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Puncturing the Waterbed or the New Green Paradox? The Effectiveness of Overlapping Policies in the EU ETS Under Perfect Foresight and Myopia☆

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Abstract

The latest reform of European Union Emission Trading System (EU ETS) enables overlapping policies, such as national coal phase-outs, to affect total emissions. For evaluating overlapping policies, this paper applies a detailed partial equilibrium model of the EU ETS. Under perfect foresight, overlapping policies decrease total emissions if implemented early on. Though, endogenous cancellation within the EU ETS mitigates the waterbed effect hardly by more than 50%. In contrast, overlapping policies mostly do not affect total emissions significantly or even increase them via the new green paradox effect if implemented late and firms anticipate their long-term impact. If overlapping policies focus on low-cost abatement options, they become more effective in mitigating the waterbed effect, with an effectiveness of up to 60%. The effectiveness of overlapping policies decreases if firms are myopic. Myopia also increases the danger of the new green paradox effect for early implemented overlapping policies. However, the absolute increase in total emissions via the new green paradox remains below a third of today's yearly emissions if overlapping policies permanently reduce allowance demand by 10%.

Keywords: Intertemporal Emission Trading, Overlapping Policies, EU ETS, New Green Paradox, Marginal Abatement Costs, Myopia.
JEL Classification: C61, H23, Q48, Q58.

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1. Introduction

1.1. Motivation

The European Union Emissions Trading System (EU ETS) is the EU's central instrument to mitigate climate change, covering about 45% of the EU's greenhouse gas emissions. A major reform transformed the EU ETS from a cap-and-trade-system with a fixed cap to a system that endogenously adjusts the allowance supply, in both volume and time, by introducing the Market Stability Reserve (MSR) and the Cancellation Mechanism.

Simultaneously, the level of ambition concerning emission mitigation among EU ETS member states is heterogeneous. Without consensus on the level of ambition among member states, decreasing the allowance supply in the EU ETS as the first best policy option of reducing total emissions is politically not feasible. Hence, overlapping policies[1] are considered a measure to keep more ambitious climate targets within reach (cf. Bertram et al. (2015)). In particular, recent decisions on national coal phase-outs, e.g., in Germany, the Netherlands, and France, underline the political relevance of overlapping policies. But such interventions potentially harm the effectiveness of the EU ETS (cf. Salant (2016)).

Before the reform, overlapping policies aiming at emission reduction in EU ETS sectors led to a spatial or temporal shift of emissions without changing total emissions (waterbed effect). In the reformed EU ETS, the endogenous cancellation of allowances affects total emissions (cf. Perino and Willner (2017),Perino (2018) or Beck and Kruse-Andersen (2018)). If the total number of allowances in circulation (TNAC[2]) is above the intake threshold of 833 Mt a pre-defined share of the TNAC is not auctioned in the following year but transferred to the MSR. The Cancellation Mechanism, which becomes active from 2023 on, invalidates allowances from the MSR exceeding previous years' auction volumes. If the TNAC falls below the reinjection threshold of 400 Mt, allowances from the MSR are re-injected via increased auction volumes. In theory, the reform enables overlapping policies to reduce total emissions via the Cancellation Mechanism (see e.g., Quemin (2020)).

1.2. Related Literature

Several articles evaluate the impact of implementing overlapping policies on total emissions. Silbye and Sørensen (2017) find that the implementation of the MSR stengthens the effectiveness of overlapping policies, i.e., subsidies to renewable energies. In a static analysis,

[1] Such as coal phase-outs, national carbon price floors, or renewable support schemes.

[2] The TNAC reflects the number of allowances, which are banked by private firms.

Perino (2018) finds that the Cancellation Mechanism temporarily reduces the waterbed effect depending on the policy's timing. Overlapping policies decrease emissions by lowering for allowances, increasing TNAC volumes and hence MSR intake. Ceteris paribus, the Cancellation Mechanism renders more allowances invalid, reducing total emissions. According to Perino et al. (2019), the waterbed effect is reduced by up to 80% for overlapping policies, if implemented early on. In contrast, overlapping policies implemented after 2025 hardly reduce total emissions. Carlén et al. (2019) and Beck and Kruse-Andersen (2018) also highlight the importance of the timing of overlapping policies.

Rosendahl (2019b) argues that this strand of literature does not take into account the dynamic effects of overlapping policies. He states that overlapping policies decrease allowance demand both today and in the future. Since firms anticipate the lower demand in the future, carbon prices drop. As a result of lower prices, emissions increase in the short run and, thus, cancellation volumes decrease. Consequently, the implementation of overlapping policies can have a detrimental effect on total emissions within the reformed EU ETS design.[3] Rosendahl (2019a) labels this effect the new green paradox.[4] All in all, overlapping policies impact total emissions via two opposing effects: The immediate implementation of overlapping policies itself increases cancellation due to immediately lower allowance demand (static effect). In contrast, anticipating lower future allowance demand due to overlapping policies decreases cancellation volumes (dynamic effect) and thus causes the new green paradox effect.

Using a Hotelling setting, Rosendahl (2019a) finds that the dynamic effect is substantial for overlapping policies, that permanently reduce allowance demand: Independent of the timing, it outweighs the higher cancellation via the static effect and thus increases total emissions (new green paradox effect). While Gerlagh et al. (2019) confirm a strong new green paradox effect, Bruninx et al. (2019) cannot replicate the new green paradox effect for permanent overlapping policies. Reacting to Rosendahl (2019b), Perino (2019) acknowledges the finding that overlapping policies can increase total emissions in theory [5] but questions whether the new green paradox effect is as substantial as found in Rosendahl (2019a). Thus,

[3]The reform itself reduces total emissions compared to the pre-reform design. The decrease in total emissions induced by the EU ETS reform, though, might be weakened by implementing overlapping policies compared to a counterfactual scenario without overlapping policies.

[4]The green paradox is introduced by Sinn (2008). He finds that taxing the extraction of fossil resources in the future incentivizes their short-run extraction.

[5]Perino et al. (2019) also show in a two-period setting that overlapping policies after the reform may even backfire, that is to increase total emissions.

Perino et al. (2019) calls for further quantification of the effects and the role of the addressed volume of overlapping policies.

Perino (2018) and Rosendahl (2019a) evaluate overlapping policies without considering the impact on Marginal Abatement Cost (MAC) curves. In reality, overlapping policies, such as coal phase-outs, address a significant share of baseline emissions within the EU ETS and, thus, affect the MAC curve (cf. Hintermayer et al. (2020)). As the MAC curve reflects the relative change in abatement costs, a change in the MAC curve influences firms' optimal banking and, hence, cancellation volumes.

Analyzing the effect of overlapping policies on banking, Herweg (2020) assumes that overlapping policies randomly target abatement options over the entire MAC curve. He takes the change in TNAC volumes as an indicator for cancellation and analytically points to the drivers for banking in the EU ETS. However, Herweg (2020) acknowledges that a thorough evaluation of the Cancellation Mechanism requires numerical modeling due to its non-linear nature.[6]

Further, Willner (2018), Quemin and Trotignon (2019) and Bocklet and Hintermayer (2020) highlight the importance of considering myopia to explain the firms' behavior within the EU ETS. Myopia reduces the firms' planning horizon and thus their anticipation of future allowance scarcity. Myopia affects the effectiveness of overlapping policies since the dynamic effect is subject to the anticipation of future allowance supply and demand.

1.3. Contribution and Structure

The contribution of this research to the prevailing literature is twofold: First, this paper adds to the controversial literature regarding the new green paradox effect of overlapping policies. The design of overlapping policies determines their effectiveness. Notably, the timing and whether overlapping policies target low-cost abatement options are crucial features for effectively reducing total emissions via endogenous cancellation. Under perfect foresight, the effectiveness decreases with the implementation year. For early implemented policies, the Cancellation Mechanism mitigates the waterbed effect partially and lowers total emissions. If firms anticipate late implemented policies early on, however, cancellation volumes decrease and total emissions increase (New Green Paradox Effect). If overlapping policies

[6] Cancellation depends on the total intake of allowances into the MSR. The intake is subject to a discrete intake threshold. The MSR absorbs allowances, equalling intake rate times the TNAC volume, as long as the TNAC exceeds the intake threshold. The intake instantly stops when the TNAC falls below the intake threshold.

explicitly target low-cost abatement options, their effectiveness increases and the danger of the new green paradox effect diminishes. Second, this paper sheds light on the role of myopia concerning the effectiveness of overlapping policies. Myopia reduces the effectiveness of overlapping policies. In contrast to perfect foresight, the effectiveness no longer declines with the implementation year but is u-shaped. The effectiveness reaches its lowest point if overlapping policies are implemented at about half of the firms' planning horizon. As a result, even early implementations of overlapping policies are at risk of increasing total emissions if firms are short-sighted.

The remainder of the paper at hand is structured as follows: After introducing the model in section 2 , section 3 quantifies the impact of overlapping policies on cancellation and total emissions, depending on the timing and design of overlapping policies as well as the planning horizon of firms. Section 4 concludes.

2. Methodology

2.1. Fundamental Model of the EU ETS

For analyzing overlapping policies, this paper applies the discrete optimization model developed in Bocklet et al. (2019). This model builds on the seminal work of Rubin (1996) and Chevallier (2012) and is introduced subsequently.

N symmetric polluting firms compete in an inter-temporal allowance market under perfect competition. Assuming rational and price-taking firms within perfect markets and abstracting from uncertainty, a representative firm faces the following optimization problem.

$$\begin{aligned} \min \quad & \sum_{t=t_0}^{T} \frac{1}{(1+r)^t} \cdot \frac{c(t)}{\alpha+1} \cdot [u(t) - e(t)]^{\alpha+1} + p(t) \cdot x(t) \\ & s.t.\ b(t) - b(t-1) = S(t) - e(t) \quad \text{for all} \quad t = 1, 2, \ldots, T \qquad (1) \\ & S(t), b(t) \geq 0 \\ & e(t), x(t) \gtreqless 0 \end{aligned}$$

The representative firm minimizes its net present value of expenditures for abating greenhouse gas emissions as well as for purchasing allowances $p(t) \cdot x(t)$[7] over a set of predefined discrete time steps t. The abatement cost function $C(e(t)) = \frac{c(t)}{\alpha+1}(u(t) - e(t))^{\alpha+1}$ increases

[7] $x(t)$ covers allowances purchased in auctions $S_a uct(t)$ or bilateral allowance trade among firms.

with the difference between baseline emissions $u(t)$[8] and realized emissions $e(t)$, where the cost parameter $c(t)$ scales the slope and α depicts the curvature of the abatement cost function. Furthermore, firms are allowed to set aside allowances in a private bank $b(t)$ for later use, whereas using allowances before they are issued (borrowing) is - in line with the EU ETS regulation - prohibited. The cumulative private bank represents the Total Number of Allowances in Circulation (TNAC). The change in TNAC volumes equals the allowance supply to the market $S(t)$, comprising auctioned and freely allocated allowances, minus the chosen level of emissions $e(t)$ in each time step t.

The first-order derivatives of the Lagrange function of the optimization problem provide the market equilibrium conditions (cf. Appendix A): First, the marginal abatement costs (MAC) must equal the carbon price in every time step t:

$$c(t)(u(t) - e(t))^{\alpha} = p(t) \tag{2}$$

Second, the price follows the Hotelling rule, which is adjusted due to the restriction imposed by the non-borrowing constraint (Hotelling, 1931):

$$\frac{p(t+1) - p(t)}{p(t)} = r - (1+r)^{t+1}\frac{\mu_b(t)}{p(t)} \tag{3}$$

As long as the TNAC is non-empty, the shadow costs of the non-borrowing constraint $\mu_b(t)$ equal zero. Hence, carbon prices rise with the interest rate r. Afterwards, the relative price increase is lowered by $(1+r)^{t+1}\frac{\mu_b(t)}{p(t)}$ where $\mu_b(t)$ reflects the shadow costs of the increase in total discounted abatement costs due to the non-borrowing restriction.

For incentivizing emission abatement, the supply of allowances $S(t)$ decreases annually. Due to the non-negativity of the TNAC (no borrowing), the following equation limits the emission path:

$$\sum_{\tilde{t}=0}^{t} e(\tilde{t}) \leq \sum_{\tilde{t}=0}^{t} S(\tilde{t}) + b_0 \tag{4}$$

For every discrete time-step t, cumulative emissions $\sum_{\tilde{t}=0}^{t} e(\tilde{t})$ have to be lower than cumulative allowance supply $\sum_{\tilde{t}=0}^{t} S(\tilde{t})$ plus the initial allowance endowment b_0. The regulatory rules for the development of $S(t)$ are presented in Appendix C.

[8] Baseline emissions reflect the level of emissions if firms have no incentive to abate, i.e., in absence of the EU ETS.

While the model used in Bocklet et al. (2019) is restricted to using linear MAC curves ($\alpha = 1$), implementing piece-wise linear approximation into the model allows for depicting more realistic convex curvatures (cf. Hintermayer et al. (2020)).

Formulating the above-mentioned optimization problem as a mixed complementarity problem allows to integrate the non-linear regulatory rules of the reformed EU ETS (cf. Appendix C) via mixed-integer optimization. Thereby, the problem becomes a feasibility problem, i.e., a set of constraints, which ensure optimality without optimizing an objective. In this setting, several optimal solutions, i.e., equilibrium price and emissions paths, might exist (compare Gerlagh et al. (2019)). In line with Hintermayer (2020), this paper chooses the equilibrium with the highest total emissions in the case of multiple equilibria. The implicit assumption is that firms in the EU ETS can coordinate themselves to reach the emissions- and thus profit-maximizing equilibrium.

2.2. Decision-Making under Myopia

According to Quemin and Trotignon (2018) and Bocklet and Hintermayer (2020), myopia plays a crucial role in understanding the firms' behavior within the EU ETS. Myopia changes firms' reactions to overlapping policies since the dynamic effect depends on whether firms anticipate the long-run impact of overlapping policies. Following the approach of Bocklet and Hintermayer (2020), consecutively solving the optimization problem $\mathcal{M}$ described in equation 1 reflects the myopic-decision making of the representative firm with planning horizon H, i.e.:

Algorithm 1: Rolling horizon optimization of the myopic firm

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for $\tau = 0, 1, .., \tilde{T}$ **do**
  Solve $\mathcal{M}(t_0 = \tau, T = \tau + H)$
  Fix $e(\tau), x(\tau), S(\tau), b(\tau)$

The representative firm optimizes today's abatement, and hence emissions and banking, anticipating allowance supply and demand of the next H years. Progressing in time, new information becomes available within the planning horizon. The firm again chooses abatement, while state variables of previous periods, e.g., banking $b(t)$, are fixed. Within each planning period, the chosen abatement path is subject to the stated equilibrium conditions (cf. section 2.1). From an ex-post point of view, though, the intertemporal link defined by the Hotelling rule does not hold anymore since additional information changes the equilibrium path from period to period (cf. Bocklet and Hintermayer (2020)).

3. Numerical Evaluation of Overlapping Policies

This section evaluates the interactions of overlapping policies, which are announced today, and the dynamics within the EU ETS. Overlapping policies directly interfere with the EU ETS by reducing the demand for allowances.[9] Among others, these policies comprise direct subsidies for low-carbon technologies (e.g., support schemes for renewable energy), indirect incentives for low-carbon investments (e.g., national carbon price floor) or technology bans (e.g., coal phase-outs). Section 3.1 introduces the framework for evaluating overlapping policies. After presenting the model results without overlapping policies in 3.2, section 3.3 assesses the impact of overlapping policies concerning timing. Section 3.4 takes a closer look at the impact of the design, i.e., the addressed volumes of overlapping policies and which abatement options are targeted. Finally, section 3.5 dissolves the assumption of perfect foresight and analyzes the impact of myopic decision-making on the effectiveness of overlapping policies.

3.1. Modeling of Overlapping Policies and Indicators for Evaluation

Overlapping policies reduce the demand for allowances and hence lower baseline emissions, leading to a shorter but steeper MAC curve. This assumption deviates from the prevailing literature, where lowering baseline emissions does not change the slope of the MAC curve, e.g., in Perino and Willner (2017) and Quemin and Trotignon (2018). Instead of decreasing backstop costs (reflecting the MAC of the last abated ton), this article assumes constant backstop costs independent from introducing overlapping policies. For evaluating the design of overlapping policies, this paper considers two stylized impacts of overlapping policies on MAC curves, which are illustrated in Figure 1.

The impact of overlapping policies is analyzed by comparing two scenarios, namely a *base* scenario without overlapping policies and a scenario with overlapping policies (*OP*), assuming convex MAC curves. The default assumption for the impact of overlapping policies is in line with Herweg (2020): Overlapping policies address abatement options that are evenly distributed along the MAC curve. Hence, overlapping policies steepen the whole MAC curve, proportionally to the decrease in baseline emissions (*OP - Evenly distributed*). For evaluating the policy design, a variation depicts overlapping policies that target only low-cost

[9]Policies, which target sectors not covered by the EU ETS, such as incentives for electrification of the transport sector, are explicitly not considered within this paper. Such policies increase the allowance demand by transferring emissions into the EU ETS.

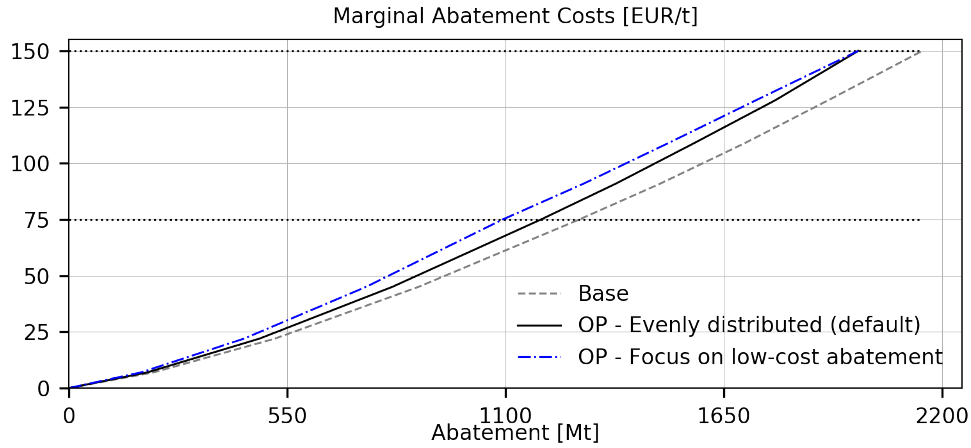

Figure 1: Marginal abatement cost curves without (*base*) and with overlapping policies (*OP - Evenly Distributed* and *OP - Focus on Cheap Abatement*).

abatement options (*OP - Focus on low-cost abatement*). By assumption, such overlapping policies steepen only the first half of the MAC curve - below a cut-off price of 75 EUR/t.
Overlapping policies reduce baseline emissions and lead to *overlapping emission reductions* ($\Delta E_{overlap}$), which reflect emission reductions within the targeted scope of the overlapping policies, e.g., the change in emissions in one country following the implementation of a national overlapping policy.
The indicator *additional cancellation* ($\Delta Cancel$) assesses how total emissions within the EU ETS change as a result of overlapping emission reductions. $\Delta Cancel$ mirrors the difference of cancellation volumes in *Base* and *OP*.[10], i.e.

$$\Delta Cancel = Cancellation_{OP} - Cancellation_{Base} \tag{5}$$

Without the Cancellation Mechanism, overlapping policies would only shift emissions in space and time, without affecting total emissions (waterbed effect). With the Cancellation Mechanism in place, overlapping policies can result in higher or lower total emissions. Consequently, they can partially mitigate the waterbed effect but can also have detrimental effects.[11]

[10]Negative additional cancellation indicate lower cancellation volumes due to the implementation of the overlapping policies compared to the *base* scenario (new green paradox effect).

[11]Total emissions under the reformed EU ETS design are always lower than in the pre-reform setting. Though, overlapping policies can reduce the cancellation volumes compared to the *base* scenario and thus increase total emissions.

For measuring the waterbed effect, the effectiveness reflects the share of *additional cancellation* ($\Delta Cancel$) with regard to *overlapping emission reduction* ($\Delta E_{overlap}$), i.e.

$$Effectiveness = \frac{\Delta Cancel}{\Delta E_{overlap}} \tag{6}$$

The effectiveness quantifies the relative degree to which the waterbed effect is mitigated in the reformed EU ETS. An effectiveness of 100% indicates that the waterbed effect is entirely mitigated, while 0% reflects that the waterbed effect persists in full. If the effectiveness becomes negative, overlapping policies have a detrimental effect on total emissions under the reformed EU ETS due to the new green paradox effect. That means the implementation of overlapping policies decreases total cancellation volumes compared to the *base* scenario.

3.2. Results of the Base Scenario

The model's parametrization follows the current EU ETS regulation. The calibration considers market outcomes in 2018 and 2019, as well as the observed MAC curve slope according to Quemin and Trotignon (2018). Appendix B presents the chosen parametrization. Figure 2 visualizes the market results for the *base* scenario without overlapping policies.

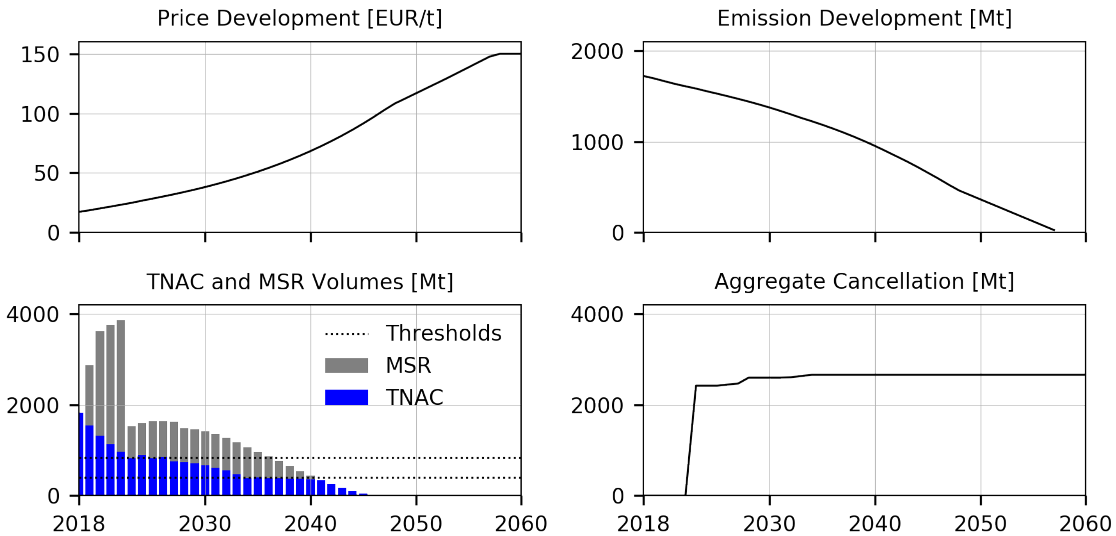

Figure 2: Prices, emissions, banking and total cancellation in the base scenario.

According to the Hotelling rule, the price increases with the interest rate as long as firms hold allowances (i.e., TNAC>0). Afterward, the binding non-borrowing constraint reduces the price increase by the constraint's shadow costs. The emissions become zero in 2057 after the last allowances are issued. Until the mid 20s, the TNAC exceeds the intake threshold. Afterward, the TNAC remains slightly below the intake threshold for a couple of years. In the mid-'30s, the TNAC falls below the reinjection threshold. Consequently, about 750 million allowances become available to the market between 2036 and 2042 via MSR reinjection. The TNAC depletes in 2046. The total cancellation volume sums up to about 2800 million allowances. The majority of canceled allowances become invalid just after the activation of the Cancellation Mechanism in 2023. Additionally, the Cancellation Mechanism invalidates small numbers in the subsequent years until the mid 30s.

3.3. Timing of Overlapping Policies under Perfect Foresight

This section evaluates the impact of overlapping policies concerning the timing of their implementation[12]. By assumption, overlapping policies reduce baseline emissions by 10% and evenly steepen the entire MAC curve proportionally to the decrease in baseline emissions (cf. section 3.1). Firms perfectly anticipate the introduction of overlapping policies, i.e., overlapping policies are announced today and firms perfectly foresee the impact of overlapping policies on baseline emissions and the MAC curve.[13]

To understand how the timing of overlapping policies affects total emissions, figure 3 shows their impact on overlapping emission reductions, TNAC volumes without (*Base*) and with overlapping policies (*OP*), and the change in cancellation volumes for implementations in 2020 or 2030, respectively.

Overlapping policies lead to overlapping emission reductions from their implementation onward. Overlapping emission reductions depend on the carbon price level. Thus, they decrease in time due to the increasing carbon price in the *base* scenario. For instance, a national coal phase-out has a smaller effect on national emissions in times of high carbon prices than in times of low carbon prices. Under higher carbon prices, inefficient coal power plants would have already decreased their production due to the stronger price signal of the EU ETS.

Whether overlapping emission reductions lead to higher cancellation largely depends on the impact on the TNAC. Only if overlapping emission reductions increase the TNAC volume as long as it is above the intake threshold, the cancellation will increase due to the static effect. For an early implementation in 2020, the TNAC increases significantly. Since the TNAC is above the intake threshold at this time, both direct cancellation increases and the

[12]Implementation refers to the point, where overlapping policies become active.

[13]Section 3.5 dissolves the assumption of perfect foresight.

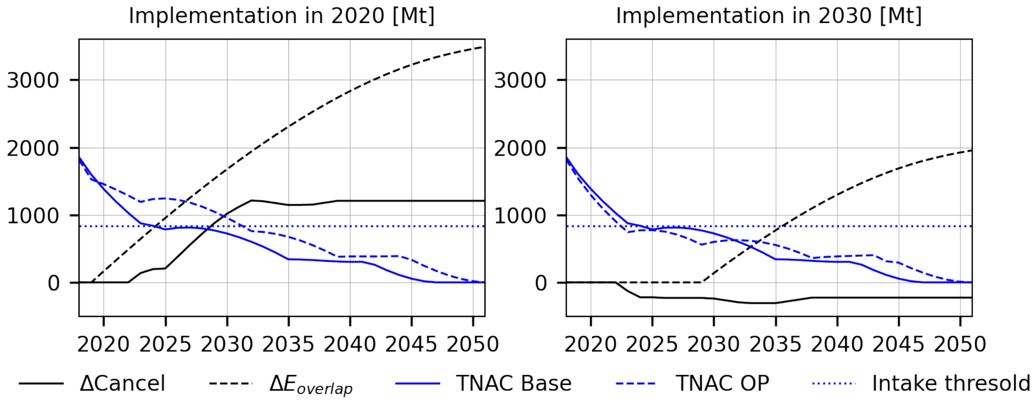

Figure 3: Cumulative overlapping emission reductions ($\Delta E_{overlap}$), change in TNAC volumes and cumulative change in cancellation ($\Delta Cancel$) for implementing overlapping policies in 2020, left, and 2030, right.

cancellation period is prolonged until the early '30s. If implemented early, the Cancellation Mechanism reduces total emissions by about one-third of the respective overlapping emission reductions. Hence, the static effect mitigates the waterbed effect partially.

If implemented in 2030, overlapping policies cause overlapping emissions reductions from 2030 onward. While the TNAC volumes increase accordingly, it does not trigger higher cancellation since the TNAC remains below the intake threshold. Hence, the static effect of overlapping policies does not unfold for late implementation years. In contrast, the dynamic effect, which decreases cancellation volumes compared to the *base* scenario, leads to lower cancellation. By anticipating lower allowance demand due to overlapping emission reductions, the market price drops before overlapping policies become active. As a result, increasing emissions in the short term lower the TNAC and hence cancellation volumes. While about 2800 million allowances are canceled in the *base* scenario, implementing overlapping policies in 2030 reduces the cancellation volume to about 2600 million allowances. Hence, total emissions increase by 200 Mt via the new green paradox effect described by Rosendahl (2019a).

To further evaluate the timing of overlapping policies, figure 4 shows total cancellation, total overlapping emission reductions, and the resulting effectiveness for implementing overlapping policies between 2020 and 2035.

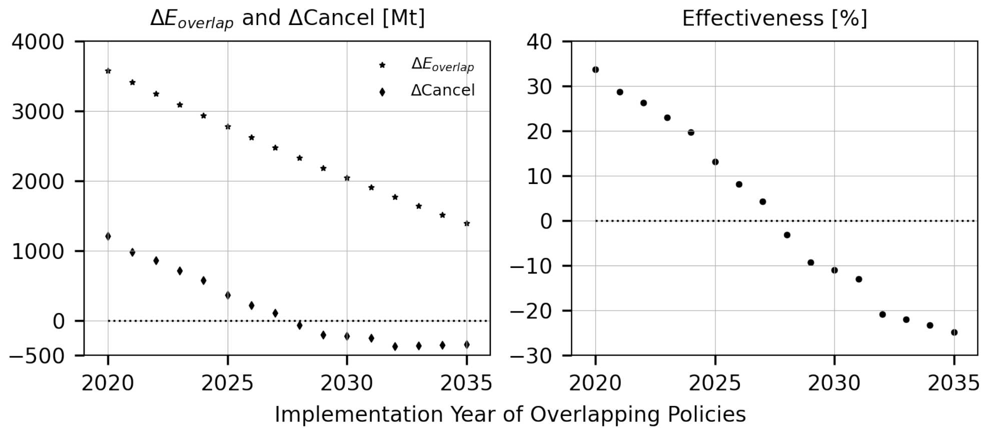

Figure 4: Overlapping emission reduction ($\Delta E_{overlap}$), additional cancellation ($\Delta Cancel$), both left, and effectiveness, right, for different implementation years of overlapping policies.

Due to the increasing carbon price in the *base* scenario, total overlapping emission reductions ($\Delta E_{overlap}$) decrease with the implementation year of overlapping policies. While early implemented overlapping policies ensure overlapping emission reduction of up to 3500 Mt, the effect lowers with later implementation. For implementation in 2035, the overlapping emission reduction falls to about 1500 Mt.

Cumulative cancellation decreases with the implementation year and becomes negative for mid- to long-term implementations after 2028. For early implementations, the TNAC volume grows above the intake thresholds, and hence the static effect increases cancellation. This effect vanishes for implementations after 2028. In contrast, the dynamic effect - namely, the price decrease due to lower future allowance demand - triggers higher emissions today and decreases cancellation volumes. That means implementing overlapping policies after 2028 increase total emissions compared to the *base* scenario.

As a result, the consequences of overlapping policies on the waterbed effect, and hence total emissions, crucially depend on the timing. In the short term, about one-third of overlapping emission reductions via overlapping policies are canceled. Hence, the reform can reduce the waterbed effect but will not wholly dispel it. However, the waterbed effect soon regains full strength if implementations of overlapping policies shift towards mid- to end-20's. For later implementations, the effectiveness becomes negative, and hence overlapping policies increase total emissions compared to the *base* scenario via the new green paradox effect.

3.4. Addressed Volume and Design of Overlapping Policies

For evaluating the design of overlapping policies, two design parameters are changed: first, the addressed volume of overlapping policies as a share of baseline emissions and, second, the impact of overlapping policies on the MAC curve. The results in section 3.3 rely on assuming that overlapping policies target abatement options, which are evenly distributed over the whole range of the MAC curve. For depicting overlapping policies, which focus on low-cost abatement options, they are assumed to affect only the lower half of the MAC curve below 75 EUR/t (cf. figure 1). Figure 5 illustrates the impact of these variations concerning the effectiveness of overlapping policies and their timing.

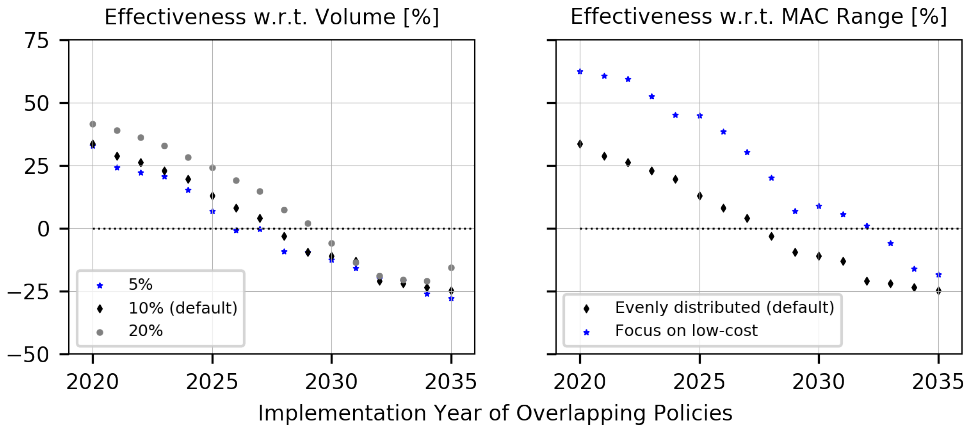

Figure 5: Effectiveness for different addressed volumes of overlapping policies (as share of baseline emissions), left, and different designs, right.

The addressed volume has a minor impact on the effectiveness of overlapping policies. For early implementations, increasing addressed volumes manifest in higher mitigation of the waterbed effect. The effectiveness increases to slightly below 50%. The addressed volume hence affects the static effect primarily. Lower short-term allowance demand due to overlapping policies instantly increase TNAC volumes. As long as the TNAC is above the intake threshold, this additional banking increases MSR volumes. Consequently, higher overlapping emission reductions cause relatively higher additional cancellations. The converging effectiveness for late implementations indicates that the dynamic effect is rather independent of the addressed volume. In particular, increasing overlapping emission reductions lead to proportionally increasing total emissions.

If overlapping policies are focused on low-cost abatement options, the mitigation of the waterbed effect roughly doubles. The effectiveness increases to about 60% for early implementations. This is due to the distribution of overlapping emission reductions over time. If overlapping policies focus on the low-cost part of the MAC curve, a larger share of emission reductions become effective early on. Early emission reductions contribute to increasing cancellation volumes via the static effect. With higher shares of expensive abatement options targeted by overlapping policies, the relative contribution to the static effect declines. Even if the policy is implemented early on, its effect will only show later when high-cost abatement measures become necessary. For later implementations, the effectiveness converges independent of the impact of overlapping policies on the MAC curve.

3.5. Overlapping Policies under Myopic Decision-Making

The subsequent section dissolves perfect foresight. The representative firm optimizes abatement only within the planning horizon H. In line with the findings of Bocklet and Hintermayer (2020), myopia leads to lower TNAC volumes and carbon prices since myopic firms neglect future allowance scarcity and emphasize short-term abatement costs. The results of the *base* scenario for different planning horizons are given in Appendix D.
Figure 6 depicts how myopic decision-making affects the effectiveness of overlapping policies for different planning horizons H compared to perfect foresight.

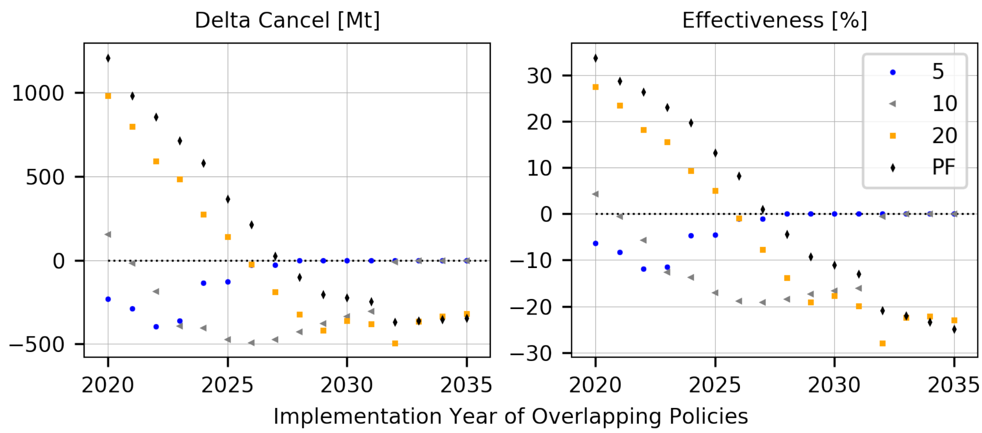

Figure 6: Additional Cancellation and Effectiveness of depending on timing and planning horizon.

When implementing overlapping policies beyond the planning horizon, cancellation does not change and overlapping policies do not affect total emissions. As soon as firms anticipate lower future allowance demand in this setting, TNAC volumes increase but do not exceed the intake threshold anymore. Consequently, myopic decision-making avoids increasing emissions via the new green paradox for late implementations of overlapping policies.

Short- to mid-term implementations of overlapping policies become less effective if firms are myopic than under perfect foresight. While such policies mitigate the waterbed effect partially under perfect foresight, shortsightedness hinders their effectiveness. In contrast to perfect foresight, firms do not anticipate allowance scarcity far into the future under myopia. As a result, a larger share of allowances, which are additionally available in the short term due to the static effect of overlapping policies, is used today rather than saved to alleviate long-term allowance scarcity. If firms are very short-sighted (e.g., for a planning horizon of five years) even short-term overlapping policies have detrimental effects on total emissions since fewer allowances are rendered invalid via the Cancellation Mechanism.

While the effectiveness declines with the implementation year under perfect foresight, its dependence on the implementation year follows an u-shape under myopia. This shape reflects the trade-off between static and dynamic effects. The static effect diminishes with later implementation years independent of the planning horizon leading to less effective overlapping policies for later implementations. However, the dynamic effect changes if firms are short-sighted. Firms anticipate that overlapping policies will lower baseline emissions from their implementation onward and alleviate future allowance scarcity. Under perfect foresight, the anticipation horizon is long and, thus, the dynamic effect does not significantly change with later implementations. Myopia limits the anticipation of firms to the planning horizon. Firms foresee only the allowance demand reduction due to overlapping policies within the planning horizon. As a result of the shorter anticipation horizon, the implementation year significantly affects the dynamic effect under myopia. Consequently, the adverse impact of overlapping policies on total emissions diminishes with later implementations. Due to this trade-off the effectiveness reaches its lowest point if overlapping policies are implemented at about half of the firms' planning horizon.

With increasing planning horizons, the effectiveness of overlapping policies converges to the results under perfect foresight. For example, the results for a planning horizon of twenty years largely replicate the observations under perfect foresight. The same setting reveals the non-linearity of the regulation due to the discrete intake threshold, which can cause outliers, such as the cancellation for an implementation in 2032. While the non-linear regulation can cause such skittish behavior, it does not affect the overall trend.

Bocklet and Hintermayer (2020) consider a planning horizon of about ten years a reasonable assumption to explain observed market results. Consequently, overlapping policies which are implemented about five years after their announcement are least effective. Against this backdrop, such intervals between announcement and implementation are quite frequent in policy-making[14] so that their effectiveness is not per se given by the reformed EU ETS.

4. Conclusion

This paper evaluates overlapping policies, such as national coal phase-outs, and their impact on total emissions within the EU ETS. The latest reform transformed the EU ETS into a system that endogenously adjusts allowance supply as a function of firms' banking behaviour, i.e., total allowance supply changes by canceling allowances from the MSR. Whereas total emissions were independent of overlapping policies due to the waterbed effect before the reform, overlapping policies can now affect total emissions.

For evaluating the effectiveness of overlapping policies, a partial equilibrium model of the EU ETS is applied. Overlapping policies entail a static effect that mitigates the waterbed effect and an opposing dynamic effect that potentially leads to higher total emissions (new green paradox effect). While overlapping policies can puncture the waterbed, three aspects determine their effectiveness: First, in line with the prevalent literature (e.g., Carlén et al. (2019), timing is essential. Under perfect foresight, the effectiveness of overlapping policies decreases with later implementations. Only short-term implementations, which foreclose the dynamic adjustment of banking volumes by firms, lead to significant additional cancellation. However, only if designed properly the endogenous cancellation mitigates the waterbed effect by more than 50%. Against this backdrop, overlapping policies increase total emissions if implemented late via the new green paradox effect. Second, if overlapping policies focus on low-cost abatement options, they are more effective in reducing total emissions. Third, higher addressed volumes tend to strengthen the static effect and thus lead to a higher reduction of the waterbed effect.

Myopia reduces the effectiveness of overlapping policies. The higher weight of today's costs reduces banking and hence cancellation. As a result, the waterbed effect is hardly mitigated and the risk of the new green paradox effect increases. Compared to perfect foresight, the role of timing becomes more complex. The effectiveness no longer declines with the implementation year but is u-shaped for myopic decision-making. The effectiveness reaches its lowest point if overlapping policies are implemented at about half of the firms' planning horizon. As a result, also early implementations of overlapping policies are at risk of increasing total emissions if firms are short-sighted.

[14]For instance, coal phase-outs in, e.g., the UK or France become active after 2023 and were announced in the last few years.

All in all, the adverse effects of the new green paradox effect remain low. Independent of the considered design and firms' planning horizon, total emissions increase less than 500 Mt due to the new green paradox if overlapping policies reduce baseline emissions by 10%. This is below a third of today's yearly emissions within the scope of the EU ETS. Against this backdrop, only deliberate overlapping policies result in waterbed reductions of more than 50%, while most implementations are less effective. Thus, the risk that overlapping policies turn out ineffective remains high under the reformed EU ETS design.

For ensuring the effectiveness concerning total emissions, the reformed EU ETS design grants member states the right to unilaterally withdraw allowances from their auction volumes in case of a nationally determined decommissioning of electricity generation capacity. Beyond coal phase-outs, allowance withdrawals are not explicitly allowed for other overlapping policies, such as subsidies to renewable energies or (multi-)national carbon price floors . A carbon price floor accurately addresses low cost abatement options (cf. Flachsland et al. (2019) or Hintermayer (2020)), and is hence theoretically more effective than other unilateral measures. However, the effectiveness of overlapping policies is hardly predictable due to the complex interactions. When enforcing more stringent climate targets within the new Green Deal, the future design of the EU ETS and the MSR will be reviewed (cf. Osorio et al. (2020)). For avoiding (potentially) ineffective overlapping policies, a compromise on the level of ambition should be a priority in future negotiations.

This paper identifies determinants for effective overlapping policies in an idealized setting. The impact of market distortions besides firms' shortsightedness, such as asymmetric information or risk-aversion under uncertainty, is subject to future research. Further, shapes of MAC curves matter for the impact of overlapping policies on total emissions. For validating the assumptions on MAC curves, they should be analyzed in detail. This paper looks at overlapping policies that reduce allowance demand within the EU ETS. Policy-driven electrification in transport or heating, which increases allowance demand, and their impact on total emissions within the EU ETS could be assessed similarly.

Appendix A. Optimization of the firm, Lagrange function and KKT conditions

The optimization problem of a rational representative firm is given as

$$\begin{aligned}
\min \quad & \sum_{t=t_0}^{T} \frac{1}{(1+r)^t} \cdot \frac{c(t)}{\alpha+1} \cdot [u(t) - e(t)]^{\alpha+1} + p(t) \cdot x(t) \\
& s.t.\ b(t) - b(t-1) = S(t) - e(t) \quad \text{for all} \quad t = 1, 2, \ldots, T \\
& \qquad S(t), b(t) \geq 0 \\
& \qquad x(t), e(t) \gtrless 0
\end{aligned} \tag{A.1}$$

By assigning Lagrange multipliers $\lambda(t)$ and $\mu_b(t)$ to the banking flow constraint and the positivity constraints, respectively, the Lagrangian function is obtained:

$$\begin{aligned}
&\mathcal{L}(\mathbf{e}, \mathbf{b}, \mathbf{S}, \lambda, \mu_{\mathbf{b}}) = \\
&= \sum_{t=0}^{T} \frac{1}{(1+r)^t} \cdot [\frac{c}{2}(u - e(t))^2 + p(t) \cdot x(t)] + \\
&\quad + \sum_{t=1}^{T} \lambda(t) \cdot [b(t) - b(t-1) - S(t) + e(t)] \\
&\quad - \sum_{t=0}^{T} \mu_b(t) \cdot b(t).
\end{aligned} \tag{A.2}$$

The optimization problem is convex and fulfills the Slater condition. Hence, the following KKT conditions are necessary and sufficient for optimality:

Stationarity conditions:

$$\frac{\partial \mathcal{L}}{\partial S(t)} = \frac{1}{(1+r)^t} p(t) - \lambda(t) = 0 \quad \forall\, t = 1, 2, \ldots, T \tag{A.3}$$

$$\frac{\partial \mathcal{L}}{\partial e(t)} = (-1) \frac{1}{(1+r)^t} c(u - e(t)) + \lambda(t) = 0 \quad \forall\, t = 1, 2, \ldots, T \tag{A.4}$$

$$\frac{\partial \mathcal{L}}{\partial b(t)} = \lambda(t) - \lambda(t+1) - \mu_b(t) = 0 \quad \forall\, t = 1, 2, \ldots, T. \tag{A.5}$$

Primal feasibility:

$$b(t) - b(t-1) - S(t) + e(t) \; = 0 \quad \forall\, t = 1, 2, \ldots, T \tag{A.6}$$

$$x(t), \quad e(t) \gtreqless 0 \quad \forall\, t = 1, 2, \ldots, T. \tag{A.7}$$

Dual feasibility and complementarity:

$$0 \leq b(t) \perp \mu_b(t) \geq 0 \quad \forall\, t = 1, 2, \ldots, T \tag{A.8}$$

$$\lambda(t) \; \gtreqless 0 \quad \forall\, t = 1, 2, \ldots, T. \tag{A.9}$$

The equilibrium conditions in equations 2 and 3 directly result from the stationarity conditions.

Appendix B. Parametrization and EU ETS Rules

Table B.1 provides an overview of the chosen parametrization in the base scenario.

Parameter	**Value**	**References**
Linear reduction factor $lrf(t)$	1.74% until 2020, 2.2% afterwards based on emissions of 2199 Mt in 2005	Current regulation[15]
Auction share	57% of issued allowances	Current regulation
MSR intake threshold	ℓ_{up}=833 Mt	Current regulation
MSR intake rate $\gamma(t)$	Reduction of auction volume by 24% of TNAC volume until 2023, 12% afterwards	Current regulation
MSR reinjection threshold	ℓ_{low}=400 Mt	Current regulation
MSR reinjection tranches	R=100 Mt	Current regulation
Cancellation Mechanism	Active from t=2023 onward	Current regulation

[15] cf. European Parliament and the Council of the European Union (2018), European Parliament and the Council of the EU (2015), European Commission (2018), European Commission (2015)

Initial endowment MSR	MSR(0)=1500 million (900 million backloaded, 600 million unallocated in 2020)	European Parliament and the Council of the EU (2015), European Commission (2015)
Initial endowment TNAC	$b(0)$=1647 million , TNAC (2018)	European Commission (2018)
Discount rate	$r = 6\%$	Similar to Quemin and Trotignon (2018) or Schopp et al. (2015)
Baseline emissions	$u(t) = 2150Mt$	In the range of literature assumptions of 1800 - 2200 Mt, e.g. Perino and Willner (2016) or Schopp et al. (2015).
Backstop costs	150 EUR/t	Best estimates for CCS costs, cf. Saygin et al. (2012) and Kuramochi et al. (2012).
Cost parameter	$c(t) = \frac{c_{backstop}}{u(t)} = 0.0698 \cdot 10^{-3}$ EUR/t^2	cf. Bocklet et al. (2019)
MAC curvature	$\alpha = 1.35$	Calibrated to observed slope (cf. Quemin and Trotignon (2018)).

Table B.1: Overview of the model parametrization

Appendix C. Rules for the intake, reinjection and cancellation

A predefined share of allowance supply ($S(t)$) is auctioned off (S_{auct}) while the rest is allocated for free (S_{free}). Overall allowance supply decreases year by year according to the linear reduction factor ($a(t)$):

$$S(t) = S_{auct}(t) + S_{free}(t) \tag{C.1}$$

$$S_{auct}(t) = auction\_share(1 - \sum_{t=0}^{t} lrf(t)) \cdot S(0) + Reinjection(t) - Intake(t) \tag{C.2}$$

$$S_{free}(t) = (1 - auction\_share) \cdot (1 - \sum_{t=0}^{t} lrf(t))S(0) \tag{C.3}$$

TNAC volume:

$$b(t) = b(t-1) + S(t) - e(t) \tag{C.4}$$

MSR volume:

$$MSR(t) = MSR(t-1) + Intake(t) - Reinjection(t) - Cancel(t) \tag{C.5}$$

Rules for MSR intake, reinjection and cancellation mechanism:

$$Intake(t) = \begin{cases} \gamma(t) \cdot TNAC(t-1) & \text{if } TNAC(t-1) \geq \ell_{up}, \\ 0 & \text{else,} \end{cases} \tag{C.6}$$

$$Reinjection(t) = \begin{cases} R & \text{if } TNAC(t-1) < \ell_{low} \wedge MSR(t) \geq R, \\ MSR(t) & \text{if } TNAC(t-1) < \ell_{low} \wedge MSR(t) < R, \\ 0 & \text{else,} \end{cases} \tag{C.7}$$

$$Cancel(t) = \begin{cases} MSR(t) - S_{auct}(t-1) & \text{if } MSR(t) \geq S_{auct}(t-1), \\ 0 & \text{otherwise.} \end{cases} \tag{C.8}$$

Appendix D. Results of the base scenario under myopia

Myopic firms have a limited planning horizon H and hence do not anticipate information beyond $t + H$. Figure D.7 visualizes market outcomes for the base scenario under myopic-decision making, namely planning horizons of 5,10 or 20 years, respectively, and compares them to the results under perfect foresight.

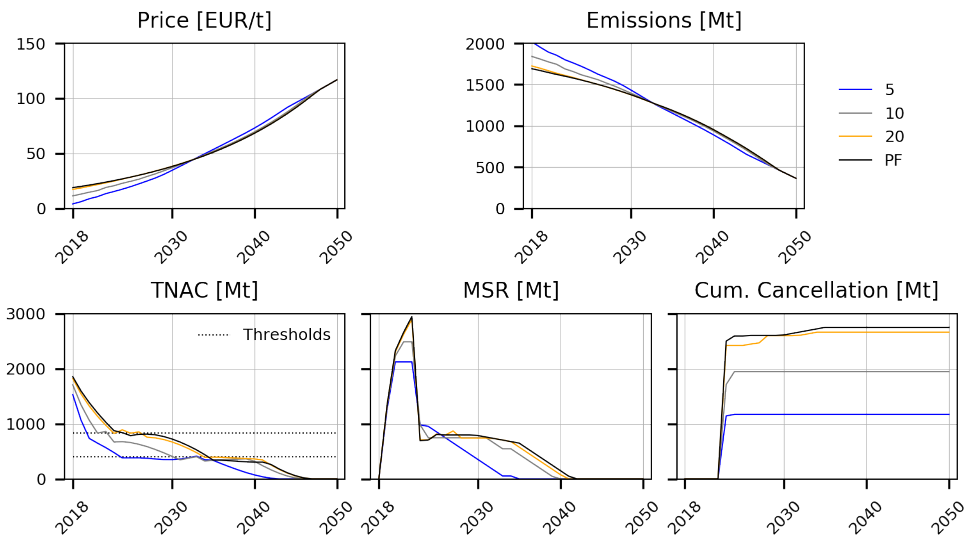

Figure D.7: Market outcomes for the base scenario under myopia (for planning horizons of 5,10 and 20 years) compared to the results under Perfect Foresight (PF).

Under myopia, firms do not anticipate future allowance scarcity at the beginning. As a result, the initial carbon price drops with shortening planning horizons. Consequently, emissions increase, TNAC and MSR volumes decrease in the short term, resulting in lower cancellation.

Progressing in time, myopic firms update their information and adjust their behavior accordingly. Under myopia, the lower initial banking efforts amplify allowance scarcity in the long run. As a result, prices increase stronger for myopic decision-making. Under perfect foresight, firms choose the optimal abatement path, where prices develop over the whole time-span according to the Hotelling rule stated in equation 3. Shortsighted firms ex-ante plan their abatement according to Hotelling within the planning horizon. When time passes and more information becomes available, they adjust the price according to the increased allowance scarcity. As a result, the (ex-post) price development deviates from Hotelling.

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