance trading program, the chlorofluorocarbons (CFC) market under the Montreal protocol, the Regional Clean Air Incentives Market (RECLAIM) in Southern California, and the Regional Greenhouse Gas Initiative (RGGI). Moreover, such systems have also been used globally under the Joint Implementation and Clean Development Mechanisms of the Kyoto protocol (Hahn and Stavins, 2010; Sovacool, 2010). The use of mechanisms of this type in broader climate change policies for the United States has also been proposed by several congressional bills (Keohane, 2009). Even in developing countries cap-and-trade systems have been used for over a decade (Caffera, 2011). Given that cap-and-trade systems are among the possibilities for future reduction of emissions tools, it is important to study the different characteristics that can help or hinder its performance. In particular, in this paper we focus on one specific dimension of the design of the system: the duration of the permits, that is on the effect of having permits that are valid for different time profiles.

According to the economics literature marketable permit systems are an efficient way to reduce emissions by equalizing the marginal cost of abatement across agents (Baumol and Oates, 1988). In a dynamic context, the possibility of banking and borrowing of permits incorporates an inter-temporal dimension into the process, allowing reductions in emissions at a cheaper cost in a horizon of more than one period (see for example Rubin, 1996; Kling and Rubin, 1997). Looking only at this perspective, the optimal solution for emission reductions is to have permits last for as long as possible, i.e., setting up a system of permits for an indefinite horizon. However there are problems related to the way these permits are allocated between agents, in particular in the presence of market imperfections (see, e.g., Hahn and Stavins, 2010; and Liski and Montero, 2006). The objective of this paper is to analyze the tradeoffs involved in the duration of permits, especially in the context of developing countries, and more specifically Latin America. On one hand, longer permits allow equalizing marginal abatement costs across agents and reduce the risk of government intervention. On the other hand, longer permits exacerbate the problems associated with the initial allocation of permits, making it more complicated to adjust to any problem of the system's design ex post.

In theory, a cap and trade system allows a market to reduce emissions to a given target at the lowest social cost. However, there are several assumptions behind this result. Hahn and Stavins (2010) analyze this particular issue and consider six conditions that affect the independence between the initial allocation of the permits and the expected outcome of an optimal final allocation. These conditions are transaction costs, market power and market structure, uncertainty, conditional allowance allocation, non-cost-minimizing behavior, and differential regulatory treatment. They study eight cap-and-trade systems[2] around the world and conclude that there is strong evidence of the independence property in half of the systems and moderate evidence in two others.

In another study Sovacool (2010) examines eight markets based on tradable quotas, seven of them related to environmental problems.[3] The most common issue arising in these markets was the existence of high transaction costs (except for the EU ETS) and some issues in program design. In particular the EU ETS exhibited some problems with the initial stage, especially the excess of allowances in the initial years (2005-2007). Nevertheless, the existence and importance of this trial stage was noted by Ellerman and Joskow (2008), recognizing the lessons that one can learn after this stage and the importance of being able to adjust the program ex post.

One of the major problems in a dynamic context is the potential market power. Hagem and Westskog (1998) explore this question using a two-period model with one monopolist in the permit market and showed that the abatement cost between periods is the same for each agent, but the monopolist has a lower marginal abatement cost. That is, the monopolist sells too few quotas. To overcome this issue they propose a system of "durable quotas" that solves this problem but does not reproduce the optimal allocation across periods. Liski and Montero (2006) show that in a model where in the long run there is market power (such as Hahn, 1984) the use of

[2] The programs are lead trading; CFCs under the Montreal Protocol; the SO_2 allowance trading program; RECLAIM in Southern California; eastern NOX markets; the EU ETS; Article 17 of the Kyoto Protocol; and the Regional Greenhouse Gas Initiative.

[3] The markets analyzed were the water permits at Fox River, Wisconsin; the U.S. leaded gasoline phase-out; the sulfur dioxide credits under the U.S. Clean Air Act Amendments of 1990; RECLAIM; renewable energy credit trading at the regional level in the United States; EU ETS; and carbon offsets permitted under the Clean Development Mechanism of the Kyoto Protocol. The other market was the transferable quotas for fisheries in New Zealand.

permits differs from the competitive outcome in all periods. Firms without market power do not equalize present-value marginal costs across all periods, while the firm with market power does.

On the other hand, Shalizi and Lecocq (2009), who focus primarily on the clean development mechanism, argue that carbon markets are not able to encourage investments in clean technologies with long lived capital stocks. The authors distinguish four groups of projects, according to their lifespan. The thresholds for each group are 15, 40 and 75 years. Among other issues they note that, although carbon markets generate an emission price, they do not necessarily enable transfers to the agent that pollutes less, since this depends on the initial allocation of permits. Moreover, the potential period where this market will work determines the time horizon where this price is relevant. Finally, if the carbon market system lasts long enough, then reduction in emission can be obtained not only by abatement, but also by investment in different technologies.

One issue associated with cap-and-trade systems is the allocation of permits. In theory, if the permit market is perfectly competitive then the initial allocation is only a lump-sum transfer between agents. The value associated with these permits depends on their duration;[4] ceteris paribus longer permits represent larger values. The importance of this value can be seen in how the allocation of permits has evolved over time. Ellerman (2009) defines three phases of this evolution, where change is based on where the value generated by the cap is allocated. The allocation of this value, generated by the restriction in the total emissions, has an effect on future investments, as we will see in the paper.

The paper that is perhaps closest to this one is Frankhauser and Hepburn (2010a), which discusses how to design (link) carbon markets across time.[5] The authors consider several possibilities, including banking and borrowing of permits, auction reserve prices and allowance reserves. The authors note that these specific policy design options increase flexibility in achieving cost-effective emission reductions and reduced price volatility. They warn, however, of the potential for moral hazard and difficulties in linking with other markets with very specific arrangements; this might reduce flexibility and increase costs if there are significant gains to be obtained from linking carbon markets across space.

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[4] Here we are assuming that there is no commitment related to future allocation.

[5] In a companion paper, Frankhauser and Hepburn (2010b) focus on the issue of linking carbon markets across space.

Finally a few studies look at the evidence for these kinds of programs in Latin America. Caffera (2011) analyzes three programs: Santiago, Chile's Total Suspended Particles' Emissions Compensation Program, Colombia's Discharge Fee for Water Effluents, and Costa Rica's Environmental Fee for Discharges. The author remarks that all three programs encounter obstacles to reaching the cost-effective reductions desired. In the case of Santiago, lack of information about the emission capacity inventory is the main issue. However, transaction costs (e.g., on average 20 months to approve a single transaction) also increase overall compliance costs.

In the Colombian case, low capacities and political economy issues affected the performance of the program. Finally, in Costa Rica the program is just starting but has faced problems similar to those in Colombia at the implementation stage. In another study on the cases of Santiago, Coria and Sterner (2010) suggest several modifications to improve the system's efficiency, particularly to allow the banking of permits in order to reduce price volatility.[6]

The objective of this paper is to analyze the temporal dimension of marketable permit systems, highlighting the tradeoffs associated to the duration of the permits, taking into consideration the initial allocation problem, which is an issue not dealt with in Frankhauser and Hepburn (2010a). The rest of the paper is organized as follow. Section 2 describes the model, showing the usual conditions for the planner's solution. Section 3 studies several cases generated by different allocation systems and different permit length, using an example to illustrate one of the main results. Section 4 provides policy recommendations, and Section 5 concludes.

2. Model[7]

There are two kinds of agents: private firms and the government. There are N private firms indexed by i. Each firm has a predetermined (optimal) unrestricted level of emissions $u_{i,t}$ for each period t and a time-invariant abatement function cost equal to $C_i(\ )$. However, this function does not include abatements generated by long-term investments.[8] In order to model this possibility, let us assume that each company can modify this abatement cost function to $\widehat{C_i}(\ )$ by undertaking a one-time investment of I. The idea behind this possibility is to allow long-run investments,

[6] A review of models of banking and borrowing can be found in Chevallier (2012).
[7] The model follows Hagem and Westskog (1998) and Liski and Montero (2006).
[8] This could be thought of as major changes in the production process that cannot be made in a relatively short period of time or that have a very high sunk costs that require long-term repayments to be profitable. Here we will work with the simplest specification, an abatement that involves only variable costs.

such as a new technology, where the abatement costs cannot be represented directly in a per-period cost since the evaluation horizon may not be fixed. For example, one can invest in a solar facility, but per period cost is different if this plant is evaluated over 10 years or over 20 years. Given that one question in this paper is the effect of the duration of tradable quotas, this distinction is necessary and relevant. Given the unrestricted level of emissions (*u*) and abatement (*q*), the total per period emissions of a given firm are $e_{i,t}= u_{i,t}- q_{i,t}$.

The government determines total emissions over the planning horizon, *E*, and the number of permits to be given per period, A_t, and a mechanism to assign permits to each firm, $a_{i,t}$. Formally:

$$\sum_{t=1}^{T} A_t = E \qquad \sum_{i=1}^{N} a_{i,t} = A_t \qquad \forall t$$

Two alternative ways to allocate permits are explored: i) a discretionary allocation, grandfathered or not; and ii) an auction. For simplicity we do not model the auction itself; rather we assume that the auction is well designed, leaving no rents in the process to private agents, and we further assume that the associated auction costs are negligible. We allow a mix between both systems, leaving open the possibility of auctioning some permits while allocating others by a discretionary method.

The world lasts *T* periods that are then subdivided into *S* stages.[9] Permits can be freely banked and borrowed within stages but not between them. The relevant (period) discount factor is equal to δ, which is assumed equal for firms and the social planner.

2.1 Social Planner's Problem

The problem from the social planner's point of view is to achieve an emission target (i.e., to reduce emissions) at the minimal social cost. Formally, given unrestricted emission $\{u_{i,t}\}$[10]

$$Min_{\{q_{i,t}\}} \sum_{t=1}^{T} \sum_{i=1}^{N} \delta^t C(q_{i,t})$$

[9] Periods can be years and stages could be quarters within a year.

[10] This formulation assumes that the relevant total emission target is *E* regardless of when emissions are released. This is probably more relevant for emissions that have long life concentration such as GHGs, rather than local pollutants.

$$s.t. \sum_{t=1}^{T} \sum_{i=1}^{N} (u_{i,t} - q_{i,t}) \leq E$$

The first order conditions of this problem are given by:

$$\frac{\partial C_{j,t}(q_{j,t})}{\partial q_{j,t}} = \frac{\partial C_{i,t}(q_{i,t})}{\partial q_{i,t}} \qquad \forall\, j,i,t$$

and

$$\frac{\partial C_{i,t}(q_{i,t})}{\partial q_{i,t}} = \delta \frac{\partial C_{i,t+1}(q_{i,t+1})}{\partial q_{i,t+1}} \qquad \forall i,t$$

Moreover, given that abatement cost functions are assumed to be strictly increasing, the optimal level of emissions is equal to the maximum amount.

2.2 Base Case

The simplest case to analyze considers only one stage (S=1), so permits can be freely banked and borrowed across the entire horizon. Baumol and Oates (1988) show that the cost-minimizing solution can be reached using a quota or permit system. In this case the option to invest in a new abatement technology is not analyzed.

The problem for a given firm *i* is given unrestricted emissions $\{u_{i,t}\}$, allocations $\{a_{i,t}\}$, market prices $\{p_t\}$, traded permits $\{x_{i,t}\}$ and beginning of period stock of permits$\{s_t\}$:

$$Max_{\{q_{i,t}\}} \sum_{t=1}^{T} \sum_{i=1}^{N} \delta^t \left(p_t x_{i,t} - C_{i,t}(q_{i,t})\right)$$

$$s.t.\, x_{i,t} = s_{i,t} - s_{i,t+1} + a_{i,t} - q_{i,t} + u_{i,t} \qquad \forall t$$

$$s_{i,0} = 0 \qquad s_{i,T+1} = 0$$

and the market prices are such that:

$$\sum_{i=1}^{I} x_{i,t} = 0 \qquad \forall t$$

Assuming that the cost of polluting zero is too high and the cost of abating low levels of emission is close to zero,[11] the competitive equilibrium is defined by:

$$\frac{\partial C_{j,t}(q_{j,t})}{\partial q_{j,t}} = \frac{\partial C_{i,t}(q_{i,t})}{\partial q_{i,t}} = p_t$$

[11] That is equivalent to saying that the slope of the abatement curve is unbounded when abatement is close to total emissions, and that the slope of this curve is close to zero when abatement is cero.

That is, the permit price is equal to the marginal abatement cost for each firm.

$$\frac{\partial C_{i,t}(q_{i,t})}{\partial q_{i,t}} = p_t = \delta p_{t+1} = \delta \frac{\partial C_{i,t+1}(q_{i,t+1})}{\partial q_{i,t+1}}$$

Between periods the marginal abatement cost for one period is equal to the marginal abatement cost of the following period times the discount factor.

The market clearing conditions implies that

$$\sum_{t=1}^{T}\sum_{i=1}^{N} a_{i,t} = \sum_{t=1}^{T}\sum_{i=1}^{N} e_{i,t}$$

and these conditions are the same as the ones of the cost minimization problem from the planner's perspective.

If we allow a new (shifted) abatement cost curve, based on investing in a new technology, this investment will be undertaken if and only if:

$$\sum_{t=1}^{T} \delta^t \left(p_t x_{i,t} - C_{i,t}(q_{i,t})\right) < -I + \sum_{t=1}^{T} \delta^t \left(\bar{p}_t \bar{x}_{i,t} - \bar{C}_{i,t}(\bar{q}_{i,t})\right)$$

where, recall, that $x_{i,t}$ is the net balance of agent *i* at period *t* in the permit market, $s_{i,t}$ is the stock of permit of agent *i* at the beginning of period *t*; and the variables with an upper bar represent the equilibrium when the agent makes the investment.

One important remark is that the profitability of this investment depends on: i) the reduction (shift) in the abatement costs; ii) the number of periods considered for the evaluation; iii) the effect on the market price of permits; and iv) potentially on the number of permits assigned to the firm. The first two variables require no further explanation, as they are typical in all project evaluations. A crucial point in this case is when the horizon is divided into stages. If permits are not valid for all periods, i.e., in the case when the number of stages is greater than one, then uncertainty in the assignment of permits in the next stage arises. In an extreme case, one can consider only the permits in the current stage and give a zero value to the subsequent stages. Thus the relevant horizon is the duration of current stage and not the total number of periods.

The third variable, the price of permits, could be irrelevant if the project is small for the whole market since small projects will not affect global abatement costs. However, if the project generates a relevant change in total abatement, for example by greatly expanding the abatement cost curve, then there will be an opposite effect. If the project reduces emissions, then the equilibrium price could be lower. If the project revenues include selling some now unused permits, then the revenues could be affected.

Finally the fourth variable, the number of assigned permits or initial allocation, is the most relevant one in this paper. This variable has two potential effects. First, the permits' price is affected by the project. In this case the relative exposure of the private agent to the permit market will affect the profitability of the project. In order to observe this we rewrite the previous equation assuming that the new equilibrium has the inter-temporal relation between prices as the original one.[12]

$$p_1 X_i - \sum_{t=1}^{T} \delta^t C_{i,t}(q_{i,t}) < -I + \overline{p_1}\overline{X_\iota} - \sum_{t=1}^{T} \delta^t \bar{C}_{i,t}(\bar{q}_{i,t})$$

where X_i is the net balance of agent *i* in all periods. If the project reduces marginal and total abatement costs, for example by shifting the marginal abatement cost curve "outwards," then in equilibrium the agent will demand fewer permits. Thus the new equilibrium prices will be lower than in the original case. Given that, if the agent needs to purchase permits to operate the new technology, that is $X_i < 0$, the reduction in the permits' price will help the project.

The second effect of the permit allocation is the potential reallocation of permits by the authority. A reallocation of permits from one agent to another should imply a monetary transfer, without affecting equilibrium prices. Now, if the authority wants to subsidize a project by reallocating permits, conditional on undertaking the investment, this will generate a subsidy to this investment. Why would the planner want to do something like this? If the market equilibrium coincides with the social planner problem there is no reason for that reallocation, but if there is some restriction, for example permits that last fewer than the necessary time for the project to be profitable, this kind of tool could be used in order to make an investment more attractive.

3. Cases Studied

The following matrix summarizes the cases of interest analyzed here. In this section we will analyze how the financial restrictions can alter the desired outcome. In the next section we will introduce the possibility of risk.

[12] In order to have this result it is necessary to have an interior solution.

		Periods per stage	
		One	All (one stage)
Allowing method	Free	Depends on allocation (Scenario 4)	Depends on allocation can replicate optimal case (Scenario 2)
	Auction	No investment incentive (Scenario 3)	Without financial restriction optimal case can be replicated (Scenario 1)

3.1 Scenario 1: Freely Banking/Borrowing Permits, Allocation by Auction

In this case the relevant variable is the existence of financial restrictions. Without financial restrictions (i.e., borrowing constraints) agents are able to replicate the planner's solution. Recall that the auction should replicate the situation where the authority sells permits to firms in a competitive market, given that the demand for permits will be given by the marginal abatement cost in the entire stage. Absent financial restrictions and given the full information structure there is no reason for trade to occur after the auction is finished. Firms will acquire the necessary permits to allow for the planner's solution.

In the presence of financial restrictions the previous result can be altered. If there exits financial restrictions, but one firm has no such limitations, then the scenario will be one where this firm ends with a dominant position in the permits market. If this happens, then transactions will occur and the situation will follow the cases of Hahn (1984) or Liski and Montero (2006).

In summary, this scenario can replicate the planner's solution if there are no credit restrictions and there is no uncertainty.

3.2 Scenario 2: Freely Banking/Borrowing Permits, Free Allocation

In this case the initial permit allocation is critical. If the allocation does not generate market power in the permits market, then the planner's solution can be replicated. The differences between this case and the previous one are the following:

- There is a transfer from the authority to the companies. In the previous case the authority receives the revenue from permits sold, while in this case these revenues go to those who obtain permits for free.

- Financial restrictions are not an important issue. In the previous case permits must be sold in advance, while here agents receive the permits and can sell if they prefer.
- There could be trade. In the previous case there is no reason to trade without some imperfections. Here the initial allocation determines whether there is trade or not.
- It is possible to generate market power in the permit markets. In the previous case the only reason for having it was financial restrictions.

3.3 Scenario 3: No Banking/Borrowing of Permits, Allocation by Auction

In this situation credit restrictions are not relevant, so the allocation by auction is efficient in the period. The marginal abatement costs are equalized between the agents within the period but not necessarily between two different periods (including the discount factor). Nevertheless, in theory this problem can be solved by correctly distributing the total permits per period, A_t. The problem is that investment in abatement cost needs a longer horizon in order to be profitable. So in this case the planner's solution may not be replicated if this solution includes the investment as a necessary condition for efficiency.

3.4 Scenario 4: No Banking/Borrowing of Permits, Free Allocation

Here we have a similar situation to the previous scenario, with two important differences. The first is the possibility of generating market power in the permit market with the initial allocation. In this case we find the situation analyzed by Hahn (1984), and the optimal allocation is not reached even after trading. The second difference is that, under some conditions, it is possible to replicate the planner's solution even when an investment is required. The reason is that one can allocate enough permits in some period (or commit to more periods) in order make the investment profitable. The restrictions are that this allocation cannot generate market power and that the authority must be credible if this allocation is to be made over more than one period.

3.5 A Simple Example

In order to fix the ideas of the previous section here we present a simple parameterization of the model in order to show some results. Consider the case with only two periods (T=2), two types of firms that will be represented by two individual firms (I=2), and a quadratic form for the abatement function cost ($C_i(q) = b_i q^2$). Let U_t be the sum of the unrestricted emission levels for a given period t ($U_t=u_{1,t}+u_{2,t}$), while U is the sum of all U_t ($U=U_1+U_2$). It is easy to check that the emission reduction that minimizes the cost is given by:

$$q_{i,1} = \frac{U-E}{\left[1+{}^{1}/_{\delta}\right]\left[{}^{1}/_{b_1}+{}^{1}/_{b_2}\right]}\frac{1}{b_i} \qquad q_{i,2} = \frac{q_{i,1}}{\delta}$$

and the total cost of reduction, C, is given by:

$$C = \frac{1}{2}\frac{[U-E]^2}{{}^{1}/_{b_1}+{}^{1}/_{b_2}}\frac{\delta}{1+\delta}$$

Without market power in the permits market and without financial restrictions, equilibrium prices will be given by the marginal cost of reduction of the planner's solution, that is:

$$p_1 = \frac{U-E}{\left[1+{}^{1}/_{\delta}\right]\left[{}^{1}/_{b_1}+{}^{1}/_{b_2}\right]} \qquad p_2 = \frac{p_1}{\delta}$$

where the value of all market permits is given by p_1E. This is the potential transfer between the authority and the companies in the two allocation permits, by auction or grandfathered.

Without banking and borrowing, which is in the case where every stage is one period, the only way to replicate the global minimizing cost solution is allocating:

$$A_t = U_t - q_{1,t} - q_{2,t}$$

Now suppose that Firm 1 has the opportunity to invest in a technology that shifts abatement costs, with a lower marginal abatement cost as a result ($d<b_1$). The required investment is given by I. Assume that the investment is made in period 1 and that it has an immediate effect in this period and the following. From the planner's point of view the investment is worth undertaking if:

$$I < C - \frac{1}{2}\frac{[U-E]^2}{{}^{1}/_{d}+{}^{1}/_{b_2}}\frac{\delta}{1+\delta}$$

where the last term is the aggregate abatement cost after the investment has been made. There are two problems here from the firm's point of view. The first is the classic problem of the externality: while the investment reduces the total abatement cost, it is not clear that it reduces the firm's abatement cost. In fact, the abatement cost of Agent 2, the one that does not make the investment, is reduced for sure, while for Agent 1 it is not clear. The second problem is that the private agent faces a risk in second period revenues. For example, if the agent is not sure about the allocation method for the second period, then the investment could be justified only if the first period gains are large enough. Let us analyze the first of these problems.

The difference in the abatement costs for Agent 1 (C_b without investment, C_d with investment) incorporating both periods is given by:

$$C_b - C_d = \frac{[U-E]^2}{2}\frac{\delta}{1+\delta}\left[\frac{1/b_1}{\left[1/b_1 + 1/b_2\right]^2} - \frac{1/d}{\left[1/d + 1/b_2\right]^2}\right]$$

If this difference is not positive, that is there is a reduction in the private cost for Agent 1, it is necessary to make a transfer from the authority to this agent in the form of permits. Formally the condition for making this transfer possible is:

$$p_1 E > I - (C_b - C_d)$$

That is, if the authority can freely allocate the permits then it can assign all of them to Agent 1. This is the extreme case.

3.6 Other Considerations

This basic model allows us to understanding why a short duration phase can make investments in desirable technologies unfeasible from the aggregate point of view. This would argue in favor of the case for long phases, but the existence of financial restrictions can generate other issues, such as an advantage to agents that have a lower financial cost for long-term projects. Aside from this problem, the extension of the phases and the allocation method can be affected by other characteristics of the market. Among these it is useful to highlight uncertainty and transactions costs.[13]

3.6.1 Uncertainty

If there is no uncertainty in abatement costs, then there are no reasons for using different stages other than the risk of generating market power. In this case the only relevant variable is transfers between the authority and firms. However, certainty about future abatement costs is a strong assumption, in particular when the relevant question is the duration of permits. Assuming perfect foresight in the abatement cost makes the case for longer duration of permits. Uncertainty

[13] The formal inclusion of these problems in the base model is left for future research.

increases the variability of the value of the future permits. In this case a longer permit could allow the agent to adjust inter-temporally, but the risks associated with the initial allocation increase. With no uncertainty it is easier for the authority to define a way to allocate the initial permits in a way that generates no distortion in the market. With uncertainty and long permits the initial allocation could generate a distortion while the uncertainty is being eliminated.

If uncertainty can be reduced or eliminated after a short period, then there is a possibility of justifying an initial stage of short duration before a longer second stage. This case could be justified by the development of some new technology in a new environment or by the possibility of the deployment of a new technology (e.g., geothermal energy, fuel cells, etc.). Another reason could be an implementation period where the involved agents can adjust to the new system or adjust the relevant parameters. For example, in the implementation of the EU ETS more than one stage was considered. These stages were Phase I from 2005 to 2007, Phase II from 2008 to 2012, and Phase III from 2013 to 2020. Some differences between these phases are the possibility of banking and the allocation method. Banking between Phases I and II was restricted, while there is unlimited banking between Phases II and III (Chevallier, 2012). The allocation method is another difference between phases. While in Phases I and II the main method was free allocation based on grandfathering (Chevallier, 2012), in Phase III the allocation by auction will be extended to a greater share of total permits (CDC Climat 2012).

3.6.2 Transaction Costs

Finally, one brief note should be made on transaction costs, as low transaction costs are a key assumption underlying the assertion that a permit system can replicate the global minimization cost solution. In the case of developing countries, however, particularly LAC, previous experiences show that transaction costs can be an important issue (Caffera, 2011). Thus, the first goal should be to attempt to reduce transaction costs as much as possible. Given that reduction of transaction costs may take time, though, some measures are important in the meantime. While transaction costs are being reduced (an important consideration given that transaction costs reduce the effective of cap-and-trade systems) it is important that the initial allocation be as close as possible to the optimal one. The problem associated to transaction costs, and the potential restrictions in the allocation while these costs are reduced, again suggests the importance of an initial stage that allows the agents to adjust to the new scheme.

4. Policy Recommendations

In this section we focus on policy recommendation for developing countries. In this area there are five issues that could affect the carbon market system:

1. Transaction costs
2. Total cap
3. Information about emissions
4. Market power
5. Regulatory credibility

Let us discuss these issues one by one.

4.1 Transaction Costs

As Caffera (2011) and Coria and Sterner (2010) found, transaction costs are an important issue in the performance of the tradable permits experience in Santiago, Chile. Hahn and Stavins (2010) incorporate transaction costs as a factor that can affect the performance of carbon markets, because when these costs are high the initial allocation can affect final outcomes.

If transaction costs can be reduced over time, for example making the required regulatory adjustments, then it is a good idea to start with an initial shorter phase where the permits last only for a short period, in order to reduce welfare losses from an initial misallocation with high transaction costs. One interesting issue is economies of scale in transactions costs, as shown in Heindl (2012) and Jaraite, Convery and Di Maria (2009). This problem can make the system inefficient for some small polluters, at least in the initial stages. If transaction costs can be reduced later, then small polluters can subsequently be added to the system. Consequently, there is the incentive to look for a different system for these emitters in the initial phases of the system, such as a command-and-control program or a carbon tax.

4.2 Total Cap

One important difference between developed and developing countries is the evolution of the total emission cap. While in the first group there is usually a reduction in total emissions, in the second group reductions in emissions are with respect to that would happen without any intervention (*Business as usual, BAU,* is the most common way to address this idea). This difference gives rise to two problems in introducing a carbon market system in a developing country.

The first problem is the clear definition of goals. The definition of the baseline and the way to monitor the accomplishment of the emissions targets is crucial. A clear definition is important not only for international agreements, but also for the decision of agents in the country. For example, a BAU scenario that assumes a high expected growth can make the targets of reduction non-binding if the final economic performance is not as good.

The second problem is associated with increases in the total emission cap. There are several decisions that change with an increasing cap. The first is the projection of how binding this cap will be. With an increasing total cap there are more incentives to use a system with borrowing, from the firms' point of view. Another important question is how to allocate permits, and particular the transfers associated with those permits if they are allocated freely.

The recommendation on this issue is to look for a stable and transparent way to assign permits, if they are allocated freely, or the rules of auctions when they are desirable. Moreover, the forecasting of future caps should be easy and transparent so that they can be included agents' optimization problems. Perhaps a mix of long and short-duration permits can generate an optimal solution. Alternatively, a system with reserve allowances or price floors, as mentioned in Frankhauser and Hepburn (2010a), could also help here.

4.3 Information on Emissions

One basic requirement for the efficient performance of a carbon market is the availability of information on emissions. As Caffera (2011) mentions in one of the lessons, "The overall costs of implementing an economic instrument in the absence of a system to keep track of existing emissions may be high enough to compromise its performance." The problem is this information system is not easy to build, and it may take years, as the Chilean case study highlights (Caffera, 2011).

The requirement of appropriate information is another reason for incorporating phases with short-run permits until the availability of information is sufficient to allow the carbon market to work properly.

4.4 Market Power

The presence of market power in the permit market can distort the performance of this instrument, as can be seen, for example, in Liski and Montero (2006). Here market power can be generated in two different ways. One is when the authority generates this power using a free allocation system. The other is when an auction that involves a relevant investment for the agents occurs in a country with financial (credit) restrictions. The first instance can be addressed by taking the problem of market power into account when permits are allocated. The second case, however, could represent a more persistent problem in many developing countries. The lesson here is to try to avoid long-term auctions if the agents have no access to financial markets, or if the auction can generate market power in the permits market. If the auction is the desirable allocation mechanism, then the terms of the permits should be set according to the potential financial restrictions without affecting the duration of these permits. That is, there could be more than one auction in a particular phase. Incorporating smaller firms into the cap-and-trade system in successive phases over time is perhaps another way of avoiding the market power issue.

4.5 Regulatory Credibility

A final issue is the credibility of regulation in a particular country. Permit validity cannot be longer than the stability of the regulatory system; if a country cannot commit to regulations over the medium run, then longer permits would not be not credible. This problem is related to the time inconsistency problem, stated in the seminal paper of Kydland and Prescott (1977). In the particular case of the climate policy this issue has been studied by Helm, Hepburn and Mash, (2003) and by Brunnera, Flachslanda and Marschinski (2012), among others. Both papers highlight the importance of a commitment device at this point. The recommendation here is to try to adjust the maximum length of permits to the stability of allocations. Longer permits could generate possible litigation issues in the future.

5. Conclusions

The optimal length of a permit system depends on some characteristics of the market. While longer permits are the best solution in an environment without imperfections, in the real world there are restrictions that make the case for shorter durations. The most relevant problem with long-lasting permits in a market with imperfections is the possibility that the market cannot “fix” an inefficient initial allocation. For instance, the market cannot "fix" a problem with the initial allocation if there are important transaction costs or if there is market power. If this happens then the initial allocation should be similar to the optimal one, or the marginal cost of emission reductions will not be equalized between agents and across periods, thus increasing total social costs.

Moreover, in the dynamic context the issue of credibility is an important problem, as in any case where long-run investments are involved. In the case studied here, permits markets, there are two possible sources of time inconsistency. One is the country's own regulatory system. The other is international agreements that may force the country to change its commitments or alternatively make them non-binding. For the first source, the country could try to eliminate the risk by committing to policies and passing laws with high quorums. The second calls for further research.

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