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The Market Stability Reserve in the EU Emissions Trading System: A Critical Review

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Abstract

Having experienced low prices for about a decade, the European Union Emissions Trading System has been supplemented with the market stability reserve (MSR) that adjusts the supply of allowances to market outcomes. We critically review the literature assessing the performance of the MSR against several policy objectives. In doing so, we cover both conceptual aspects and quantitative assessments. We conclude by pointing out important policy implications and open issues for further research.

1. INTRODUCTION

The European Union Emissions Trading System (EU ETS) is often described as the cornerstone of European climate policy and the prototype for other ETSs that followed. Introduced in 2005, the EU ETS is now in its fourth phase (2021–2030). The system went through several reforms over the years, in a sort of fine-tuning process operated by European institutions to improve its design and adjust it to different circumstances arising along the way. Among these reforms, the EU ETS market stability reserve (MSR) is certainly one of the most remarkable, if not the single most important change in the system's design so far.

Starting operation in 2019, the MSR is intended to address the large market imbalances observed in the EU ETS in the past and to prevent such a buildup in the future. Indeed, several factors such as overallocation of free allowances, the financial crisis in 2008, and policy overlaps with renewable energy and energy efficiency policies have generated a large surplus of emission allowances on the market, which comprised approximately 140% of annual ETS emissions in 2018 (Eur. Union 2018, Rosendahl 2019).

To address this glut, the MSR adjusts allowance supply by transferring to the reserve allowances withheld from auctions and either releasing or canceling them at a later stage. This mechanism, governed by predefined rules, is meant to increase the system's resilience to major shocks and foster synergies with other climate policies such as renewable support schemes and coal phaseouts.

Globally, the MSR is one of a kind. It is a regulatory innovation introduced by the European Union (EU) to save its ETS when its credibility and viability seemed to be at risk due to low allowance prices. The novel component is to adjust the future supply of allowances based on the number of allowances banked by firms, which turned out to be successful in the short run: The introduction of the MSR and the accompanying revision of the rules in 2018 reinvigorated allowance prices in the EU ETS. The 2018 reform strengthened the MSR and increased the linear reduction factor, i.e., the speed at which the cap is reduced over time to stay in line with EU emission reduction targets for the ETS sector. Both measures increased expected scarcity of allowances, and the price response confirmed the point that the EU ETS is an intertemporal market that is sensitive to policy interventions even if they affect market fundamentals only in the medium term (Koch et al. 2016, Salant 2016).

However, some MSR features cast doubt on its capacity to address emerging problems in the future. To begin with, when the MSR was already conceived, Gollier & Tirole (2015) pointed out that there is no immediate economic rationale to condition supply adjustments on the intertemporal use of allowances rather than on the allowance price. This pertains to the intervention itself, because it could be argued that price levels in 2013–2017 were too low not because the surplus (i.e., banking) was too large as conventional wisdom often goes, but rather because it was not large enough, as market participants did not sufficiently anticipate future scarcity. The choice of values for the volume-based triggers to take in or release allowances was motivated to reflect typical hedging needs (Eur. Union 2014), but neither is there apparent economic rationale for it nor was it ever justified or explained in legal documents. Furthermore, as our review shows, a large body of research that followed the implementation of the MSR suggests that, contrary to its stated aims, it may generate larger price volatility, higher vulnerability to speculation, and potentially counterproductive impacts on emissions and prices. This led to a heated debate between scholars and policy makers on whether and how the instrument should be reformed.

Building on the literature and evidence at our disposal, this review intends to contribute to this ongoing debate and to a better understanding of potential problems looming ahead. In doing so, we provide the main findings and policy insights emerging from extant studies in nontechnical language to make this complex issue accessible to both nonexperts and the ever-growing audience of professionals working or interested in climate policies. At the time of writing, the EU's legislative procedure to revise the EU ETS and MSR for the rest of the decade was in full swing. Following the European Commission's proposal of June 2021 and statements from the European Parliament and Council, a political agreement was reached at the formal trialogue meetings on December 18, 2022 (Eur. Parliam. 2022; Eur. Union 2021, 2022; Marcu et al. 2023). While briefly touching upon key points of the latest reform consensus, our goal is to capture and discuss structural aspects of the MSR and implications that might emerge in the long run.

The structure of the review is as follows. Section 2 briefly illustrates the events that eventually led to the introduction of the MSR and describes its functioning and price effect. Section 3 reviews the rapidly growing literature on the MSR, emphasizing the main findings that emerge from both theoretical contributions and applied studies. Section 4 discusses the future perspectives of the MSR, focusing particular attention on the open research and policy issues that need to be addressed in the next few years. Section 5 provides some concluding remarks.

2. HISTORY AND DESIGN OF THE MARKET STABILITY RESERVE

To meet its obligations arising from the Kyoto Protocol of 1997, the EU implemented an ETS to reduce greenhouse gas (GHG) emissions from the energy sector and large emitting industries. Due to several constraints caused by, for example, the retention of sovereignty in taxation by its member states, an EU-wide harmonized carbon tax was politically infeasible (Christiansen & Wettestad 2003, Ellerman & Buchner 2007). Instead, member states agreed on an ETS, allowing for national accountability of allowances and creating distinct auction revenues, ultimately avoiding fiscal problems. In 2005, the EU ETS started to operate with a three-year pilot phase, generating a price for about half of the EU's GHG emissions by regulating the energy sector and emitters in heavy industry. However, numerous exogenous factors, allowance allocation rules, and design problems led to a supply-demand imbalance and slumping prices. This became particularly pronounced following the economic crisis starting in 2008, which led to decreasing demand for allowances (De Perthuis & Trotignon 2014, Koch et al. 2016). From its start, the system's evolution has been marked by questions about allowance allocation, leading to a series of interventions and design changes, as elaborated recently by Sato et al. (2022).

With prices persistently within the range of €4–10 since the end of 2011, legislators began to adjust the supply of allowances in the EU ETS in response to market outcomes well before a scheduled formal revision of the system. In a first attempt to curb supply and boost prices, allowances were backloaded; i.e., 900 million allowances otherwise auctioned in 2014–2016 were kept from the market to return via auctions in 2019 and 2020. There was no sustained impact on prices as would be expected in a market with well-functioning intertemporal arbitrage (Koch et al. 2014, Richstein et al. 2015, Salant 2016, Chaton et al. 2018). Upon this realization, the European Commission proposed the establishment of the MSR to institutionalize a mechanism to reduce short-term supply and store allowances to be released back to the market at a later date, hence without altering the long-run cap of the EU ETS (Perino & Willner 2016).

The MSR adjusts supply by taking in allowances from or releasing them to auctions, thus affecting short-term scarcity. The intake of allowances is determined by two parameters, the total number of allowances in circulation (TNAC) and the intake rate. The former is the amount of allowances banked by market participants for future use at the end of each year.[1] The latter determines what percentage of the TNAC will be withheld from future auctions and moved into the

[1]The TNAC is computed as the contemporaneous excess supply of allowances: TNAC = supply – (demand + MSR), where the supply is given by the total number of allowances issued under the EU ETS from the current phase plus the ones banked from the previous phase and the international credits (CERs) exercised by

MSR. Depending on the TNAC, the MSR acts in one of three modes: If the TNAC exceeds an upper threshold of 833 million allowances, the MSR takes in allowances in proportion with the intake rate, and if it drops below 400 million allowances, the MSR releases 100 million allowances from its holdings spread over a 12-month period. For TNAC values in between these thresholds, the MSR remains idle (Eur. Union 2015).

The legislation of the MSR in 2015 had no substantive impact on prices, again in line with the predictions based on well-functioning intertemporal arbitrage because it did not adjust the long-run cap; i.e., all allowances moved to the MSR would eventually be released back into circulation (Perino & Willner 2016). This first version of the MSR never became operational, though, and was supplanted by a reformed version in 2018, which then became operational in 2019. The reform introduced a major change to the MSR's functioning and thus to its market impacts. In particular, the long-run cap became endogenous to market outcomes because a provision for automatic cancellations of MSR holdings was added. De facto, the reserve now acts as a tool to increase policy stringency, making the cap of the EU ETS a function of market participants' banking behavior and hence of current and anticipated demand for allowances.

Although previous theoretical (Roberts & Spence 1976, Pizer 2002, Newell et al. 2005, Murray et al. 2009, Burtraw et al. 2022) and most practical [Regional Greenhouse Gas Initiative (RGGI), California's cap-and-trade program] attempts at managing allowance markets have explicitly defined allowance supply functions, this is not the case for the MSR. By linking supply adjustments to the total number of permits banked, i.e., to the TNAC instead of to price levels, the link between shifts in allowance demand and price changes is not directly observable. While the Eur. Union (2021) suggests—and apparently has designed the MSR on this presumption—that total banking and price levels are negatively related, treating the MSR as an upward-sloping allowance supply function has turned out to be misleading. Bereft of the established and intuitive supply-demand curve analysis for comparative statics, environmental economists, ourselves among them, strived to understand how the MSR affected quantity and price responses to exogenous shifts in demand, e.g., in the form of overlapping climate policies, business cycles, and regulatory reforms. Only recently, Perino et al. (2022a) derived an explicit representation of the MSR in a simple supply-demand curve framework and showed that the slope of the implicit allowance supply curve induced by the MSR depends on the timing of shifts in the allowance demand curve. This case-specific implicit allowance supply curve can be upward or downward sloping, driven exclusively by the timing of the exogenous shock to be analyzed. The following sections present the current state of knowledge about the MSR and provide the intuition behind key results in the literature.

3. CRITICAL REVIEW OF THE MARKET STABILITY RESERVE PERFORMANCE

In this section, we critically review the literature on the MSR and its impacts on market outcomes. We begin with contributions of a conceptual and theoretical nature before turning to applied and simulation-based studies.

3.1. Conceptual Analysis

The quest for environmental regulation that automatically adjusts to shocks in marginal abatement costs has been ongoing for half a century. The very last paragraph of Weitzman's seminal

installations up to 2018. The demand side is represented by the allowances and credits already surrendered for compliance or canceled, plus the allowances held in the MSR (Eur. Union 2015).

contribution (Weitzman 1974) already hints at mixing price- and quantity-based instruments, which was then formalized to show the superiority of this hybrid approach in his later work (Weitzman 1978). Roberts & Spence (1976) follow a similar line of reasoning. However, these hybrid schemes were not yet referring to allowance markets. Pizer (2002) moves the debate to cap-and-trade schemes, followed by many others.[2] Murray et al. (2009) summarize the benefits of price-based allowance reserves, and more recently, Burtraw et al. (2022) combine theory, experimental evidence, and real-world examples to advocate in favor of defining explicit allowance supply functions in cap-and-trade schemes. Karp & Traeger (2021) propose a smart cap that optimally adjusts the volume of emissions an allowance can cover based on changes in the allowance price that are caused by shocks.

Newell et al. (2005) are the first to consider a flexibility mechanism that adjusts the cap based on allowances banked by market participants. They build on the work of Kling & Rubin (1997), who suggested a time-dependent trading ratio to move allowances from one period to the next and combine it with a rule to set the cap in the final period that includes counterbalancing the bank of allowances. Lintunen & Kuusela (2018) build on that and propose a Markov policy that offsets the bank in each period. Offsetting the amount of allowances held by market participants has become somewhat of a common practice in the RGGI (Reg. Greenhouse Gas Init. 2017). Gerlagh & Heijmans (2018) consider a pure stock pollutant and derive an optimal mechanism that adjusts the cap as a linear function of the number of banked allowances and keeps a one-to-one trading ratio. While their mechanism shares properties with the MSR, they differ in that the adjustment rate in the optimal mechanism accounts for new information revealed by the market over time. Kollenberg & Taschini (2016) consider a design that comes close to the MSR after the 2018 reform; i.e., it features a target corridor for the number of banked allowances and an adjustment rate of the future cap if the bank is outside this corridor. They show that such an instrument spans the entire range between a pure quantity-based and pure price-based instrument. This foreshadows a later finding by Perino et al. (2022b), who point out that a reform proposal by the European Commission contained in the Fit-for-55 package of 2021 and adopted in 2023, at least temporarily, converts the EU ETS into a pure price instrument, albeit without ever explicitly specifying price levels. These contributions were all concerned with designing a mechanism with desirable properties and show that conditioning future allowance supply on the number of banked allowances can indeed improve market stability and welfare.

Next, we turn to the literature that takes the actual design of the MSR as a starting point for analysis and checks whether it is suitable to achieve the objectives stated in the legislation or assesses it against other objectives, e.g., increasing welfare or incentivizing low-carbon investments. In order to structure the discussion, aside from impacts on short- and long-term price levels, we focus on two prominent policy objectives of the MSR, namely increasing the resilience of the EU ETS to shocks and raising synergies with other climate and energy policies applied to sectors already regulated by the system.

3.1.1. The 2015 MSR. Perino & Willner (2016) show that, because of its long-term cap-neutrality, the 2015 MSR only affects price and emission paths in both the short and long run when its interventions make the original path of abatement infeasible due to artificially induced temporary scarcity (i.e., firms would like to borrow allowances from the future but cannot be due to a binding borrowing constraint). The fixed long-run cap gives rise to the waterbed effect, the phenomenon whereby any policy overlapping an ETS with a fixed cap only shifts allowance use

[2] In parallel, Laffont & Tirole (1996a,b) initiated a different yet complementary theoretical strand of analysis using a mechanism design approach.

in time and space but does not increase stringency. Hence, the regulator's objective of increasing synergies with other climate policies that apply to EU ETS sectors cannot be achieved. Perino & Willner (2016), as well as Richstein et al. (2015), Holt & Shobe (2016), Chaton et al. (2018), Kollenberg & Taschini (2019), and Quemin & Trotignon (2021), find mixed results concerning the MSR impacts on the resilience to supply-demand imbalances if measured as the price responses induced by such shocks. Notably, Kollenberg & Taschini (2019) expand their analysis to risk-averse firms and show that changes in the probabilistic distribution of the length of the banking period induced by a reserve mechanism may lead to higher price variability. The MSR reduces liquidity in the short run, thereby increasing the risk that the nonborrowing constraint becomes binding, leading to an increase in short-run price volatility. In the long run, the cap-preserving 2015 version of the MSR increases liquidity and decreases price volatility. This entails higher risk premia for holding allowances. As a result, firms will deplete their holdings faster, entailing lower abatement and price levels. Much like Perino & Willner (2019), they find that without a permanent invalidation of allowances from the reserve, the original MSR could have a negative impact on investment incentives.

3.1.2. The 2018 MSR. The 2018 revision of the MSR doubled its intake rate, but most importantly, it introduced an add-on feature to permanently cancel allowances from 2023 onward. This rendered the long-run cap endogenous (Perino 2018). Because of the intertemporal character of the allowance market, the new rules imply that even past events that affected emission and hence banking decisions by firms since 2008 now have an impact on the long-run cap. This required a reassessment of the MSR's performance with respect to its ability to increase resilience in the face of shocks and foster synergies with overlapping climate policies.

With a flexible long-run cap, climate policies targeting installations covered by the EU ETS can reduce total emissions and substantially shift price paths. As Rosendahl (2019) initially pointed out, there is now also the risk that such policies may backfire. Gerlagh et al. (2021) and Perino et al. (2022a) formally show that adjusting the long-run cap based on the number of banked allowances is a double-edged sword. An unanticipated reduction in allowance demand induced by a climate policy overlapping the EU ETS reduces total emissions (see **Figure 1*a***). However, an expected reduction in future scarcity (e.g., due to the announcement by a large member state to phase out coal-fired electricity production) induces a drop in current prices without shifting current marginal abatement cost curves. Hence, emissions increase in the short run, reducing the number of allowances banked and, in consequence, also the number of allowances moved into the MSR and being cancelled later. If at the time the actual demand reduction takes place the MSR has stopped taking in allowances, then the net effect of announcing a future allowance-demand-reducing climate policy is to increase total emissions (see **Figure 1*b***). This is the opposite of the intended effect and undermines the coherence of the European climate policy mix (Willner & Perino 2022b). Gerlagh & Heijmans (2019) point out another side effect of the cancellation mechanism: Additional cancellations by intrinsically motivated individuals or member states become less effective as they partly substitute automatic cancellations by the MSR. This effect can be avoided if allowances are bought immediately but are only canceled once the MSR has stopped taking in allowances. This highlights the crucial importance of timing of any intervention under the MSR.

This finding does not contradict the more optimistic findings of the papers that recommend banking-based flexibility mechanisms discussed above. These papers only consider unanticipated shocks for which the performance of such mechanisms is high. Because they do not look at shocks that are anticipated by market participants well in advance, they are not able to detect the fundamental downside of banking-based approaches. Specifically, banking is negatively

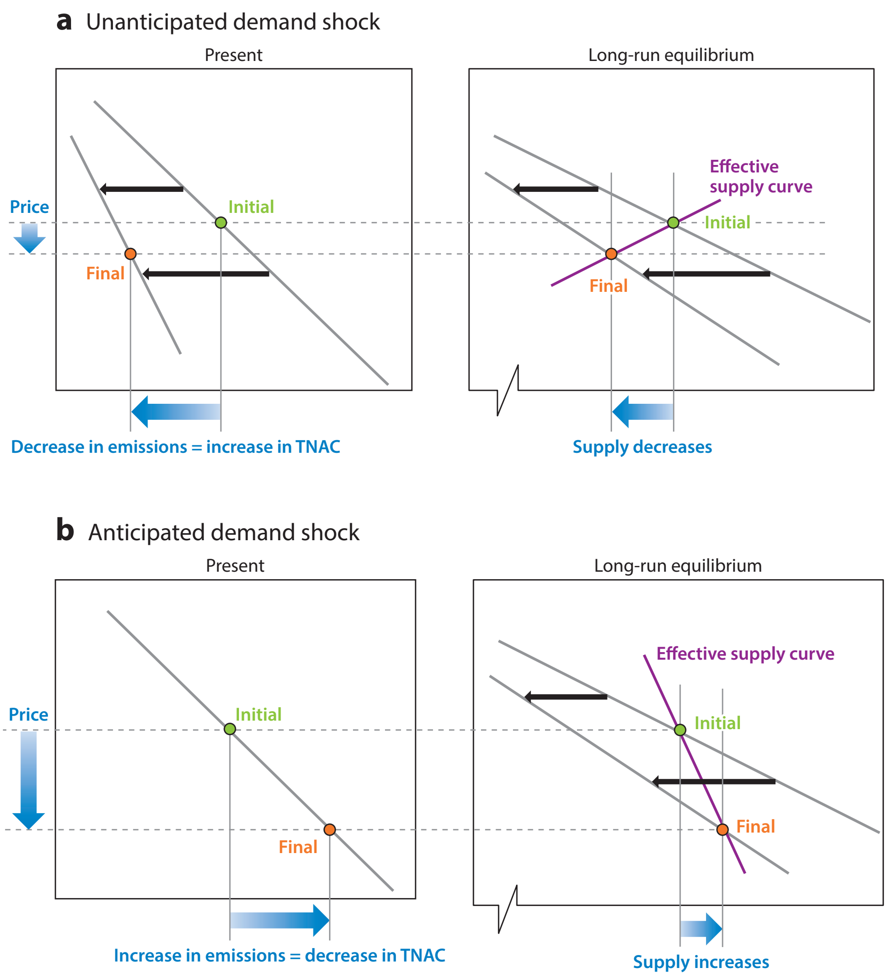

Figure 1

The market stability reserve (MSR) response translates into a case-specific effective supply curve. Graphs illustrate the demand shocks that induce identical shifts in long-run demand. (*a*) The shift in the demand curve is unanticipated and immediate: Present emissions decrease, the total number of allowances in circulation (TNAC) increases, and the MSR cancels additional allowances in response. Prices and long-run supply drop; i.e., the effective supply curve is upward sloping. (*b*) The demand shift is anticipated, but the present demand curve is unaffected: Present emissions increase, and the TNAC and cancellations by the MSR both decrease, implying a ceteris paribus increase in long-run supply. Prices drop (more than in panel *a*) while supply increases; i.e., the effective supply curve is downward sloping. The response of a price-based flexibility mechanism with a strictly upward-sloping supply curve would be akin to panel *a* and, most importantly, exactly identical for both types of shocks. Figure adapted from Perino et al. (2022a).

correlated with past and current scarcity but positively correlated with expected future scarcity. This makes banking—in contrast to the allowance price—an unsuitable indicator of scarcity in an intertemporal allowance market (Perino et al. 2022b). Moreover, the literature that proposed banking-based flexibility mechanisms assumes that the mechanism is active throughout the entire remaining time horizon of the cap-and-trade scheme. Again, this is not the case for the MSR, as the flexibility, at least at the margin, stops once the TNAC drops below the intake threshold (currently 833 $MtCO_2$). The soft spot of the MSR—namely, anticipation of changes in medium- to long-term scarcity—was not part of the set of scenarios looked at by this literature.

In terms of price effects, the assessments are sensitive to modeling approaches. Changes in price levels crucially depend on how many allowances are cancelled by the MSR, which in turn is determined by the time profiles of allowance demand and supply. Both are hard to predict due to economic, technological, and political sources of uncertainty. The banking-based approach of the MSR is sensitive to the precise timing of any future event, and, hence, price predictions can vary substantially across different modeling assumptions (see Section 3.2 for details). Although Perino & Willner (2017) predicted only minor price impacts of the design implemented in 2018 using a highly stylized model, larger shares of the observed price jump have been attributed to the MSR by more sophisticated approaches (Bruninx et al. 2020, Quemin & Trotignon 2021). With respect to price responses to shocks, i.e., the resilience of the system, anticipations again are crucial. Perino et al. (2022a) show that there are case-specific supply-curve representations of the long-run cap adjustments induced by the MSR. For unanticipated shocks such as those illustrated in **Figure 1*a***, the implicit allowance supply curve is upward sloping. Hence, it stabilizes prices, as has been illustrated by the COVID-19 pandemic (Gerlagh et al. 2020, Azarova & Mier 2021, Bruninx & Ovaere 2022). For anticipated shocks such as those shown in **Figure 1*b***, the implicit supply curve can rotate to an extent that it slopes downward. If this is the case, the MSR escalates price responses, creating partially self-fulfilling prophecies (Perino et al. 2022b). Note that the effective shift in the demand curve is the same in both parts of **Figure 1** in the long run: They only differ in terms of timing.

3.1.3. The 2023 reform.

As part of the process to adjust the EU's set of climate policies to the new targets agreed on in 2021, the EU legislative bodies have adopted several changes to the MSR (Marcu et al. 2023). First, the decrease of the intake rate from 24% to 12% has been postponed from 2023 to 2030. Second, to avoid threshold effects around the upper intake corridor of the MSR, as identified by Osorio et al. (2021) and Quemin (2022), a 100% marginal intake rate will be applied when the TNAC is between 833 and 1,096 million allowances. Third, the complex cancellation trigger has been simplified and fixed ex ante. In other words, from 2023 onward, the MSR will hold no more than 400 million allowances, resulting in the cancellation of any quantity currently stored beyond this amount and of all allowances entering the reserve while it is at full capacity.

However, the reform leaves several key concerns raised in the literature unaddressed. Most importantly, it sticks to the banking-based approach. Because the TNAC continues to serve as the indicator for scarcity, the proposed increases in the marginal intake rate would strengthen both the stabilizing and destabilizing effects of the MSR (Perino et al. 2022b, Willner & Perino 2022b): Unanticipated shocks will be buffered more effectively while the effects of anticipated changes in supply or demand will be amplified. The increase in the marginal intake rate may also aggravate MSR impacts on price stability (Gerlagh et al. 2022, Perino 2022) and make its asymmetric potency in reducing supply versus expanding it even more prevalent (Quemin 2022). In this context, there are thus calls for a price-based mechanism based on, e.g., Article 29a of the EU ETS Directive. The reform amends Article 29a, such that the price-change trigger, which so far has never been activated, will be somewhat more responsive and less discretionary. However, it remains an addition to, not a replacement of, the MSR. Moreover, it only responds to price increases, not to price drops. Hence, the future EU ETS might feature two mechanisms affecting supply that pursue different objectives: increasing the cap's stringency and reducing price fluctuations. Willner & Perino (2022a) analyze the resulting incoherence and propose a single, symmetric, price-based instrument to merge the MSR with Article 29a to form a new, multipurpose instrument capable of achieving the MSR's tasks coherently. Such price-based flexibility mechanisms allow the policy maker to transparently determine an upward-sloping allowance supply function that reflects society's trade-off between climate change mitigation and the economic burden of internalizing the externality. In the context of **Figure 1**, the response of such a mechanism would be identical and stabilizing to both types of shocks.

3.2. Applied Analysis

The previous section has identified a number of theoretical mechanisms—intended and unintended by the regulator—through which the MSR can affect market outcomes. However, questions arise as to the extent to which these effects will materialize in the EU ETS. Quantification requires models that are better calibrated to the specifics of the EU ETS and the sectors it regulates than the ones typically used in the theoretical works reviewed in Section 3.1. Although stylized models are convenient and useful for identifying and decomposing specific theoretical effects in idealized setups, this section focuses on more elaborated models and calibration approaches (Fell 2016, Mauer et al. 2020, Quemin & Trotignon 2021, Tietjen et al. 2021) as well as detailed simulation models (Bruninx et al. 2020, Osorio et al. 2021). This allows us to complement the previous section and review existing quantitative assessments of the MSR performance.

We structure the discussion of the main applied works and numerical results in line with the theoretical mechanisms identified above in Section 3.1, namely the MSR's impacts on (*a*) price levels in the short and long term; (*b*) price volatility, stability, and resilience to shocks; and (*c*) interactions with companion climate and energy policies. This structure provides indicators and metrics that allow us to assess the effectiveness and performance of the MSR against its three main objectives individually as indicated in the MSR decision: (*a*) introduce resilience to structural shocks, (*b*) increase synergies with other climate and energy policies (i.e., mitigate the waterbed effect), and (*c*) increase investment incentives in low-carbon technologies.[3]

Our structured review of the applied literature focuses primarily on the design of the MSR as per the 2018 reform and current reform proposals. The main results from the literature review are summarized in **Table 1**. For each theoretical dimension, the table provides, if available, the range of quantitative estimates of direction and size or else summarizes the ambiguity. It also highlights some takeaways with practical and policy relevance.

The key overarching insight from this review is that MSR impacts are extremely sensitive to modeling approaches and parameters as well as to assumptions about firm behavior (e.g., the degree of cost optimization, discount rate, and planning horizon and risk aversion). In effect, changes in any parameter that influences firms' banking decisions or constrains their intertemporal use of allowances will translate into changes in supply adjustments through the MSR. This adds a layer of model uncertainty on top of the uncertainty on market outcomes inherent to the MSR itself, as identified in the theoretical mechanisms in Section 3.1. Arguably, such model uncertainty may reinforce the unintended consequences of the MSR in terms of market destabilization. That said, some effects seem to be more prevalent and dominant than others, as the following review suggests.

Before distilling several quantitative results that illustrate this overarching insight when we discuss the papers in question, we briefly highlight some key results that prefigure our detailed review. First note that Osorio et al. (2021, table 1) provide a useful summary of the estimates of cumulative MSR cancellations found in the literature. Their wide range (1–13 $GtCO_2$) is in large part

[3]There is thus no single metric to define and measure the effectiveness of the MSR. Objective *c* is the most difficult to quantify and hence the least quantified objective, as our review attests.

Table 1 Summary of impacts of the MSR on key market outcome measures

Type of impact	Direction	Size	Explanation	Policy implication
Price level (short term)	Price increases	Small/medium (medium uncertainty)	In the short term, prices rise only marginally in simple/standard models with perfect intertemporal arbitrage Effect size larger in models with rolling finite planning horizons, risk aversion, transaction costs, or heterogeneity in trading behaviors and motives Short-term effect usually smaller than long-term effect and depends on degree of deviation from standard model	MSR initially provides limited price support
Price level (long term)	Price increases	Small/large (high uncertainty)	Cancellations increase overall scarcity and raise long-term price Total cancellation volume and hence scale of price rise highly uncertain (1–15 $GtCO_2$ range), hinging on firms' banking behavior (i.e., discount rate, planning horizon, cap trajectory, economic shocks, timing and predictability of overlapping policies)	Scale of long-term impact is highly uncertain and a function of behavioral traits of firms and features of demand shocks MSR adds large uncertainty to long-run cap and price path
Price volatility	Ambiguous	Small/medium (high uncertainty)	Results can be formally derived only with stochastic models and vary across studies MSR can increase volatility by shortening the banking period and constraining the hedging feasibility space Reinjections can dampen volatility when banking is low relative to no MSR (but less so than with an equivalent price collar)	MSR is likely to increase price volatility, at least relative to a price collar
Price stability (e.g., against speculation)	Stability decreases	Small/high (high uncertainty)	MSR induces instabilities of its own, i.e., multiple equilibria and oscillatory behavior when TNAC is close to the intake threshold MSR sustains self-fulfilling prophecies and amplifies price impacts of changes in expectations (rather than current fundamentals) due to implied downward-sloping effective supply curve	MSR instabilities may increase vulnerability to speculation Planned MSR revision removes threshold effects but raises likelihood of self-fulfilling prophecies

(*Continued*)

Table 1 (*Continued*)

Type of impact	Direction	Size	Explanation	Policy implication
Resilience to shocks and other climate policies	Ambiguous	Small/high (high uncertainty)	Size and direction (relative to shock) of MSR response to demand shocks are highly dependent on their timing and structure Sensitivity of long-run cap can be above 100% of shock size (for shocks shifting demand to the future), below −100% (for policies reducing expected demand in the future) or anywhere in between Size and duration of effect also depend on behavioral traits of market participants (e.g., smaller and shorter with rolling finite horizons compared to perfect intertemporal arbitrage) MSR designed to constrict, not expand, supply irrespective of the direction of demand shocks; hence, it supports prices rather than making them responsive For unexpected demand reductions such as those caused by COVID-19, simulations suggest that shock is largely absorbed unless there is a large impact on long-run demand For complex policies such as coal phaseouts, stabilizing response to unanticipated short-run demand reduction is (partially) offset by destabilizing response to anticipated long-run demand reduction	Scale of waterbed puncture and green paradox remains an open question partly due to the uncertainty created by the MSR itself MSR complicates the design of overlapping policies and national or voluntary cancellation measures (e.g., coal phaseout)

Abbreviations: MSR, market stability reserve; TNAC, total number of allowances in circulation.

explained by different modeling assumptions, including notably different discount rates.[4] In a similar vein, Quemin & Trotignon (2021) compare market outcomes when firms use an infinite versus rolling finite horizon and when they are fully sophisticated versus unsophisticated in their cost optimization over time with the MSR in operation. When firms use an infinite horizon, their degree of sophistication has little impact on price levels and cumulative cancellations (∼5 $GtCO_2$). When firms use a rolling finite horizon, their degree of sophistication matters for price trajectories and

[4]A graphic in Osorio et al. (2021, figure C.1) also shows how banking volumes and horizon—and in turn MSR intakes and cancellations—are extremely sensitive to the chosen discount rate.

cumulative cancellations. Specifically, both are higher with full sophistication, with cancellations of around 10.5 versus 8 $GtCO_2$ without sophistication.

We now turn to our detailed review and start with the works that leverage detailed simulation models. A first analysis by Bruninx et al. (2020) employs a detailed, long-term investment model capturing the interactions between the electricity sector, industry sector, energy and renewable energy certificate markets, and the EU ETS, including the MSR. An important feature of the model is that the marginal abatement cost function for electricity and industry sectors is endogenously determined, time dependent, and nonlinear. This better captures the relationship between emissions and prices at high abatement levels. Their detailed quantitative analysis illustrates the large uncertainty about cumulative emissions depending on a variety of factors such as the MSR parameters, value of the linear reduction factor, reach and stringency of overlapping policies, and other changes in the electricity and industry sectors. In their framework assuming perfect foresight and rational agent behavior,[5] Bruninx et al. find that increasing the linear reduction factor is the most cost-effective way of raising ambition in the EU ETS. But even holding EU ETS and MSR parameters fixed at the 2018 reform levels, they find cancellations by the MSR spanning 5.6 to 17.8 $GtCO_2$ for different demand trajectories.

Osorio et al. (2021) also use a detailed model of the electricity sector in combination with a stylized representation of the industry sector, which they couple with an MSR simulation model to systemically analyze the impact of changes in key MSR parameters to inform the MSR review.[6] They quantify how the effect of the MSR on the long-term price is highly dependent on the discount rate (a higher discount rate implies less banking and thus fewer cancellations) and the linear reduction factor (LRF; a higher LRF implies more banking and thus more cancellations but this effect saturates). MSR parameters also matter but display less-systematic effects, though the intake rate plays a greater role than the outtake quantity. Osorio et al. also quantify the MSR-induced price volatility due to oscillatory intake behavior when the TNAC is near the intake threshold (this effect is addressed in the current reform).

The model developed by Osorio et al. (2021) also illustrates how the extent of waterbed puncture by the MSR is sensitive to modeling assumptions and, in turn, how the design of effective overlapping policies is made more complex. We here focus on the specific example of the German coal phaseout because identifying comparable quantitative results is difficult if not impossible in more general contexts. This is because the MSR response to shocks and overlapping policies is highly dependent on their size, timing, and structure.[7] Specifically, Pahle & Edenhofer (2021) discuss the complexity of determining the number of allowances that Germany should buy and cancel to compensate for the waterbed effect induced by the coal phaseout, net of MSR cancellations (i.e., net of the partial MSR-induced waterbed puncture). The analysis shows emission estimates to be very uncertain and sensitive to assumptions (e.g., about the structure of allowance demand over time). In some cases, the coal phaseout is found to induce a green paradox (increasing overall emissions), while in others its effect on overall emissions is essentially negligible.[8]

[5]The model is solved as a large-scale complementarity problem over a 45-year period with fully rational (i.e., forward-looking price-taking risk-neutral) economic agents.

[6]The industry is represented in a stylized form through an exogenously given marginal abatement cost curve.

[7]The limited comparability of results across studies is particularly salient for large shocks that alter the MSR intake cutoff date. While this should in principle be less pronounced in the case of marginal demand shocks that do not change the cutoff date, quantitative estimates of the MSR response to such shocks are also found to vary drastically, showing a sensitivity in the long-run cap that can be above 100% of the shock size, below −100%, or anywhere in between.

[8]This is also reflected in the work of Rosendahl (2019) and Perino (2019).

We now turn to less-detailed models that nonetheless enable the analysis of market facets typically not considered in the theoretical analysis above: (*a*) uncertainty and risk aversion and (*b*) path-dependent investments and more realistic firm behavior. Beginning with uncertainty and risk aversion, to the best of our knowledge, only Fell (2016) and Tietjen et al. (2021) develop proper stochastic dynamic optimization models, which permit a fully fledged characterization of price volatility under different supply adjustment mechanisms.[9] Analyzing the 2015 variant of the MSR, Fell (2016) finds that it has the potential to reduce allocation and increase prices in the short term and reduce price volatility relative to no MSR.[10] He also shows that a price collar can achieve the same expected cumulative emissions with less price volatility and at lower expected costs.[11] Tietjen et al. (2021) develop an intertemporal stochastic equilibrium model with investment calibrated to the power sector where firms can be risk neutral or risk averse.[12] Without MSR, risk aversion induces a demand for hedging that distorts the standard Hotelling price path into a U-shape price path. The MSR amplifies this by increasing the hedging value of permits, i.e., further constraining hedging opportunities. Specifically, the MSR reduces the size of the bank, so that relative to risk neutrality the price is higher in the short term but grows at a lower rate. Adding cancellations essentially entails an upward shift in the price curve due to higher stringency overall (level effect) and is also found to increase price volatility. Overall, it is difficult to assess whether the identified effect sizes are realistic, as these analyses do not do backcasting.

Turning to path-dependent investments and more realistic firm behavior, Quemin & Trotignon (2021) develop a stylized model where a representative firm has a rolling finite planning horizon and exhibits bounded responsiveness to the MSR. Using model parameters calibrated to replicate past annual price and banking dynamics, they quantify how MSR impacts differ considerably depending on the firm's horizon and degree of responsiveness. For instance, compared to an infinite horizon, cancellations are doubled with a rolling horizon, and MSR-induced supply changes in response to small one-off demand shocks are even more limited in size and time. Using the same model with a slightly different calibration,[13] Quemin (2022) seeks to inform the MSR review by assessing a suite of MSR parameter changes and characterizing the interaction between the MSR and the LRF. Notably, dynamic MSR thresholds declining over time—a feature not taken up in the current reform—are found to increase overall cost-effectiveness and alleviate MSR-induced oscillatory behavior. However, MSR-induced resilience to shocks always remains limited and one-sided; i.e., by design, the MSR acts more as an unconditional price support provider than as a responsive price stabilizer. Finally, Mauer et al. (2020), using a model with path-dependent

[9]Kollenberg & Taschini (2019) also develop a stochastic model for a formal analysis that is less amenable to quantitative simulations. The other models studying the MSR response to shocks typically consider one-off permanent shocks but do not resort to a formal dynamic programming setup. In between these two types of approaches, Quemin & Trotignon (2021) derive expected equilibrium paths along certainty-equivalent paths for baseline emissions, invoking a first-order approximation first suggested by Schennach (2000).

[10]However, these results hinge on the MSR taking in substantially more allowances than effectively released in the long run. Although there is no dedicated cancellation mechanism in the 2015 variant, Fell (2016) assumes that allowances still in the MSR in 2050 will never be used for compliance against emissions. For scenarios where the MSR is empty in 2050 (i.e., the MSR is cap-neutral), impacts on price levels and volatility are minor.

[11]Additionally, the effectiveness of the 2015 MSR in removing excess allowances and providing price support decreases with the firm's discount rate (the converse holds for price collars).

[12]Specifically, Tietjen et al. (2021) consider a model populated by a polluting firm, a clean firm, and a speculator (i.e., an economic agent without compliance obligations). We discuss in more detail the importance of having some market microstructure embedded in ETS models in Section 4.2.

[13]Also note that a simplified version of this model was used for the European Commission's MSR reform impact assessment in 2021; see Eur. Union (2021).

investments, show how the mere auction postponement through the MSR sustains long-term effects on price and emission levels due to the path dependency of capital investments.[14]

A common finding of these works is that MSR-driven changes in transitional stringency of the emissions cap have implications that go beyond changes in long-term price levels and cancellation volume (i.e., cumulative stringency). In particular, under a rolling finite horizon, the MSR front-loads abatement and improves effectiveness, partly compensating for firms' truncated planning horizon. In turn, directly raising ambition through a higher LRF is not equivalent to indirectly raising ambition through the MSR (the latter can be more cost-efficient than the former). Similar effects exist when MSR-induced auction postponement triggers permanent investments in abatement technologies.

To summarize, despite an arguably wide range of numerical results, e.g., in terms of overall cancellations, a general message from the literature is that the MSR is helpful in reducing the allowance overhang in the short term. However, the MSR does not increase resilience to shocks and interaction with companion policies as intended, and it also lowers price predictability in the mid- to long term. More research on refined models is thus needed to enhance both our understanding and estimates of the sizes of MSR-induced effects. In the following section, we discuss several ways to do so.

4. PERSPECTIVES FOR THE MARKET STABILITY RESERVE: OPEN RESEARCH AND POLICY ISSUES

In this section, we offer some perspectives for future research on the MSR and ETS modeling more generally, highlighting some open research questions as well as policy issues.

4.1. Improving the Representation of Market Participant Behavior

ETS modelers should strive to better integrate and account for various behavioral and bounded rationality factors that affect firms' ability to trade and cost-optimize allowance use. As we explain below, this has important implications for ex post assessments of market performance and firm behavior as well as for ex ante assessments of market design elements and reforms, such as the MSR. We also refer the reader to Abrell et al. (2022), Baudry et al. (2021), and Quemin & Trotignon (2021) for recent reviews of the empirical, experimental, and theoretical literature on these topics.

In static models, firms' trading behavior depends on (*a*) transaction costs, whose fixed and variable components capture various types of frictions, and (*b*) their evaluation of the opportunity costs of holding allowances. Transaction costs can rationalize firms' observed participation in and intensity of trading (Naegele 2018, Baudry et al. 2021), and their compliance and trading behavior is strongly related to their size, market position net of allocation, sector, productivity, and location (Jaraitė-Kažukauskė & Kažukauskas 2015, Abrell et al. 2022). Illustrating the importance of these factors, Baudry et al. (2021) find that ignoring transaction costs can lead to underestimating the price increase in response to a reduction in supply (as is the case under the current MSR withdrawal mode). Indeed, if firms holding excess allowances do not offer them for sale on the market due to transaction costs, biased opportunity cost evaluation, or other behavioral reasons (e.g., endowment effect), then the resulting price increase can be larger than in the optimum.[15]

[14]Mauer et al. (2020) also quantify how the MSR can increase short-term price volatility because of a shorter banking regime that leaves firms more exposed to unanticipated shocks (when outtake is insufficient).

[15]This also suggests that free allocation does not incentivize firms to trade and use allowances efficiently, partly contradicting the Coasean independence property (Zaklan 2023). As long as free allocation is not phased out,

In dynamic models, firms' cost-optimization behavior depends on their degree of risk aversion (Kollenberg & Taschini 2019, Tietjen et al. 2021), their planning horizon and responsiveness to supply adjustment mechanisms (Quemin & Trotignon 2021), and imperfect information and forecast errors (Aldy & Armitage 2022).[16] For instance, Quemin & Trotignon (2021) show how a rolling finite horizon reconciles the past banking dynamics with observed discount rates and replicates the past price dynamics (including the post-MSR price regime) better than the standard case of an infinite horizon. Section 3.2 has already shown how the MSR's impacts on price and cancellation volumes greatly depend on underlying modeling (i.e., ultimately behavioral) assumptions. Against this background, agent-based modeling seems to be a fruitful approach to assessing market design performance against a broad range of realistic trading and optimization behaviors and is already utilized for energy markets (Richstein et al. 2015, Kraan et al. 2019).

4.2. Accounting for Noncompliance Market Participants

The role and impact of noncompliance actors and financial traders in allowance markets should be given increased consideration, both theoretically and empirically. Although financial intermediaries such as banks have always been active and played a key hedging market-making function in the EU ETS (Cludius & Betz 2020), numerous new types of financial actors recently entered the market concurrently with the reinforcement of both the MSR and overall emissions cap stringency (ESMA 2022). However, their trading motives and strategies are little known, and adequate analysis tools are wanting (Quemin & Pahle 2023). Importantly, this also applies to nonfinancial, noncompliance actors whose trading behavior is heterogeneous and can at times resemble that of some financial actors (Lausen et al. 2022).

In spite of this, however, allowance markets are seldom studied from a financial market perspective or with frameworks using a market microstructure of heterogeneous agents with different trading motives and behaviors (Friedrich et al. 2020b, Quemin & Pahle 2023). On the empirical front, notable exceptions include studies by Lucia et al. (2015), Rannou & Barneto (2016), Creti & Joëts (2017), and Friedrich et al. (2020a). On the theoretical front, models with extra financial or market microstructure elements have been developed by Germain et al. (2004), Colla et al. (2012), Cantillon & Slechten (2018), and Perino (2022). Advancing and expanding these approaches would allow better monitoring of the financial dimension of allowance markets (Pirrong 2009) as well as adequately conceiving and assessing the impacts of market design changes.

Supply flexibility mechanisms should neither invite speculative trading nor undermine market stability in the sense of ensuring the ability of market forces to keep prices in line with fundamentals (i.e., anticipated allowance scarcity) and keep the impact of noise trading in check (De Long et al. 1990). As currently designed, however, the MSR does not meet these criteria. First, it sustains multiple equilibria and affects market liquidity in ways that blur predictability of market outcomes (Gerlagh et al. 2021, Perino et al. 2022b), possibly leading to excess speculation and price volatility. Second, Perino (2022) shows how a banking-based mechanism such as the MSR undermines market self-stabilizing forces (i.e., rational responses to dampen noisy price moves through arbitrage) because it induces effective supply curves that are downward sloping. Price-based collars as used in US allowance markets (Burtraw et al. 2022, MacKenzie 2022) do not suffer from this shortcoming, though they may not be entirely immune to speculative attacks either (Stocking 2012).

it should ideally be supplemented by consignment auctions in order to enhance opportunity cost evaluation, instill an increased dynamism in the market, and improve efficiency (Burtraw & McCormack 2017).

[16]The last point highlights the advantage of having some price certainty: The carbon price can be treated by firms as a known input to production (Davis et al. 2020), and sufficient predictability of the carbon price signal is a key element in efficiently supporting low-carbon investment (Nemet et al. 2017).

4.3. The Political Dimension of the MSR

Another direction for further research is to gain a better understanding of the political dimension of the MSR, mainly in a bid to explain why EU policy makers have chosen this mechanism and not an economically preferable one such as a price corridor. This comprises two aspects. The first one is the belief of policy makers about the alleged effects of the MSR, in contrast to its actual effects. What exactly do they believe, and how is this belief formed? To the best of our knowledge, no research has been done on this issue so far. Yet, insights would definitely help economists to provide more targeted advice and communicate it more effectively.

The second aspect is the extent to which political constraints influenced—and continue to influence—the policy choice space that led to the implementation of the MSR and its particular design. Some research by political scientists on this issue already exists, notably the work by Wettestad & Jevnaker (2019), who argue that the MSR instantiates smokescreen politics to overcome political barriers to increasing stringency. In a similar vein, price floors are typically combined with price ceilings to get political buy-in; they are also often set at relatively low levels initially but then gradually increase over time (Newbery et al. 2019). Further economic research could complement and extend this line of work, notably in the tradition of endogenous environmental policy in a common agency model of politics (see, notably, Aidt 1998). Another direction of research would be to investigate the quality and durability of the rules defining the MSR, expanding previous work by Pahle & Edenhofer (2021). A recent example relates to policy discussions to tap into the MSR to fund part of the REPowerEU plan, literally transforming the MSR into a money supply reserve and possibly undermining confidence in the system overall.

4.4. Linking and the International Dimension of the MSR

Achieving abatement targets becomes increasingly costly as emissions abatement increases in volume and becomes more urgent over time. This makes finding cheaper abatement opportunities particularly important and attractive in pursuing more ambitious emissions reduction targets and climate neutrality. In this perspective, linking ETSs can become increasingly important at the international level as a key instrument to lower compliance costs and raise ambition (e.g., Doda et al. 2019).

However, linking requires alignment across ETSs on a few key features, one of these being the adoption and kind of price-control mechanism (PCM).[17] In practice, different jurisdictions have thus far adopted different PCMs. These can be grouped in two categories, price-based and quantity-based PCMs, depending on whether the PCM is triggered by a price or quantity indicator. In the former case, the PCM activates when a given price threshold (ceiling or floor) is reached, and in the latter case, when the ETS reaches a given quantity threshold (e.g., in terms of over- or undersupply of allowances). Price-based PCMs have been implemented in most jurisdictions, though with slightly different rules in terms of trigger prices and mechanisms and the degree of discretion in the government intervention.[18]

Despite the different mechanisms in place, price-based PCMs all look pretty similar so that they do not seem to represent a main obstacle to linking. In contrast, the MSR adopted by the

[17] See, inter alia, Freestone & Streck (2009), Mehling & Haites (2009), Tuerk et al. (2009), Burtraw et al. (2013), Borghesi et al. (2016), Ranson & Stavins (2016), Quemin & De Perthuis (2019), and Doda et al. (2022) for discussions of the main barriers to linking and the necessary versus optional features that should be aligned for linking to take place.

[18] See Galdi et al. (2020), MacKenzie (2022), and information available on the International Carbon Action Partnership (ICAP) webpage (**https://icapcarbonaction.com/en/ets-map**) for detailed descriptions of the different price-based PCMs.

EU ETS is a quantity-based mechanism. It is a unique PCM that currently isolates the EU in the international context and, as such, may obstruct or even prevent linking with other jurisdictions. Indeed, a price-based and quantity-based PCM may have opposite reactions to the same event. Suppose, for instance, that agents expect future allowance prices to grow. Through intertemporal arbitrage and anticipation, this drives up current price levels accordingly. In the jurisdiction with a price-based PCM (e.g., a cost containment reserve), additional allowances will be injected into the market if prices reach the predefined price threshold. In contrast, in the jurisdiction with a quantity-based PCM (e.g., the MSR), the volume of auctioned allowances will be reduced to cut down on a perceived oversupply deriving from increased banking (which is a rational response by market participants). Because the EU has a PCM that may react in the opposite way compared to other ETSs, this is likely to pose material obstacles to linking.

It is certainly true that being one of a kind is not an issue per se and that a jurisdiction should not necessarily mimic the others. Indeed, the EU ETS was a unique and isolated system at its start and good things came from the fact that the EU set a new way of approaching climate change mitigation. But now that others have followed that way, remaining isolated in the use of a quantity-based PCM may hinder the EU's ability to link to other ETSs and thus reduce compliance costs that are bound to keep rising over time. Moreover, regardless of what others do, a quantity-based PCM may run into trouble at some point, as we have already pointed out. This calls for a reconsideration of the EU PCM and the possible adoption of a price-based mechanism in the future.

5. CONCLUSIONS

The MSR has been the object of heated debate since preliminary conceptual ideas for its design were first floated. Scholars and policy makers have often expressed opposite views on its effectiveness, probably because they have contrasting opinions on the economic versus political principles underlying this instrument. From an economic point of view, the gravest concerns are (*a*) the lack of a clear rationale for both the general banking-based approach and specific design parameters of the MSR. Without a clear rationale, there is a high risk that these rules become an entry point for ever more discretionary interventionism, undermining the capacity to make credible commitments in the long term. In fact, this is the direction the evolution of MSR has taken (Pahle & Edenhofer 2021). (*b*) Relatedly, as this review has shown, the MSR has made the EU ETS increasingly complex, rendering price formation only more difficult to fathom and leading to detrimental impacts on market functioning more broadly (Perino 2018).

The absence of a solid economic rationale notwithstanding, the MSR certainly had a clear political rationale. As Burtraw (2015) rightfully argued, the MSR was politically important to demonstrate that the doctor had not given up on the patient. Stated differently, the MSR was key to signaling that the regulator was willing to save the system whatever it takes. The signal turned out to be effective: To the credit of EU regulators, it instilled confidence in the system and ensured its survival in the short run, relaunching it after a protracted period of low prices.

However, building upon the medical metaphor suggested by Burtraw (2015), the long-term use of the MSR medicine as it currently stands might have undesirable side effects for the patient, which could emerge in the years to come. Indeed, as it happens with some emergency drugs, the MSR has solved a short-run problem, albeit at the cost of an increased degree of uncertainty in the future that entails several long-run problems. While a price-based price control mechanism could be politically difficult to implement—being less palatable to some EU countries—it could be a more direct and simpler instrument giving more certainty to market participants. Moreover, by aligning the flexibility mechanism in the EU ETS with those of most other ETSs, it could help linking in the future, an endeavor that might gain appeal as allowance prices increase in the EU

ETS. Finally, replacing somewhat complicated rules with much simpler ones could garner public support. If all of these benefits were clearly conveyed, the same doctor who saved her patient in the past might now consider prescribing a different treatment to provide a sustainable maintenance medication for the future.

DISCLOSURE STATEMENT

G.P. has consulted for the European Commission (DG CLIMA), the German Federal Ministry of Economic Affairs and Climate Action, and the German Environment Agency on issues related to the market stability reserve. He is also an unpaid member of the scientific advisory boards of three nongovernmental organizations that retire EU ETS allowances. S.Q. has consulted for the European Commission (DG CLIMA) on issues related to the MSR and hereby declares that this article neither was commissioned by Électricité de France nor reflects its views and opinions. M.P. has consulted for the German Federal Ministry of Economic Affairs and Climate Action and for DG CLIMA on issues related to the market stability reserve. The other authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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