Time Horizons And Emissions Trading

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Abstract

I study the effect of time horizons on emissions trading. When a cap and trade scheme is complemented with a quantity-based stabilization mechanism, a binding final period beyond which emissions are not allowed unambiguously raises aggregate emissions compared to the case in which allowances have an infinite lifetime. This paradox does not arise if instead the cap and trade schemes uses price-based stabilization. My results thus favor price-based stabilization.

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1 Introduction

Governments across the globe have instituted emissions trading, or cap and trade, to curb greenhouse gas emissions and mitigate climate change. Well-known examples of cap and trade schemes currently in operation include the EU Emissions Trading System (EU ETS), Korea's Emissions Trading Scheme (K-ETS), the Regional Greenhouse Gas Initiative (RGGI), California's cap and trade scheme, China's up and coming national ETS, and others.

The cap and trade schemes mentioned above, and indeed many others, share a common denominator: they are complemented with a stabilization mechanism that makes the cap on emissions endogenous to conditions prevailing in the market. As a

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rule, stabilization mechanisms are based either on the price of emissions allowances or on the number of allowances surrendered (see ICAP, 2021, for an overview). Examples of price-based stabilization mechanisms include price floors and collars, used for example in RGGI and California's cap and trade scheme (Schmalensee and Stavins, 2017). An example of quantity-based stabilization is a quantity collar, currently used in the EU ETS (Holt and Shobe, 2016) and planned for the Swiss ETS.[1]

On top of being widespread, stabilization mechanism have a tangible effect on climate policy. Borenstein et al. (2019) show that the equilibrium allowance price in California's cap and trade scheme is determined by the administrative price collar with 98.9 percent probability. The market stability reserve – a quantity-based stabilization mechanism – similarly has a sizeble effect on the EU ETS, causing the European allowance price to triple (Kollenberg and Taschini, 2019). It is therefore important to develop a complete understanding of stabilization mechanisms in cap and trade policy.

This paper establishes a paradoxical result on the interaction of stabilization mechanisms and the time horizon of emissions trading. When the policymaker fixes a point in time beyond which emissions are not allowed, aggregate emissions are strictly higher compared to the case in which allowances have an infinite lifespan if the cap and trade scheme is complemented with a quantity-based stabilization mechanism. No such paradox arises when instead the cap and trade scheme is implemented with a price-based stabilization mechanisms. These contrasting results provide a strong case for price-based stabilization.

As governments across the globe pledge climate neutrality for the future, the time horizon of emissions trading is likely to become a prominent dimension along which policy discussions will develop.[2] The results in this paper illustrate that policymakers must be careful: policies affecting the time horizon of emissions trading may work if the cap an trade scheme is complemented with a price-based stabilization mechanisms – however, the same policy can backfire if instead it affects a scheme that is complemented with a quantity-based stabilization mechanism.

[1]See the *Teilrevision der Verordnung über die Reduktion der CO2-Emissionen* (in German) for details of the Swiss ETS. Interestingly, though the EU and Swiss ETSs are bilaterally linked and both operate a quantity-based stabilization mechanism, the Swiss ETS is not subject to the EU ETS Market Stability Reserve.

[2]More than 120 countries have made climate neutrality pledges by now (Nature Editorial, 2021).

2 Analysis

2.1 Emissions trading

Given is a cap and trade scheme that regulates emissions of some pollutant in a number of periods $t = 1, 2, \ldots$. 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 $t \geq 1$, allowing me to write the demand for allowances in any period as a function of $p = p_1$ only.[3] 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 that can substitute for polluting technologies are developed and become cheaper over time (Salant, 2016; Gerlagh et al., 2021). 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 (or baseline) case in which allowances have an infinite lifetime; that is, in which an allowance issued in period t can be used in any period $s \neq t$.[4] 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

[3]This assumption is a generalized version of Hotelling's Rule. It is a reasonable assumption only if the scheme is dynamically integrated such as through a banking provision, see below.

[4]In most cap and trade schemes, emissions must be covered entirely by historic supply. 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.

demand for allowances is a function of p. The term $B_t(p)$ is usually referred to 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 many cap and trade schemes, the supply path of allowances (s_t) is not fixed but rather depends on developments in the market through some sort of stabilization mechanism. There essentially are two prominent classes of stabilization mechanisms: those that input the allowance price and those that input the use of 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 $t \geq T^*$. I refer to $(s_t(p^*))$ as the baseline path of emissions supply under price-based stabilization.

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 have *more* allowances 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 effect of the allowance price on banking, that is, the sign of dB_t/dp. In period 1, this is easy:

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

where the inequality is strict for all p such that $d_1(p) > 0$. A little more work is required to determine the sign of dB_t/dp for $t > 1$. In general, one has:

$$\begin{aligned} \frac{dB_t(p)}{dp} &= \frac{dB_{t-1}(p)}{dp} + \frac{ds_t(B_{t-1}(p))}{dB_{t-1}(p)} \frac{dB_{t-1}(p)}{dp} - \frac{dd_t(p)}{dp} \\ &= \left(1 + \frac{ds_t(B_{t-1}(p))}{dB_{t-1}(p)}\right) \frac{dB_{t-1}(p)}{dp} - \frac{dd_t(p)}{dp}. \end{aligned} \tag{5}$$

Using (4), I can evaluate (5) at $t = 2$:

$$\frac{dB_2(p)}{dp} = \left(1 + \frac{ds_2(B_1(p))}{dB_1(p)}\right) \frac{dB_1(p)}{dp} - \frac{dd_2(p)}{dp} \geq 0, \tag{6}$$

which follows from the facts that $ds_t/dB_t > -1$ and $dd(p)/dp \leq 0$. Induction on (6) establishes that $dB_t(p)/dp \geq 0$ for all t:

$$\frac{dB_t(p)}{dp} \geq 0, \tag{7}$$

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:

$$D(p^{**}) = S(B(p^{**})), \tag{8}$$

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 allowances 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 $t \geq T^{**}$. I refer to $(s_t(B_t(p^{**})))$ as the baseline path of emissions supply under price-based stabilization.

2.3 A finite 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 counterintuitive 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 operates 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:

$$B_{\bar{T}}(\bar{p}^*) = 0. \tag{9}$$

To see why (9) 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:

$$B_{\bar{T}}(p^*) > 0, \tag{10}$$

which follows from the fact that the final period $\bar{T} > T^*$ is binding. Now recall that the bank of allowances is decreasing in the allowance price in every period; in particular, therefore, $B_{\bar{T}}(p)$ 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:

$$\bar{p}^* < p^*. \tag{11}$$

As the cap and trade scheme operates a price-based stabilization mechanism, (11) implies:

$$s_t(\bar{p}^*) \leq s_t(p^*), \tag{12}$$

for all $t \geq 1$. Summing over periods, I find:

$$S(\bar{p}^*) = \sum_t s_t(\bar{p}^*) \leq \sum_t s_t(p^*) = S(p^*). \tag{13}$$

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 time, 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 (11)), which, by virtue of the price-based stabilization mechanism, reduces the aggregate supply of allowances and thus 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:

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

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

$$B_{\bar{T}}(p^{**}) > 0. \tag{15}$$

Plugging (14) and (15) into (7) yields:

$$\bar{p}^{**} < p^{**}, \tag{16}$$

which by (7) implies that the bank of allowances is lower at any point in time when there is a binding final period:

$$B_t(\bar{p}^{**}) < B_t(p^{**}), \tag{17}$$

for all $t \geq 1$. Given the mechanics of a quantity-based stabilization mechanism, (17) implies:

$$S(B(\bar{p}^{**})) = \sum_t s_t(B_{t-1}(\bar{p}^{**})) \geq \sum_t s_t(B_{t-1}(p^{**})) = S(B(p^{**})). \tag{18}$$

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 *increases* emissions in cap and trade schemes supplemented with a quantity-based stabilization mechanism (*c.f.* Gerlagh et al., 2021). The reason is 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 and the bank shrinks. A quantity-based stabilization mechanism in turn translates the increased demand for emissions into a higher supply of allowances in subsequent periods. The greater aggregate supply of allowances leads directly to higher emissions overall.

Note that Proposition 2 implies a green paradox (Van der Ploeg and Withagen, 2012, 2015). A green paradox occurs when emissions happen earlier in time due to some future policy, possibly causing the net discounted value of environmental damages to increase. In typical green paradox models, however, aggregate emissions are either constant or lower in response to the policy. In my model, in contrast, emissions speed up and aggregate emissions *increase*. This result resembles findings due to Novan (2017) and Gerlagh et al. (2021), who, for existing cap and trade schemes, show that additional abatement policies may increase emissions.

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 on emissions unambiguously reduces emissions compared to a situation in which allowances have an infinite lifetime. This intuitive result is reversed for cap and trade schemes with a quantity-based stabilization mechanism, where a binding final period on emissions unambiguously increases emissions.

My result on quantity-based stabilization is related to the green paradox literature (Van der Ploeg and Withagen, 2012, 2015). My result is stronger, however, as aggregate emissions *increase* when the time horizon of emissions trading is restricted. The possibility of increased emissions in response to overlapping climate policies was also observed by Novan (2017) and Gerlagh et al. (2021). In contrast to the theoretical models in these papers, my model allows for more than one or two periods. Another distinction between my work and that due to Novan (2017) and Gerlagh et al. (2021) is that I model both quantity- and price-based stabilization.

An explanation for the asymmetric performance of price- and quantity-based stabilization mechanisms may be found in the differential quality of information that price- and quantity signals provide. Compared to quantities, prices are highly efficient information aggregators. 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. Quantity-based stabilization is therefore bound to cause mistakes every once in a while. All in all these results provide a rather strong argument to favor price-based stabilization in cap and trade policies. For the European context in particular, this paper thus reinforces calls for a price collar to complement the EU ETS (Flachsland et al., 2020).

While I study price- and quantity-based stabilization within a cap and trade scheme generally, many other types of market-based environmental policies exist, see for example Fowlie et al. (2016), Böhringer et al. (2017), or Fowlie and Muller (2019). The critical message regarding quantity-based stabilization does not necessarily extend to other kinds of endogenous policies.

The results in this paper are particularly important in light of recent EU policy developments. As part of its “Fit for 55” legislation package, in July 2021 the EU announced a new emissions trading scheme for buildings and road transport which should be established and running as a separate self-standing system from 2025 onward. Like the already existing EU ETS this new system will be complemented with a Market Stability Reserve. Unlike the EU ETS, however, the triggering mechanism for the new MSR will be based on the increase in the average allowance price and not on the surplus of allowances in the market.[5] In the near future, the EU will therefore operate two seperate ETSs, one with a quantity-based stabilization mechanism, the other with a price-based stabilization mechanism. My results illustrate one dimension along which the two systems respond rather differently to a given policy, illustrating the need for tailor-made (rather than general) policymaking in both systems.

This paper makes several restrictive assumptions. First, I assume that the binding final period is not accompanied by discrete supply-adjustments; changes in the supply of allowances come about entirely through the stabilization mechanism in place. In reality, the introduction of a final period on allowances would counstitute a rather major reform which the policymaker might reasonbaly be expected to consider only within the context of a broader set of changes, including perhaps exogenous supply adjustments. Second, I assume that the final period is set after the baseline equilibrium supply of allowances stops. If the policymaker fixes the final period on emissions before the baseline supply reaches zero, aggregate emissions might go down irrespective of the kind of stabilization mechanism in place; (though it remains true that emissions go down *more* with a price-based mechanism). Lastly, I assumed perfect information and foresight even though uncertainty is an important factor in real-world emissions trading (Borenstein et al., 2019) – my results straightforwardly generalize to stochastic environments.

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