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EUROPEAN CARBON MARKET:

Lessons on the Impact of a Market Stability Reserve using the Zephyr Model

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In January 2014, the European Commission proposed the introduction of a Market Stability Reserve (MSR) to improve the functioning of the European carbon emission trading scheme. This article is an attempt to enlighten the possible effects of such a reserve on the functioning of the EU ETS using the behavior-based simulation model Zephyr, specifically designed for representing imperfect inter-temporal compliance behavior in a simple framework. Our results suggest that the MSR can indeed raise the price in the short-medium term, reduce the number of allowances in circulation and foster earlier emission reductions. Nevertheless, it would do so at the expense of higher overall costs, because allowances are unlikely to be returned entirely to the market when needed, thus reinforcing the cap. The MSR also does not seem to have the desired dampening effect in case of external shocks. We conclude that although the MSR can help trigger early abatement and put Europe on a more ambitious abatement pathway over the long term, in the frame of our methodology, it seems unlikely that such a reserve make market participants and the public authority more able to deal with uncertainties in the future.

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1 Introduction

The European Union Emission Trading Scheme (EU ETS) provides the most complete experience to date of carbon pricing through a quantitative tool, a cap-and-trade program (Goulder, 2013). It covers more than 12,000 industrial installations in 30 European countries responsible for almost half of European CO2 emissions. The detailed rules were established in a directive that has been progressively amended and completed by other texts; see European Parliament and the Council of the EU, 2003 and 2009.

The launch of this instrument and its functioning during the first trading period (2005-2007) has been analyzed by Ellerman *et al.* (2010) among others, who considered this experience as a major innovation in the field of climate policies. Since the publication of this first ex post evaluation, the EU-ETS has faced new challenges (de Perthuis and Trotignon, 2014; Grosjean *et al.*, 2014): the unexpected economic recession strongly affected the industries under the cap and contributed to reduce their CO2 emissions (Declercq *et al.*, 2011); the interactions with other climate-energy policies also reducing CO2 emissions independently of the carbon price (Weigt *et al.*, 2013); the large possibility of using offset (Trotignon, 2012b). Those three factors contributed to reduce the expected stringency of the cap defined for the second trading period (2008-2012) which ended with a carbon price collapse and the accumulation of a large number of unused allowances (Trotignon, 2012a). At the current price (between 5 and 10 Euros per ton of CO2) and with the current number of unused allowances (around 2.5 billion in 2014), most observers consider that the EU ETS does not send the right incentives to reduce emissions both in the short and the long term; see State of the Carbon Market in 2012 (European Commission, 2012) and the outcome of the EC stakeholder consultation (European Commission, 2014a).

In a cap-and-trade system with unlimited banking and borrowing provisions, the accumulation of unused allowances is in itself not an issue, and even a necessary condition of the inter-temporal cost-efficiency of the policy, as long as participants have a good visibility on the cap and a sufficiently long foresight, as well as reliable anticipations of their future reduction costs and of the general policy packages and macro-economic context which will drive emissions over this period of time (Rubin, 1996). This has been the case in the US SO2 market (Ellerman and Montero, 2007; Schmalensee and Stavins, 2013). In such a framework, market inefficiencies such as shortsightedness and imperfect information can indeed impede on the inter-temporal efficiency of the scheme, as seems to be the case in the EU ETS.

The European Commission considered that the presence of a large surplus reduces the incentives for low-carbon investment and thereby negatively affects the cost-efficiency of the system. Where economic actors take investment decisions against the background of an oversupply of allowances in the market and the corresponding price signal, overall costs relevant for the climate change challenge are bound to increase when considered over the mid- and long-term. If not addressed, these imbalances will profoundly affect the ability of the EU ETS to meet the ETS target in future phases in a cost effective manner (European Commission, 2014b). In other words, the policy makers feared that leaving the EU ETS unchanged would induce a delay in low-carbon investment thus making the overall cost of reaching the long term reduction target too high.

The European Commission thus launched a process of consultation to come up with a structural reform of the EU ETS, aiming at resolving the identified issue. It has been made clear by the EC that the proposed measure should be i) non-discretionary and rule-based to remove the need for future ad hoc intervention, and ii) volume-based to allow for continued price discovery by the market, and neutral to the overall cap. In January 2014, the European Commission came forward with a formal proposal for the establishment of a Market Stability Reserve or MSR (European Commission 2014b). The MSR is designed as an objective and rule-based mechanism on the basis of which the auction volumes are adjusted in an automatic manner under pre-defined conditions, applied as of phase 4 of the EU ETS starting in 2021. The MSR set out in the proposal functions by triggering adjustments to annual auction volumes in situations where the total number of allowances in circulation (banking) is outside a certain predefined range:

- Adding allowances to the reserve by deducting them from future auction volumes if the total number of unused allowances (banking) is higher than 833 million allowances;

- Releasing allowances from the reserve and adding them to future auction volumes if the total number of unused allowances (banking) is below 400 million allowances.

Allowances are thus placed in and released from the market stability reserve in relation to the total number of allowances in circulation. It is then quite clear that the aim of the MSR is to intervene automatically on the market to correct the symptoms of identified market imperfections (high banking, low price). Indeed in an ideal market with perfect information and unlimited banking and borrowing provision, displacing the supply over time should have no effect on the equilibrium price as long as the total quantity of allowances (the cap) remains unchanged (Rubin, 1996, Chevallier *et al.*, 2011). The intention behind the MSR proposals is thus based on the idea that the market currently suffers from failures in terms of visibility of the cap, quality of information and anticipations, and inter-temporal arbitrage, which is also the opinion of other observers mentioned in (European Commission, 2014a) and (Climate Strategies, 2015).
The Zephyr model can help in assessing such effects as it has been designed to simulate such imperfect inter-temporal compliance behavior and their effect on the carbon price and abatement trajectories, in a simple framework. In Section 2 of this article, we describe the general framework of the Zephyr model. Section 3 focuses on the establishment of a dedicated version of Zephyr aiming at assessing the impact of the MSR in the framework of an international model comparison exercise convened by Climate Strategies and coordinated by DIW Berlin (Climate Strategies, 2015). Section 4 presents the results of the MSR assessment from the Zephyr model under various policy and economic scenarios and Section 5 concludes.

2 The Zephyr model framework

The Zephyr model has been created as part of a research program aiming at evaluating the first two phases of the EU ETS and simulating the possible outcomes of subsequent phases (see Trotignon, 2012a). By construction, it is not an optimization model seeking to minimize the overall compliance costs over the entire time-horizon of the program. By contrast, the Zephyr model is a simulation model, aiming at both replicating the imperfect inter-temporal compliance behavior observed ex post (e.g. due to shortsightedness and imperfect response from market participants to uncertainty and complexity) and observing how they may interact with exogenous scenarios (involving for example a change of the cap, allowance backloading (European Commission, 2014c), an economic crisis, or a Market Stability Reserve).

Theory has it that the equilibrium allowance price should both result from and indicate market fundamentals, as characterized by marginal abatement costs, see e.g. (Montgomery, 1972, Rubin, 1996, Bertrand, 2013), as well as by other factors influencing business-as-usual emissions, be they linked to prices for input fuels (fuel-switching) or purely exogenous as economic activity or weather conditions (Bréchet and Jouvet (2008), Ellerman et al., 2010). Many studies empirically analyses the determinants of the carbon in Phases I and II of the EU ETS. In short, while fundamentals limitedly drove EUA prices in Phase I, they have seen their role increasing in Phase II (Créti *et al.*, 2012). From 2011 on, a conjunction of three factors have been put forth to account for the persistent depressed EUA prices, namely the economic slowdown, the overlapping climate policies, and an extensive use of credits as compliance instruments (de Perthuis and Trotignon, 2014). However, more recently and more interestingly, (Koch et al., 2014) extended and complemented such analysis up until the first year of Phase III to investigate such issues. Checking for the relevance of MAC-related price drivers (fuel switch, economic activity, wind/solar, hydro and CERs) they find that these factors only contribute to 10% of the price formation, of which 40% pertain to variations in economic conditions. Given that abatement-related fundamentals are to a large extent not reflected in price variations, it seems relevant to us to tackle the problem from a behavioral point of view, allowing strategies off the theoretically optimal path. In this respect, some experimental studies have produced noteworthy results, in particular regarding the comparative effectiveness of various dynamic price management mechanisms, e.g. banking provisions or price collar or a combination of both (Stranlund *et al.*, 2014) or price collars separately or together with a market stability reserve (Holt and Shobe, 2015). As detailed below, our analysis can help bridge the gap between ex post analysis such as that of Ellerman and Trotignon, 2009 (and experimental evidence) and theoretical predictions by decomposing price formation into two communicating layers or blocks: one for modeling price formation based on marginal abatement costs and another providing compliance behaviors that can be calibrated in light of observed patterns.

2.1 General Structure and Framework

Participants to trading in the model are economic sectors in each of the 31 countries included in the EU ETS (EU-28 plus Norway, Liechtenstein, and Iceland), indexed below by c. There are six large economic sectors in each country: electricity, rest of combustion, refineries, iron and steel, cement, and rest of industry, indexed by s. The model is solved on an annual basis over the time period covering 2008 to 2050 (years indexed by t). As will be elaborated upon in the following sections, the model takes allocation (section 2.2), annual marginal abatement cost curves and macro-economic scenarios (section 2.3) as exogenous inputs. It then computes the reaction of participants to those inputs in a simulated compliance framework, where each can buy or sell allowances depending on its anticipations (section 2.4). The model solves annual supply-demand equilibriums iteratively and the outputs are the resulting carbon price and abatement trajectories (Section 2.5). Figure 1 below describes the general framework of the model in a dynamic fashion, showing how the different blocks of the model are connected with one another. We now turn to the specifics of each of these blocks in the following subsections.

2.2 Supply-side

In a given year t, the overall allowance cap, i.e. across countries and sectors, reads

$$Cap_t = \sum_{c} N_t^c + \sum_{c,s} A_t^{c,s}, \tag{1}$$

where N_t^c is the amount of allowances auctioned by country c, $A_t^{c,s}$ the amount of free allocation distributed to economic sectors in each country. For past years, N_t^c takes the observed values from the existing auctioning platforms and $A_t^{c,s}$ reflects the data as reported in the EU transaction log (EUTL, 2014). For subsequent years, the values are calculated from the auctioning and free allocation rules as provided in the ETS directive, under the considered cap scenario, see e.g. (Lecourt, 2014). The Zephyr framework can also integrate interactions between the EU ETS and other systems (see section 2.5).

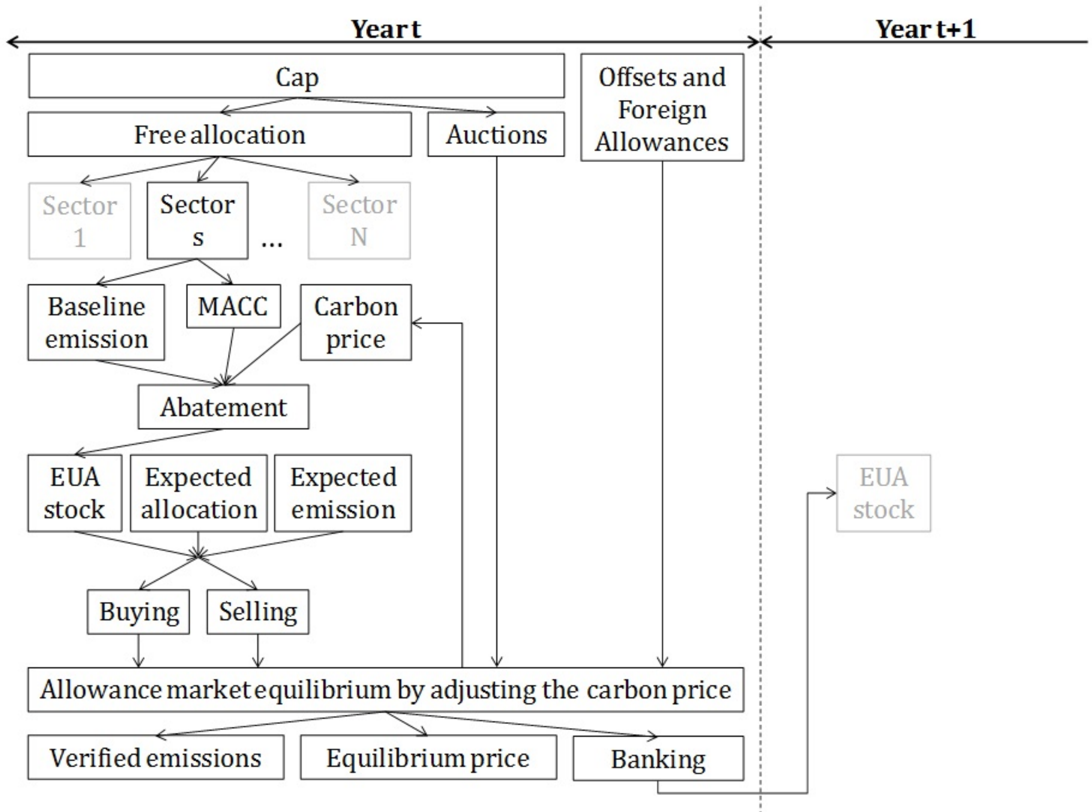

Figure 1: Schematic Zephyr model framework

2.3 Demand-side

2.3.1 Baseline emissions

On the demand side, the model considers annual baseline emissions (counterfactual emissions as they would be absent the EU ETS), which are driven by $I_t^{c,s}$, the industrial production change rate (in percent compared to previous year) for each sector and each country, that we relate to economic growth via an elasticity of production to GDP $\sigma_t^{c,s}$ according to

$$I_t^{c,s} = \sigma_t^{c,s} GDP_t^c. \tag{2}$$

Then if we denote by $\epsilon_t^{c,s}$ the elasticity of emissions to production, the annual baseline emissions change rate writes

$$G_t^{c,s} = \epsilon_t^{c,s} I_t^{c,s}. \tag{3}$$

For past years, the industrial production index is taken from (Eurostat, 2014) using a matching between sectors covered by the EU ETS and NACE activity codes in the Eurostat database. Past elasticities of production to GDP $\sigma_{t\leq 2014}^{c,s}$ are then fitted to align observed industrial production indexes with GDP levels.These changes in production are then multiplied by an elasticity of emissions to production, $\epsilon_t^{c,s}$ calculated prior to the introduction of the EU ETS to obtain past annual change of baseline emissions $G_t^{c,s}$, see (Trotignon, 2012a).

Note that for the electricity sector, past baseline emissions are given by a separate electricity sector model, ZEPHYR-Elec, which aims at replicating the short-term equilibrium between electricity supply and demand in Europe, see (Solier, 2014). Therefore Equation (3) holds true for all s but $s = 1$.

For future years, we proceed in a similar fashion except that baseline emissions changes are now derived from a GDP growth scenario taken from the latest Commissions European Economic Forecasts available (see (Trotignon, 2012a)).

Annual baseline emissions are then derived from an initial exogenous value $B_0^{c,s}$ and the following iterative relation

$$B_t^{c,s} = [B_{t-1}^{c,s} - (\gamma_{t-1}^{c,s} R_{t-1}^{c,s})](1 + G_t^{c,s}). \tag{4}$$

The parameter $\gamma_{t-1}^{c,s} \in [0, 1]$ allows us to capture the persistence of emission reductions $R_{t-1}^{c,s}$. It represents the share of emission reductions that are deemed to be long-term in the sense that they result from investments in low-carbon equipment rather than mere fuel-switching or reduced output. As formally studied by (Slechten, 2013), the standard result for cost-effectiveness that compliant firms must equalize marginal benefits and abatement across periods does not hold when long-term effects from investments are accounted for, the reason being that investments in a given period explicitly generate both an additional marginal benefit from reduced pollution and an additional marginal cost from less abatement opportunities available in subsequent periods. The parameter $\gamma_t^{c,s}$ therefore serves as a surrogate for an explicit and endogenous modeling of investment but still incorporates some long-term effects. In essence, for positive values of $\gamma_t^{c,s}$ investments and banking can be seen as substitutes while one is back to a situation where baseline emissions are solely driven by growth when it is nil.

2.3.2 Marginal Abatement Costs

Annual marginal abatement cost curves are exogenous and integrated in the model using the representation form borrowed from (DeCara and Jayet, 2011). This allows us to fit abatement curves from the literature in a parameterized exponential form that can display inflexion points. Emission reductions at price p_t relative to baseline emissions therefore write

$$R_t^{c,s} = \alpha_t^{c,s} B_t^{c,s} \left(1 - e^{(-\frac{p_t}{\tau_t^{c,s}})^{\beta_t^{c,s}}}\right), \tag{5}$$

where $\alpha_t^{c,s}$ describes the share of baseline emissions that can be abated at an infinite price, $\beta_t^{c,s}$ and $\tau_t^{c,s}$ are the two parameters that conjointly determine the shape of the abatement curve (essentially the existence, location and degree of the inflexion, see (DeCara and Jayet, 2011) for further details). Provided $\alpha_t^{c,s} \leq 1$, this specification guarantees that one cannot abate more than what one emits without any additional constraints on the abatement levels as is the case for more standard MAC functional forms, be they linear (Newell and Stavins, 2003) or polynomial (Böhringer et al., 2006) for instance.

2.3.3 Demand of permits by country and sector

Combining equations (4) and (5) yields the following dynamics for baseline emissions as a function of both input parameters and the market price

$$B_t^{c,s} = B_{t-1}^{c,s}\left[1-\gamma_t^{c,s}\alpha_{t-1}^{c,s}\left(1-e^{(-\frac{p_{t-1}}{\tau_{t-1}^{c,s}})^{\beta_{t-1}^{c,s}}}\right)\right](1+G_t^{c,s}). \tag{6}$$

In a given year, abatement is modeled as cost-efficient in the sense that there is a perfect recognition from participants of the opportunity cost of emission reductions, i.e. marginal abatement costs are equalized across countries and sectors to the market price. This allows us to express simply the demand of permits by country and sector, denoted $E_t^{c,s}$ to reflect that it is equal to verified emissions, as a function of both baseline emissions and the carbon price

$$E_t^{c,s} = B_t^{c,s} - R_t^{c,s}. \tag{7}$$

2.4 Anticipations

The essential feature of the model is the representation of participants anticipations which serves as the basis for inter-temporal compliance decisions. Indeed, participants do not base their banking decisions on some standard arbitrage between price (understand interest rate) and future abatement costs, but rather make their decisions via quantitative anticipations about their future allocation and emissions over a given time horizon. The degree of participants' farsightedness is measured by the length, in year, of this anticipation period, $H_t^{c,s} \geq 1$, and is a flexible parameter of the model. Let $T_t^{c,s} = t + H_t^{c,s}$ denote the last year of the anticipation period which cannot extend beyond 2050.

Each year t, participants anticipate two quantitative aspects for year $t+i$, $i \in [1; H_t^{c,s}]$:

- the future amount of free allocation they should receive in each subsequent year, as seen from year t, $\tilde{A}_{t,t+i}^{c,s}$,
- and their future annual emissions over the anticipation period, $\tilde{E}_{t,t+i}^{c,s}$.

Then, the cumulated anticipated free allocation for sector s in country c as seen from year t and over the anticipation period writes

$$\tilde{D}_t^{c,s} = \sum_{i=1}^{H_t^{c,s}} \tilde{A}_{t,t+i}^{c,s}, \tag{8}$$

and the cumulated anticipated emissions for sector s in country c in year t over the anticipation period is then

$$\tilde{F}_t^{c,s} = \sum_{i=1}^{H_t^{c,s}} \tilde{E}_{t,t+i}^{c,s}, \tag{9}$$

where $\tilde{E}_{t,t+i}^{c,s} = E_t^{c,s} \prod_{j=1}^{i}(1 + \tilde{G}_{t+j}^{c,s})$, with $\tilde{G}_t^{c,s}$ the exogenous anticipated annual growth rate of emissions for year t. We opted for the most simple form for the anticipation of future emissions, that is one that is based on the emission level of the current year increased by anticipated growth of emissions, which could reasonably represent a context of imperfect information on the participants side.
The difference between cumulated anticipated allocation and cumulated anticipated emissions thus represents the necessary emission reduction effort as anticipated over the anticipation period, and is given by

$$\tilde{\Delta}_t^{c,s} = \tilde{D}_t^{c,s} - \tilde{F}_t^{c,s}. \tag{10}$$

To meet annual compliance, each participant has to surrender a number of allowances equivalent to their verified emissions over the year. Given the unlimited banking provision in the EU ETS, any allowance not used for compliance in a given year stays valid as a compliance instrument for subsequent years. Thus, at the beginning of each year, participants hold a certain positive stock of allowances on their accounts $S_t^{c,s} \geq 0$ equal to unused allowances from previous years, that is banking that we note $K_{t-1}^{c,s}$, plus freely allocated allowances received for the current year

$$S_t^{c,s} = K_{t-1}^{c,s} + A_t^{c,s}. \tag{11}$$

Each participant faces a situation where, at a given permit price p_t, they either hold a surplus or have a deficit of allowances. This annual position $P_t^{c,s}$ is given by

$$P_t^{c,s} = S_t^{c,s} - E_t^{c,s}, \tag{12}$$

and its sign depends on whether sector s in country c is long or short.

This dynamics is closed as we define banking in year t as position in year t plus EUA purchases minus EUA sales on the market, denoted $Y_t^{c,s}$ and $Z_t^{c,s}$ respectively and defined below and in Table 1. Note that the model does not include a borrowing provision in its current version so that $K_t^{c,s}$ is forced to take only positive values

$$K_t^{c,s} = P_t^{c,s} + Y_t^{c,s} - Z_t^{c,s}. \tag{13}$$

If $P_t^{c,s} < 0$, the participant is short and has the obligation to acquire a number of allowances on the market at least equivalent to $|P_t^{c,s}|$ or it would face a non-discharging penalty for non-compliance (recall that borrowing is not permitted). By contrast, if $P_t^{c,s} > 0$, the participant is long and has the option of either selling the corresponding amount on the market or keeping it for later use. These choices are modeled as shown in Table 1 below, which describes the different market behaviors (buy or sell EUAs, denoted by $Y_t^{c,s}$ and $Z_t^{c,s}$) simulated depending on the signs of the current position and of the anticipated emission reduction effort over the anticipation period, namely $P_t^{c,s}$ and $\Delta_t^{c,s}$.

Again we underline that this table represents a simple framework where participants market behaviors depend solely on a quantitative and imperfect anticipation of the future, and not on inter-temporal cost optimization. In this framework, two levels of behaviors are superimposed:

- the first step is related to the current deficit or surplus held by a given participant. If one holds a surplus, $P_t^{c,s} \geq 0$, one will sell the corresponding amount on the market. If one faces a deficit, $P_t^{c,s} < 0$, one will buy a corresponding amount on the market;

- on top of that, a second step simulates the effect of anticipations in a context

Table I: Behavioral representation table

Criteria 1 $P_t^{c,s}$	Criteria 2 $\Delta_t^{c,s}$	Bought EUAs $Y_t^{c,s}$	Sold EUAs $Z_t^{c,s}$
> 0	> 0	0	$\lvert P_t^{c,s} \rvert$
	< 0	$\omega_t^{c,s} \frac{\lvert \Delta_t^{c,s} \rvert}{H_t^{c,s}}$	$\lvert P_t^{c,s} \rvert$
< 0	> 0	$\lvert P_t^{c,s} \rvert$	0
	< 0	$\lvert P_t^{c,s} \rvert + \omega_t^{c,s} \frac{\lvert \Delta_t^{c,s} \rvert}{H_t^{c,s}}$	0

where unlimited banking is allowed, *i.e.* buying or keeping more allowances than actually needed in the short term to face future allowance scarcity, as measured by $\Delta_t^{c,s}$. If one expects a deficit over the anticipation period $\Delta_t^{c,s} < 0$, it will buy a quantity of allowances equal to the average annual deficit anticipated $|\Delta_t^{c,s}|/H_t^{c,s}$.

This is a way of simulating hedging behaviors by representing a physical side of it, as it were, without explicitly accounting for the derivatives markets nor the participation of non-covered actors. Thus the additional abatement effort as anticipated is evenly apportioned across periods of the anticipation horizon. It corresponds to the optimal banking path when present-valued permit prices are equalized over the anticipation period, absent uncertainty (Rubin, 1996). To allow for deviations from this certain banking path and thereby replicate observed banking behaviors or integrate other considerations involved in banking decisions, the parameter $\omega_t^{c,s}$ is introduced to scale the intensity of such hedging strategies.

2.5 Market equilibrium

In this subsection we provide a sketch of how we solve for the market equilibrium. First note that once compliance behaviors as described in Table 1 are accounted for, other standard market imperfections are ruled out. That is, transaction costs are assumed away although they might reduce exchange levels (Stavins, 1995). In the same vein, market power is taken as inexistent even though (Liski and Montero, 2006) show that

dominant participants can credibly manipulate spot prices. We also rule out any kind of uncertainty on abatement costs, yet aware that this has a bearing on banking decisions (Feng and Zhao, 2006; Zhao, 2003) and that, coupled with risk aversion, could lead to reduced dynamic efficiency (Baldursson and von der Fehr, 2004). As it provides a simple yet novel treatment of compliance behaviors, our approach enables us to replicate past compliance patterns and extrapolate them for future years.
Second, using notations introduced in the preceding subsections, the aggregate supply and demand on the market, i.e. incorporating market effects, respectively write

$$\sum_{c} N_t^c + O_t + \sum_{c,s} Z_t^{c,s}, \tag{14}$$

and

$$\sum_{c,s} Y_t^{c,s} + X_t, \tag{15}$$

where O_t represents the use of carbon offsets and X_t the net allowance exchange coming from (≤ 0) of going to (≥ 0) other cap-and-trade systems. Carbon offsets such as CERs and ERUs can be considered as net supply of permits that comes under the cap in addition to allocation, auctions and allowances sold by participants. As long as the price of offsets is inferior to the internal market price, it is reasonable to think that participants will tap into offsets for compliance and use their entitlement to the full. For past years, O_t corresponds to observed aggregate use of credits and the remaining of the overall entitlement for offsets is evenly allocated over future years. Note that the model can also include a net demand from other cap-and-trade systems, X_t, to which the EU ETS could be linked to in the future (e.g. Switzerland ETS). Indeed, the Zephyr approach is set to be extended to other ETSs and these various model blocks would be connected to one another.

Then, the annual computation of the market equilibrium is realized via a loop on an incrementally increasing carbon price p_t. Each year the model starts at $p_0 = 0$. At this price, verified emissions are equal to baseline emissions and there is no abatement.

The model then computes compliance behaviors of participants as presented above, calculates supply and demand as defined by (14) and (15) and checks whether there is a market equilibrium. If supply equals demand, then the equilibrium price is set to zero for this year and the model moves on to the resolution of next year's equilibrium. If supply is less than demand, then the model increments p_t by a given amount, which has the effect of triggering further abatement among sectors, changing the value of $P_t^{c,s}$. Supply and demand are then recalculated using this new price. The price is gradually incremented throughout this process, which is set to stop as soon as it reaches the first or minimal value of p_t that allows a supply-demand equilibrium to form on the market. Each year, abatement is thus made at least cost, given the behavioral representation described in Table 1, and banking levels obtain as we suppose market clears.

3 Specific model design for MSR proposal analysis

The Market Stability Reserve is designed to automatically adapt auctioned volumes as a function of cumulated banking, while leaving the cap unchanged over the long term. The aim is to compensate for inter-temporal efficiency failures and to cushion exogenous shocks. In a classical theoretical framework with inter-temporal cost optimization under perfect information, such a change in the calendar of auctions should have no effect on emissions and price trajectories, and would have no reason to exist. As stated in the introduction, the European Commission recognizes market failures such as short-sightedness and imperfect information and based its proposal on the idea that such imperfections could be corrected.

Interesting questions then arise: can a Market Stability Reserve compensate for an imperfect inter-temporal behavior of the market? Over which time horizon will it stay neutral to the cap? Can it help absorb all types of unpredictable short term shocks? We tried to enlighten those questions using the Zephyr model in the context of an international model comparison exercise convened by Climate Strategies and coordinated by DIW Berlin (see Climate Strategies, 2015). This section focuses on the establishment of a dedicated version of Zephyr for this project. Two kinds of changes in the model are necessary: changes needed to fit the constraints of the model comparison exercise; and changes needed to include the MSR in the simulated anticipation framework of participants. For comparison purposes, the different modeling teams involved in the project defined a common set of inputs:

- A set of annual marginal abatement cost curves defined for the EU ETS perimeter as a whole over 2015-2050 (see Landis, 2015). The MACCs in Zephyr as described by equation (5) were replaced by those,
- Scenarios for annual allocations and annual baseline emissions, for the EU ETS as a whole, were also integrated in Zephyr. As a consequence, the baseline emissions dynamics described by equation (6) and the economic drivers in (2), (3) and (4) were disabled.

More profoundly, this one-sector representation of the EU ETS was not directly compatible with the compliance behavior simulation and market equilibrium features of Zephyr. In the model, one sector as a whole (one market participant), could not at the same time buy and sell allowances as the result of only one anticipation calculation. To preserve the general relationship between anticipated scarcity, emissions and banking, but in the absence of explicit trading, the anticipation framework was modified to achieve an explicit link between annual changes of emissions and the annual expected scarcity Δ_t:

$$E_t = E_{t-1} + \frac{\Delta_t}{H_t} \tag{16}$$

Emission changes (annual abatement) can be capped between a certain range (for example -/+ 5%/yr) to avoid or smooth unrealistic oscillations. With this modification, the banking dynamics becomes:

$$S_t = S_{t-1} + A_t - E_{t-1} - \frac{\Delta_t}{H_t} \tag{17}$$

The second modification necessary compared to the general framework of zephyr is related to the possible presence of an MSR that is expected to modify the supply of allowances over time in a context where participants have a limited anticipation horizon. This required adding an anticipation of the MSR effect on supply over time in the expectations of agents, i.e. in the calculation of Δ_t. If the total number of allowances in circulation is above the known high threshold of the reserve, the model considers that participants will anticipate a reduction of the supply in the short/medium term. Conversely, if the reserve is not empty and the number of allowances in circulation (banking) is low, participants expect those to be supplied back in the market in the short medium term.

The rest of the model is unchanged. Three market imperfections are still represented in the model: the knowledge of future costs (intertemporal costs are not considered in the abatement/banking decisions); participants limited foresight/myopia controlled by H_t; the potential over/under estimation of future emissions controlled by $\tilde{G}_t$. A sensitivity analysis to those two parameters is presented in Annex 1.
On the basis of this sensitivity analysis, we define two scenarios representing different degree of market imperfections, with backloading and without an MSR:

- Scenario A: $H_t = 5$, $\tilde{G}_t = 2\%$, backloading, no MSR
- Scenario B: $H_t = 15$, $\tilde{G}_t = -0.5\%$, backloading, no MSR

The results of the model in those two scenarios, in terms of price, banking and emissions are presented below.

Both scenario represent a situation with myopia or inefficient inter-temporal behavior, but with different degrees. In scenario A, banking decreases progressively starting from 2020 (after backloaded allowances are returned to the market: a common feature across models in this setting of the comparison exercise, see (Climate Strategies, 2015)), down to zero in 2050. The carbon price thus stays low until the mid-2020s when emissions start to get reduced. Because of the low availability of banked allowances toward the end of the period, high reductions are necessary and the price gets up to 100 euros per tonne. The corresponding emission trajectory represents a situation with almost no early reductions; abatements are delayed toward the end of the phase, at higher costs given the MACCs used.

Comparatively, in scenario B, the carbon price rises earlier and banking is maintained at a stable level compared to current estimates, up to 2040. Emission reductions are triggered earlier than in scenario B. Towards the end of the phase, more allowances are

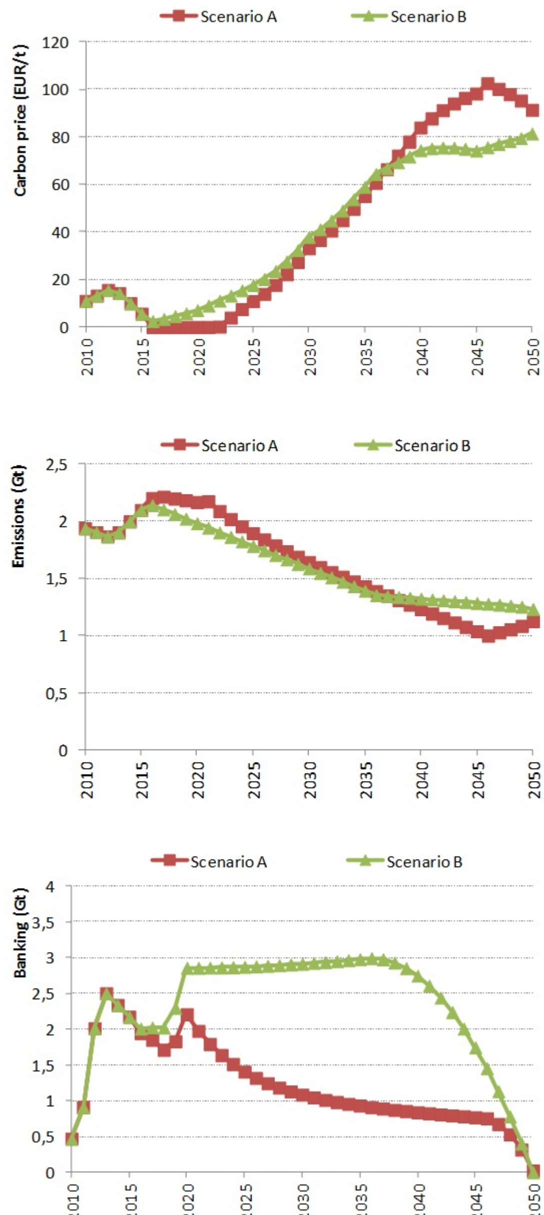

Figure 2: Price, emissions, banking and abatement costs in scenarios A and B

available for use from the bank and thus less emission reductions are necessary: the price gets relatively lower than in scenario A, to some value around 80 euros per tonne.

4 Effect on the MSR on price, emissions, and banking

Given the current level of banking in the EU ETS, what is defined by the Commission as the total number of allowances in circulation (around 2500 Mt) is higher than the higher MSR threshold (833 Mt). Consequently in both scenarios, when the Market Stability Reserve is introduced, it has the effect of first reducing auctions in the short term, and second sending a scarcity signal to participants for the future as long as banking stays at levels higher than the upper threshold. Those two effects lead participant to abate more and earlier, which raises the price in the short term. In both scenario, this short term effect on the price is observed and the price is higher in 2025 with the MSR than without (see Figure 3 below). In scenario B where the anticipation horizon is longer, the anticipation of the MSR has an effect on the price even prior to its effective entry into force, which smoothes the effect over a larger number of years. In scenario A, the myopia of 5 years leads the reaction of the market to be more volatile.

This price increase goes in parallel with the reserve getting filled. In 2030, the MSR holds 1.5 billion allowances in scenario A and 2.5 billion in scenario B (see Figure 6 below). After 2030, one would then expect the total number of allowances in circulation to align progressively within the trigger thresholds, so that the MSR would have no additional effect on the price. This is indeed the case in scenario A (Figure 3c). Participants unbank allowances quicker than without the MSR, which leaves the MSR inactivate up to 2040. But the total number of allowances in circulation depends on banking behavior and thus on participants anticipations. In scenario B participants have a longer anticipation horizon, and therefore they continue to bank significant amounts of allowances because of the scarcity signal sent by the presence of the MSR. The total banking diminishes, but not as fast as to prevent the reserve from being triggered. In that case, the reserve continues to absorb allowances from auctions, and the price continues to be higher than in the no MSR scenario. Banking crosses the higher threshold around 2040.

At that date, the reserve in scenario A still holds 1.5 Gt, and the reserve in scenario B now contains 4 Gt (Figure 6).

For the mechanism to be really efficient up to 2050, the reserve would then have to progressively reintroduce the set-aside allowances on the market, to prevent unnecessary and more costly reductions toward the end of the phase. It also has to reintroduce these allowances to remain cap-neutral, as required in the Commissions proposal. One would then expect the reserve to be progressively emptied to finally hold zero allowances in 2050. In both scenarios, it is indeed the case that, due to lower and lower level of allowances in circulation, the MSR progressively starts to reintroduce allowances on the market. But in both case it fails to do it completely. In scenario A, the behavior of participants makes banking oscillate around the lower threshold up to after 2045. The reserve really starts emptying toward 2050 when the model forces banking to go to zero (terminal condition). In this scenario, the reserve still holds around 1 Gt in 2050. The price is comparatively the same as in a scenario without MSR, if not a little higher. From 2040 on in scenario B, the total number of allowances in circulation does not decrease fast enough to allow the reserve to empty itself. In this scenario, the reserve still holds 3.5 Gt in 2050. The price in scenario B is consistently higher than without the reserve because of this retention phenomenon (Figure 3).

In terms of emissions over 2010-2050 (Figure 4), the MSR has induced more reductions in both scenarios. As expected it triggered earlier emission reductions over 2020-2030. But it also did not decrease end of period reductions (in scenario A) or even increase this number (in scenario B) because of retention issues. The banking behavior of participants reacts to the potential scarcity signal sent by the reserve, which in turn prevents participants from quickly reducing the total number of allowances in circulation.

The major lesson from this sub-section is that the reserve seems to be (at least in our framework) well designed to effectively induce earlier reductions in the short term. But it also lays doubts on its capacity to reintroduce allowances on the market quickly enough, so as to remain economically efficient relative to the agreed upon reduction target and to remain cap neutral over the considered horizon.

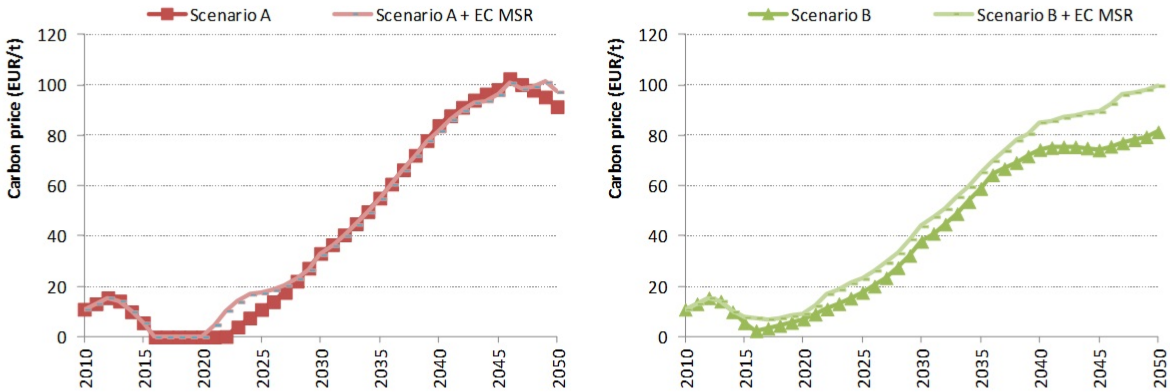

Figure 3: Effect of the MSR on the carbon price in the two scenarios

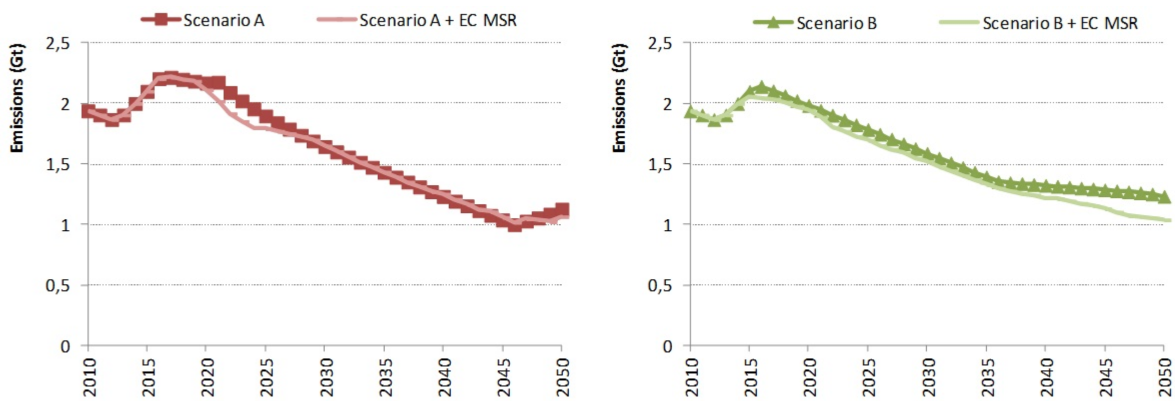

Figure 4: Effect of the MSR on emissions in the two scenarios

4.1 Effect of the MSR in case of external shocks

In this sub-section we turn to another aspect of the Market Stability Reserve: its ability to smooth out shocks, whether positive such as in the case of a strengthening of the ETS reduction target, or negative such as in the case of an economic crisis. Both kinds of shocks have been tested on scenarios A and B, both in the absence and in the presence of the MSR. The resulting impacts on price trajectories are presented in Figures 7 and 8 below.

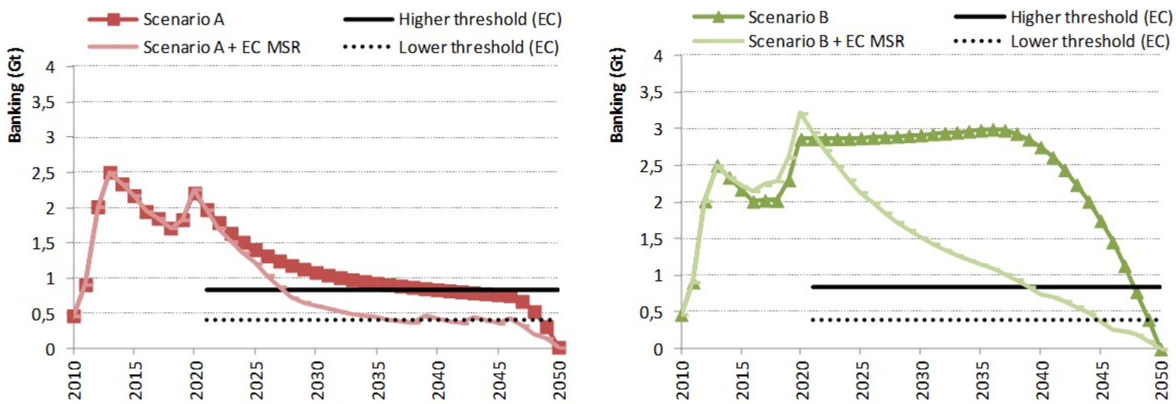

Figure 5: Effect of the MSR on banking in the two scenarios

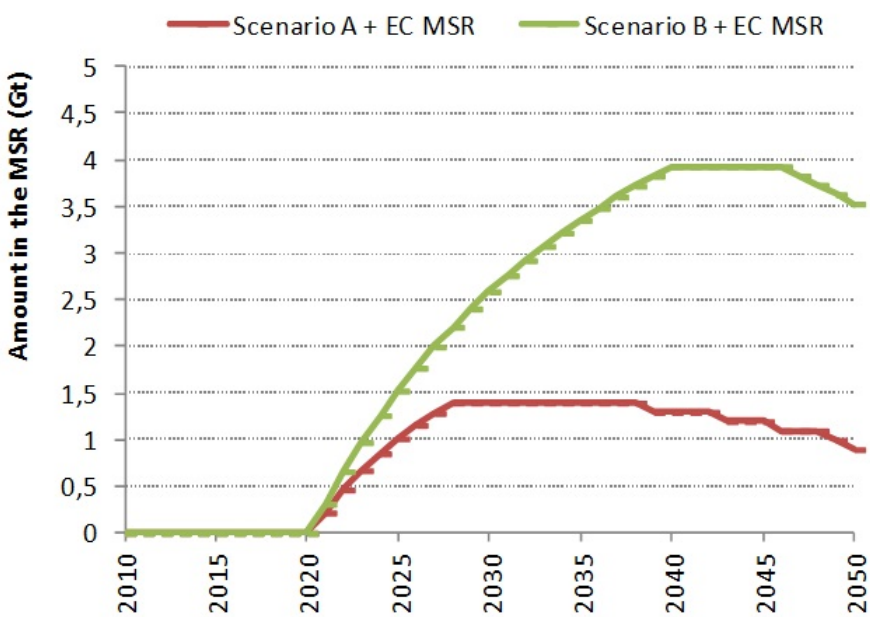

Figure 6: Number of allowances in the reserve in the two scenarios

The policy shock is simulated as a reinforcement of the cap happening in 2030. The number of allowances to be put on circulation over 2030-2050 is diminished by 23%, which corresponds to an amount linearly decreasing from its 2030 value (1.6 Gt) down to 280Mt in 2050, compared to 833Mt in 2050 without policy shock. Although it could be discussed that such a strengthening of the target would be anticipated by the market, we aim at judging the reaction of the reserve to an unanticipated shock. To achieve that, we run the model without the shock up to 2030, then fix the results for the years 2010-2030, introduce the revised cap in the model, and solve for the years 2030 to 2050, now including the effects of the shock on auctions and in participants anticipations.

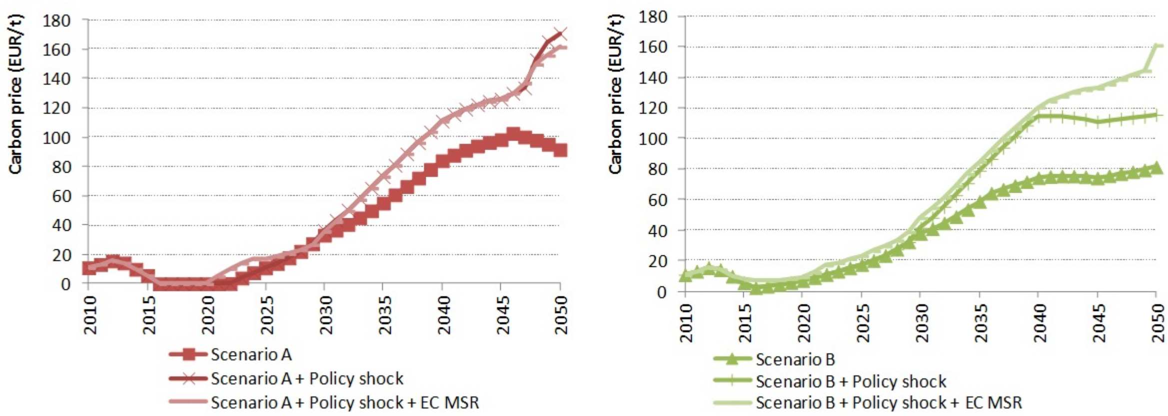

Figure 7: Effect of an unanticipated strengthening of the cap in 2030, with and without an MSR

In the absence of a reserve, the effect of the policy shock is to raise the price from 100€/t in 2050 to 160€/t in scenario A, and from 80/t to 120€/t in scenario B. In both case this is the expected consequence of a reinforcement of the cap given the marginal abatement curves used. In scenario B, the rapid decrease of banking over the last decade limits the price increase, whereas in scenario A the low level of banking in the last year on the contrary increase the effect on the price. When a reserve is present, we observe a stronger increase in the price. In scenario A, this effect is very limited and concentrated on the last two years of the period. In scenario B, the effect is more pronounced and the price goes as high as 160€/t in 2050. The reason is that the banking needs of participants are high due to, first, the effect on anticipations of strengthening the cap, and second to the additional scarcity signal sent by the MSR in this context. All in all, in this framework, in case more constraint on supply occurs, the reserve seems to have the effect of tightening the cap even more. This could induce higher price and compliance costs compared to a situation with the same revised cap but without MSR.

The second type of unanticipated shock is a negative one, for example an economic crisis strongly reducing demand for allowances. This is simulated in the model as a shock on emissions. In 2030, baseline emissions are cut by 20% (from 2,400 Mt to 1,925 Mt) and then linearly increase to reach the same value in 2050 as in the absence of the crisis. Given the model framework, the shock has to materialize on verified emissions in 2030 to propagate to later years, thus we consider that in 2030 half of the shock on baseline emissions is passed down to verified emissions, *i.e.* verified emission decrease by 240 Mt. After 2030, we let the model solve for the new price and emission trajectories, now including the adapted baseline.

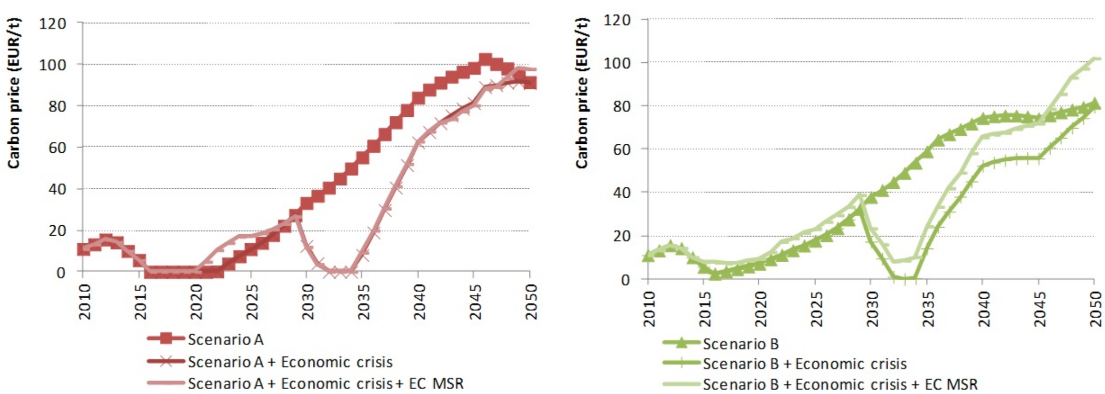

Figure 8: Effect of an unanticipated economic crisis in 2030, with and without an MSR

In the absence of a reserve, the price drops immediately in 2030 in both scenarios, stays very low during a few years, and then goes progressively back up as baseline emissions recover to reach around the same value in 2050 as in the case without shock. With the MSR in place, there is almost no effect in scenario A. The drop of emissions does not allow banking to reach a level sufficiently high to induce additional absorption of allowances by the reserve. The presence of the MSR in that case does not make the market reaction to the shock smoother. In scenario B, the reserve actually gets triggered and removes more allowances following the shock. But due to the banking needs of participants over the rest of the period, which stay high even after the shock because of a longer anticipation horizon, the reserve does not put those allowances back on the market in later years. Instead, it continues to absorb allowances, propping up the price to a level even higher than in the absence of the shock and without reserve. Thus, even if the reserve seem to have a dampening effect preventing the price to drop too low and too quickly after the shock, it also fails at keeping costs down by not being prompt enough to empty itself in later years.

5 Conclusion

The Zephyr model was designed and adapted to answer the following questions: can a Market Stability Reserve compensate for an imperfect inter-temporal behavior of the market? Over which time horizon will it stay neutral to the cap? Can it help absorb all types of unpredictable short term shocks?

In this article, we show that the reserve is indeed capable of raising demand for allowances in the short term, thus inducing earlier emission reductions and compensating for an abatement profile perceived as inefficient, which is the case when participants suffer from myopia. But we also show that the reserve raises the price even in the medium-long term, and, all in all, raises total costs. This is a consequence of the limited ability of the reserve to put back allowances on the market when needed. This is due first to the position of the thresholds, in particular the lower one, and second to the limit of 100 Mt on amounts it can annually put back on the market. The result is that the presence of the market stability reserve changes the cap over the selected horizon, in other words the MSR is not empty in 2050, and allowances that enter it in 2021 may stay there for 30 years.

The smoothening effect of the reserve in case of shocks is also shown to be unclear. In particular, in case of a positive shock, the reserve seems to be unable to reintroduce allowances in the market quickly enough to dampen the price increase. In case of a negative shock the reserve is shown to be able to limit price drops, but, on the flipside, it does so at the expense of higher overall cost because of the same inability to reintroduce allowances on the market. Contrary to what is aimed at by the Commission, it seems that the reserve could not have the desired effect on overall efficiency for a given reduction target.

To investigate the effect of the MSR in more details, further research and additional tests are necessary. Some tests have been performed with other inputs, designs and parameterization (different MACCs, early start and backloading in the reserve, other MSR designs, see Climate Strategies, 2015). The main lesson from these tests complement those presented in this article, i.e. the crucial role of anticipation and how banking needs evolve (which conditions the reaction of the reserve over time). In the Zephyr framework, potential problems arise when the banking/hedging behavior of participants interact with the reserves automatic rules.

Based on what we learned from the Zephyr simulations, we can add a few more general comments. First, there is the risk of wrong reaction on the part of the reserve due to the built-in two year delay between a shock occurring and the reserve reacting. This could induce more volatility given the nature of the shock and the context in which the shock materializes. Second, we can also point out the potential risk of strategic behavior because of the purely automatic and known-in-advance rules of the reserve (especially in a context of potential dominant position of a limited number of players). Indeed the MSR only deals with new allowances introduced on the market through auctions, when the total quantity of allowances in circulation (i.e. the triggering criteria for the reserve) depends on the banking/hedging behavior of participants, dealing with existing allowances (already on market participants accounts). Finally, these simulations were performed in a context where there are no interactions between the EU ETS and outside schemes until 2050 (offsets or linking with other ETS). More research is needed to evaluate the effects of the reserve in case the EU ETS gets connected to other cap-and-trade schemes in the coming years. New demand or supply could arise on the market for that reason, and the lessons from the shock analysis above suggest that the reserve could potentially be seen as an impediment to linkage on the part of partnering schemes.

Table II: Summary of abatement, abatement costs and net effect of the reserve on the cap in all scenarios

Scenario	Cumulated abatement (Gt)	Cumulated abatement costs (G EUR)	Average cost (EUR/t)	Amount in the reserve in 2050 (Gt)
Scenario A	47	684	14,7	
Scenario B	47	532	11,4	
Scenario A + EC MSR	47	690	14,5	0,9
Scenario B + EC MSR	50	738	14,7	3,5
Scenario A + Policy shock	53	1323	25,1	
Scenario B + Policy shock	53	1068	20,3	
Scenario A + Policy shock + EC MSR	53	1297	24,3	0,7
Scenario B + Policy shock + EC MSR	57	1445	25,4	4,2
Scenario A + Economic crisis	41	428	10,4	
Scenario B + Economic crisis	41	285	7,0	
Scenario A + Economic crisis + EC MSR	42	449	10,6	1,1
Scenario B + Economic crisis + EC MSR	45	470	10,4	4,0

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6 Annex - Sensitivity analysis on the parameters

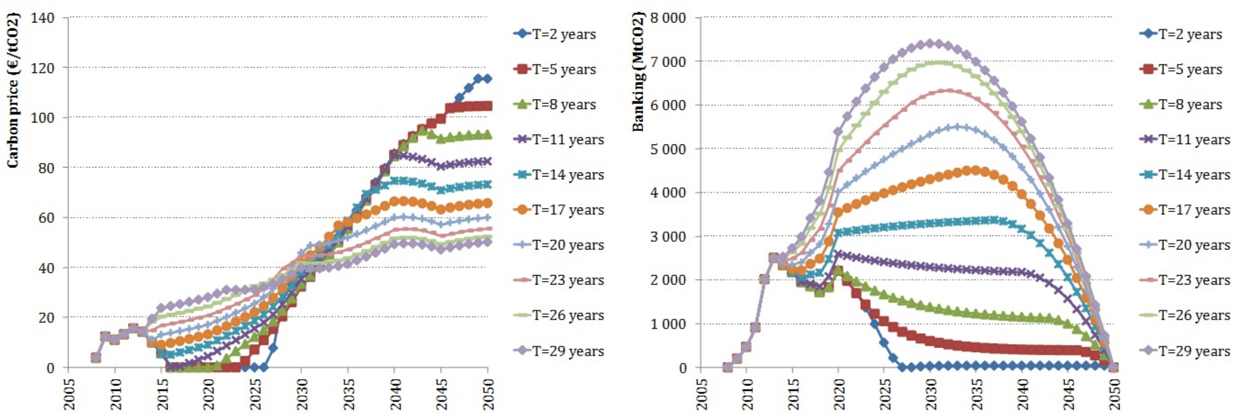

Figure 9: Influence of T on carbon price and banking, at G constant (G=0% per year)

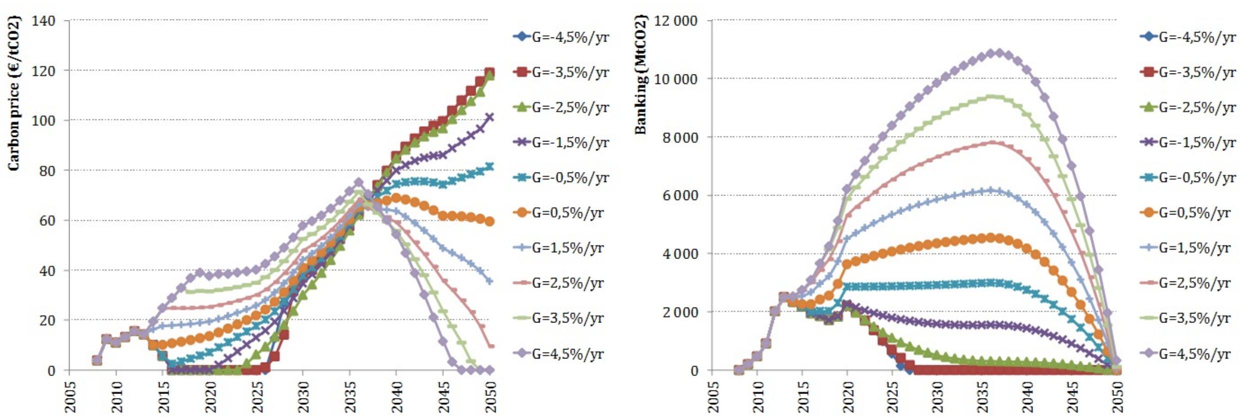

Figure 10: Influence of G on carbon price and banking, at T constant (T=15 year)

WORKING PAPER

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