Time Horizons And Emissions Trading

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Abstract

I study the effect of a binding final period on emissions in cap and trade schemes

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1 Introduction

Growing concerns about climate change motivate a call for stringent policies to curb greenhouse gas emissions. Many governments have instituted a cap and trade scheme, or emissions trading, in response.

EU ETS, Regional Greenhouse Gas Initiative, California's cap and trade scheme, ...

All cap and trade schemes mentioned above have a particular feature in common: they are complemented with a stabilization mechanism that makes the cap on emissions endogenous to conditions prevailing in the market. There are various reasons to favor cap and trade with a stabilization mechanism over emissions trading with a fixed cap. One is based on the recognition that polluters possess private information about, say, abatement costs. Because prevailing conditions in the market for allowances partly reflects this private information, stabilization mechanisms provide a way to incorporate aggregate market signals about abatement costs (Dasgupta et al., 1980) into the cap and trade policy. A related argument is that a stabilization mechanism allows governments to respond to unforeseen developments and resolving uncertainties in the market for

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allowances (Heutel, 2020; Pizer and Prest, 2020). Lastly, stabilization mechanisms may enable governments to effectively implement policies that overlap with the cap and trade scheme, avoiding a waterbed effect (cf. Burtraw et al., 2018).

As a rule, stabilization mechanisms are based either on the price of allowances or on the number of allowances surrendered (see ICAP, 2021, for an overview of stabilization mechanisms in existing cap and trade schemes). Examples of price-based stabilization mechanisms include price floors and collars, used for example in California's cap and trade scheme. An example of a quantity-based stabilization mechanisms is a quantity collar (Holt and Shobe, 2016), used in the EU's emissions trading system, the world's largest market for carbon.

Stabilization mechanisms also have practical relevance. Recent work by Borenstein et al. (2019) shows that the equilibrium allowance price in California's cap and trade scheme is determined by the administrative price collar with 98.9 percent probability.

A growing number of governments has made pledges of net-zero greenhouse gas emissions in the (near) future. Such promises are obviously well-intentioned and spur from an intuitive line of reasoning: if there is less time to emit, future emissions are cut short so emissions overall must go down. To confirm this assumption, I study the effect of a binding final period beyond which emissions are not allowed on aggregate emissions. Depending on the type of stabilization mechanism in place, I obtain diametrically opposed results. A binding final period decreases emissions in a cap and trade scheme complemented with a price-based stabilization mechanism. In contrast, a binding final period *increases* emissions in a cap and trade scheme complemented with a quantity-based stabilization mechanism. If atmospheric emissions are reasonably persistent and environmental damages not too concave, the latter result implies a strictly higher net present value of environmental damages due to the binding final period on emissions. In this sense, the time horizon of emissions trading can have a counter-intuitive effect on the environment.

2 Analysis

2.1 Emissions trading

Given is a cap and trade scheme that regulates emissions of some pollutant in a number of periods $t = 1, 2, ...$ In any period t, the supply of emission allowances is denoted s_t. Demand for allowances, or emissions, is given by $d_t(p_t)$ and depends on the allowance price p_t. As is standard, I assume that $d_t(p_t)$ is decreasing in the price p_t in every period t and that polluters are price takers. I also assume that prices are positively associated across periods, i.e. $dp_{t+1}/dp_t > 0$ for all $t \geq 1$, which allows me to write the demand for allowances in any period as a function of $p = p_1$ only (formally this assumption is only reasonable if the scheme is dynamically integrated such as through a banking provision, see below). I furthermore assume that for every period t there exists a finite choke price at which demand becomes zero and that $d_{t+1}(p) \leq d_t(p)$ for any $p > 0$ and any $t \geq 0$, expressing the idea that cleaner modes of production are developed over time that can substitute for polluting technologies. Note that my assumptions are generalized versions of those typically entertained in the literature (Salant, 2016; Gerlagh et al., 2020, 2021), such as Hotelling's Rule (implying $dp_{t+1}/dp_t > 0$) and exogenous (linear) demand reductions over time (implying $d_{t+1}(p) \leq d_t(p)$). Let aggregate demand, or emissions, be denoted $D(p) = \sum_t d_t(p)$.

The idea of a cap and trade policy is that any amount of emissions requires polluters covered by the scheme to surrender an equivalent number of allowances. Let s_t be the supply of allowances in period t and define $S = \sum_t s_t$. I first study the unrestricted case in which an allowance issued in period t can be used in any period $s \neq t$.[1] Let b_t denote the excess supply of allowances in period t:

$$b_t(p) = s_t - d_t(p), \tag{1}$$

and let B_t be the aggregate excess supply summed over all period up to and including t:

$$B_t(p) = \sum_{s=1}^{t} b_s(p), \tag{2}$$

where the dependence of both b_t and B_t on the price p derives from the fact that the demand for allowances is a function of p. Many authors refer to $B_t(p)$ as the *bank* of allowances in period t. I write $B(p) = (B_1(p), B_2(p), ...)$ for the vector of aggregate excess supplies in each period t.

In most cap and trade schemes, the supply path of allowances (s_t) is not fixed but

[1] In most cap and trade schemes, emissions must be covered entirely by historic supply; that is, an allowance issued in period t can be used in periods $s \geq t$ only. While such a borrowing constraint would make my model more realistic, it is of no importance for the key mechanism behind my results. To simplify the notation, I hence allow for both banking and borrowing in my model (Heutel, 2020; Pizer and Prest, 2020). Importantly, borrowing constraints haven't been binding in most actual cap and trade schemes anyway.

rather depends on developments in the market through some sort of stabilization mechanism. I next introduce two particularly prominent classes of stabilization mechanisms: those that input the allowance price and those that input the demand for allowances.

2.2 Stabilization mechanisms

If the scheme operates a *price-based stabilization mechanism*, the supply of allowances in any period t is weakly increasing in the allowance price p. That is, for any period t and any two price levels p and p' it holds that $s_t(p) \geq s_t(p')$ if and only if $p > p'$. While not necessary for the main results in this paper, I assume that $s_t(p)$ is continuous (though not necessarily differentiable) in p. Continuity rules out the possibility that a stabilization mechanism introduces equilibrium multiplicity in the market (cf. Gerlagh et al., 2021).

Since $s_t(p)$ is increasing in p while $d_t(p)$ is decreasing, observe by (1) that by $b_t(p)$ is increasing in p in every period t. It then follows from (2) that $B_t(p)$, the bank of allowances in period t, is increasing in p when the cap and trade scheme is supplemented with a price-based stabilization mechanism.

Writing $S(p) = \sum_t s_t(p)$, the market for allowances is in equilibrium, given the price-based stabilization mechanism, if:

$$D(p^*) = S(p^*), \tag{3}$$

where p^* is the unrestricted equilibrium allowance price when the scheme operates a price-based stabilization mechanism. Define T^* to be the (endogenous) final period in which the supply of emissions drops to zero in the unrestricted equilibrium of a cap and trade scheme with a price-based stabilization policy, i.e. for which it holds that $s_t(p^*) = 0$ if and only if $t \geq T^*$.

If the scheme operates a *quantity-based stabilization mechanism*, the supply of allowances in period $t+1$ is weakly increasing in the aggregate excess supply in period t. That is, for any period t and any two B_t and B'_t, it holds that $s_{t+1}(B_t) \geq s_{t+1}(B'_t)$ if and only if $B_t < B'_t$. While not strictly necessary for my main results, I assume that $s_{t+1}(B_t)$ is continuous (though not necessarily differentiable) in B_t. I also assume that $-1 < ds_t/dB_t$ for all t to preempt the counter-intuitive scenario in which polluters have an incentive to bank *less* today in order to pollute *more* in the future – there should remain an incentive for polluters to bank allowances in the face of future scarcity.

To analyze the equilibrium of a cap and trade market supplemented with a quantity-based stabilization mechanism, I need to determine the influence of the allowance price on banking, that is, the sign of dB_t/dp. In period 1, this is unambiguous:

$$\frac{dB_1(p)}{dp} = -\frac{dd_1(p)}{dp} \geq 0, \tag{4}$$

where the inequality is strict for all p such that $d_1(p) > 0$. A little more work is required to determine dB_2/dp:

$$\begin{aligned}\frac{dB_2(p)}{dp} &= \frac{dB_1(p)}{dp} + \frac{ds_2(B_1(p))}{dB_1(p)}\frac{dB_1(p)}{dp} - \frac{dd_2(p)}{dp} \\ &= \left(1 + \frac{ds_2(B_1(p))}{dB_1(p)}\right)\frac{dB_1(p)}{dp} - \frac{dd_2(p)}{dp} \geq 0,\end{aligned} \tag{5}$$

where the term $1 + ds_2/dB_1$ is strictly positive since it was assumed that $ds_t/dB_t > -1$. The sign of dB_2/dp then follows from (4). Note that the inequality in (5) is strict for all prices p that support positive demand in period 1. Induction on (5) establishes that $dB_t(p)/dp \geq 0$ for all t:

$$\frac{dB_t(p)}{dp} = \left(1 + \frac{ds_t(B_{t-1}(p))}{dB_{t-1}(p)}\right)\frac{dB_{t-1}(p)}{dp} - \frac{dd_t(p)}{dp} \geq 0, \tag{6}$$

with a strict inequality as long as p satisfies $d_1(p) > 0$.

Writing $S(B) = \sum_t s_t(B_t)$, a cap and trade scheme supplemented with a price-based stabilization mechanism is in equilibrium if and only if:

$$D(p^{**}) = S(B(p^{**})), \tag{7}$$

where p^{**} is the unrestricted equilibrium allowance price when the scheme operates a quantity-based stabilization mechanism. Define T^{**} to be the (endogenous) final period in which the supply of emissions drops to zero under a quantity-based stabilization policy, i.e. for which it holds that $s_t(B_t(p^{**})) = 0$ if and only if $t \geq T^{**}$.

2.3 A restricted time horizon

Suppose now that the policymaker fixes some future period $\bar{T}$ starting from which emissions are no longer allowed, so $d_t(p) = 0$ for any $t \geq \bar{T}$. Let the end date $\bar{T}$

be binding in the sense that, without this intervention, the unrestricted equilibrium dictates strictly positive emissions in some periods $t \geq \bar{T}$. (Formally the assumption is that $d_{\bar{T}}(p^*) > 0$ and $d_{\bar{T}}(p^{**}) > 0$). It would be somewhat strange to have $\bar{T} < T^*$ and/or $\bar{T} < T^{**}$ since, if this were true, a strictly positive number of allowances is supplied even as they cannot be used. I therefore assume that $\bar{T} > \max\{T^*, T^{**}\}$. The question of interest is whether a binding final period curbs emissions.

I first consider a cap and trade scheme that relies a price-based stabilization mechanism. Let $\bar{p}^*$ denote the restricted equilibrium allowance price. Since emissions are not allowed starting from period $\bar{T}$, the price $\bar{p}^*$ is implicitly defined by:

$$B_{\bar{T}}(\bar{p}^*) = 0. \tag{8}$$

To see why (8) pins down the restricted equilibrium price, observe that in the equilibrium no allowances can be left unsurrendered after period $\bar{T}$, which means that $\bar{p}^*$ must solve $d_{\bar{T}}(\bar{p}^*) = s_{\bar{T}}(\bar{p}^*) + B_{\bar{T}-1}(\bar{p}^*)$. This implies that $s_{\bar{T}}(\bar{p}^*) + B_{\bar{T}-1}(\bar{p}^*) - d_{\bar{T}}(\bar{p}^*) = 0$, so $B_{\bar{T}-1}(\bar{p}^*) + b_{\bar{T}}(\bar{p}^*) = B_{\bar{T}}(\bar{p}^*) = 0$, as given.

In the unrestricted equilibrium allowances can be used at any point in time, so it holds that:

$$B_{\bar{T}}(p^*) > 0, \tag{9}$$

which follows from the fact that the final period $\bar{T} > T^*$ is binding. Now recall that the demand for allowances is decreasing in the allowance price; in particular, therefore, $d_{\bar{T}}(p)$ is decreasing in p. The implication is that the restricted equilibrium allowance price is strictly higher than the unrestricted equilibrium price when allowances can be used at any point in time:

$$\bar{p}^* < p^*. \tag{10}$$

As the cap and trade scheme operates a price-based stabilization mechanism, (10) implies:

$$s_t(\bar{p}^*) \leq s_t(p^*) \quad \text{for all} \quad t \leq \bar{T}. \tag{11}$$

Summing over all periods, I find:

$$S(\bar{p}^*) = \sum_t s_t(\bar{p}^*) \leq \sum_t s_t(p^*) = S(p^*). \tag{12}$$

Proposition 1. *A binding final period after which emissions are not allowed decreases* *emissions in a cap and trade scheme complemented with a price-based stabilization mechanism.*

Proposition 1 gives the intuitive result that, compared to a situation in which emission allowances may be surrendered at any point in the future, a binding final period beyond which emissions are not allowed unambiguously reduces emissions in cap and trade schemes that are supplemented with a price-based stabilization mechanism. Roughly speaking, the price of an allowance is dictated by the opportunity cost of using it now rather that later. In excluding the use of allowances for a range of future periods, the policymaker effectively reduces the opportunity cost of using an allowance today. The decreased opportunity cost translates directly into a lower allowance price (see (10)), which, by virtue of the price-based stabilization mechanism, reduces the supply of allowances and therefore emissions.

A more paradoxical result obtains when the cap and trade scheme is supplemented with a quantity-based stabilization mechanism. Since emissions are not allowed starting from period $\bar{T}$, the restricted equilibrium price $\bar{p}^{**}$ has to solve:

$$B_{\bar{T}}(\bar{p}^{**}) = 0. \tag{13}$$

Because the final period $\bar{T} > T^{**}$ is binding, it is known:

$$B_{\bar{T}}(p^{**}) > 0. \tag{14}$$

Combining (13) and (14) with the fact that $dB_t(p)/dp > 0$ when the cap and trade schemes operates a quantity-based stabilization mechanism (see (6)) yields:

$$\bar{p}^{**} < p^{**}, \tag{15}$$

which, again by (6), implies that the bank of allowances is lower at any point in time when there is a binding final period:

$$B_t(\bar{p}^{**}) < B_t(p^{**}). \tag{16}$$

Given the mechanics of a quantity-based stabilization mechanism, (16) implies:

$$S(B(\bar{p}^{**})) = \sum_t s_t(B_{t-1}(\bar{p}^{**})) \geq \sum_t s_t(B_{t-1}(p^{**})) = S(B(p^{**})). \tag{17}$$

Proposition 2. *A binding final period after which emissions are not allowed increases emissions in a cap and trade scheme complemented with a quantity-based stabilization mechanism.*

Proposition 2 gives the paradoxical result that, compared to the situation in which allowances may be surrendered at any point in time, a binding final period after which emissions are not allowed unambiguously increases emissions in cap and trade schemes supplemented with a quantity-based stabilization mechanism. The reason behind this increase is essentially as follows. A binding final period on emissions eliminates any incentive to bank unused allowances beyond the final period. The number of allowances surrendered in early periods therefore goes up. A quantity-based stabilization mechanism in turn translates the increased demand for emissions into a higher supply of allowances in subsequent periods, reinforcing the initial increase in demand.

2.4 Environmental damages

Observe that Proposition 2 implies a 'weak' green paradox (Van der Ploeg and Withagen, 2015) but is stronger as emissions both occur earlier and in larger quantities due to the binding final period:

$$\sum_{s=1}^{t} d_s(\bar{p}^{**}) \geq \sum_{s=1}^{t} d_s(p^{**}), \tag{18}$$

for all $t \geq 1$, which is true by (15) and the fact that emissions are decreasing in the allowance price.

It may be tempting to think that because aggregate emissions are higher under a binding final period environmental damages must be higher also; that is, to believe that Proposition 2 implies a 'strong' green paradox. This is not, in general, true.

Given a path of emissions $(d_t)_{t=0}^{\infty}$, let A_t denote the stock of atmospheric pollution which develops according to:

$$A_t(p \mid \delta) = \sum_{s=1}^{t} (1-\delta)^{t-s} d_s(p) = (1-\delta) \cdot A_{t-1}(p) + d_t(p), \tag{19}$$

where δ represents the decay factor and satisfies $0 \leq \delta \leq 1$.[2] Given a stock A_t, let

[2] It is not entirely innocuous to assume that the decay factor δ is constant as the absorbtive capacity of important carbon sinks such as the oceans tends to go down as greater amnounts of carbon were absorbed already (Archer et al., 2009).

$C_t(A_t)$ denote environmental damages in period t. Assume that C_t is strictly increasing in A_t for any $t \geq 1$: higher atmospheric pollution levels cause higher damages. For given discount factor $\beta \leq 1$, the net present value (NPV) of environmental damages is the discounted sum of damages in all periods:

$$NPV(p) = \sum_{t=1}^{\infty} \beta^{t-1} \cdot C_t(A_t(p \mid \delta)). \tag{20}$$

It is immediate from (19) and (20) that for $\delta = 1$ the net present value of environmental damages is higher under a binding final period when the cap and trade scheme is complemented with a quantity-based stabilization mechanism, see (18) and (19). Similarly, a sufficiently low discount factor β – giving relatively high weight to damages in the near future – will make the net present value of damages higher under a binding final period, emissions being frontloaded in that case.

Under the uncontroversial assumption that environmental damages are convex in atmospheric pollution levels (Coronese et al., 2019; Iverson and Karp, 2021),

Proposition 3. *A binding final period after which emissions are not allowed increases the net present value of environmental damages in a cap and trade scheme complemented with a price-based stabilization mechanism provided that the decay of emissions is sufficiently small and the environmental damage function C_t is not too concave.*

Proof. Define $\hat{T} = \inf\{t \mid d_t(p^{**}) = 0\}$. Observe that $\bar{T} < \hat{T}$ since $\bar{T}$ was assumed to be a binding final period (compared to the unrestricted equilibrium). Next define $\hat{\delta}$ as the decay factor that solves $A_{\hat{T}}(\bar{p}^{**} \mid \hat{\delta}) = A_{\hat{T}}(p^{**} \mid \hat{\delta})$. First note that $A_t(\bar{p}^{**} \mid \hat{\delta}) = A_t(p^{**} \mid \hat{\delta})$ for all $\geq \hat{T}$ as emissions are zero in both the restricted and the unrestricted equilibrium after $\hat{T}$. Second note that $A_t(\bar{p}^{**} \mid \hat{\delta}) > A_t(p^{**} \mid \hat{\delta})$ for all $t < \hat{T}$.

$$A \tag{21}$$

□

3 Discussion and Conclusions

I study the effect of time horizons on emissions trading. When a cap and trade scheme is complemented with a price-based stabilization mechanism, a binding final period beyond which emissions are not allowed unambiguously reduces emissions compared to a situation in which allowances may be surrendered at any point in the future. This intuitive result stands in stark contrast to the case of cap and trade schemes with a quantity-based stabilization mechanism, where a binding final period beyond which emissions are not allowed unambiguously increases emissions.

My result on quantity-based stabilization resembles recent work due to Gerlagh et al. (2021) who show that anticipated future abatement policies overlapping with a cap and trade scheme may increase emissions when the scheme is complemented with a type of quantity-based stabilization mechanism. These authors do not study price-based stabilization. An important distinction between the present analysis and the work by Gerlagh et al. is the "severity" of future policy. Gerlagh et al. consider policies that lower the demand for emissions for a given allowance price. This implies that, provided a sufficient reduction in the allowance price, the demand for emissions need not go down in any period. When instead there is a binding final period beyond which emissions are not allowed, no allowance price, however low, supports positive emissions after the final period by construction.

It is important to emphasize that my results are not critical of cap and trade per se but rather offer an argument against the use of quantity-based updating in cap and trade policies. The choice between price or quantity instruments depends on a score of factors not considered in this model (Hoel and Karp, 2001; Newell and Pizer, 2003).

One explanation for the contradictory performance of price- and quantity-based stabilization mechanisms may be found in the differential quality of information price- and quantity signals provide. Compared to quantities, prices are highly efficient information aggregators. Simply put, a high allowance price has an unambiguous interpretation: scarcity. A high demand for emissions, in contrast, may signal one of two mutually exclusive causes: scarcity *or* a low allowance price. Without using additional information on prices, there is no way of telling which factor drives the demand for emissions and a purely quantity-based stabilization mechanism needs to "guess". Quantity-based stabilization is therefore set up in a way that is bound cause mistakes every once in a while. Overall my paper suggests a strong advantage of price-based stabilization in cap and trade policies.

Several assumptions are important for my results.

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