Time Horizons And Emissions Trading

Roweno J.R.K. Heijmans*

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Abstract

I study the effect of the time horizons of emissions trading on pollution. 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 schemes relies on price-based stabilization. My results thus favor price-based stabilization.

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1 Introduction

Emissions trading is among the commonest of policies to price carbon and curb greenhouse gas emissions. In its most basic form, emissions trading – or cap and trade – fixes the total amount of emissions but allows participating parties to decide on the allocation of emissions under this cap, creating a market for greenhouse gases. In practice, emissions trading schemes (ETSs) frequently deviate from this canonical model by making the cap on emissions endogenous to conditions prevailing in the market. Thus California's cap and trade scheme, China's National ETS, the EU ETS, Germany's National ETS, Korea's ETS, New Zealand's ETS, the Massachusetts Limits on Emissions from Electricity Generator, the Regional Greenhouse Gas Initiative (RGGI), and

*Department of Economics, Swedish University of Agricultural Sciences, Box 7013, 750 07 Uppsala, Sweden. Email: roweno.heijmans@slu.se. I thank Torben Mideska for very useful comments and great patience.

Switzerland's ETS all are complemented with a stabilization mechanism that maps ETS market outcomes onto the supply of (new) emissions allowances. An endogenous emissions cap is motivated by the idea that it makes a policy more resilient to economic fluctuations and uncertainties which would otherwise make the system unstable or ineffective (Fell, 2016; Lintunen and Kuusela, 2018; Pizer and Prest, 2020).

As a rule, and indeed in all schemes mentioned above, stabilization mechanisms are based either on the carbon price or on the quantity of greenhouse gases emitted (see ICAP, 2021, for an overview). Examples of price-based stabilization mechanisms include price collars, used for example in RGGI and California's ETS (Schmalensee and Stavins, 2017). An example of quantity-based stabilization is a quantity collar, used in the EU ETS (Fell, 2016; Holt and Shobe, 2016) and planned for the Swiss ETS.[1]

This paper establishes a paradoxical result on the interaction between 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 complemented with a price-based stabilization mechanisms, in which case a final period unambiguously curbs emissions. While price- and quantity-based stabilization mechanisms are superficially similar, they interact very differently with the time horizon of emissions trading.

Stabilization mechanisms have a notable 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 EU ETS's quantity-based stabilization mechanism similarly caused the European carbon price to triple (Kollenberg and Taschini, 2019). It is therefore important to understand the effect of stabilization mechanisms on emissions trading.

As more and more governments pledge future climate neutrality (Nature Editorial, 2021), the time horizon of emissions has become a prominent dimension of policy discussions. The results in this paper call for careful policymaking in emissions trading schemes complemented with a quantity-based stabilization mechanism. Restricting the time horizon of emissions trading may backfire in unexpected ways, making ambitious climate goals harder to achieve. The more intuitive interaction between pollution and the time horizon of emissions trading under price-based stabilization could be used as

[1]See the *Teilrevision der Verordnung über die Reduktion der CO2-Emissionen* (in German) for details of the Swiss ETS.

an argument to favor price-based over quantity-based stabilization, though I hasten to add that such an interpretation is by no means unambiguous as the advantage of one over the other will depend on a score of other factors not captured by my model as well.

2 Model

I first set up a generic model of emissions trading and stabilization mechanisms. Equilibrium analyses are relegated to Section 3

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 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 polluters are price takers and that $d_t(p_t)$ is decreasing in the price p_t in every period t. 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.

The traditional version of my assumption on the price path is Hotelling's Rule, which very roughly states that prices should rise with the interest rate. It is easy to see that Hotelling's Rule implies my assumption: for $r \geq 0$ the interest rate, Hotelling's rule says that $dp_{t+1}/d_t = 1 + r > 0$. Unfortunately, factors including asymmetric information (Martimort et al., 2018), technological progress (Livernois, 2009), and arbitrage opportunities (Anderson et al., 2018) are all known to cause violations of the rule in its canonical formulation. For these reasons, I maintain the more general assumption that prices are positively correlated across periods, $dp_{t+1}/dp_t > 0$, without specifying the exact magnitude of this correlation. Note that the literature broadly supports my assumption both theoretically and empirically, even as it rejects the Hotelling Rule (Livernois, 2009; Anderson et al., 2018; Martimort et al., 2018).

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 ("backstop technologies") are developed and/or become cheaper over time (Golosov et al., 2014; Salant, 2016). 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 $t' \neq t$.[2] 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:

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

The term $B_t(p)$ is usually referred to as the *bank* of allowances, the act of adding to $B_t(p)$ as *banking*. 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 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 $p > p'$. Price floors, ceilings, and collars work this way (Fell et al., 2012). To guarantee existence of an equilibrium I assume that $s_t(0) \leq d_t(0)$ and $s_t(\infty) \geq d_t(\infty)$ for all t, with a stict inequality for at least one t. To rule out existence of more than one equilibrium I also assume that $s_t(p)$ is continuous (though not necessarily differentiable) in p (cf. Gerlagh et al., 2021).

[2] 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 (Heutel, 2020; Pizer and Prest, 2020). Note that borrowing constraints have not been binding in most existing cap and trade schemes.

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 under a price-based stabilization regime. 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.

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 $B_t' > B_t$. I assume that $s_t(B_{t-1}(0)) \leq d_t(0)$ and $s_t(B_{t-1}(\infty)) \geq d_t(\infty)$, with a stict inequality for at least one 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 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:

$$\frac{dB_1(p)}{dp} = -\frac{dd_1(p)}{dp} \geq 0, \tag{3}$$

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:

$$\begin{aligned}\frac{dB_t(p)}{dp} &= \frac{dB_{t-1}(p)}{dp} + \frac{ds_t(B_{t-1}(p))}{dB_{t-1}(p)}\frac{dB_{t-1}(p)}{dp} - \frac{dd_t(p)}{dp} \\ &= \left(1 + \frac{ds_t(B_{t-1}(p))}{dB_{t-1}(p)}\right)\frac{dB_{t-1}(p)}{dp} - \frac{dd_t(p)}{dp}.\end{aligned} \tag{4}$$

Using (3), induction on t establishes that $dB_t(p)/dp \geq 0$ for all t:

$$\frac{dB_t(p)}{dp} \geq 0, \tag{5}$$

which follows from the facts that $ds_t/dB_t > -1$ and $dd_t(p)/dp \leq 0$ for all t. The inequality is strict as long as p satisfies $d_1(p) > 0$.

A natural objection to the model outlined above is that it studies stabilization mechanisms in a deterministic setting even though the primary motivation behind stabilization mechanisms is uncertainty. While such an objection is justified, I motivate my simplification in two ways. The first is convenience: a deterministic setup provides the cleanest environment in which to carry the main message of this paper home. Second, at the cost of additional notation the analysis is easily extended to include stochastic elements. For example, suppose that the demand for emissions were in fact a stochastic function $d_t(p, \theta_t)$, where θ_t is a random variable affecting the demand for allowances in period t (for a given price path p). The demand function $d_t(p)$ can then be interpreted as *expected demand*, i.e. $d_t(p) = \mathbb{E}_{\theta_t} d_t(p, \theta_t)$, and the ensuing analysis as pertaining to expected equilibrium emissions. Importantly, it is immediate from the analysis that Propositions 1 through 3 will remain true for any given sequence (θ_t).

3 Analysis

To study the environmental consequences of a restricted time horizon of emissions trading, I need a benchmark. This benchmark is called the baseline, or unrestricted, equilibrium and represents the case in which allowances can be used to cover emissions at any point in the future. I then introduce a binding final period on emissions beyond which allowances cannot be used and compare aggregate pollution between the unrestricted and restricted equilibrium for price- and quantity-based stabilization mechanisms, respectively.

3.1 Baseline equilibrium

A cap and trade scheme is in equilibrium if the aggregate supply of emissions allowances is equal to the aggregate demand. Writing $S(p) = \sum_t s_t(p)$ for the aggregate supplyf allowances given a price-based stabilization mechanism, the market is hence in equilibrium if

$$D(p^*) = S(p^*), \tag{6}$$

where p^* is the unrestricted equilibrium allowance price when the scheme operates a price-based stabilization mechanism.

To see that the baseline equilibrium p^* exists, recall that $d_t(0) \geq s_t(0)$ and $d_t(\infty) \leq s_t(\infty)$ for all t, with a strict inequality for at least one, implying $D(0) > S(0)$ and $D(\infty) < S(\infty)$. Moreover, $D(p)$ is decreasing in p while $S(p)$ is increasing by construction. Existence of p^* follows immediately.

With a stabilization mechanism, the supply of allowances is endogenous. Let T^* denote the final period in which the supply of emissions drops to zero in the unrestricted equilibrium under 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.

In much the same way, one can analyze the unrestricted equilibrium under a quantity-based stabilization regime. Let $S(B(p)) = \sum_t s_t(B_t(p))$ denote the aggregate supply of allowances given quantity-based stabzilization. The market 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.

Establishing existence of p^{**} is slightly more involved. Recall from (5) that the bank $B_t(p)$ is increasing in p under a quantity-based stabilization mechanism. Using the definition of B_t, it is therefore known that

$$\frac{d}{dp} \underbrace{\left[\sum_{s=1}^{t} s_s(B_{s-1}(p)) - d_s(p) \right]}_{=B_t(p)} > 0, \tag{8}$$

for all t. Splitting up the terms under the summation and evaluating at the limit as $t \to \infty$ gives

$$\lim_{t \to \infty} \quad \frac{d}{dp} \left[\sum_{s=1}^{t} s_s(B_{s-1}(p)) - \sum_{s=1}^{t} d_s(p) \right] > 0. \tag{9}$$

Now recall that $\sum_{s=1}^{\infty} d_s((p)) = D(p)$ and $\sum_{s=1}^{\infty} s_s(B_{s-1}(p)) = S(B(p))$ by definition. Using this, (9) can therefore be rewritten as

$$\frac{d}{dp} \left[S(B(p)) - D(p) \right] > 0. \tag{10}$$

In words, the inequality in (10) says that the aggregate surplus of allowances is increasing in the allowance price in a cap and trade scheme complemented with a quantity-based stabilization mechanism. Note that the same is true under price-based stabilization.

Lastly, recall that $S(B(0)) - D(0) < 0$ and $S(B(\infty)) - D(\infty) > 0$. From (10) then follows that a p^{**} solving (7) exists.

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 quantity-based stabilization.

3.2 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 $t \geq \bar{T}$: $d_{\bar{T}}(p^*) > 0$ 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 $\bar{T} > \max\{T^*, T^{**}\}$. I also assume that the final period is known starting from period 1; observe that this is mostly a definition in that I may define period 1 to be the first period in which the final period $\bar{T}$ is common knowledge.

I first consider 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:

$$B_{\bar{T}}(\bar{p}^*) = 0. \tag{11}$$

To see why (11) pins down the restricted equilibrium price path, observe that the incentive to bank allowances for periods in which they cannot be used is evidently non-existent; from the firm's perspective, doing so would amount to pure capital destruction as it leaves valuable allowances permanently un-surrendered. The restricted equilibrium price path therefore adjusts to ensure that the entire supply of allowances is used up by the time the final period is reached. In the notation of the model, this means that $\bar{p}^*$ must solve $d_{\bar{T}}(\bar{p}^*) = s_{\bar{T}}(\bar{p}^*) + B_{\bar{T}-1}(\bar{p}^*)$, or $s_{\bar{T}}(\bar{p}^*) + B_{\bar{T}-1}(\bar{p}^*) - d_{\bar{T}}(\bar{p}^*) = B_{\bar{T}-1}(\bar{p}^*) + b_{\bar{T}}(\bar{p}^*) = B_{\bar{T}}(\bar{p}^*) = 0$, which is (11).

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

$$B_{\bar{T}}(p^*) > 0. \tag{12}$$

To see that the inequality in (12) is strict, recall that the binding final period satisfies $\bar{T} > T^*$, meaning it is set *after* baseline equilibrium supply dries up. Moreover, it was assumed that $\bar{T}$ is binding, so demand in period $\bar{T}$ is strictly positive at baseline. To cover the strictly positive demand in $\bar{T}$ even as no new allowances are supplied, banking at the start of period $\bar{T}$ must be strictly positive at baseline.

Now recall from (5) 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:

$$\bar{p}^* < p^*. \tag{13}$$

By the mechanics of a price-based stabilization mechanism, the inequality in (13) implies:

$$s_t(\bar{p}^*) < s_t(p^*), \tag{14}$$

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

$$S(\bar{p}^*) = \sum_t s_t(\bar{p}^*) < \sum_t s_t(p^*) = S(p^*). \tag{15}$$

This is my first main result.

Proposition 1. *A binding final period on emissions unambiguously* decreases *emissions in cap and trade schemes 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 on emissions unambiguously reduces aggregate emissions in cap and trade schemes complemented 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 (13)), which, by virtue of the price-based stabilization mechanism, reduces the aggregate supply of allowances and thus emissions. A price-based stabilization mechanism can thus support a pledge of climate neutrality in, say, 2050.

A more paradoxical result obtains when the cap and trade scheme is complemented 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:

$$B_{\bar{T}}(\bar{p}^{**}) = 0. \tag{16}$$

The intuition behind (16) is the same as for price-based stabilization: allowances cannot be used in periods $\bar{T}$ and beyond, so it is never an equilibrium to leave allowances unsurrendered by that time. This means that in equilibrium the bank must be depleted by period $\bar{T}$ the latest, or $B_{\bar{T}}(\bar{p}^{**}) = 0$.

Because the final period is binding and satisfies $\bar{T} > T^{**}$, baseline demand in period $\bar{T}$ is positive even though new allowances are no loner supplied. The unrestricted equilibrium price p^{**} should hence dictate a strictly positive bank at the start of period $\bar{T}$. Formally,

$$B_{\bar{T}}(p^{**}) > 0. \tag{17}$$

Recall from (5) that the bank $B_t(p)$ is increasing in the allowance price p. From (16) and (17) then follows:

$$\bar{p}^{**} < p^{**}. \tag{18}$$

Inequality (18) has an important implication. For although it is a consequence of the fact that $\bar{p}^{**}$ has to solve (16), its effects trickle down on all periods prior to $\bar{T}$. To see why, note (by (5)) that the bank of allowances is decreasing in p at any point in time. The major implication of (18) is therefore that banking is *always* less in the restricted equilibrium:

$$B_t(\bar{p}^{**}) < B_t(p^{**}), \tag{19}$$

for all $t \geq 1$.[3] The inequality in (19) has a natural intuition. When the policymaker introduces a binding final period on emissions, the incentive to bank allowances is reduced. Rather than bank the same amount of allowances as in the unrestricted equilibrium only to use all of it up at once just before the final period arrives, condition (19) tells us that firms instead smooth the increased use of allowances out over all periods leading up to it.

Given the mechanics of a quantity-based stabilization mechanism, the immediate

[3]Recall the assumption that firms are permitted to both bank and borrow allowances. If one in addition were to impose (as most existing cap and trade schemes do) a borrowing constraint, then (19) changes to $B_t(\bar{p}^{**}) \leq B_t(p^{**})$, with a strict inequality for all t at which $B_t(p^{**}) > 0$.

implication of (19) is:

$$S(B(\bar{p}^{**})) = \sum_t s_t(B_{t-1}(\bar{p}^{**})) > \sum_t s_t(B_{t-1}(p^{**})) = S(B(p^{**})). \tag{20}$$

This is my second main result.

Proposition 2. *A binding final period on emissions unambiguously* increases *emissions in cap and trade schemes 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 on emissions unambiguously *increases* emissions in cap and trade schemes complemented with a quantity-based stabilization mechanism. A quantity-based stabilization thus does not support pledged of climate neutrality in, say, 2050.

At its core, Proposition 2 is the product of two effects. The first effect, *leakage*, is well known among environmental economists and very simply says that any allowances firms cannot surrender in the future will be surrendered today. Polluters under the cap and trade scheme bank allowances to cover their future demand for emissions. Once the final period is put in place, part of the incentive to bank gets eliminated. Firms consequently bank strictly fewer allowances in response to the final period on emissions.

With a fixed cap, leakage implies a reshuffling of emissions over time but no change in emissions overall; this is called a green paradox (Van der Ploeg and Withagen, 2012). The second effect, however, says that the reduction in banking implied by the leakage effect causes the supply of allowances to go up. This effect is immediate from the construction of the quantity-based stabilization mechanism. Since every allowance supplied will be used in equilibrium, aggregate emissions are unambiguously higher after the binding final period is introduced.

3.3 A signal extraction problem

The rationale to append cap and trade schemes with a stabilization mechanism derives from the economics of incomplete information (Kwerel, 1977; Dasgupta et al., 1980). Climate policy aims to strike a balance between the (marginal) costs and benefits of abatement. While this is an easy task in a world of complete and perfect information, a major complication is that the policymaker does not know – or at least knows with substantially less precision – the exact abatement cost function of the firms whose emissions it regulates. In the context of cap and trade, this means that policymakers have to guess the efficient cap on emissions.

The advantage of cap and trade is that it allows firms to use their private information on abatement costs and achieve a given cap – efficient or not – at least cost. Profit-maximization leads firms to distribute allowances among each other and across periods until marginal abatement costs are equalized, minimizing costs overall. For a policymaker, the resulting distribution of allowances provides a signal of firms' true abatement costs and therefore the efficient emissions cap. Thus authors have argued for cap adjustments in response to observed market outcomes (Fell, 2016; Lintunen and Kuusela, 2018; Pizer and Prest, 2020).

When adjusting the cap in response to observed market outcomes, the policymaker essentially solves a signal extraction problem (Kwerel, 1977; Dasgupta et al., 1980). Two types of signals are readily available in the market for allowances: prices and quantities. By prices, I mean the price at which an emissions allowance is traded. By quantites, I mean the number of allowances surrendered or, perhaps more empirically relevant, the number of allowances banked. A price-based stabilization mechanism is a policy that uses price signals to extract firms' private information and update the emissions cap; a quantity-based stabilization mechanism does the same but using quantity signals.

Price signals have an unambiguous interpretation. In equilibrium, the allowance price equals marginal abatement costs. A high price hence indicates high abatement costs and therefore a high demand (vis-à-vis supply) for emissions, which all else equal motivates a looser cap.

Quantity signals in contrast have a much less straightforward interpretation. A large bank of allowances is typically interpreted as a signal of low demand (vis-à-vis supply) for emissions, which in turn motivates a tightening of the cap (Fell, 2016; Lintunen and Kuusela, 2018; Pizer and Prest, 2020).

The problem with this kind of reasoning is that the amount banking at any point in time does not so much provide a signal of demand per se but rather of *relative demand*, that is, of the demand for allowances today relative to demand in the future. It is perfectly possible for the bank of allowances to be large while demand is very high also, provided future demand (vis-à-vis supply) is even higher. Without additional information, a large bank of allowances does not have a clear, unambiguous interpretation in terms of abatement costs and, therefore, the efficient emissions cap.

With the above considerations in mind, the results of this paper gain some economic intuition. A binding final period on emissions artificially eliminates a part of the future demand for allowances. This reduction in demand leads to a decline in the allowance price, which a price-based stabilization mechanism correctly translates into a lower supply of allowances (Proposition 1).

A binding final period on emissions similarly eliminates part of the future demand for allowances when the cap and trade scheme is complemented with a quantity-based stabilization mechanism, leading to both a lower allowance price and less banking. The policy then, by construction, interprets the decline in banking as a surge in demand and allocates additional allowances to the market (Proposition 2). In reality, as we know, the change in banking does not derive from an increased demand for emissions; it derives from a decrease in future demand, which implies that (at any given price) the ratio of demand today over demand in the future has gone up, reducing firms' incentive to bank. Importantly, though, the *aggregate* demand for emissions has declined. The quantity-based stabilization mechanism wrongly interprets the quantity signal extracted from the market in response to the binding final period on emissions.

4 Discussion and Conclusions

I study the effect of the time horizons of emissions trading on pollution. 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 schemes relies on price-based stabilization, in which case a binding final period on emissions unambiguously curbs emissions.

My result on quantity-based stabilization is related to the green paradox (Van der Ploeg and Withagen, 2012). 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 Gerlagh et al. (2021). In contrast to these studies, my paper allows for a general number periods and studies both quantity- and price-based stabilization.

Price- and quantity-based stabilization mechanisms perform so differently in part due to the quality of information price- and quantity signals provide. Compared to quantities, prices are highly efficient information aggregators. A high allowance price has an unambiguous interpretation: scarcity. A large surplus of emissions, in contrast, may signal one of two things: excess supply *or* expected future scarcity. 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 once in a while.

While I study stabilization stabilizations within a cap and trade scheme generally, many other types of market-based environmental policies exist, see for example Böhringer and Lange (2005), Böhringer et al. (2017), and Fowlie and Muller (2019). The critical message regarding quantity-based stabilization does not necessarily extend to other kinds of endogenous policies.

The important distinction between price- and quantity-based stabilization mechanisms cut to the core 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 allowance price.[4] 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, scheme-specific policymaking in the EU.

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 reality, the introduction of a final period on emission would counstitute a major reform which the policymaker might consider only within the context of a broader set of changes, including perhaps exogenous supply adjustments. Second, I consider a particular kind of finite time horizon in which allowances can be used at any time prior to the final period independent of when they were issued. Alternatively, policymakers could write off unused allowances depending on when they were supplied, e.g. allowances can be kept for five years at most.

[4] For more details, see the July 14, 2021, Proposal *COM(2021) 551 final*, pages 19-22 in particular.

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