The unintended consequences of the EU ETS cancellation policy

Bruninx, Kenneth and Ovaere, Marten and Gillingham, Kenneth and Delarue, Erik

9 October 2019

The unintended consequences of the EU ETS cancellation policy

Kenneth Bruninx[1,2,3], Marten Ovaere[4], Kenneth Gillingham[4], and Erik Delarue[1,3]

[1]Division of Applied Mechanics & Energy Conversion, Mechanical Engineering, KU Leuven
[2]VITO, The Flemish Institute for Technological Research
[3]EnergyVille
[4]School of Forestry & Environmental Studies, Yale University

October 9, 2019

With the Phase 4 cancellation provision, the cumulative emissions cap of the EU ETS has become dependent on the amount of surplus allowances and future emissions abatement costs. In this paper, we discuss how the design of the market stability reserve greatly increases uncertainty over cumulative emissions and implies that there will be more cancellation when future abatement is more costly, making the policy more stringent when the cost of compliance is higher. Moreover, we illustrate how overlapping policies may lead to paradoxical effects on cumulative emissions.

Key policy insights:

- **The cancellation policy of the market stability reserve may puncture the waterbed of the European Emission Trading System for decades, which results in significant uncertainty on the cumulative emissions.**
- **A counter-intuitive, self-reinforcing relation between the future cost of abatement and the cancellation volume makes this policy more stringent when it is more costly to meet.**
- **Depending on how overlapping policies affect the waterbed puncture and future abatement costs, they may trigger paradoxical cumulative emission reductions or increases.**

Keywords: European Emission Trading System, Market Stability Reserve, Cancellation, Waterbed, Marginal Abatement Cost

To bring its greenhouse gas emission abatement targets in line with the Paris Agreement, the EU strengthened the European Union Emissions Trading System (EU ETS) by adding a cancellation policy to its market stability reserve (MSR) (European Union, 2018). If the number of allowances in circulation surpasses a fixed threshold, the MSR absorbs a share of the allowances to be auctioned, so that they can be released again from the reserve in the future. Starting in 2023, however, a cancellation policy will be in effect, such that allowances held in the MSR exceeding the amount auctioned during the previous year will be canceled (European Union, 2018). In this comment, we shed light on two important unintended consequences of the cancellation policy: the high uncertainty on the effective cumulative emissions cap and the counterintuitive relation between the future cost of abatement and cancellation volumes.

Without the cancellation policy, individual actions to reduce emissions only affect who emits and at what price, but not what ultimately matters, which is how much is emitted in total under the fixed cap – the so-called waterbed effect (described using the analogy of a waterbed because you can push down on a waterbed in any location, but the total volume of water in the bed remains the same). However, with a cancellation policy in effect, actions to reduce emissions, such as other overlapping policies (Bertram et al., 2015; Perino, 2018; Perino et al., 2019; Rosendahl, 2019b) or strategies to buy, bank, and burn allowances (Gerlagh and Heijmans, 2019), may result in changes to cumulative emissions – puncturing the waterbed.

Perino (2018) correctly points out that the effect of additional actions to reduce emissions on the effective emissions cap depends on past and future emissions, which determine how long the waterbed will be punctured. In this contribution, however, we show that there is a more general phenomenon going on as well: the surplus of allowances, and thus the degree of cancellation and duration of the waterbed puncture, depends on the market's expectation of future emissions abatement costs. For example, if firms expect higher abatement costs in the future, they would likely choose to abate more today and bank the surplus allowances for future use. But because of the cancellation policy, if more allowances are banked today, more will be cancelled, and the cumulative emissions reductions would be greater. In contrast, if firms expect future abatement costs to be low, e.g., because of technological learning (Creutzig et al., 2017), they would likely choose to postpone abatement and bank fewer allowances. With fewer banked allowances, fewer would be cancelled, and cumulative emissions reductions would be lower (Rosendahl, 2019b).

Thus, the cumulative emissions under the EU ETS with a cancellation policy will depend in an important way on market's expectations about future emissions abatement costs. This insight can have considerable ramifications for the effects of the EU ETS cancellation policy, especially because future marginal abatement costs are highly uncertain (Borenstein et al., 2019). To explore this, we perform a set of simulations to more profoundly expose how uncertainty about future marginal abatement costs can affect the overall stringency of the EU ETS with the current cancellation policy.

Ramifications of Abatement Cost Uncertainty

We examine uncertainty over the marginal abatement costs (MAC) under the EU ETS over time by varying the annual growth rate of baseline emissions, the slope capturing how marginal abatement costs rise with increased emissions reductions and the curvature of the MAC curve. We solve our EU ETS model, which assumes current policies remain in place until the end of our horizon, leveraging an iterative price-search algorithm (Bruninx et al., 2019). In each simulation, we impose recorded emission levels in 2017-2018 and calibrate the slope of the MAC curve such that the emission allowance price in 2018 equals the average price observed after the adoption of the strengthened MSR (20.7 €/tCO_2). For more information on the methodology, we refer the reader to the Appendix.

Figure 1 summarizes the results of our analysis. The left-hand panel shows that, in our simulations, cumulative emissions in the period 2017-2062 could be as high as 41.4 GtCO_2 or as low as 28.0 GtCO_2, depending on ratio between the MAC today (approximated as the MAC in 2018, calculated at recorded emission levels) and in the future (approximated as the MAC in 2050, calculated at expected emission levels). These simulation results show that for every tenfold increase in the ratio of today's and future MAC, cumulative emissions decrease by 4.9 GtCO_2 and prolong the puncture in the waterbed by 12 years. The relative difference between today's and future MAC increases with the curvature of the MAC curve, increasing baseline emissions and lower technological learning rates.

These trends are confirmed in both a simple analytical two-period model of emissions abatement and banking with cancellation (see Appendix) and a detailed modeling exercise of the European-wide long-term abatement cost function (Bruninx et al., 2019). For a more extensive discussion of the methodology and discussion of the results, we refer the reader to the Appendix.

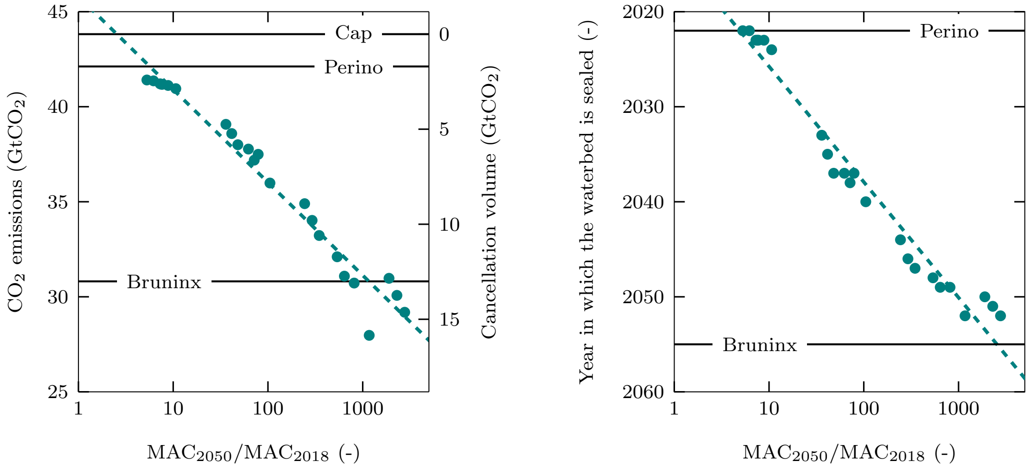

Figure 1. Cumulative CO_2 emissions, cancellation volumes and year in which the water bed is sealed as a function of the ratio between future and present marginal abatement costs (MAC) for a wide range of parameter settings of the MAC curve. The dots correspond to simulation results, whereas the dashed lines visualize a fitted trend line. Future marginal abatement costs are approximated as the marginal abatement cost in 2050 given emission levels in that year. The MAC in 2018 is calculated at historical emission levels. Additional anchor points include the estimates by Perino and Willner (2017) and Bruninx et al. (2019) and the cumulative emissions cap over the period 2017-2060.

Implications for Policy

Our results illustrate two key points that have not been fully recognized in the academic literature nor the policy debate. First, because the markets' perception of present and future costs of abatement constantly changes, the allowance cancellation rules generate substantial uncertainty in the cumulative emissions reductions from the EU ETS. In our simulations, allowance cancellation ranges from 2 to 16 $GtCO_2$, and the waterbed may be punctured (allowing for additional emissions reductions) anywhere from 3 to 33 years. We posit that this combined uncertainty in what the cumulative cap actually will be and the future marginal abatement costs may generate further allowance price volatility.

Second, our simulations reveal that the cancellation rules imply that there will be more cancellation of allowances when the market expects future abatement costs to be higher (e.g., due to growth of baseline emissions, low rate of technological learning or higher curvature and slope of the MAC curve). This implies that there now is a built-in mechanism in EU ETS that has the perverse incentive that when it is more expensive to abate, the policy is more stringent. This unintended self-reinforcing effect would serve to increase the costs of the policy, and possibly increase allowance prices above values that are justifiable. Interestingly, the same reinforcing effect exists between the emissions cap trajectory and cancellation. We find that cumulative emissions decrease more than proportionally when the rate at which the annual emissions cap decreases (i.e., the linear reduction factor), increases, because a faster decreasing emissions cap increases the future cost of abatement.

Interaction with Overlapping Policies

The described reinforcing effect of the cancellation policy also has important consequences for overlapping policies (Perino, 2018; Perino et al., 2019; Rosendahl, 2019b), such as energy efficiency measures, additional national carbon taxes, or targets and support for renewable energy sources. By changing the future cost of abatement and the duration of the waterbed puncture, these policies themselves may counter-intuitively affect the cancellation volumes. To illustrate this interaction, we simulate the effectiveness of overlapping policies that reduce or increase CO_2 emissions or the supply of allowances by 1, 10 or 100 $MtCO_2$ in 2019, 2050 or in every year of the studied period (2019-2060). The slope and curvature of the MAC curve is unaffected by the overlapping policy. Baseline emission growth or technological learning is not considered in these simulations.

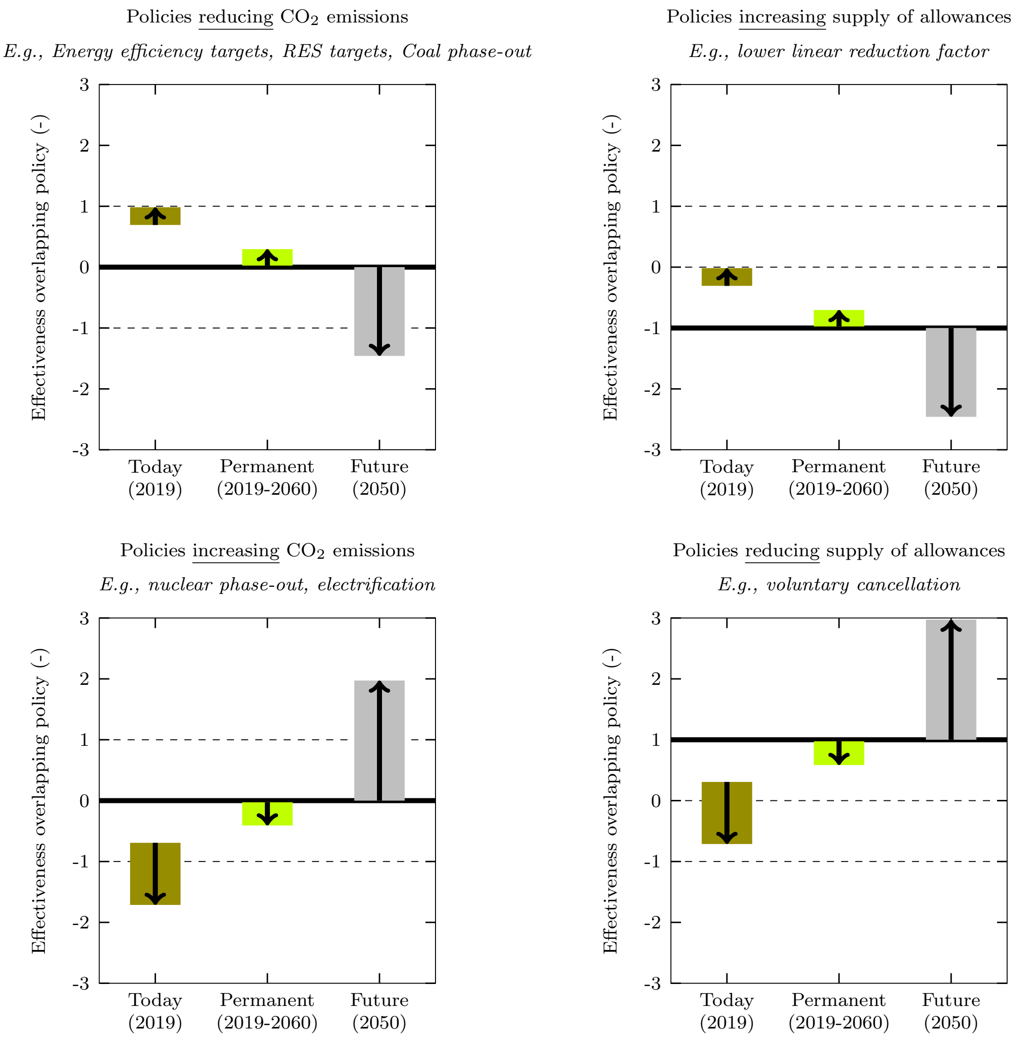

Figure 2. The impact of various overlapping policies that reduce or increase emissions or the supply of allowances by 1, 10 or 100 $MtCO_2$ in 2019, 2050 or the period 2019-2060. The effectiveness of the overlapping policy is defined as the effective cumulative emission reduction relative to the emissions targeted by the policy directly. As a reference, the impact of these policies in absence of the MSR are indicated by the solid, black lines. The arrows indicate how the effectiveness changes with an increasing ratio of future and current marginal abatement costs.

Figure 2 summarizes the results of our numerical analysis. Although the ratio of future and current MAC remains the most important determinant of the cumulative emissions and the year in which the waterbed puncture is sealed, we here focus on the effectiveness of the overlapping policies. The effectiveness is defined as the effective cumulative emission reduction relative to the volume of emissions targeted by the policy directly. Consequently, a policy that reduces emissions by 1 $MtCO_2$ should ideally have an effectiveness of 1, whereas a policy that increases the supply of allowances by 1 $MtCO_2$ should have an effectiveness of -1. Note that all results can be checked analytically changing $\overline{E}_1$, $\overline{E}_2$, $\overline{q}_1$ and $\overline{q}_2$ in Equation (13).

The upper-left panel shows the effect of reducing EU ETS CO_2 emissions, e.g., triggered by energy efficiency investments, targets on renewable electricity generation, a coal phase-out or support for renewables. When we assume that policies reducing CO_2 emissions today have no effect on the duration of the waterbed puncture, their effectiveness will always be below one, because every year only 24% (before 2023) or 12% (after 2023) of the additional surplus is absorbed and cancelled (Perino, 2018). The longer the duration of the puncture, the closer the effectiveness will be to one.[1] On the contrary, when CO_2 reductions are announced now but only come into effect after the waterbed is sealed again, they will have a negative effect on total emissions. As pointed out by Rosendahl (2019b), future CO_2

[1]In theory, the reduction of CO_2 emissions today may prolong the duration of the punctured waterbed, which would result in the effectiveness of CO_2-reducing policies today to exceed one. However, the odds of this happening are low because only a small fraction of additional surplus is still available when the puncture would be sealed again.

emission reductions will lower the future price of allowances, decreasing surplus before the waterbed is sealed by making banking less profitable and, hence, reduce cancellation volumes. Similarly, when this decreases the duration of the puncture, the effectiveness will be below minus one. When the abatement effort is permanent, the net effect on cumulative emissions is low but positive.[2] Permanent abatement efforts may affect the duration of the waterbed puncture, but this does not increase the effectiveness of the policy above one in any of our simulations.

The bottom-left panel shows the effect of increasing EU ETS CO_2 emissions, e.g. because of a nuclear phase-out, a tax on non-ETS emissions or the electrification of transportation or heating. Similar effects occur, but the relation between the timing of the abatement efforts and the effectiveness is inverted. Cumulative emissions increase (negative effectiveness) when emissions increase now, while they decrease (positive effectiveness) when emissions are announced to increase in the future. Increasing CO_2 emissions today may seal the waterbed sooner, which results in an effectiveness below minus one.[3] Permanent increases in emissions, triggered by, e.g., electrification or a nuclear phase-out, result in small, negative effectiveness values. On the contrary, increases in emissions in the far future announced today increase the cost of meeting the cap, hence, provide incentives to bank allowances, which increases cancellation volumes. As a result, announced increases in future baseline emissions never trigger increase in cumulative emissions – such actions may even prolong the duration of the waterbed puncture, hence, reach an effectiveness exceeding one.

In each case, a higher ratio of the future and current marginal abatement costs reinforces the positive or negative effect of a policy (arrows in Fig. 2). Indeed, the effects described above are relevant during the period that the waterbed is punctured, which increases with this cost ratio (Fig. 1). Larger changes in baseline emissions or the supply of allowances are more likely to change the duration of the waterbed puncture, which reinforces the effect described above.

The panels on the right show the effectiveness of policies that change the supply of allowances, e.g., because of voluntary cancellations or changes to the EU ETS emissions profile (Gerlagh and Heijmans, 2019). The effectiveness of such policies $\epsilon(\cdot)$ is very similar to that of policies acting on baseline emissions and can be related as:

$$\epsilon(\text{reducing supply}) \approx \epsilon(\text{increasing emissions}) + 1$$
$$\epsilon(\text{increasing supply}) \approx \epsilon(\text{reducing emissions}) - 1$$

The impact of increasing or decreasing the surplus today or in the future on the MSR's actions does not depend on whether it is caused by changing emissions or the supply of allowances. However, policies increasing or decreasing supply will increase or decrease cumulative emissions by the amount specified by the policy, on top of which one needs to account for the effects described above.

Mitigating the unintended consequences

There are several possibilities to ameliorate these outcomes. Most simply, the cancellation policy could be removed and the EU ETS could be tightened rather than have countries implement overlapping policies. For example, a one-time, lump-sum cancellation policy could be used to remove the current surplus of allowances and decrease emissions by the same amount. Alternatively, further increasing the rate at which the annual emissions cap decreases would bring the cap in line with emissions. Another proposal that could help would be a price-based MSR (Borenstein et al., 2019), which would avoid emission allowance price volatility.

[2]Rosendahl (2019a) reports a negative effectiveness for permanent abatement efforts – a finding we were unable to reproduce in this study.

[3]Compared to the effect described in footnote 1, it is more likely that the waterbed is sealed sooner when CO_2 emissions would increase today, especially when the puncture would be sealed shortly after 2023.

Funding details

The work of K. Bruninx was supported by the Research Foundation - Flanders (FWO) and the Flemish Institute for Technological Research (VITO).

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Bertram, C., Luderer, G., Pietzcker, R. C., Schmid, E., Kriegler, E., Edenhofer, O., 2015. Complementing carbon prices with technology policies to keep climate targets within reach. Nature Climate Change 5 (3), 235–239.

Borenstein, S., Bushnell, J., Wolak, F. A., Zaragoza-Watkins, M., 2019. Expecting the Unexpected : Emissions Uncertainty and Environmental Market Design. American Economic Review (Forthcoming).

Bruninx, K., Ovaere, M., Delarue, E., 2019. The long-term impact of the market stability reserve on the eu emission trading system. KU Leuven Energy Institute Working Paper EN2019-07.

Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., Pietzcker, R. C., 2017. The underestimated potential of solar energy to mitigate climate change. Nature Energy 2 (9), 1–9.

EEX, Last accessed: August 1, 2019. Emission Spot Primary Market Auction Report. Available online: `https://www.eex.com/en/products/environmental-markets/emissions-auctions/archive`.

European Union, 2018. Directive (EU) 2018/410 of the European Parliament and the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814. Official Journal of the European Union 76, 3–27.

Gerlagh, R., Heijmans, J., 2019. Climate-conscious consumers and the buy, bank, burn program. Nature Climate Change 9 (June), 431–433.

Perino, G., 2018. New EU ETS Phase 4 rules temporarily puncture waterbed. Nature Climate Change 8 (4), 262–264.

Perino, G., Ritz, R. A., Van Benthem, A., 2019. Understanding overlapping policies: Internal carbon leakage and the punctured waterbed. EPRG Working Paper 1910 – Cambridge Working Paper in Economics 1920.

Perino, G., Willner, M., 2017. EU-ETS Phase IV: allowance prices, design choices and the market stability reserve. Climate Policy 17 (7), 936–946.

Rosendahl, K., 2019a. Eu ets and the new green paradox. NMBU Working Papers No. 2/2019.

Rosendahl, K. E., 2019b. EU ETS and the waterbed effect. Nature Climate Change 9 (734), 734–735.

Appendix

Decision problem of a representative firm under the EU ETS & MSR

In equilibrium, the representative firm abates until its marginal abatement cost (MAC) equals the emission allowance price (Perino and Willner, 2017). Hence, given an emission allowance price path, the representative firm's emissions are know (Eq. (3)) and the firm minimizes the procurement cost of the required emission allowances to cover these emissions, assuming a discount rate r:

$$\text{Min.} \quad \sum_{t \in \mathcal{T}} \frac{p_t \cdot \tilde{q}_t}{(1+r)^t} \tag{1}$$

subject to

$$\forall t \in \mathcal{T}: \quad \sum_{t^*=1}^{t} \tilde{q}_{t^*} \geq \sum_{t^*=1}^{t} q_{t^*} \tag{2}$$

$$\forall t \in \mathcal{T}: \quad q_t = \mathcal{F}_t^{-1}(p_t) \tag{3}$$

$$\forall t \in \mathcal{T}: \quad \tilde{q}_t, q_t \geq 0 \tag{4}$$

The representative firm must buy sufficient allowances $\tilde{q}_t$ ahead of time to cover its emissions q_t (Eq. (2)). Note that Eq. (2) implies that the representative firm may bank allowances, but that borrowing is not allowed. Equation (3) relates the emissions q_t to the emission allowance price p_t via the marginal abatement cost curve (MACC) $\mathcal{F}_t(p_t)$. In this contribution, we consider the following functional form for the MACC:

$$\forall t \in \mathcal{T}: \quad p_t = \beta_t \cdot (\overline{E_t} - q_t)^\gamma \tag{5}$$

Emissions q_t are restricted to positive values and limited to 2017-levels. The functional form of the MACC is defined by baseline emissions $\overline{E_t}$, a slope β_t and a curvature γ. Higher baseline emissions increase the abatement needed to meet the emissions trajectory, while higher values of β_t and γ increase the marginal cost of abatement. If $\gamma > 1$, the MACC is convex, meaning that the cost of additional abatement increases more than proportionally.

The constraint which enforces the balance between the demand for and supply of emission allowances, and hence, links the decisions of all firms, can be expressed as follows:

$$\forall t \in \mathcal{T}: \quad \overline{q}_t - \tilde{q}_t \geq 0 \qquad (p_t) \tag{6}$$

The dual variable associated with this constraint p_t may be interpreted as the emission allowance price that ensures that the representative firm's strategy coincides with its long-run equilibrium strategy. In other words, presented with these prices, the representative firm does not have an incentive to change its strategy. Note that the supply of allowances $\overline{q}_t$ is the net supply of emission allowances, corrected for the actions of the MSR.

This model is, in fact, similar to the one employed by Perino and Willner (2017). However, our solution strategy allows, i.a., for non-linear MACCs, as discussed below.

Numerical solution strategy

To determine the equilibrium ETS price over the studied period (2018-2062) which ensures that the supply of and demand for allowances is balanced (Eq. (6)), we leverage an iterative price-search algorithm, based on ADMM, as introduced by Bruninx et al. (2019). In each iteration, the algorithm proposes a new emission allowance price p_t for each considered year, depending on the imbalance between the allowances requested by the firms $\tilde{q}_t$ and the net supply of allowances $\overline{q}_t$. Furthermore, the MSR actions are imposed in each price update step, i.e., in each iteration, the total number of allowances in circulation is calculated. This metric governs the intake and outflow of allowances in the MSR, whereas cancellation volumes are determined by the foreseen auction volumes in the preceding year. For details, see Bruninx et al. (2019).

After each update of the price and net supply of emission allowances, the representative firm re-optimizes its decisions. If the emission allowance price, MSR actions, hence, net supply of emission allowances, and the representative firm's strategy no longer change between iterations, we accept the solution as an equilibrium solution.

By adopting this solution strategy, one effectively parameterizes the decision problem of the representative firm in the emission allowance price, which in turn is a function of the net supply and MSR actions. Consequently, the emissions of the representative firm may be calculated ex-ante and the representative firm's decision problem becomes a linear programming problem, which can be solved efficiently using off-the-shelf solvers. For details on the adopted solution strategy and its convergence, the interested reader is referred to Bruninx et al. (2019).

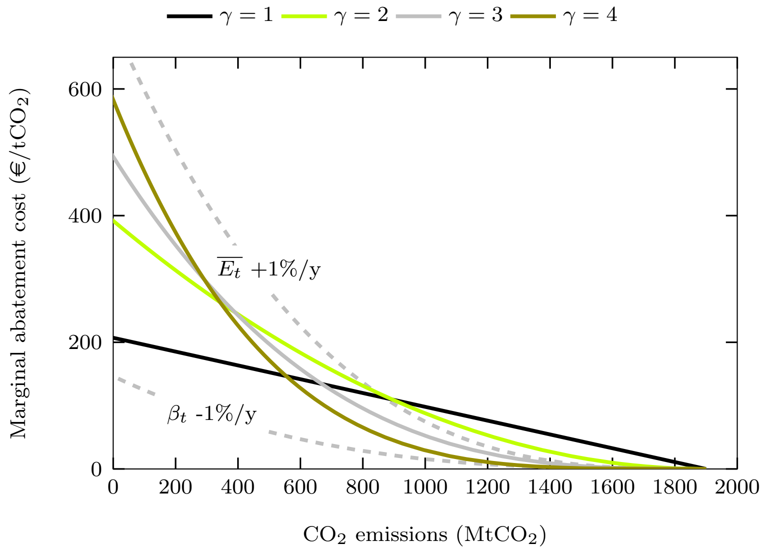

Figure 3. Marginal abatement cost curves for the year 2018 for MAC curvatures (γ) between 1 and 4. The solid lines indicate the cases without technological learning and growth of baseline emissions. The dashed lines visualize the impact of increasing baseline emissions ("$\overline{E_t}$ +1%/y", no technological learning) and technological learning ("β +1%/y", no growth in baseline emissions) for $\gamma = 3$.

Calibration of the MAC curve: assuming a wide parameter space

As the actual MAC curve is fundamentally uncertain (Borenstein et al., 2019), we vary all three parameters of Eq. (5). First, baseline emissions in 2018 ($\overline{E_{2018}}$) are equal to 1.9 $GtCO_2$, as in Perino and Willner (2017), and may grow at a predetermined, annual growth rate between 0 and 1%. Second, the curvature parameter γ is set to a discrete value between 1 and 4, indicating increasing curvature. Third, β_{2018} is calibrated in each simulation individually such that the emission allowance price in 2018 approximates 20.7 €/tCO_2, i.e., the average emission allowance price since the adoption of the market stability reserve (EEX, Last accessed: August 1, 2019). The slope parameter β_t decreases with a predetermined, annual rate between 0 and 1%, reflecting the impact of, e.g., technological learning on abatement costs. In some cases, this calibration effort results in very low MAC in 2018. Therefore, we reject all MAC curves that imply a MAC in 2018 below 0.1€/tCO_2, as they would lead to unrealistic high abatement efforts in the near future in response to the MSR reform. For each set of retained MAC parameters, we solve our EU ETS model leveraging the iterative price-search algorithm described above (Bruninx et al., 2019), assuming a real discount rate of 8%. Figure 3 represents marginal abatement cost curves for the year 2018 for MAC curvatures between 1 and 4.

Detailed simulation results: the effect of baseline emissions, technological learning, the slope and curvature of the MAC curve

Complementary to Figure 1 above, Figure 4 summarizes the same results of our analysis, but zooming in on the separate effect of the three MAC parameters (baseline emissions, slope and curvature). This figure represents cumulative emissions (left-hand panel) and the year in which the waterbed is sealed again (right-hand panel), for the different assumed values of baseline emissions, technological learning and MAC curvature. Overlapping policies are not considered.

First, the horizontal markers indicate the values without technological learning or growth of baseline emissions. The left-hand panel shows that cumulative emissions until 2062 could be as high as 41.2 $GtCO_2$ or as low as 28.0 $GtCO_2$, depending on the convexity (γ) of the MAC curve (in abscence of technological learning or baseline emission increases). If we expect high costs for higher levels of emissions abatement (higher γ), we might abate more now and bank allowances for later use, such that the increased surplus will trigger more cancellation. If we expect future abatement to be relatively cheap (lower γ), we might abate less, which decreases the surplus and cancellation. Consequently, if we expect a linear MAC curve (Perino and Willner, 2017; Perino, 2018), the right-hand panel shows that the waterbed is again sealed by 2023, while the waterbed could be punctured until 2052 when the MAC curve is highly convex.

Second, the values above the horizontal markers correspond to simulations in which technological learning reduces the cost of future abatement (the upper value is characterized by an annual learning rate of 1%). Since technological learning decreases the cost of future abatement compared to abatement today, it leads to less banking, lower cancellation and higher cumulative emissions and seals the waterbed sooner.

Third, the values below the horizontal markers indicate increasing baseline emissions (the bottom-most value is characterized by an annual growth rate of 1%). Increasing baseline emissions inflates the cost of future abatement efforts and thus triggers lower emissions today, a higher surplus and cancellation volume, thus lower cumulative emissions. Similarly, it leads to more persistent punctures.

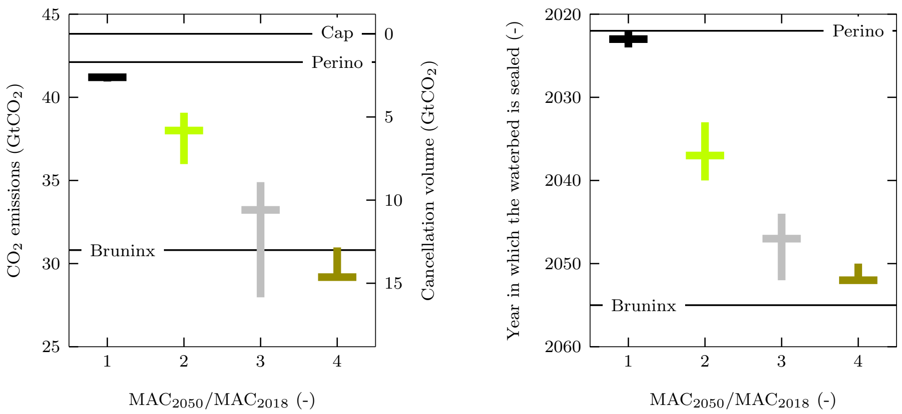

Figure 4. Cumulative CO_2 emissions, cancellation volumes and the year in which the waterbed is sealed (i.e., the year in which the TNAC drops below 833 $MtCO_2$) for γ-values between 1 and 4. The horizontal markers indicate the values without technological learning or growth of baseline emissions. The vertical bars indicate the range of possible outcomes for the parameter space described above. Technological learning leads to higher emissions, lower cancellation volumes and a TNAC that drops earlier below 833 $MtCO_2$ (values above the horizontal markers). In contrast, increasing baseline emissions lead to lower emissions, higher cancellation volumes and a TNAC that stays longer above 833 $MtCO_2$ (values below the vertical markers). Additional anchor points include the estimates for the cancellation volume and the year in which the waterbed is sealed by Perino and Willner (2017) and Bruninx et al. (2019) and the cumulative EU ETS emissions cap over the period 2017-2062.

Analytical solution of a stylized two-period model

For two-period cases, however, one may solve the model above analytically if one assumes the impact of the MSR on the net supply of emission allowances is known. Consider the following explicit reformulation, in which we introduce a new banking variable b:

Period 1:

$$\text{cap with banking} : \overline{q_1} = q_1 + b \tag{7}$$

$$\text{MACC} : p_1 = \beta_1(\overline{E}_1 - q_1)^\gamma \tag{8}$$

Period 2:

$$\text{cap with banking and cancellation} : \overline{q_2} + \alpha b = q_2 \tag{9}$$

$$\text{MACC} : p_2 = \beta_2(\overline{E}_2 - q_2)^\gamma \tag{10}$$

$$\text{price path} : p_2 = (1+r)p_1 \tag{11}$$

In the model above, p_t is allowance price in period t=1,2, q_t the quantity emitted in period t and b the number of allowances banked from period 1 to period 2, i.e., the difference between the emissions and the procured allowances. We assume that b>0, i.e. no borrowing is allowed. As above, the parameters β_t, γ and baseline emissions $\overline{E_t}$ determine the (non-persistent) MACC, r is the discount rate between the two periods, $\overline{q_t}$ is the emissions cap in period t, and α is the share of banked allowances that is transferred to the next period. To account for technological learning, β_1 may differ from β_2 ($\beta_2 \leq \beta_1$). The value of α decreases with the duration of the punctured waterbed, see Perino (2018), and is assumed an exogenous parameter in this simplified, two-period model. The total number of allowances cancelled is $(1-\alpha)b$. All parameters are positive.

Solving the set of 5 equations and 5 unknowns leads to

$$p_1 = \beta_1 \left(\frac{\overline{E}_2 - \overline{q}_2 + \alpha(\overline{E}_1 - \overline{q}_1)}{A + \alpha} \right)^\gamma \text{ with } A = \big(\frac{(1+r)\beta_1}{\beta_2}\big)^{\frac{1}{\gamma}} > 1 \text{ if } \beta_1 \geq \beta_2 \tag{12}$$

This shows that, as expected, the emission allowance prices are positive as long as the cumulative emissions cap is below baseline emissions.

The price in period 1 decreases in the discount rate r, $\overline{q}_1$ and $\overline{q}_2$, and increases in baseline emissions $\overline{E}_t$, β_t (if β_2 is proportional to β_1) and γ (because $\beta_2 \leq \beta_1$). This means that the price is higher when abatement is more costly (β and γ higher). The effect of α depends on the parameter values. The effect on the price in period 2 is the same, except that it increases in the discount rate r.

Cancellation equals:

$$(1-\alpha)b = \frac{1-\alpha}{A+\alpha}\left(\overline{E}_2 - \overline{q}_2 - A(\overline{E}_1 - \overline{q}_1)\right) \text{ with } A = \big(\frac{(1+r)\beta_1}{\beta_2}\big)^{\frac{1}{\gamma}} > 1 \text{ if } (1+r)\beta_1 \geq \beta_2 \tag{13}$$

It is straightforward to see that cancellation increases in $\overline{q}_1$, $\overline{E}_2$ and β_1, and decreases in $\overline{q}_2$, $\overline{E}_1$, β_2, α and r. This means that cancellation increases faster if the emissions cap trajectory decreases faster ($\overline{q}_2 < \overline{q}_1$) and the baseline emissions increase faster ($\overline{E}_2 > \overline{E}_1$). In addition, the more β_2 is lower than β_1 (technological learning), the more cancellation decreases. Because $\beta_2 \leq \beta_1$, cancellation increases with γ.[4] That is, cancellation is higher when abatement is more costly.

[4]This is still true as long as the slope of the MAC increases slower over time than the discount rate, i.e. $\beta_2 < \beta_1(1+r)$.