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Why the EU Market Stability Reserve deters long-term low-carbon investments

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Abstract

Postponing the issue date of allowances in a cap-and-trade scheme as instituted e.g. in the Market Stability Reserve (MSR) of the EU ETS has an impact on abatement technology adoption. Stimulating low-carbon investments is a key objective of the MSR. We show that postponing allowances has an ambiguous effect on investments. By constraining intertemporal arbitrage, it shifts investments towards short-term reductions. Long-term investments are deterred. Reform proposals for Phase IV of the EU ETS are suitable to counteract the negative effects of the MSR on long-term investments but undermine the very idea of the MSR. The effects crucially depend on how firms form expectations about future allowance prices.

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1 Introduction

Since its start of operation in 2005, the European Union Emission Trading System (EU ETS) has produced carbon prices between 0 and 30€. In Phase III of the scheme (2013-2020), the price for one ton of CO_2-equivalent has so far moved in the range of 4 to 9€. The European Commission and researchers in the field argue that the current price-level is not sufficient to incentivize the amount of low-carbon investment needed to substantially transform the European economy in line with targets for 2050 (European Commission, 2014a; Salant, 2016). Different estimates propose prices 5-10 times their current level to spur technological change and to reflect the social cost of carbon adequately (van den Bijgaart et al., 2016).[1]

Several reasons for the system's present performance have been identified. Mainly, an inflow of offset credits from linked mechanisms under the Kyoto Protocol, the rigid allocation schedule of allowances in times of slumping demand following the economic downturn of 2009 as well as strategic banking behavior of forward-contracting firms led to a structural surplus of allowances in circulation (Böhringer et al., 2009; Koch et al., 2014; Hintermann et al., 2015; Koch et al., 2016; Fuss et al., 2017; Jarke & Perino, 2017). On 31st December 2016, market participants held about 1.69 billion allowances in their portfolios[2] not including 900 million allowances withheld due to the so-called 'backloading' intervention of the EU.[3]

Besides the issues related to the design of the EU ETS, there is growing concern that the market is not intertemporally efficient (European Commission, 2014b). This, however, is not simply due to a flaw in design but rather caused by firms subject to the EU ETS not putting enough weight on future scarcity. This again can be a perfectly rational response to regulatory uncertainty about the future stringency, design and existence of the EU ETS (Salant, 2016; Fuss et al., 2017) or driven by shortsightedness of firms (Holt & Shobe, 2016; Fuss et al., 2017). However, there is not yet a common understanding of the nature of this shortsightedness. Several versions have been suggested: at least some firms featuring a discount rate above that of the regulator (Neuhoff et al., 2012), firms only taking into account the next x years with x in the region of two to six years (Holt & Shobe, 2016; Fuss et al., 2017), or firms using heuristics to form price expectations (Hommes et al., 2004). As we will show, the effect of the MSR on investment profiles will crucially depend on the nature of firms' shortsightedness.

The EU has been working on a reform to help generate a stronger price signal and less price variation in the market for allowances - both to assure stronger incentives for the development and deployment of abatement technologies and to reduce uncertainty about the future price path (European Commission, 2014b; European Parliament, 2014). A key element of this reform is the Market Stability Reserve (MSR) legislated in 2015 (European Commission, 2015). Its purpose is to further spur low-carbon investments, increase resilience to demand-supply imbalances

[1] Perino & Requate (2012) show that for many relevant technologies the relationship between the carbon price and adoption incentives is only monotonic for sufficiently low price levels.

[2] See European Commission (2017).

[3] Starting in 2014, the EU reduced auction quantities of EUAs by 900 million over three years. Though initially the plan was for them to be fed back via auctions in 2019 and 2020 as part of the package introducing the MSR, they will be placed in the MSR once it becomes operational in 2019. The effects of backloading are investigated by Koch et al. (2016); Richstein et al. (2015) and Salant (2016).

and to reap synergies with overlapping policies all by reducing the aforementioned surplus of allowances. One of the rationales for introducing the MSR both common in the literature and referred to by policy makers is the perceived dynamic inefficiency of the EU ETS due to a shortfall of low-carbon investments in line with long-run reduction targets (European Commission, 2014b; Holt & Shobe, 2016; Fuss et al., 2017).

The MSR reduces yearly allocations depending on the size of the surplus. Later, it injects stored allowances back into the market once a certain scarcity threshold is reached. Hence, it shifts the auction date of allowances into the future.[4] The EC seems to assume that a reduced surplus today should increase prices and incentivize more timely investment by market participants. However, several economic analyses have shown that this will instead lead to lower prices in the long run when intermittently stored allowances are fed back in future times of higher scarcity (Salant, 2016; Perino & Willner, 2016). Features of the ongoing reform process setting the rules of Phase IV of the EU ETS encompass a more rapid reduction of the cap over time by increasing the 'linear reduction factor' (LRF), a cancellation of allowances stored in the reserve and changes to the design parameters of the MSR. While the MSR will be introduced as planned, further reforms are currently underway and have not yet passed the legislative process (Perino & Willner, 2017).

With respect to the adoption of low-carbon technologies, we focus on the MSR's impact on time profiles of diffusion rates of different types of technologies since the dynamic inefficiency of investment decisions was a key motivation for implementing the MSR.[5] We consider a technology reducing emissions immediately and another technology doing so only in the future, needing time to be put into place. The latter entails the transformation of production on a larger scale, such as building new power plants, fundamentally changing production processes or setting up new, low-carbon infrastructure while the former is a proxy for small scale and comparably quick changes like fuel switching.

Our analysis shows that the MSR has differing effects on the two technologies. Through its influence on price levels the MSR increases adoption incentives of technologies effective in the short-term but reduces them for transformational, long-term technologies. Hence, the MSR induces a time profile of investment that corresponds to firms being more, not less shortsighted. We further include recent reform proposals for Phase IV. These measures counteract the reserve's price impacts in the short run and hence support long-term investments by increasing future prices (Perino & Willner, 2017).

Our contribution is also relevant for the literature studying the impact of instrument choice and design technology choice. Early contributions (Milliman & Prince, 1989; Requate & Unold, 2003) address the impact of instrument choice on adoption incentives of a given technology. More recently, the choice between different types of technologies has been analyzed e.g. by Krysiak (2008, 2011) and Lechthaler-Felber & Krysiak (2017). The key dimension added by

[4] For a detailed description of the functioning of the reserve, see European Union (2017).

[5] The European Commissions Impact Assessment (European Commission, 2014a) on the MSR states under 'Operational objective': "[...] this refers to the optimal balance between the carbon price signal and low-carbon investment that is needed now, and those that will be needed in the future" [p. 11].

the present paper is the effect of real world design choices in cap-and-trade schemes on the time profile of technology adoption.

In the following, we will present a deterministic two period model to check the effect of postponing the issue date of allowances on market participants' investment decisions for low-carbon and abatement technologies. It is the aim of the analysis to provide an intuition for relative effects on short-term adjustments and long-term transformational investment decisions - keeping in mind that profound technological change is necessary to ensure decarbonization of the economy (see e.g. Nordhaus (2011) or Clò et al. (2013)). In section 2 we present the model and discuss its basic properties and results. Section 3 comprises the analysis of firms' decisions to adopt a new technology and the implications of the reserve for short- and long-term investments, while 4 delves into the implications of recent reform proposals from EU institutions. Section 5 concludes.

2 The Model

2.1 Basic properties

To analyze the reserve mechanism's effect on investment decisions, we choose a lean representation of an intertemporal allowance market in discrete time. There is a continuum of identical polluting firms with mass one in a perfectly competitive market for emission allowances. Banking but not borrowing of allowances is allowed as is both the case in the EU ETS and much of the literature on intertemporal allowance markets (Rubin, 1996; Schennach, 2000; Perino & Willner, 2016). Firms are represented by an abatement cost function, $C_i(\alpha)$, with $\alpha = u_i - e_{i,t}$. We assume period-invariant baseline emissions $u_i > 0$ and denote actual emissions of firm i at time t with $e_{i,t} \in [0, u_i]$. Abatement is thus defined as the difference in emissions between the business-as-usual scenario without any regulation and a scenario with an ETS in place. The abatement cost function is quadratic, $C_i(e_{i,t}) = c/2(u_i - e_{i,t})^2$. This approach follows loosely that of Cronshaw & Kruse (1996). Firms minimize their abatement costs over both periods facing an overall allocation of auctioned allowances of $S = S_1 + S_2$, with $S_1 > S_2$ to imply a decreasing cap as foreseen in the EU ETS by means of the LRF. Additionally, each firm is endowed with allowances banked from earlier periods, $b_0 \geq 0$, which amounts to an initial stock of banked allowances in the market at time $t = 0$ with size $\int_{i=0}^{1} b_{0,i} \, \mathrm{d}i = B_0 > 0$.

In the market, firms operate by selling or buying emission allowances from auctions or intermediate markets. We use a single market price for allowances, p_t, at which the market clears per period. Net sales of an individual firm, $x_{i,t}$ can thus be positive or negative. In each period, however, the aggregate sales of firms equal the number of allowances auctioned during the respective period, $\int_{i=0}^{1} x_{i,t} \, \mathrm{d}i = S_t \geq 0$. Aggregate values are represented by corresponding capital letters. At the end of period 2, we assume the cap to bind, i.e. $2U > B_0 + S_1 + S_2$, implying $p_t > 0$. We call the latter inequality the overall scarcity condition.

2.2 Firm Level

Each firm solves the following optimization problem:

$$
\begin{aligned}
& min_{e_{t,i},x_{t,i}} \sum_{t=0}^{2} C(e_{t,i}, x_{t,i}) \\
s.t.: \quad & x_{1,i} \geq e_{1,i} - b_{0,i} \\
& x_{1,i} \leq S_1 + B_0 - b_{0,i} \\
& 0 \leq e_{t,i} \leq u_i
\end{aligned}
$$

For the sake of convenience, we drop the subscript i and restrict our analysis to two periods. One period can be thought of as 15-20 years, making the end of period 2 fall together with the EU's emission reduction goal of at least -80% for 2050 relative to 1990 levels. By then scarcity will be of such a magnitude that we assume firms to not leave a bequest, i.e. $B_2 = 0$. Due to constraints on the choice variables, case distinctions need to be made to find an interior solution.[6] Firstly, if the price of allowances rises at the rate of interest, $p_2 = (1+r)p_1$, firms emit less than their unregulated emissions, $0 < e_1 < u$, and engage in banking to minimize their abatement costs, $x_1 > e_1 - b_0$ and $x_2 = e_2 - b_1$. If this is the case, we refer to the system to be in banking mode (b). Secondly, if the price for allowances rises at a rate less than the interest rate, $p_2 = (1+r)(p_1 - \lambda_{x_{11}})$ with $\lambda_{x_{11}} > 0$, firms do not bank allowances, $x_1 = e_1 - b_0$ and $x_2 = e_2$. The multiplier $\lambda_{x_{11}}$ stems from the binding non-borrowing constraint. In this case, we refer to the system to be in no-banking mode (nb). Firms' optimal behavior thus endogenously depends on the mode of the system. This is summarized in lemma 1.

Lemma 1.
If prices rise at the rate of interest (b-mode, $x_1 > e_1 - b_0$):

$$
\begin{aligned}
e_1 &= u - \frac{p_1}{c} \\
e_2 &= u - \frac{(1+r)p_1}{c} \\
x_1 + x_2 &= 2u - \frac{(2+r)p_1}{c} - b_0.
\end{aligned}
$$

If firms bank allowances they are indifferent between acquiring an additional allowance in period 1 and 2. Only the sum but not the two individual quantities x_1 and x_2 are thus uniquely defined. If prices rise at less than the rate of interest (nb-mode, $x_1 = e_1 - b_0$):

$$
\begin{aligned}
e_1 &= u - \frac{p_1}{c} \\
e_2 &= u - \frac{p_2}{c} \\
x_2 &= e_2.
\end{aligned}
$$

Furthermore, since we assume the aggregate bank at the end of period 2 to be zero it holds in both scenarios that

[6] see appendix A.1 for a more detailed description.

$$x_2 = u - \frac{p_2}{c} - b_0 - x_1 + e_1.$$

Based on these findings on firms' optimal behavior, we can now turn to price formation at market level.

2.3 Market Level

In the market equilibrium it needs to hold that allowances are either surrendered or banked, total emissions over both periods are equal to the sum of available allowances and the non-borrowing constraint is satisfied. Formally, this translates to the following conditions:

$$\begin{aligned}\int_{i=0}^{1} e_{t,i} \, \mathrm{d}i = \int_{i=0}^{1} b_{t-1,i} - b_{t,i} + x_{t,i} \, \mathrm{d}i \\ X_t = S_t \\ E_1 + E_2 = B_0 + S_1 + S_2 \\ E_1 \leq S_1 + B_0\end{aligned}$$

Using the information on firms' optimal behavior depending on the system's mode and inserting this into the market equilibrium conditions leads to corresponding price levels for allowances:

Lemma 2.

$$p_{1,nb} = \frac{c}{(2+r)}(2U - B_0 - S_1 - S_2)$$

$$p_{2,nb} = \frac{(1+r)c}{(2+r)}(2U - B_0 - S_1 - S_2)$$

if the system is in b-mode, and

$$\begin{aligned}p_{1,b} &= c(U - B_0 - S_1) \\ p_{2,b} &= c(U - S_2)\end{aligned}$$

if the system is in nb-mode.

Next we derive the condition to distinguish one mode from the other. Firms have an incentive to bank allowances as long as the market interest rate r is (weakly) smaller than the maximum relative increase in the effective stringency of the cap $\zeta = (A_1 - A_2)/A_1$, where A_1 are baseline emissions less the maximum number of allowances available in period 1 and $A_2 = U - S_2$ are baseline emissions less the minimum number of allowances available in period 2. In this case the transfer of an emission allowance from period 1 to period 2 yields a return that is (weakly) larger than an alternative investment. Hence, given a set of exogenous variables, we can uniquely identify whether the system is in banking or non-banking mode.
This is summarized as follows:

Lemma 3.
If $r \leq \zeta$, firms have an incentive to bank a weakly positive amount and in equilibrium allowance

prices rise at the interest rate.
If $r > \zeta$, firms have an incentive to borrow allowances but are prohibited to do so. In equilibrium, the price of allowances rises at less than the interest rate.

2.4 Technology Adoption

To investigate the effect of the MSR on the time profile of low-carbon investments, we consider two technologies that affect baseline emissions of adopting firms in one of the two periods. In concreto, a technology j reduces BAU-emissions u in period j by a fraction of $1 - \theta_j$ with $0 \leq \theta_j < 1$ and $j \in [1; 2]$. The smaller θ_j, the more effective the technology. Adoption entails costs of installation and maintenance which are known to firms and are denoted by $F_j > 0$. Firms can irreversibly invest in either one or both technologies before the start of period 1, i.e. at $t = 0$ or they can decide to not invest at all. Technology 1 represents immediate changes to production methods like fuel switching. Technology 2 represents long-term investments with extensive planning horizons and a more profound impact on production such as new plants or new power stations for the generation of heat or electricity.
Note that in principle, widespread adoption of sufficiently clean technologies could undermine the scarcity assumption of allowances. However, for technologies with strictly positive adoption costs this is ruled out under a cap-and-trade scheme in equilibrium. As soon as allowances cease to be scarce, the allowance price drops to zero. Adoption would then not be profitable and the corresponding diffusion rates cannot be an equilibrium.
When faced with the possibility to adopt a technology at the beginning of period 1, the firm decides by comparing potential cost savings, i.e. a firm will invest if the expected savings by reducing the costs of abatement are greater than the costs of the technology in question. Costs and savings will again depend on market prices. Given the above representation of technological progress the adoption decision is determined by the following condition[7]:

$$p_1(x_1 - x_{1,I}) + \frac{p_2}{1+r}(x_2 - x_{2,I}) \geq F_j$$

Using aggregate values, this translates to the general rule to invest iff in equilibrium (denoted by "*"):

$$\frac{p_t^* U(1-\theta_j)}{(1+r)^{t-1}} - F_j \geq 0 \tag{1}$$

If this holds with equality, the firm is indifferent between adopting and not adopting, i.e. technology j and the zero-option coexist in equilibrium. With this condition in mind, it is straightforward to construct threshold price levels depending on the mode of the system at which, given F_j, a firm becomes willing to adopt a technology. This mirrors the idea of a price signal 'strong enough' to incentivize low-carbon investment as aimed at by the EU.

[7] The derivation can be found in appendix A.2. Subscript I denotes values under adoption of a technology.

However, diffusion of abatement technologies reduces the scarcity of allowances which in turn reduces allowance prices (Requate & Unold, 2003). Thus diffusion shares γ_{θ_j}, with $0 \leq \gamma_{\theta_j} \leq 1$ are endogenously determined. Additionally, the threshold value between modes, ζ, is no longer exogenous because technology adoption changes the overall scarcity of allowances and thus the maximum relative stringency of the cap.

Lemma 4.
Depending on the mode of the system, we get the following diffusion shares for technology 1:

$$\gamma_{\theta_1,b} = \frac{2U - B_0 - S_1 - S_2 - \gamma_{\theta 2,b}U(1-\theta_2)}{U(1-\theta_1)} - \frac{(2+r)F_1}{cU^2(1-\theta_1)^2}$$

$$\gamma_{\theta_1,nb} = \frac{U - B_0 - S_1}{U(1-\theta_1)} - \frac{F_1}{cU^2(1-\theta_1)^2}$$

and for technology 2:

$$\gamma_{\theta_2,b} = \frac{2U - B_0 - S_1 - S_2 - \gamma_{\theta_1,b}U(1-\theta_1)}{U(1-\theta_2)} - \frac{(2+r)F_2}{cU^2(1-\theta_2)^2}$$

$$\gamma_{\theta_2,nb} = \frac{U - S_2}{U(1-\theta_2)} - \frac{(1+r)F_2}{cU^2(1-\theta_2)^2}.$$

It is apparent that the diffusion share of either technology decreases in the total cost of installation F_j. With respect to a marginal increase in the efficiency of a technology, the diffusion share first increases and then decreases again. This is driven by the endogeneity of allowance prices in a cap-and-trade scheme. For higher diffusion rates, an incremental increase in a technology's efficiency has higher leverage on allowance prices than for lower diffusion rates If firms bank allowances, the investment decisions of the two technologies are highly interrelated. By definition, firms are indifferent between abating an additional unit in either period. Since both technologies provide – from the firms' perspective – an identical service, they choose the one that has a lower per-unit price $F_j/(1-\theta_j)$. Investment in both technologies occurs if per-unit prices are identical ($F_1/(1-\theta_1) = F_2/(1-\theta_2)$). In this case firms are indifferent between the two technologies. Any combination of diffusion shares that induces total emissions equal to the cap is hence an equilibrium. Both technologies are used even if one has strictly lower per-unit costs, if once all firms have adopted the more attractive one, investment in the other technology is still profitable at least for the first firm. The less attractive technology diffuses unit either investment by a further firm becomes unprofitable or all firms use both technologies. Table 2.4 gives an overview of the set of feasible diffusion scenarios. In the absence of banking intertemporal arbitrage is restricted. Thus, ceteris paribus, firms prefer abating in period 1. The scarcer allowances in period 1 relative to period 2, the larger the incentives to invest in technology 1 relative to technology 2. This is a crucial insight for the analysis of how the MSR impacts the investment profile which is what we turn to next.

Eq.1 w.r.t. 0		technologies used in equilibrium
technology 1 (T1)	technology 2 (T2)	
$<$	$<$	T0
$<$	$=$	T0 and T2
$<$	$>$	only T2
$=$	$<$	T0 and T1
$=$	$=$	T0, T1 and T2
$=$	$>$	all T2 and some T1
$>$	$<$	only T1
$>$	$=$	all T1 and some T2
$>$	$>$	T1 and T2

Table 1: **Technology adoption in equilibrium:** Given different sets of exogenous variables, the resulting combination of signs of equation 1 for either technology (T1, T2) determines whether they are adopted in equilibrium, independent of the system's mode. T0 denotes the choice of not adopting.

3 The impact of postponing allowances

3.1 Basic functioning

In the EU ETS both 'backloading' and the MSR shift allowances intertemporally. We model the reserve by adding an exogenous shift of allowances in the form of removing $R \in [0, B_0 + S_1]$ allowances from auctions in period 1 and re-introducing them in period 2. In line with Salant (2016) we ignore the endogeneity of the amount R inherent in the MSR. This allows us to reduce complexity without losing the crucial features relevant for the impact of postponing the issue date of allowances on investment profiles in a deterministic setting. As shown by Perino & Willner (2016) and Salant (2016), the introduction of a cap-neutral reserve mechanism into a cap-and-trade scheme where firms currently bank either has no effect (if the system remains in the banking mode) or it induces banking to cease, i.e. leads to a reduction of the threshold value, i.e. $\partial\zeta/\partial R < 0$. In the latter case, prices increase in period 1 and drop in period 2.

Consequently, if firms still choose to bank allowances after the introduction of the MSR, their incentives to invest are not affected. We thus concentrate our analysis on a system that is in banking mode in the absence of an intervention but shifts to the no-banking mode after the intervention. The size of the reserve's intervention necessary to push the system to nb-mode, i.e. the critical reserve size, is given by:

$$R^* = \frac{(1+r)}{(2+r)}(B_0 + S_1) - \frac{rU + S_2}{(2+r)}.$$

Hence, for all $R > R^*$, the system switches from banking to no-banking mode, which is a necessary condition for the MSR to have an effect on equilibrium prices and investment profiles.

3.2 Investment Decisions and the MSR

Having described the impact of the reserve mechanism in our model, we now take a look at the interplay with the decision to adopt a low-carbon technology as laid out in subsection 2.4. In the no-banking mode the diffusion rates now also depend on R.

Taking a system in banking mode as starting point, a unique continuum of triplets of R and γ_{θ_j} describes the threshold between both modes. We rephrase this to a function of R in relation to the diffusion shares.

Critical reserve size for transition between b- and nb-mode:

$$R^*(\gamma_{\theta_1,b}, \gamma_{\theta_2,b}) = \frac{1+r}{2+r}[U\gamma_{\theta_1,b}(1-\theta_1) + B_0 + S_1] - \frac{U\gamma_{\theta_2,b}(1-\theta_2) + S_2 + rU}{2+r}$$

Observe that at the point of transition from one mode to the other, prices are continuous. Consequently so are diffusion shares:

$$\gamma_{\theta_{j,b}} = \gamma_{\theta_{j,nb}} \quad \text{at} \quad \zeta_R = r$$

As long as the system is in banking mode, diffusion is not influenced by the reserve mechanism as it doesn't affect prices. Once across the threshold however, the diffusion shares react to R.

$$\begin{aligned}
\gamma_{\theta_1,nb}(R) &= \frac{U - B_0 - S_1 + R}{U(1-\theta_1)} - \frac{F_1}{cU^2(1-\theta_1)^2} \\
\gamma_{\theta_2,nb}(R) &= \frac{U - S_2 - R}{U(1-\theta_2)} - \frac{(1+r)F_2}{cU^2(1-\theta_2)^2} \\
&\text{with}\, \theta_j \in [0,1].
\end{aligned}$$

It is straightforward to see that in the no-banking case, the diffusion share of technology 1 is strictly increasing and that of technology 2 strictly decreasing in R if the respective diffusion shares are an interior solution. Backloading or the introduction of the MSR thus either has no impact on diffusions shares or it makes short-term investments more and/or long-term investments less attractive. In other words, the profile of low-carbon investments moves – at least in a relative sense - towards a more short-term profile if it has any effect at all.

Figure 3.2 illustrates a scenario where the system starts out with an initial bank, i.e. it is in banking mode with $R < R^*$ and where technology 2 would be adopted with $0 < \gamma_{\theta_2,b} < 1$ and technology 1 would not be profitable in equilibrium, $\gamma_{\theta_1,b} = 0$.

We choose this scenario as it best illustrates the effects of R on both technologies.[8] If technology 2 is not adopted initially, this would not change by postponing the issue date of allowances. As long as the reserve does not increase stringency in period 1 sufficiently such that banking ceases and intertemporal arbitrage breaks down, it does not affect diffusion shares. However, if a sufficiently large number of allowances is shifted from period 1 to period 2 by the reserve,

8 Recall that the case where both technologies are used in the banking mode requires a knife-edge condition and implies that diffusion rates are not uniquely defined.

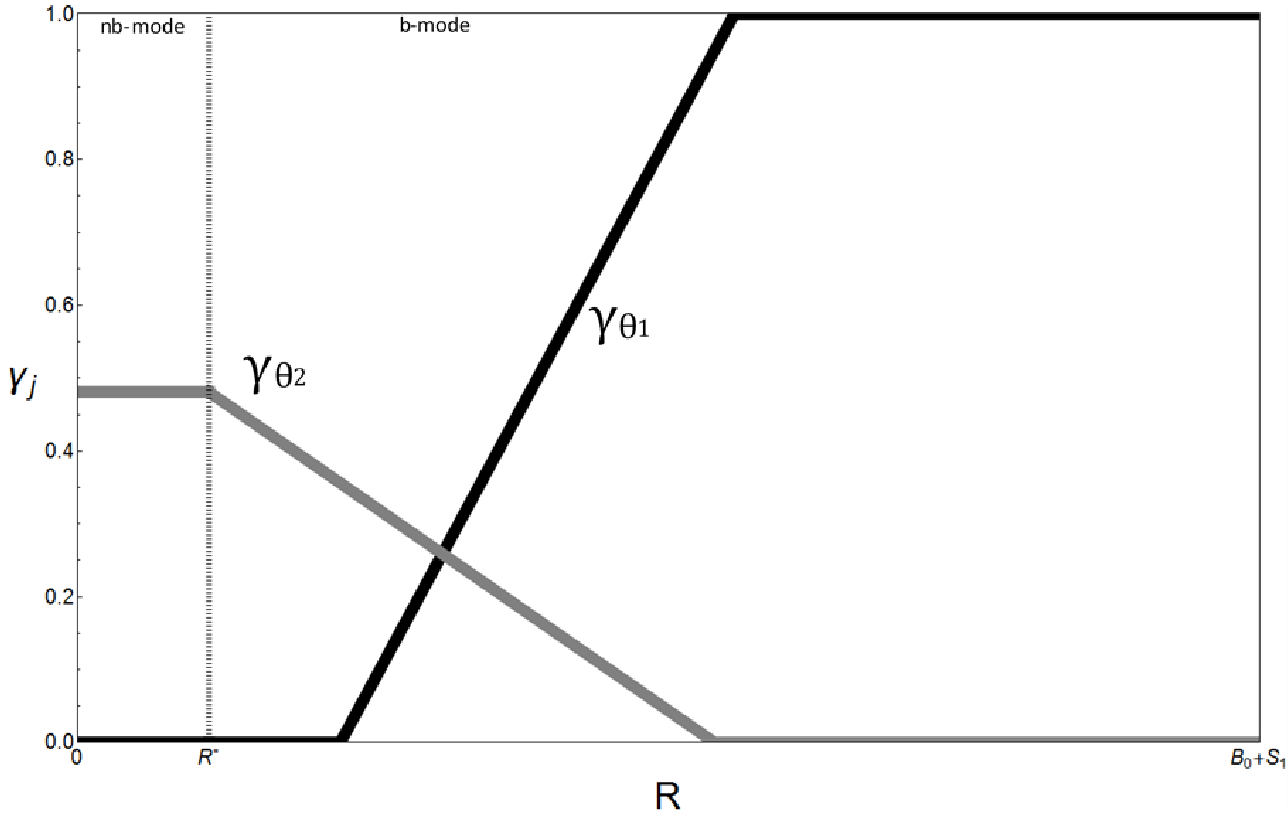

Figure 1: **Diffusion Shares vs. Reserve Size**: The graph illustrates diffusion shares for technologies 1 (black line, γ_{θ_1}) and 2 (grey line, γ_{θ_2}) depending on R in a system starting out with an initial surplus, i.e. in b-mode. The dotted vertical line marks the critical reserve size $R*$ where the system switches to nb-mode. Parameters chosen for this scenario: $U = 100$; $S_1 = 70$; $S_2 = 20$; $B_0 = 10$; $c = 1$; $r = 0.05$; $F_1 = 1200$; $F_2 = 2400$; $\theta_1 = 0.7$; $\theta_2 = 0.2$.

the link between price levels and investment incentives between the two periods breaks down. Beyond this threshold, a further increase in the size of the reserve reduces the diffusion share of technology 2 and (weakly) increases the adoption rate of technology 1. The intuition is as follows: With the breakdown of intertemporal arbitrage, firms are no longer indifferent between abating an additional ton of carbon in period 1 or 2. The increase (decrease) in stringency in period 1 (2) makes abatement in period 1 (2) more (less) attractive compared to a situation without the reserve.

Hence, given firms are forward looking and fully informed about the functioning of the reserve and anticipate the corresponding price dynamics, the introduction of a cap-neutral reserve mechanism of sufficient stringency promotes immediate investment into readily available technologies through a stronger price signal in period 1. However, technologies that need longer planning and construction times and are only operational in period 2 such as new power stations, new production sites or long R&D-processes are adversely affected due to comparably lower prices in period 2.

4 Recent reform proposals

In 2017, the Commission, the Parliament and the Council of the EU started working on reforms for Phase IV of the EU ETS. Discussed were a further increase of the LRF, an increased intake rate of allowances into the reserve and a cancellation of different quantities of allowances. For a detailed analysis of the different proposals' impacts on price paths and emission developments, we refer to Perino & Willner (2017). In the two period model at hand, reducing the cap either by an increased LRF or by cancelling stored allowances increases scarcity. Consequently, we cover both actions by assuming partial or full cancellation of allowances absorbed by the reserve, i.e. we consider a decrease of R in period 2. If the scheme is in banking mode, increasing scarcity by cancellation increases prices in both periods. If the scheme starts out in a situation where the reserve mechanism induces firms to prefer borrowing of allowances from period 2, a marginal increase in the number of cancellations increases both prices in period 2 as well as the diffusion share of technology 2 and makes borrowing less attractive. The cancellation of allowances from the reserve might push the scheme from the non-banking to the banking mode. In consequence, while introducing a reserve mechanism into a cap-and-trade scheme with banking makes banking less attractive, cancelling allowances from the reserve dampens and potentially reverses this effect. The combination of both interventions might hence be equivalent to a simple reduction in the overall cap. In this case the first intervention, the reserve mechanism, is a redundant burden adding unnecessary complexity to the existing trading scheme.

5 Discussion

In the model presented above, investment decisions are (at least in a second-best sense) socially optimal if firms bank allowances, given the long-run cap on emissions and assuming there are no further market failures and that the firms' discount rate equals the social discount rate. The MSR, by postponing the issue date of allowances and hence potentially restricting intertemporal optimization by firms, affects the time-profile of investment decisions. Short-term investments become more attractive while long-term ones are deterred. Given that the European Union controls both the long-run cap and devised the MSR, it seems prudent to assume that the perceived investment inefficiency without the MSR is not caused by the long-run cap being off target. However, concerns about short-sighted or myopic behavior by polluting firms have been raised (Holt & Shobe, 2016; Fuss et al., 2017). So one rationale for introducing the MSR might be a deviation between the social discount rate and the one driving firms' investment choices. If firms were short-sighted (but dynamically consistent), then their discount rate is higher than society's and an intervention aiming to correct this would need to induce a time profile of investments that is in line with a smaller discount rate than is observed in the banking case in the above model. As we have shown, the MSR does exactly the opposite. The time-profile of investments induced by the MSR is more in line with one where firms have a higher discount rate, i.e. are more short-sighted, than in the absence of the MSR. Hence, at least to the extent that our model captures a relevant aspect of the time-profile of low-carbon investments by firms subject to the EU ETS, the MSR is counterproductive in achieving a key objective it has been devised for.

The MSR could help induce long-term low-carbon investments if firms' deviation from intertemporal optimization is more complex than can be captured by a higher discount rate. This requires firms to be dynamically inconsistent which happens, if for example they build their expectations over prices in period 2 based on prices in period 1, instead of on the mechanics of the regulatory framework and rational firm behavior. Simple rules of thumb have been shown to well explain price expectations in other context such as inflation (Roberts, 1997; Lines & Westerhoff, 2010) or asset price forecasting (Hommes et al., 2004). Hence, if price expectations for period 2 are an increasing function of prices in period 1 – a heuristic that typically works in intertemporal markets – then the MSR might induce additional long-term investments in low-carbon technology. However, this is driven by a systematic upward bias in the expectations of allowance prices in period 2. Once period 2 is reached, firms realize that they invested more than they would have if they were able to correctly predict allowance prices in period 2 at the time of investment. While there is a negative feedback between expectations and future prices, the time lag is too long (up to several decades) and a singular event and therefore does not allow for learning.[9]

The formation of price expectations by firms in the EU ETS is a crucial aspect of predicting the effect of the MSR on investment patterns. Our current paper assumes that firms are rational or at least understand that the MSR reverses the typically positive link between current and future allowance prices. In order for the MSR to create the desired effect on investments it is not sufficient to constitute that firms are more short-sighted than the regulator. The MSR can only induce more long-term low-carbon investments if firms are not only short-sighted but also dynamically inconsistent, e.g. by using heuristics that assume that future prices are an increasing function of current prices. A feature that typically holds in intertemporal allowance markets but is turned on its head by the very nature of the MSR (Perino & Willner, 2016). Hence, the 'trick' the MSR is supposed to perform fails if firms understand what it is doing.

[9] Empirical evidence suggests that real expectations match those of rational agents well, if there is a negative feedback between average expectations and prices (Heemeijer et al., 2009).

A Appendix

A.1 Optimization Problem

Rephrasing the problem into a maximization problem, the accompagnying Lagrangian reads:

$$
\begin{aligned}
\mathcal{L}(e_1, e_2, x_1) = & -\frac{c}{2}(u - e_1)^2 - p_1 x_1 - \frac{c}{2(1+r)}(u - e_2)^2 - \frac{p_2 x_2}{1+r} \\
& - \lambda_{e_1,u}(e_1 - u) - \lambda_{e_2,u}(e_2 - u) \\
& + \lambda_{x_{11}}(x_1 - e_1 + b_0) - \lambda_{x_{12}}(x_1 - S_1 - B_0 + b_0) \\
& + \mu_1 e_1 + \mu_2 e_2,
\end{aligned} \tag{2}
$$

where λ_k are the shadow prices of the constraints on purchases or sales in period 1, x_1 and the non-negativity constraints on emissions and abatement in both periods.

A.2 Investment Incentives

From appendix A.1, we can elicit the first order conditions of the maximization problem. Equilibrium values are denoted by a star of with $e_t^* = u - p_t/c$ and are independent of the system's mode. With this in mind, we can then insert this into the cost function and receive the minimal cost. Now, we can find the difference between adoption and no adoption for each technology, i.e. $C(e_t^*, x_t) - C(e_{t,I}^*, x_{t,I})$. A firm will only invest in a technology iff this difference is greater zero. Hence:

$$
\begin{aligned}
& \frac{c}{2}(u - e_1^*)^2 + p_1 x_1 + \frac{c}{2(1+r)}(u - e_2^*)^2 + \frac{p_2 x_2}{1+r} \\
& - \frac{c}{2}(u - e_{1,I}^*)^2 + p_1 x_{1,I} + \frac{c}{2(1+r)}(u - e_{2,I}^*)^2 + \frac{p_2 x_{2,I}}{1+r} - F_j > 0
\end{aligned}
$$

Substituting in e_t^* and $e_{t,I}^*$ leads to the cancellation of the abatement cost parts of the inequality, leaving::

$$
p_1(x_1 - x_{1,I}) + \frac{p_2}{1+r}(x_2 - x_{2,I}) > F_j.
$$

If prices rise at the interest rate, firms bank allowances. If prices rise at a rate less than the interest rate, firms would like to borrow allowances which is prohibited by assumption. In the banking scenario, we can replace p_2 by $(1 + r)p_1$. Additionally, it must hold that $x_1 + x_2 = e_1^* + e_2^* - b_0$. Using this, the inequality above simplifies to $p_1 u(1 - \theta_j) > F_j$. In the latter scenario, we can determine purchases and sales for each period separately, i.e. $x_1 = e_1^* - b_0$ and $x_2 = e_2^*$. Plugging this into the inequality above yields $p_1 u(1 - \theta_1) > F_1$ for technology 1 and $[p_2 u(1 - \theta_2)]/(1 + r) > F_2$ for technology 2. Thus, using aggregate values, we can state that a technology is adopted by a firm iff

$$
\frac{p_t U}{(1+r)^{t-1}}(1 - \theta_j) > F_j.
$$

References

Böhringer, C., Löschel, A., Moslener, U., & Rutherford, T. E. (2009). EU climate policy up to 2020: An economic impact assessment. *Energy Economics*, 31, 295–305.

Clò, S., Battles, S., & Zoppoli, P. (2013). Policy options to improve the effectiveness of the EU emissions trading system: A multi-criteria analysis. *Energy Policy*, 57, 477–490.

Cronshaw, M. B. & Kruse, J. B. (1996). Regulated firms in pollution permit markets with banking. *Journal of Regulatory Economics*, 9(2), 179–189.

European Commission (2014a). *COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT Accompanying the document Proposal for a Decision of the European Parliament and of the Council concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC*. Technical report, European Commission.

European Commission (2014b). *Q&A on ETS market stability reserve*. Technical Report MEMO/14/39, European Commission.

European Commission (2015). European Parliament and of the Council of 6 October 2015 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC. *Decision (EU) 2015/1814*.

European Commission (2017). *Public of the total number of allowances in circulation for the purposes of the Market Stability Reserve under the EU Emissions Trading System established by Directive 2003/87/EC*. Technical Report C(2017) 3228 final, European Commission.

European Parliament (2014). *Briefing: Reform of the EU carbon market: From backloading to the market stability reserve*. Technical report, European Union, Brussels.

European Union (last checked 9/5/2017). Market stability reserve. `https://ec.europa.eu/clima/policies/ets/reform_en`.

Fuss, S., Flachsland, C., Koch, N., Kornek, U., Knopf, B., & Edenhofer, O. (2017). An assessment framework for intertemporal economics performance of cap-and-trade systems: lessons from the EU-ETS. *Review of Environmental Economics and Policy*, forthcoming.

Heemeijer, P., Hommes, C., Sonnemans, J., & Tuinstra, J. (2009). Price stability and volatility in markets with positive and negative expectations feedback: An experimental investigation. *Journal of Economic Dynamics and Control*, 33(5), 1052–1072.

Hintermann, B., Peterson, S., & Rickels, W. (2015). Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature. *Review of Environmental Economics and Policy*, 10(1), 108–128.

Holt, C. A. & Shobe, W. M. (2016). Price and quantity collars for stabilizing emission allowance prices: Laboratory experiments on the EU ETS market stability reserve. *Journal of Environmental Economics and Management*, 76, 32–50.

Hommes, C., Sonnemans, J., Tuinstra, J., & Van de Velden, H. (2004). Coordination of expectations in asset pricing experiments. *The Review of Financial Studies*, 18(3), 955–980.

Jarke, J. & Perino, G. (2017). Do renewable energy policies reduce carbon emissions? On caps and inter-industry leakage. *Journal of Environmental Economics and Management*, 84, 102–124.

Koch, N., Fuss, S., Grosjean, G., & Edenhofer, O. (2014). Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything? New evidence. *Energy Policy*, 73, 676–685.

Koch, N., Grosjean, G., Fuss, S., & Edenhofer, O. (2016). Politics matters: Regulatory events as catalysts for price formation under cap-and-trade. *Journal of Environmental Economics and Management*, 78, 121–139.

Krysiak, F. C. (2008). Prices vs. quantities: The effects on technology choice. *Journal of Public Economics*, 92(5), 1275–1287.

Krysiak, F. C. (2011). Environmental regulation, technological diversity, and the dynamics of technological change. *Journal of Economic Dynamics and Control*, 35(4), 528–544.

Lechthaler-Felber, G. & Krysiak, F. C. (2017). Quota Market and Technological Change. *Journal of the Association of Environmental and Resource Economists*, 4(4), 1199–1228.

Lines, M. & Westerhoff, F. (2010). Inflation expectations and macroeconomic dynamics: the case of rational versus extrapolative expectations. *Journal of Economic Dynamics and Control*, 34(2), 246–257.

Milliman, S. R. & Prince, R. (1989). Firm incentives to promote technological change in pollution control. *Journal of Environmental Economics and Management*, 17, 247–265.

Neuhoff, K., Schopp, A., Boyd, R., Stelmakh, K., & Vasa, A. (2012). Banking of surplus emissions allowances: Does the volume matter? *DIW Berlin Discussion Paper*, 1196.

Nordhaus, W. (2011). Designing a friendly space for technological change to slow global warming. *Energy Economics*, 33(4), 665 – 673. Special Issue on The Economics of Technologies to Combat Global Warming.

Perino, G. & Requate, T. (2012). Does more stringent environmental regulation induce or reduce technology adoption?: When the rate of technology adoption is inverted U-shaped. *Journal of Environmental Economics and Management*, 64(3), 456–467.

Perino, G. & Willner, M. (2016). Procrastinating reform: The impact of the market stability reserve on the EU ETS. *Journal of Environmental Economics and Management*, 80, 37–52.

Perino, G. & Willner, M. (2017). EU-ETS Phase IV: allowance prices, design choices and the market stability reserve. *Climate Policy*, 17/7, 1–11.

Requate, T. & Unold, W. (2003). Environmental policy incentives to adopt advanced abatement technology: Will the true ranking please stand up? *European Economic Review*, 47, 125–146.

Richstein, J. C., Chappin, É. J., & de Vries, L. J. (2015). The market (in-) stability reserve for EU carbon emission trading: Why it might fail and how to improve it. *Utilities Policy*, 35, 1–18.

Roberts, J. M. (1997). Is inflation sticky? *Journal of Monetary Economics*, 39(2), 173–196.

Rubin, J. D. (1996). A model of intertemporal emission trading, banking, and borrowing. *Journal of Environmental Economics and Management*, 31(3), 269–286.

Salant, S. W. (2016). What ails the European Union's Emissions Trading System? *Journal of Environmental Economics and Management*, 80, 6–19.

Schennach, S. M. (2000). The Economics of Pollution Permit Banking in the Context of Title IV of the 1990 Clean Air Act Amendments. *Journal of Environmental Economics and Management*, 40(3), 189–210.

van den Bijgaart, I., Gerlagh, R., & Liski, M. (2016). A simple formula for the social cost of carbon. *Journal of Environmental Economics and Management*, 77, 75–94.