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Unilateral mitigation of climate damage via purchase of fossil fuel deposits*

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Abstract

In a multi-country model with interconnected markets for fossil fuel and deposits some countries fight climate damage by purchasing and preserving fossil fuel deposits, which would be exploited otherwise. We analyze the effectiveness of such a deposit policy, when that policy stands alone or is combined with fuel cap policies. If the stand-alone deposit policy is non-strategic, it implements the first-best allocation; otherwise, it distorts the allocation in the coalition's favor. Following Harstad (2012), we then analyze the policy mix consisting of the deposit policy, a fuel-supply-cap policy and a fuel-demand-cap policy. The fuel-supply-cap policy turns out to be redundant and so is the fuel-demand-cap policy, if it is non-strategic. Whenever the coalition acts strategically on one of the markets or on both, it distorts the allocation in its own favor and is better off than in the efficient price-taking scenario which contrasts the efficiency result of Harstad.

JEL classification: F55, H23, Q54, Q58

Key words: fuel deposits, deposit policy, fuel-supply cap
fuel-demand cap

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1 The problem

Scientific evidence strongly suggests that global warming is caused by anthropogenic greenhouse gas emissions, notably by emissions of carbon dioxide from burning fossil fuels. The substantial reduction of global carbon emissions necessary to retard global warming calls for an effective international environmental agreement. The first legally binding agreement, the Kyoto Protocol, stipulated rather unambitious commitments and therefore accomplished only little more than global noncooperation. The Kyoto Protocol expired in 2012. If any post-Kyoto cooperation will be reached at all, it will most likely be sub-global. That motivates the assumption of the present paper that some countries do not engage in reducing climate damage while others cooperate in a climate treaty and form a climate coalition, which we treat as one agent.

We consider a world with asymmetric countries all of which extract, trade, and consume fossil fuel. All countries' carbon emissions from fuel consumption generate climate damage. The coalition may choose among three types of policies to mitigate climate damage. It may reduce own fuel consumption and hence own carbon emissions (*fuel-demand-cap policy*),¹ it may reduce own fuel production (*fuel-supply-cap policy*) or it may purchase fossil fuel deposits to prevent their exploitation (*deposit policy*). The present paper aims to analyze the effectiveness of the deposit policy as a unilateral means to reduce climate damage, when that policy stands alone or is combined with fuel cap policies.

To see that the deposit policy is mutually advantageous for the coalition and the non-coalition countries, observe that if the coalition purchases and preserves a small deposit that would have been exploited otherwise, it reduces global emissions by a small amount and its benefit from that purchase approximately equals the marginal climate damage. All countries are willing to sell a deposit that stores some fuel in the ground, as long as the deposit price covers at least the profit forgone of exploiting that deposit. Since extraction costs increase progressively, the profit of the last unit of fuel extracted is zero. It follows that in the no-policy regime the minimum asking price for the highest-cost deposit to be exploited is approximately zero, while the coalition's maximum willingness-to-pay for that deposit approximately equals the strictly positive marginal climate damage. Hence, there is room for mutually advantageous deposit trades.

The rationale of the coalition's deposit policy is to buy some of those deposits, which would have been exploited otherwise, and thus reduce global fuel production. Which deposits would have been exploited otherwise depends on the fuel price, for in the absence of

¹We denote by fuel cap policy any policy, such as fuel taxation or 'cap and trade' schemes, that reduces the coalition's fuel consumption or production compared to the no-policy scenario.

deposit purchases extraction firms exploit all deposits with marginal extraction costs less than or equal to the fuel price. That observation points to the fundamental interdependence of the markets for deposits and fuel, which we will investigate in an analytical model of interconnected markets for fuel and deposits. Since the coalition is a monopsonist on the deposit market, special emphasis needs to be placed on the coalition's strategic behavior, that is, on the extent to which the coalition accounts for the effects of its policy on the terms of trade. To elaborate the impact of strategic behavior on the outcome, we also compare the allocative distortions and the coalition's benefits under conditions of strategic and non-strategic action.

Fuel-demand-cap policies are the prevailing approach to unilateral climate policy in practice, and they fill the bulk of the climate literature (see e.g. Copeland and Taylor 1995, Ulph 1996, Kiyono and Ishikawa 2013). In contrast, fuel-supply-cap policies and the deposit policy are not much explored.² As for the deposit policy, Bohm (1993) and Harstad (2012) are the only studies, to our knowledge, with an analytical approach to deposit policy. In a stylized parametric model, Bohm considers a sub-global coalition that aims to reduce global emission by a predetermined small amount either through reducing its fuel demand or through a special mix of deposit policy and fuel-demand-cap policy, which leaves the fuel price at its pre-policy level.³ Bohm derives conditions under which the policy mix implements the emission cap at lower costs than the stand-alone fuel-demand-cap policy. Our approach differs from Bohm's in that we set up an analytical model with endogenous interdependent prices for fuel and deposits. Neither do we set an exogenous global emission reduction goal, nor do we compare policies with and without the purchase of deposits. Rather, our focus is on the strategic deposit policy and supplementary fuel-cap policies.

Harstad (2012) adds the deposit policy to Hoel's (1994) mix of fuel-demand-cap and fuel-supply-cap policies. He models the deposit market as a set of bilateral trades to the mutual advantage of the trading partners. "The market clears when there exists no pair of countries that would both strictly benefit from trading some of their deposits at some price" (Harstad 2012, p. 92). His remarkable result is that if the coalition pursues the fuel caps policies strategically and purchases deposits as described above, it is able to restore efficiency in unilateral action.⁴ Harstad's design of the deposit market suits well for markets with few

²For studies combining the unilateral climate policies of capping fuel demand and supply in the absence of a market for deposits see e.g. Hoel (1994), Eichner and Pethig (2014) and Faehn et al. (2014).

³In Bohm's view, the stand-alone deposit policy is "rather farfetched" because of its high costs in the form of the expenditure on deposits and the fuel price increase.

⁴Crucial for Harstad's restoration of first best is his assumption that the non-coalition countries do not suffer from climate damage. In the present paper, we take up that assumption to enable the comparison of outcomes.

sellers and buyers. Arguably, the supply side of the deposit market is not thin, however, for worldwide there are many potential sellers of deposits. In contrast, the demand side is truly thin, since the coalition is the only demander, i.e. the monopsonist. We therefore suggest modeling the deposit market in an alternative way as a market with a uniform price, with price-taking suppliers and with the coalition exerting monopsonistic market power.⁵

Section 2 formalizes the interdependent markets for deposits and fuel and shows that the stand-alone deposit policy implements the first-best allocation in the benchmark case in which all agents – including the coalition – act as price takers. Keeping the focus on the stand-alone deposit policy, Section 3 dismisses the unrealistic assumption of a price-taking monopsonist and shows how the strategically acting coalition distorts the terms of trade in its own favor. In Section 4, we take up Harstad’s mix of the deposit policy, the fuel-supply-cap policy and the fuel-demand-cap policy and assume that the coalition pursues the deposit policy as well as the fuel-caps policies strategically. The coalition distorts the terms of trade in its own favor, as expected, and the fuel-supply-cap policy turns out to be redundant.

Section 5 explores the role of the coalition’s strategic behavior by comparing scenarios with and without strategic action. A general conclusion is that whenever the coalition acts strategically on the fuel market, on the deposit market or on both, it distorts the allocation in its own favor and hence is better off than in the efficient price-taking regime of Section 2. In sharp contrast, Harstad (2012) concludes that the allocation is first best in spite of strategic fuel-caps policies. Thus, Harstad’s efficiency result is not robust with regard to the alternative analytical concept of the deposit market developed in the present paper.

In Section 5, we also show that if the coalition combines the deposit policy with the fuel-supply-cap policy but does not act strategically at all, the result is the same as in the efficient regime of Section 2 with its stand-alone deposit policy; hence in that case the cap policy is redundant. If the deposit policy is strategic but the fuel-supply-cap policy is not, the outcome is the same as in the model of Section 3 with the stand-alone deposit policy; hence in that case the cap policy is also redundant. Finally, based on a simple parametric version of the model we show that the mix of the strategic deposit policy and the strategic fuel-supply-cap policy is better for the coalition than the strategic stand-alone deposit policy, which is better, in turn, than the completely non-strategic policies.

⁵Bohm (1993) appears to have taken that route, but his setup and illustration of the deposit market provides limited insight into how the market works and how it is linked with the fuel market.

2 Non-strategic deposit policy

We consider a world economy with two groups of countries, M and N . The members of group M participate in an international climate agreement. To simplify, we treat group M as one agent, referred to as coalition M . The countries of group $N = \{1, \dots, n\}$ are no signatories of the agreement. Each country $i \in \{M\} \cup N$ produces fossil energy (quantity e_i^s), called fuel, from domestic fossil energy deposits. The cost of extracting fuel is $C^i(e_i^s)$ with⁶ $C_{e_i^s}^i > 0$, and $C_{e_i^s e_i^s}^i > 0$. Following Harstad (2012, p. 85), we interpret the extraction cost function as a function that implicitly orders country i 's (small) deposits according to their extraction costs such that $C_{e_i^s}^i(e_i^s)$ "... is a mapping from country i 's deposits, ordered according to costs, to the marginal extraction cost of these deposits."⁷ Fuel consumption generates the greenhouse gas carbon dioxide proportional to fuel consumption. With a suitable choice of units, e_i^d represents both fuel consumption and emissions. Global emissions cause climate damage $D^i\left(\sum_{\{M\} \cup N} e_j^d\right)$ in country i . The function D^i is increasing and convex in global emissions. As indicated in the introduction, we follow Harstad (2012) in setting

$$D^i(\cdot) \equiv 0 \quad \text{for all } i \in N \quad \text{and} \quad D^M(\cdot) = D(\cdot) > 0 \quad (1)$$

throughout the paper.

The representative consumer of country i , consumer i for short, derives utility from consuming fuel, $B^i(e_i^d)$, with $B_{e_i^d}^i > 0$ and $B_{e_i^d e_i^d}^i < 0$ and suffers from climate damage $D^i(\cdot)$. Her utility is

$$u_i = B^i(e_i^d) + \psi_i - p_e e_i^d - D^i\left(\sum_{\{M\} \cup N} e_j^d\right), \quad i \in \{M\} \cup N, \quad (2)$$

where p_e is the fuel price and ψ_i denotes net income that includes profits. Consumer i takes the prevailing climate damage as given and maximizes her consumption utility,⁸ $B^i(e_i^d) + \psi_i - p_e e_i^d$, with respect to e_i^d . The first-order condition

$$B_{e_i^d}^i(e_i^d) = p_e, \quad i \in \{M\} \cup N, \quad (3a)$$

readily yields the fuel demand

$$e_i^d = E^{di}(p_e) := \left(B_{e_i^d}^i\right)^{-1}(p_e), \quad (3b)$$

⁶Upper-case letters denote functions and subscripts attached to them indicate derivatives.

⁷A deposit is characterized by the amount of fossil fuel in the ground that can be extracted from it and by the cost of extracting that fuel. Deposits are supposed to contain very small but finite amounts of fuel. To reduce clutter we refer to $C_{e_i^s}^i(e_i^s)$ as the cost of extracting the fuel contained in the deposit.

⁸It is straightforward to turn the model into a simple general equilibrium model by introducing a numeraire consumption good with linear production technology. Denote the demand for this good by x_i^d , consider the quasi-linear utility $B^i(e_i^d) + x_i^d$ and observe that consumer i 's budget constraint is $p_e e_i^d + x_i^d = \psi_i$. See e.g. Harstad (2012) or Eichner and Pethig (2013).

where $\left(B_{e_i^d}^i\right)^{-1}$ is the inverse of the marginal benefit function $B_{e_i^d}^i$.

Each country i hosts a firm, firm i for short, that owns the country's fossil fuel deposits. The firm extracts the amount e_i^s of fuel to sell it on the fuel market at price p_e , and it offers at price p_z the amount z_i^s of 'fuel in the ground' on the deposit market.⁹ More precisely, the item the firm offers on the deposit market is the right to exploit specific deposits that embody the amount z_i^s of fuel. However, to avoid clumsy wording we will simply call z_i^s and z_i^d the deposits supplied and demanded.

Next, we specify the deposits firm i exploits, or sells unexploited, or leaves in the ground unsold. To that end, suppose for the time being there is no deposit market. Then the firm maximizes the profit $p_e e_i^s - C^i(e_i^s)$. The first-order condition $C_{e_i^s}^i(e_i^s) = p_e$ readily yields the fuel supply

$$e_i^s = \mathcal{E}^{si}(p_e) := \left(C_{e_i^s}^i\right)^{-1}(p_e),$$

where $\left(C_{e_i^s}^i\right)^{-1}$ is the inverse of the marginal cost function $C_{e_i^s}^i$. In terms of deposit language, firm i exploits all deposits with extraction costs $C_{e_i^s}^i(e_i^s) \leq p_e$. Firm i obviously has an incentive to offer deposits with extraction costs $C_{e_i^s}^i(e_i^s) > p_e$, which it would not exploit in the absence of deposit trading. However, the coalition's one and only purpose of buying deposits is to reduce total fuel extraction. That is, it seeks to prevent the consumption of fuel that is stored in those deposits which firm i would have exploited in the absence of deposit trading. It therefore buys only deposits with extraction costs $C_{e_i^s}^i(e_i^s) \leq p_e$. Since the deposit selling firm i observes that constraint, its fuel supply is

$$e_i^s = \mathcal{E}^{si}(p_e) - z_i^s, \tag{4}$$

when it offers the deposits z_i^s for sale. Suppose, the deposit price is $p_z = p_e$. In that case, all firms offer *all* deposits for sale with extraction costs $C_{e_i^s}^i(e_i^s) \leq p_e$, because their revenues from selling those deposits, $p_z \mathcal{E}^{si}(p_e) = p_e \mathcal{E}^{si}(p_e)$, is higher than their profit $p_e \mathcal{E}^{si}(p_e) - C^i[\mathcal{E}^{si}(p_e)]$ in the absence of deposit trading. Therefore, the fuel price p_e is an upper bound for the deposit price p_z .¹⁰ In contrast, if $p_z = 0$, no country gives away free any deposit with extraction costs $C_{e_i^s}^i(e_i^s) \leq p_e$, because the extraction of those deposits generates a profit. We conclude that $p_z \in [0, p_e]$.

⁹Our implicit assumption is that firm i is entitled to sell (the right to exploit) deposits. Harstad's (2012, p. 86) alternative assumption is that governments own the deposits and decide on selling (the right to exploit) the country's deposits. The deposit supply of welfare-maximizing price-taking governments is the same as that of profit-maximizing price-taking firms.

¹⁰The coalition will not accept prices $p_z > p_e$, since it can purchase all non-coalition countries' profitable deposits already at the price $p_z = p_e$.

That information serves to derive the firm's supply of fuel and deposits as follows. The firm not only generates a profit from producing and selling fuel, but also receives the revenues $p_z z_i^s$ from selling the deposits z_i^s . Taking p_e and p_z as given, it maximizes its total income

$$p_e [\mathcal{E}^{si}(p_e) - z_i^s] - C^i [\mathcal{E}^{si}(p_e) - z_i^s] + p_z z_i^s$$

with respect to z_i^s . The first-order condition is

$$C_{e_i^s}^i(e_i^s) = p_e - p_z, \quad i \in \{M\} \cup N. \quad (5a)$$

(5a) implies that firm i extracts fuel from all deposits with extraction costs¹¹ $C_{e_i^s}^i(e_i^s) \leq p_e - p_z$. Correspondingly, the fuel supply is

$$e_i^s = E^{si}(p_e - p_z) := \left(C_{e_i^s}^i\right)^{-1}(p_e - p_z), \quad i \in \{M\} \cup N, \quad (5b)$$

and we obtain the deposit supply

$$z_i^s = \mathcal{E}^{si}(p_e) - E^{si}(p_e - p_z), \quad i \in \{M\} \cup N \quad (6)$$

when combining (5b) and (4). The simultaneous determination of the supply functions (5b) and (6) highlights the strong interdependence of the markets for deposits and fuel.

Figure 1 illustrates firm i 's simultaneous choice of fuel and deposit supplies for given p_e and p_z . If there is no deposit market, the firm's fuel supply is $e_i^s = \mathcal{E}^{si}(p_e)$ and its profit equals the triangle Fp_eH . If there is a deposit market and the price is $p_z \in]0, p_e[$, firm i 's optimal fuel supply is $E^{si}(p_e - p_z)$ in Figure 1, its revenues from selling deposits are $GLHK$, and its profit is the area Fp_eLG . Hence, the firm gains the triangle $GCHK$ when the deposit market is in operation. Figure 1 also shows that the firm offers all deposits with extraction costs between $p_e - p_z$ and p_e , that is, it offers the least profitable of those deposits, which it would have exploited in the absence of deposit trading. This selection of deposits for sale is also in the coalition's interest. To see that suppose, the firm would offer deposits with extraction costs less than $p_e - p_z$ subject to the constraint that it receives the same total amount of money $GLHK$ as in Figure 1. Then it would offer a number of deposits whose total amount of stored fuel is smaller than z_i^s in Figure 1, because the firm requires to be compensated for the higher loss of profits.

In view of the fuel demand in (3b) and the fuel supply in (5b), the fuel-market clearing condition is

$$\sum_{\{M\} \cup N} E^{dj}(p_e) = \sum_{\{M\} \cup N} E^{sj}(p_e - p_z). \quad (7)$$

¹¹A (very) small deposit is fully characterized by the cost of extracting the fuel it contains. That cost is (approximately) equal to the marginal extraction cost $C_{e_i^s}^i(e_i^s)$.

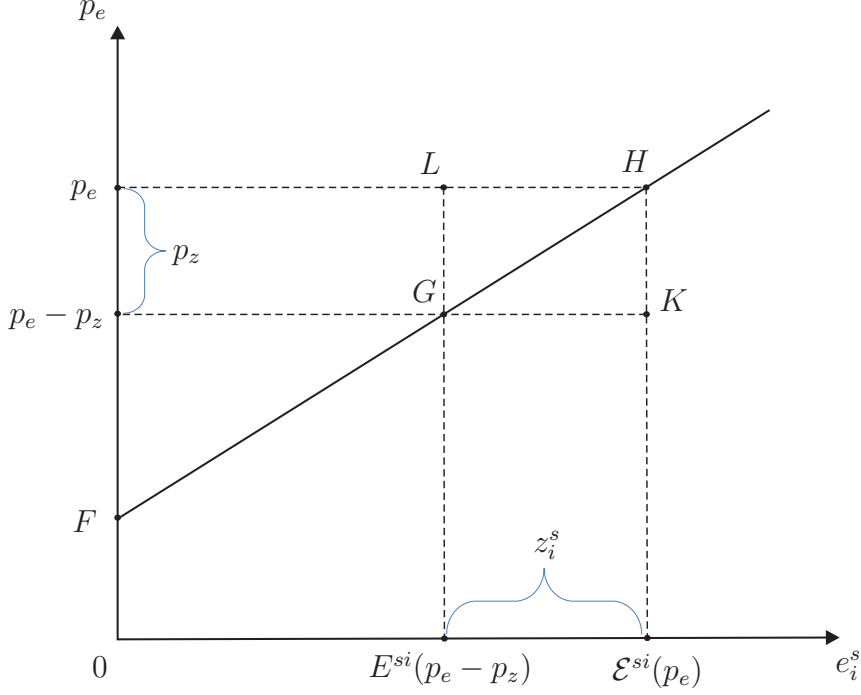


Figure 1: Firm i 's supply of fuel and deposits for given p_e and p_z

We have already specified the firms' deposit supply in (6). It remains to derive the demand for deposits. By assumption (1), the non-coalition countries refrain from mitigating climate damage and hence do not buy deposits ($z_i^d = 0$ for all $i \in N$). In this section the coalition's executive body, the coalition for short, is assumed to act as a price-taker on the fuel market and on the deposit market. The coalition accounts for $e_M^s = \mathcal{E}^{sM}(p_e) - z_M^s$ from (4), takes p_e, p_z, e_M^d and z_M^s as given and maximizes with respect to z_M^d the welfare

$$\begin{aligned}
u_M &= B^M(e_M^d) - C^M[\mathcal{E}^{sM}(p_e) - z_M^s] - p_e \{e_M^d - [\mathcal{E}^{sM}(p_e) - z_M^s]\} \\
&\quad - D \left[\sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - z_M^d \right] - p_z (z_M^d - z_M^s). \tag{8}
\end{aligned}$$

The first-order condition reads

$$D_e \left[\sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - z_M^d \right] = p_z \quad \text{with } D_e := \frac{dD}{d \sum_{\{M\} \cup N} e_j^d}, \tag{9a}$$

which is equivalent to

$$z_M^d = \sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - D_e^{-1}(p_z). \tag{9b}$$

In (9a), the marginal climate damage $D_e[\cdot]$ is the marginal benefit and p_z is the marginal cost of purchasing deposits. In view of (6) and (9b), the deposit market is in equilibrium if

$$\sum_{\{M\} \cup N} E^{sj}(p_e - p_z) = D_e^{-1}(p_z). \tag{10}$$

According to (7) and (10), equilibrium on each market depends on both prices, p_e and p_z . Hence, solving (7) and (10) for p_e and p_z simultaneously establishes the equilibrium on both markets.

Finally, we wish to know whether the perfectly competitive equilibrium on both markets is efficient. The straightforward implication of (3a), (5a) and (9a) is that the equilibrium is characterized by

$$\underbrace{B_{e_i^d}^i(e_i^d)}_{=p_e} = \underbrace{B_{e_j^d}^j(e_j^d)}_{=p_e} \quad i, j \in \{M\} \cup N \quad \text{and} \quad (11)$$

$$\underbrace{D_e \left(\sum_{\{M\} \cup N} e_j^d \right)}_{=p_z} = \underbrace{B_{e_i^d}^i(e_i^d) - C_{e_i^s}^i(e_i^s)}_{=p_e - (p_e - p_z)} \quad i \in \{M\} \cup N. \quad (12)$$

The equations (11) and (12) turn out to be the first-best – or efficient – allocation rules.¹² Equation (11) represents the rule for efficient fuel consumption across countries and equation (12) is the rule for the coalition’s efficient purchase of deposits. The marginal benefit of purchasing deposits, D_e , equals the marginal cost of purchasing deposits, p_z .

Proposition 1. *Suppose the coalition purchases fossil fuel deposits and preserves them. If all agents – including the coalition – are price-takers on the markets for fuel and deposits, the resultant perfectly competitive equilibrium is efficient.*

Proposition 1 is remarkable, because efficiency is reached without any regulatory action other than the coalition’s price-taking purchase of deposits. The coalition’s dilemma is that by assumption, the non-coalition countries contribute to its climate damage through their carbon emissions, but the coalition has no *direct* lever at its disposal for inducing non-coalition countries to curb their emissions. The coalition’s purchase of deposits is to be an *indirect* instrument to reduce the non-coalition countries’ fuel supply. It is an effective measure, because it accomplishes the full internalization of the non-coalition countries’ transfrontier pollution. Since the (executive body of the) coalition also buys deposits from its own extraction firm, it also fully internalizes the ‘home-made’ pollution.¹³

Figure 2 illustrates the equilibrium of the world economy with and without non-strategic stand-alone deposit policy. In the right-hand side panel, the intersection of the

¹²See also Harstad (2012), equation (1).

¹³Recall the assumption in equation (1) that the non-condition countries do not suffer from climate damage. If they would do and still abstain from climate policy, the world allocation would not be efficient.

¹⁴In Figure 2 we use the notation $e^h := \sum_{\{M\} \cup N} e_j^h$ for $h = d, s$, $z^s := \sum_{\{M\} \cup N} z_j^s$ and point $E \hat{=} \sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e^*)$.

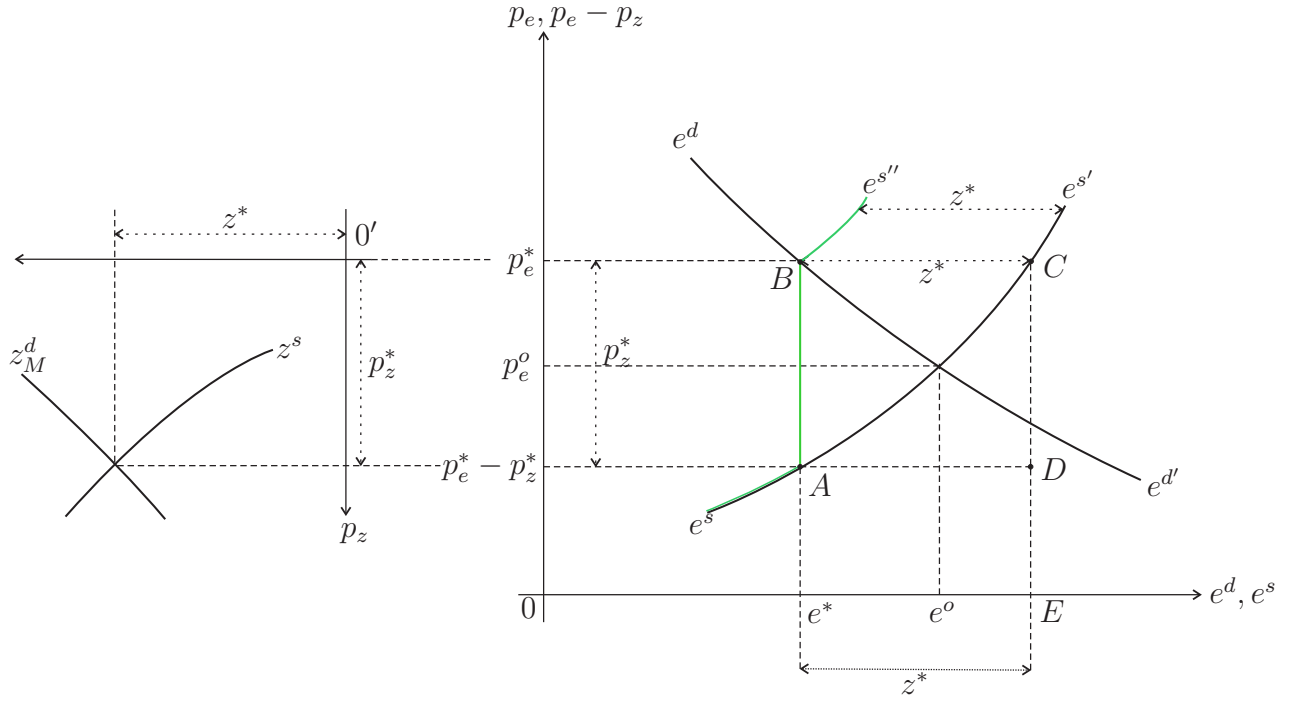


Figure 2: The interdependent, perfectly competitive markets for fossil fuel and deposits¹⁴

aggregate fuel demand curve $e^d e^{d'}$ and the aggregate fuel supply curve $e^s e^{s'}$ determines the inefficient equilibrium (p_e^o, e^o) in the absence of deposit policy. It is characterized by $p_e^o = B_{e_i^d}^i(e^o) = C_{e_i^s}^i(e^o)$ for all $i, j = \{M\} \cup N$. If deposits are traded, the fuel demand curve $e^d e^{d'}$ remains unchanged, but now the aggregate fuel supply curve is $e^s A B e^{s'}$. The consumer price of fuel increases from p_e^o to p_e^* , the producer price of fuel decreases from p_e^o to $p_e^* - p_z^*$, and total fuel consumption declines from e^o to e^* , reducing climate damage from $D(e^o)$ to $D(e^*)$. The coordinate system with origin $0'$ in the left-hand side panel of Figure 2 shows how the deposit price p_z clears the deposit market when the equilibrium fuel price $p_e = p_e^*$ is given.

Returning to the fuel market, we observe that the amount of deposits bought and sold in equilibrium is $z^* = BC = AD = e^* E$ and the coalition's expenditure on deposits is $p_z^* z^* = ABCD$. Interestingly, the coalition not only buys the deposits with extraction costs $C_{e_i^s}^i(e_i^s) \in [p_e^* - p_z^*, p_e^o]$, that would have been extracted in the absence of deposit trading, but it also purchases all deposits with extraction costs $C_{e_i^s}^i(e_i^s) \in [p_e^o, p_e^*]$, although these deposits would not have been extracted in the absence of deposit trading.

3 Strategic deposit policy

We consider the efficiency result of the previous section as an important benchmark rather than as an empirically relevant case. Since the coalition is a monopsonist on the deposit market, price-taking purchase of deposits is unrealistic. We now replace price-taking by assuming that the coalition acts strategically in the sense that it takes the impact of its deposit policy on the equilibrium prices of fuel and deposits into account. To analyze such strategic action, we set up the two-stage game illustrated in Figure 3. At stage 1, the coalition decides on its purchase of deposits, z_M^d , anticipating that both markets clear at stage 2 and that its choice of z_M^d influences the equilibrium prices p_e and p_z .

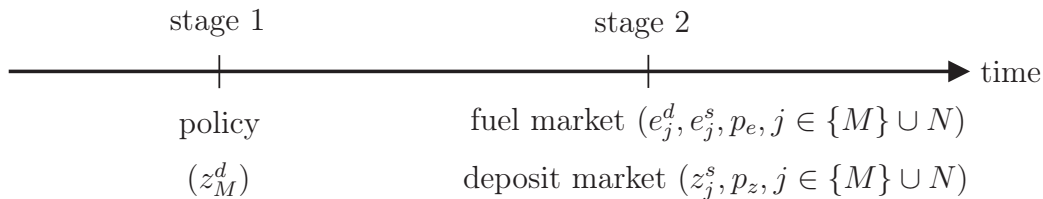


Figure 3: Timing of the game with strategic deposit policy

At stage 2, the fuel-market equilibrium condition (7) is satisfied as well as the condition for equilibrium on the deposit market,

$$z_M^d = \sum_{\{M\} \cup N} [\mathcal{E}^{sj}(p_e) - E^{sj}(p_e - p_z)], \quad (13)$$

that builds on (6) and on the information that z_M^d has already been determined at stage 1. Back at stage 1, the coalition chooses its demand for deposits. It does so by anticipating the equilibrium conditions (7) and (13). The coalition realizes that its deposit purchase influences the equilibrium prices of both markets. In formal terms, (7) and (13) imply price functions P^e and P^z such that the equilibrium prices are¹⁵

$$p_e = P^e(z_M^d) \quad \text{and} \quad p_z = P^z(z_M^d), \quad (14)$$

with $P_{z_M^d}^e > 0$, $P_{z_M^d}^z > 0$ and $\frac{d(p_e - p_z)}{dz_M^d} = P_{z_M^d}^e - P_{z_M^d}^z < 0$, if the coalition chooses z_M^d . Since $p_e - p_z$ is the producer price of fuel, $d(p_e - p_z)/dz_M^d < 0$ implies that all firms reduce their fuel supply, which in turn raises the equilibrium fuel price, $P_{z_M^d}^e > 0$. In addition, if (13) holds initially and the deposit demand increases, $dz_M^d > 0$, the firms are not willing to reequilibrate the market by raising their supply of deposits, unless the deposit price increases, $P_{z_M^d}^z > 0$.

¹⁵The functions P^e and P^z in (14) result from solving (7) and (13) for predetermined z_M^d . The sign of their derivatives is derived in Appendix A.

The coalition lets its firm sell deposits as in the last section. However, it takes into account how the firm's deposit supply $z_M^s = \mathcal{E}^{sM}(p_e) - E^{sM}(p_e - p_z)$ from (6) changes when the equilibrium prices (14) change with variations of z_M^d . Accounting for that information, the coalition maximizes

$$u_M = B^M [E^{dM}(p_e)] - C^M [E^{sM}(p_e - p_z)] - p_e [E^{dM}(p_e) - E^{sM}(p_e - p_z)] - D \left(\sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - z_M^d \right) - p_z [z_M^d - \mathcal{E}^{sM}(p_e) + E^{sM}(p_e - p_z)] \quad (15)$$

with respect to z_M^d subject to (14). The first-order condition is¹⁶

$$(D_e - p_z) \underbrace{\left(1 - \mathcal{E}_{p_e}^{sM} P_{z_M^d}^e \right)}_{>0} = (z_M^d - z_M^s) P_{z_M^d}^z + \left(D_e \sum_N \mathcal{E}_{p_e}^{sj} + e_M^d - e_M^s \right) P_{z_M^d}^e. \quad (16)$$

A straightforward implication of (16) is that the outcome is efficient, if $P_{z_M^d}^e = P_{z_M^d}^z = 0$, that is, if the coalition refrains from exerting its market power. That special case restates the efficiency result of Section 2. However, if the coalition acts strategically ($P_{z_M^d}^e, P_{z_M^d}^z > 0$) the right-hand side of (16) is non-zero, in general,¹⁷ which renders the equilibrium allocation inefficient. To get more specific results we assume in the sequel that all countries have identical benefit and cost functions ($B^i = B^j$ and $C^i = C^j$ for all $i, j \in \{M\} \cup N$). That symmetry assumption yields $e_i^d = e_i^s$ for all $i \in \{M\} \cup N$ and secures that the right-hand side of (16) is positive.

To compare the outcomes of strategic and non-strategic deposit policy, we attach a 'tilde' to the solution values of the former and a 'star' to the solution values of the latter. Consider the term $D_e - p_z$ on the left-hand side of (16). Since $D_e - p_z = 0$ if $\tilde{z}_M^d = z_M^{d*}$ due to (3a), (5a) and (9a), it is true that $D_e - p_z > 0$ implies $\tilde{z}_M^d < z_M^{d*}$, if and only if $(D_e - p_z)$ is monotone declining in z_M^d . Differentiation yields $d(D_e - p_z)/dz_M^d = \left(\sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} P_{z_M^d}^e - 1 \right) D_{ee} - P_{z_M^d}^z$. From $D_{ee} \geq 0$, $P_{z_M^d}^z > 0$ and $\sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} P_{z_M^d}^e = \frac{\sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj}}{\sum_{\{M\} \cup N} (\mathcal{E}_{p_e}^{sj} - E_{p_e}^{dj})} < 1$ follows $d(D_e - p_z)/dz_M^d < 0$ and hence $\tilde{z}_M^d < z_M^{d*}$. If we start with $z_M^d = z_M^{d*}$ and reduce z_M^d successively, the equality (16) is eventually restored.¹⁸ To put it differently, for any given z_M^d the coalition realizes that its marginal benefit of purchasing deposits is smaller and/or its marginal cost of purchasing deposits is larger with than without strategic action, and it therefore chooses $\tilde{z}_M^d < z_M^{d*}$. From $\tilde{z}_M^d < z_M^{d*}$ follows, in turn, that $\tilde{p}_e < p_e^*$, $\tilde{p}_z < p_z^*$ and

¹⁶The derivation of (16) can be found in Appendix A.

¹⁷We cannot exclude the possibility that the distortionary effects in (16) cancel out. However, it is reasonable to neglect such extremely exceptional cases.

¹⁸Strictly speaking, that conclusion presupposes that the coalition's welfare u_M in (18) (subject to (17)) is single-peaked in z_M^d . In Appendix C we show for parametric functions B , C and D that the coalition's welfare u_M in (18) is strictly concave in z_M^d .

$\tilde{p}_e - \tilde{p}_z > p_e^* - p_z^*$, because $P_{z_M^d}^e > 0$, $P_{z_M^d}^z > 0$ and $d(p_e - p_z)/dz_M^d < 0$. Moreover, the inequality $\tilde{p}_e - \tilde{p}_z > p_e^* - p_z^*$ implies $\tilde{D} > D^*$. That is, the climate damage the coalition chooses in case of strategic deposit policy is above its first-best level.

Next we turn to answer the question, whether strategic action pays for the coalition. Clearly, it could have purchased the first-best amount of deposits, z_M^{d*} . Therefore, its choice to distort the allocation proves that it is better off with than without strategic action. However, it is unclear, how the partial welfare loss of higher climate damage is overcompensated. Either, the coalition's consumption of fuel is sufficiently higher than the first-best level or the higher income due to lower expenditures on fuel and deposits is used to buy a standard consumption good not explicitly considered in our formal model.¹⁹ In any case the welfare gain from higher consumption over-compensates the welfare loss from higher climate damage. The results are summarized in

Proposition 2. *Suppose that the coalition purchases fossil fuel deposits to preserve them and that it acts strategically in the two-stage game of Figure 3.*

- (i) *Then the allocation is inefficient, in general.*
- (ii) *Suppose the benefit and cost functions are the same across countries. Compared to the first-best non-strategic deposit policy (Proposition 1), the prices of fuel and deposits are lower, the coalition buys fewer deposits and hence puts up with higher climate damage. However, it is better off with than without strategic action, because it overcompensates the welfare loss from higher climate damage by higher consumption.*

Essentially, the coalition takes advantage of its monopsonistic market power to distort the efficient allocation in its own favor. Since the markets for deposits and fuel are interdependent, the deposit price change caused by the demand for deposits triggers a change of the fuel price, which, in turn, spills back to the deposit market.

4 Strategic deposit- and -caps policy

Following Harstad (2012), we now suppose the coalition purchases deposits, as before, and regulates its own demand and supply of fuel in the form of caps on fuel consumption and production.²⁰ To avoid clumsy wording, we denote that policy as deposit-and-caps policy. Since carbon emissions are proportional to fuel consumption, the cap on fuel consumption

¹⁹See footnote 8.

²⁰See Hoel (1994) and Harstad (2012) for the discussion of various means such as taxes or emission trading to implement these fuel caps.

amounts to the conventional demand-side emission-reduction policy. Hoel (1994) showed in an analytical framework without deposit trading that under certain conditions the coalition prefers capping fuel demand and supply to capping fuel demand only. Harstad (2012) extended Hoel's two-instrument fuel regulation by the purchase of deposits. As pointed out in the introduction, Harstad finds that the coalition's three-instrument policy attains efficiency although it acts strategically. That result is remarkable and intriguing, in fact, since we showed in the last section for the case of stand-alone deposit policy that the coalition's move from price-taking (Section 2) to strategic (Section 3) action distorts the first-best allocation. The principal question we wish to answer in the present section is whether it is possible to "replicate" Harstad's efficiency result with our analytical design of the deposit market which differs significantly from Harstad's.

Throughout the present section, the non-coalition countries' supply and demand of fuel and supply of deposits are as in the previous sections, i.e. the equations

$$e_i^d = E^{di}(p_e), \quad e_i^s = E^{si}(p_e - p_z), \quad \text{and} \quad z_i^s = \mathcal{E}^{si}(p_e) - E^{si}(p_e - p_z), \quad i \in N \quad (17)$$

from (3b), (5b) and (6) are still satisfied. The coalition's fuel demand and supply are now regulated by the fuel production cap \bar{e}_M^s and the fuel consumption cap \bar{e}_M^d . Correspondingly, the deposit supply of the coalition's firm is zero ($z_M^s \equiv 0$). Since a non-binding fuel production cap $\bar{e}_M^s \geq \mathcal{E}^{sM}(p_e)$ is redundant, the coalition will set the cap \bar{e}_M^s , if any, such that $\bar{e}_M^s < \mathcal{E}^{sM}(p_e)$. That is, setting the cap \bar{e}_M^s amounts to the preservation of the amount

$$\bar{z}_M^s := \mathcal{E}^{sM}(p_e) - \bar{e}_M^s > 0 \quad (18)$$

of the coalition's deposits, which its firm would have exploited in the absence of climate policy.²¹ Although \bar{z}_M^s is not offered for sale on the deposit market, it is relevant for the coalition's mitigation policy, because now total emission reduction is $\hat{z}_M^d := z_M^d + \bar{z}_M^s$ instead of z_M^d . The coalition's welfare is

$$u_M = B^M(\bar{e}_M^d) - C^M(\bar{e}_M^s) - p_e(\bar{e}_M^d - \bar{e}_M^s) - D \left[\sum_N \mathcal{E}^{sj}(p_e) + \bar{e}_M^s - z_M^d \right] - p_z z_M^d,$$

when it implements the fuel production cap \bar{e}_M^s , the fuel consumption cap \bar{e}_M^d and buys the amount z_M^d of deposits. The coalition's policy instruments interfere directly either with the fuel market (\bar{e}_M^d, \bar{e}_M^s) or with the deposit market (z_M^d). Accordingly, it may act strategically on both markets, on either market or on neither market. Put differently, the coalition may choose a strategic or non-strategic fuel-caps policy and a strategic or non-strategic deposit policy. We will place our main emphasis on – and begin with – the case of strategic action on both markets, but will then also take up the other policy scenarios.

²¹Note, however, that $\mathcal{E}^{sM}(p_e) - \bar{e}_M^s$ is not offered for sale on the deposit market.

Modeling strategic policies on both markets requires constructing a sequential game. Similar as in the previous section, one could employ a two-stage framework, where all policy parameters $(\bar{e}_M^d, \bar{e}_M^s, z_M^d)$ are set at stage 1 and both markets equilibrate at stage 2. However, since we wish to compare Harstad's and our approach, we adopt the four-stage time structure illustrated in Figure 4, because that is closer than a two-stage approach to Harstad's (2012) three-stage game model. To solve the game we follow the standard procedure of backward induction.

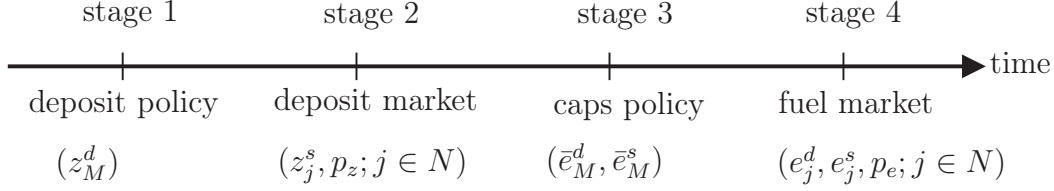


Figure 4: Timing of the game with strategic deposit-and-caps policy²²

Stage 4: Fuel market equilibrium. The non-coalition countries form their demand and supply of fuel, $e_i^d = E^{di}(p_e)$ and $e_i^s = E^{si}(p_e - p_z)$, according to (17). The fuel caps \bar{e}_M^d and \bar{e}_M^s have already been chosen at stage 3 and hence are given at stage 4. With this information, the fuel market equilibrium is

$$\sum_N E^{dj}(p_e) + \bar{e}_M^d = \sum_N E^{sj}(p_e - p_z) + \bar{e}_M^s. \quad (19)$$

Stage 3: Strategic fuel-caps policy. At this stage, the coalition anticipates the fuel market equilibrium (19). It also anticipates $E^{si}(p_e - p_z) = \mathcal{E}^{si}(p_e) - z_i^s$, $i \in N$ from (17), $\bar{e}_M^s = \mathcal{E}^{sM}(p_e) - \bar{z}_M^s$ from (18) and accounts for the deposit market equilibrium $\sum_N z_j^s = z_M^d$, attained at the earlier stage 2, to replace equation (19) by

$$\sum_N E^{dj}(p_e) + \bar{e}_M^d = \sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - \hat{z}_M^d \quad \text{with } \hat{z}_M^d := z_M^d + \bar{z}_M^s. \quad (20)$$

Recall that \bar{z}_M^s are the non-marketed deposits the coalition preserves by choosing \bar{e}_M^s and that $\hat{z}_M^d := z_M^d + \bar{z}_M^s$ are all marketed and non-marketed deposits preserved by the coalition's deposit-and-caps policy. The coalition infers from (20) that the equilibrium fuel price depends on \bar{e}_M^d and \hat{z}_M^d . Formally, (20) implies a function P^e , such that

$$p_e = P^e(\bar{e}_M^d, \hat{z}_M^d). \quad (21)$$

²²Harstad (2012, FIG. 3) employs a three-stage game, because in his analytical approach to the deposit market the coalition's deposit policy is not analyzed at a stage of its own.

Hence the coalition's problem is to maximize

$$u_M = B^M(\bar{e}_M^d) - C^M(\bar{e}_M^s) - p_e(\bar{e}_M^d - \bar{e}_M^s) - D \left[\sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - \hat{z}_M^d \right] - p_z [\hat{z}_M^d - \mathcal{E}^{sM}(p_e) + \bar{e}_M^s] \quad (22)$$

with respect to \bar{e}_M^d and \bar{e}_M^s subject to (21). The corresponding first-order conditions are

$$\frac{du_M}{d\bar{e}_M^d} = B_{\bar{e}_M^d}^M - p_e - \left(\bar{e}_M^d - \bar{e}_M^s + D_e \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} - p_z \mathcal{E}_{p_e}^{sM} \right) P_{\bar{e}_M^d}^e = 0, \quad (23)$$

$$\frac{du_M}{d\bar{e}_M^s} = -C_{\bar{e}_M^s}^M + p_e - p_z = 0. \quad (24)$$

Implicitly, (23) and (24) determine the coalition's fuel caps for the prevailing prices p_e and p_z .²³ We denote the solution of (23) and (24) with respect to the fuel caps by

$$\bar{e}_M^d = \bar{E}^{dM}(p_e, p_z) \quad \text{and} \quad \bar{e}_M^s = \bar{E}^{sM}(p_e, p_z) = E^{sM}(p_e - p_z) := \left(C_{\bar{e}_M^s}^M \right)^{-1} (p_e - p_z). \quad (25)$$

The surprising conclusion from (24) and (25) is that the coalition chooses \bar{e}_M^s exactly as the coalition's firm would choose e_M^s in the absence of fuel policy. Thus, the three-instrument policy mix studied by Harstad is equivalent to a policy mix consisting of the fuel-demand-cap policy and the deposit policy.²⁴ In other words, the coalition should refrain from regulating the fuel supply and leave that supply at the discretion of its extraction firm, instead, as in the previous Sections 2 and 3.

The fuel-supply-cap policy is redundant for the following reason. It is clear from (18) that the choice of \bar{e}_M^s determines \bar{z}_M^s and vice versa. At the earlier stage 1, the coalition has already made a decision on z_M^d and \hat{z}_M^d in anticipation of the deposit market equilibrium. Thus, it has implicitly also chosen \bar{z}_M^s taking into consideration (at stage 1) that the reduction of total fuel supply at minimum cost is a necessary condition for minimizing its climate damage burden. Cost minimization requires, in turn, equalizing marginal extraction costs across countries. The coalition anticipates that all firms in non-coalition countries choose their fuel supply according to (5a) and (5b) that therefore must be satisfied too for its own extraction firm with or without fuel-demand-cap regulation. In conclusion, the coalition chooses

$$\bar{z}_M^s = \mathcal{E}^{sM}(p_e) - E^{sM}(p_e - p_z), \quad (26)$$

²³Note that \hat{z}_M^d is contained in (22), but not in (23) and (24).

²⁴Interestingly, Bohm (1993) has discussed a special form of that policy. To avoid notational confusion, we continue analyzing the three-instrument policy, because switching to the equivalent two-instrument policy would require slight purely formal modification, e.g. in (19).

Stage 2: Deposit market equilibrium. At stage 2, the deposit market clears. The non-coalition countries' firms supply the deposits $z_i^s = \mathcal{E}^{sj}(p_e) - E^{si}(p_e - p_z)$, $i \in N$, according to (17), while the coalition has already made a decision at stage 1 on its purchase of deposits, z_M^d and on the own deposits to be preserved, \bar{z}_M^s . Hence, the deposit-market clearing condition is

$$\sum_{\{M\} \cup N} [\mathcal{E}^{sj}(p_e) - E^{sj}(p_e - p_z)] = \hat{z}_M^d, \quad \text{where } \hat{z}_M^d := z_M^d + \bar{z}_M^s. \quad (27)$$

Stage 1: Strategic deposit policy. At stage 1, the coalition purchases deposits anticipating the market equilibria (20) and (27). Specifically, it accounts for the functions (18), (21), (25) and

$$p_z = P^z(p_e, \hat{z}_M^d), \quad (28)$$

where (28) solves (27) for p_z . The function P^e specifies the dependence of the equilibrium fuel price on \bar{e}_M^d and \hat{z}_M^d as at stage 3.²⁵ The functions \bar{E}^{dM} and E^{sM} express the dependence on p_e and p_z of the caps and the function P^z captures the dependence on p_e and \hat{z}_M^d of the equilibrium deposit price. (21), (25) and (28) highlight that due to the interdependence of the markets for fuel and deposits the coalition's deposit policy at stage 1 has direct and indirect effects not only on the equilibrium prices of both markets, but also on the fuel caps at stage 3. The coalition maximizes

$$u_M = B^M(\bar{e}_M^d) - C^M(\bar{e}_M^s) - p_e(\bar{e}_M^d - \bar{e}_M^s) - D \left[\sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - \hat{z}_M^d \right] - p_z [\hat{z}_M^d - \mathcal{E}^{sM}(p_e) + \bar{e}_M^s] \quad (29)$$

with respect to \hat{z}_M^d subject to (21), (25) and (28). The corresponding first-order condition is²⁶

$$\frac{du_M}{d\hat{z}_M^d} = D_e - p_z + \left(B_{\bar{e}_M^d}^M - p_e \right) \mu_d - \mu_e \frac{dp_e}{d\hat{z}_M^d} - z_M^d \frac{dp_z}{d\hat{z}_M^d} = 0, \quad (30)$$

where $\mu_d := \bar{E}_{p_e}^{dM} \frac{dp_e}{d\hat{z}_M^d} + \bar{E}_{p_z}^{dM} \frac{dp_z}{d\hat{z}_M^d}$, $\mu_e := \bar{e}_M^d - \bar{e}_M^s + D_e \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} - p_z \mathcal{E}_{p_e}^{sM}$,

$$\frac{dp_e}{d\hat{z}_M^d} = - \frac{P_{\bar{e}_M^d}^e \bar{E}_{p_z}^{dM} P_{\hat{z}_M^d}^z + P_{\hat{z}_M^d}^e}{P_{p_e}^z P_{\bar{e}_M^d}^e \bar{E}_{p_z}^{dM} + \left(P_{\bar{e}_M^d}^e \bar{E}_{p_e}^{dM} - 1 \right)} \quad \text{and} \quad \frac{dp_z}{d\hat{z}_M^d} = - \frac{P_{p_e}^z P_{\hat{z}_M^d}^e - P_{\hat{z}_M^d}^z \left(P_{\bar{e}_M^d}^e \bar{E}_{p_e}^{dM} - 1 \right)}{P_{p_e}^z P_{\bar{e}_M^d}^e \bar{E}_{p_z}^{dM} + \left(P_{\bar{e}_M^d}^e \bar{E}_{p_e}^{dM} - 1 \right)}. \quad (31)$$

²⁵The coalition considers (21) twice. However, at stage 3 it takes \hat{z}_M^d as given, whereas at stage 1 it also accounts for the dependence of the fuel equilibrium price on \hat{z}_M^d .

²⁶The derivation of (30) and (31) is delegated to Appendix B.

Efficiency check of the deposit-and-caps policy. It remains to investigate whether the equilibrium allocation of the strategic deposit-and-caps policy satisfies the efficiency conditions (11) and (12). According to (3a), (5a) and (9a), the equilibrium allocation satisfies $B_{e_i^d}^i = p_e$ and $C_{e_i^s}^i = p_e - p_z$ for all $i \in N$ and $p_z = D_e$, which are necessary conditions for (11) and (12). However, the coalition's allocation rules (23) and (30) contain distortionary terms such that, in general,²⁷ $B_{\bar{e}_M^d}^M \neq p_e$ in (23) and $D_e \neq p_z$ in (30). Combined with $B_{e_i^d}^i = p_e$ and $C_{e_i^s}^i = p_e - p_z$ for all $i \in N$, these inequalities yield $B_{e_i^d}^i \neq B_{\bar{e}_M^d}^M$ for all $i \in N$ and $D_e \left(\sum_{\{M\} \cup N} e_j^d \right) \neq B_{e_i^d}^i(e_i^d) - C_{e_i^s}^i(e_i^s)$ for all $i \in \{M\} \cup N$. Hence, the allocation is inefficient although production is globally efficient.

To gain further insights into the outcome of the strategic deposit-and-caps policy, we resort to the parametric functional forms²⁸

$$B_i(e_i^d) = ae_i^d - \frac{b}{2}(e_i^d)^2, \quad C_i(e_i^s) = \frac{c}{2}(e_i^s)^2, \quad D \left(\sum_{\{M\} \cup N} e_j^d \right) = \delta \sum_{\{M\} \cup N} e_j^d, \quad i \in \{M\} \cup N. \quad (32)$$

In the Appendix C, we calculate the first-best allocation with the parametric functions (32) as well as the equilibrium allocation and prices in the four-stage game of the strategic deposit-and-caps policy. We find that the coalition uses the instrument triple $(\bar{e}_M^d, \bar{e}_M^s, \hat{z}_M^d)$ strategically to reduce the prices of fuel²⁹ ($p_e < p_e^*$) and deposits ($p_z < p_z^*$) compared to their first-best level such that the coalition preserves fewer deposits ($\hat{z}_M^d < z_M^{d*}$) and suffers from higher climate damage ($D > D^*$). Its overall welfare is higher than the first-best welfare ($u_M > u_M^*$). These deviations from first best are the same, in qualitative terms, we found in case of the stand-alone strategic deposit policy in the non-parametric model of Section 3. Our parametric approach gives rise to the same results that are more specific than those reported in Proposition 2. With the strategic deposit-and-caps policy the coalition turns out to consume less ($e_M^d < e_M^{d*}$) but produces more fuel ($e_M^s > e_M^{s*}$) than in the first-best regime.³⁰ Consequently, its expenditures on fuel and deposits are lower such that the coalition can consume more of the standard consumption good not explicitly considered in our formal model.³¹ The coalition's welfare increases compared to the efficient allocation since the welfare loss from lower fuel consumption and higher climate damage is smaller than the welfare gain from higher consumption of the standard consumption good. We summarize our conclusions in

²⁷See footnote 17.

²⁸The parametric version (32) of the game model is an illustration with no claim of generality. We kept it deliberately simple to allow for straightforward comparisons of different assumptions on strategic behavior. All results based on the parametric functions (32) we report here and later in the paper are proved in the Appendix C.

²⁹The superscript * indicates efficient levels of variables.

³⁰Note also that $e_M^d < e_M^{d*}$ and $e_M^s < e_M^{s*}$ imply that the coalition exports fuel.

³¹See footnote 8.

Proposition 3. *Suppose the coalition purchases fossil-fuel deposits to preserve them (deposit policy), and caps its fossil-fuel production and consumption (fuel-caps policy).*

- (i) *If the coalition pursues both policies strategically in the four-stage game of Figure 4,*
 - *the allocation is inefficient, in general;*³²
 - *the fuel-supply-cap policy is redundant.*
- (iia) *Compared to the efficient **non-strategic** stand-alone deposit policy of Section 2, the prices of fuel and deposits are lower and their difference is larger; hence fuel production is higher in all countries and so is the climate damage; the coalition consumes less but produces more fuel and buys fewer deposits; it overcompensates the welfare loss from higher climate damage and lower fuel consumption by a welfare gain from higher non-fuel consumption.*
- (iib) *Compared to the **strategic** stand-alone deposit policy of Section 3, the coalition’s welfare is higher; the prices of fuel and deposits are lower, but their difference is smaller; hence fuel production is lower in all countries and so is the climate damage, although the coalition buys fewer deposits; non-coalition countries consume more, but the coalition consumes less fuel.*³³

Some remarks are in order on the comparison of the strategic stand-alone deposit policy and the strategic deposit-and-cap policy in Proposition 3(iib). The prime message is that the two-instrument policy is better for the coalition than the stand-alone deposit policy. Since the fuel demand cap is binding, the consumer fuel price is higher inside than outside the coalition, and this price wedge induces carbon leakage. However, the leakage is so small that it does not prevent the reduction of total fuel consumption. Thus, the fuel-demand-cap enhances the coalition’s welfare above the level achieved under the stand-alone deposit policy because it reduces fuel consumption for the benefit of less climate damage and more non-fuel consumption.

5 Fully or partly non-strategic deposit- and -caps policy

In the preceding Section 4, we have analyzed the coalition’s deposit- and -caps policy with strategic action in both the deposit and fuel market. Now we briefly investigate the scenarios

³²The symmetry assumption $B_i = B$ and $C_i = C$ for all $i \in \{M\} \cup N$ is sufficient but not necessary for $B_{e^d}^M \neq p_e$ and hence for Proposition 3(i).

³³Proposition 3(iia) and 3(iib) follow from the first column of Table 3 and from Table 4, respectively, of the Appendix C.

in which the coalition acts non-strategically either in the deposit market or in the fuel market or in both markets. Although we found (Proposition 3(i)) that the fuel-supply-cap policy is redundant, we will stick to the three-instrument deposits-and-caps policy to ease the exposition.

Non-strategic fuel-caps policy ($P_{\bar{e}_M^d}^e = 0$) **and non-strategic deposit policy** ($P_{\hat{z}_M^d}^e = P_{\hat{z}_M^d}^z = 0$). $P_{\bar{e}_M^d}^e = 0$ in (23) yields $B_{\bar{e}_M^d}^M = p_e$ and $P_{\bar{e}_M^d}^e = P_{\hat{z}_M^d}^z = P_{\hat{z}_M^d}^e = 0$ in (31) leads to $\frac{dp_e}{d\hat{z}_M^d} = \frac{dp_z}{d\hat{z}_M^d} = 0$ such that (30) turns into $D_e = p_z$. The allocation rules $B_{\bar{e}_M^d}^M = p_e$, $C_{\bar{e}_M^s}^M = p_e - p_z$ from (24), and $D_e = p_z$ yield (11) and (12). Hence, the coalition attains the first-best allocation, if it refrains from strategic action altogether. Moreover, the policies of capping the production and consumption of fuel are redundant in this scenario, because the coalition's caps-setting rules $C_{\bar{e}_M^s}^M = p_e - p_z$ and $B_{\bar{e}_M^d}^M = p_e$ are the same as those the coalition's firm and consumer, respectively, follow in the absence of any fuel-caps policy. We conclude that the scenario of non-strategic action on both markets is equivalent to the perfectly competitive regime studied in Section 2. As already emphasized, this scenario serves as a benchmark only, because it is extremely implausible to assume that the monopsonist purchases deposits as a price taker.

Non-strategic fuel-caps policy ($P_{\bar{e}_M^d}^e = 0$) **and strategic deposit policy** ($P_{\hat{z}_M^d}^e, P_{\hat{z}_M^d}^z \neq 0$). $P_{\bar{e}_M^d}^e = 0$ in (23) yields $B_{\bar{e}_M^d}^M = p_e$, and $P_{\bar{e}_M^d}^e = 0$ in (31) leads to $\frac{dp_e}{d\hat{z}_M^d} = P_{\hat{z}_M^d}^e \neq 0$ and $\frac{dp_z}{d\hat{z}_M^d} = P_{p_e}^z P_{\hat{z}_M^d}^e \neq 0$, which implies $D_e \neq p_z$ via (30), in turn. The allocation rules $B_{\bar{e}_M^d}^M = p_e$, $C_{\bar{e}_M^s}^M = p_e - p_z$ from (24), and $D_e \neq p_z$ satisfy (11) but violate (12) such that the pertaining equilibrium allocation is inefficient. As in the scenario of the last paragraph, the policies of capping the production and consumption of fuel are redundant, because the coalition's caps-setting rules are the same as those of the coalition's firm and consumer, respectively, in the absence of fuel-caps policies. In fact, we show in the Appendix B that the scenario of non-strategic fuel-caps policies and strategic deposit policy is equivalent to the two-stage game with stand-alone deposit policy studied in Section 3. Hence the deviations from the efficient allocation are as recorded in Proposition 2(ii).

Strategic fuel-caps policy ($P_{\bar{e}_M^d}^e \neq 0$) **and non-strategic deposit policy** ($P_{\hat{z}_M^d}^e = P_{\hat{z}_M^d}^z = 0$). As the case of non-strategic action on both markets, this scenario appears to be empirically irrelevant, because it portrays the monopsonist as price taker. Nonetheless, we briefly make the efficiency check for the sake of completeness. $P_{\bar{e}_M^d}^e \neq 0$ in (23) yields $B_{\bar{e}_M^d}^M \neq p_e$, and $P_{\hat{z}_M^d}^z = P_{\hat{z}_M^d}^e = 0$ in (31) leads to $\frac{dp_e}{d\hat{z}_M^d} = \frac{dp_z}{d\hat{z}_M^d} = 0$ such that (30) turns into $D_e = p_z$. The allocation rules $B_{\bar{e}_M^d}^M \neq p_e$, $C_{\bar{e}_M^s}^M = p_e - p_z$ from (24), and $D_e = p_z$

violate (11) and (12) such that the pertaining equilibrium allocation is inefficient. The Appendix C applies the parametric model (32) to the scenario under review and shows that, in qualitative terms, the equilibrium allocation deviates from the efficient allocation as described in Proposition 3(iia).

Proposition 4 summarizes these results – and also ranks the coalition’s payoff in the scenarios of strategic and non-strategic action discussed above.

Proposition 4. *Suppose the coalition purchases fossil-fuel deposits to preserve them (deposit policy), and caps its fossil fuel production and consumption (fuel-caps policy).*

- (i) In the scenario of non-strategic policies on both markets, the allocation is efficient. This scenario is equivalent to the perfectly competitive world economy of Section 2.*
- (ii) If the coalition acts strategically on one market and non-strategically on the other, the allocation is inefficient, in general.*
- (iii) The scenario in which the coalition pursues a non-strategic fuel-caps policy and a strategic deposit policy is equivalent to the strategic stand-alone deposit policy of Section 3.*
- (iv) Suppose the parametric functional forms (30) apply.*
 - (iva) If the coalition sets the fuel caps strategically but purchases deposits non-strategically, the equilibrium allocation deviates from the efficient one, in qualitative terms, as in the case of strategic action on both markets (as described in Proposition 3(via)).*
 - (ivb) If the coalition pursues both policies strategically, its payoff is highest. If it acts strategically on one market only, its payoff is higher than in case of non-strategic action on both markets. The ranking of the scenarios in which the coalition acts strategically on one market only depends on parameters.*

Proposition 4 provides a number of interesting results. First, the strategic pursuit of both policies is better for the coalition than the stand-alone strategic deposit policy. The use of three instruments instead of one enables the coalition to distort the allocation further in its own favor. Moreover, if we disregard the unrealistic scenarios with non-strategic deposit policies, we conclude that there is a case for the deposit-and-caps policy only, if the coalition pursues both policies strategically.

The common feature of Harstad’s model and ours is that the coalition pursues a strategic fuel-caps policy in the sense that the coalition takes the influence of its fuel-caps policy on the equilibrium fuel price into account (ibidem, p. 85).³⁴ As shown above, strategic

³⁴Another common feature is that the non-coalition countries choose their fuel demand and supply as price-takers (ibidem, p. 84).

fuel-caps policy implies inefficiency in our approach, but efficiency in Harstad's. Therefore, our finding that efficiency cannot be attained unless the coalition refrains from strategic action altogether is at variance with Harstad's (2012) efficiency result. The principal reason for that striking difference appears to lie in the profoundly different design of the deposit market. As indicated in the introduction, Harstad does not model that market as a textbook market with a uniform price, as we do, but rather conceives of that market as a series of bilateral trades of deposits with unspecified and not necessarily uniform exchange rates. His conclusions are based on the notion that the deposit market is in equilibrium, "...if and only if there exists no pair of countries ... [i and j] and no price of deposits such that both [countries] i and j strictly benefit from transferring the right to exploit a deposit from i to j at that price." (ibidem, p. 86).

Harstad's design of the deposit market implies that the bilateral deposit trades endogenize each country's extraction cost function, whereas in our model extraction cost functions are invariant. More importantly, in our model the coalition's monopsony power on the deposit market is explicitly defined by $P_{z_M^d}^z, P_{z_M^d}^e \neq 0$ and spills over to the fuel market due to the strong interdependence of both markets. As shown above, in our approach the equilibrium allocation differs markedly when the coalition acts strategically ($P_{z_M^d}^z, P_{z_M^d}^e \neq 0$) or non-strategically ($P_{z_M^d}^z = P_{z_M^d}^e = 0$) when purchasing deposits. In contrast, Harstad's formal analysis does without the distinction between strategic or non-strategic deposit policy, and it appears to play no role for his results how the gains from bilateral trades are shared between the bargaining agents.

6 Concluding remarks

The aim of the paper is to improve our understanding of how the deposit market works, how it is interconnected with the fuel market and what the differences are in outcome when the coalition implements strategically, semi-strategically or non-strategically the deposit policy or a combination of the deposit policy with the fuel cap policies. The efficiency result we attained in the case that all agents are price-takers is an interesting benchmark. Through the purchase of deposits the coalition reduces the non-coalition countries' – and its own - fuel supply by an appropriate amount and thus fully internalizes the 'home-made' negative externality as well as the negative externalities generated by non-coalition countries. The coalition's purchase of deposits from non-coalition countries satisfies the pollutee-pays-principle. As expected, the coalition's strategic action always influences the terms of trade such and reduces its burden of unilateral climate policy. That result is at variance with Harstad's (2012) finding of full internalization in spite of strategic action. The reason for

that intriguing discrepancy appears to be the difference in design of the deposit market in his model and ours.

For the benefit of informative results we followed Harstad (2012) in seeking analytical relief by employing additive, quasi-linear consumer preferences and, more importantly, by assuming that no non-coalition country suffers from climate damage. From an analytical viewpoint, the absence of climate damage in non-coalition countries sharpens the focus on the coalition's climate policy because that assumption is a rationale for disregarding climate policy or other responses of non-coalition countries to the coalition's policy.³⁵ However, allowing for climate damage not only in the coalition but also in non-coalition countries is a desirable extension of the model and an important item on the agenda of further research. Such an extension is non-trivial, because it reintroduces the free-rider problem. To see that suppose non-coalition countries also suffer from climate damage and consider buying deposits. These countries are willing to pay for deposits and hence have an incentive to take action, but they would clearly benefit even more from the purchase of deposits by the coalition or other non-coalition countries. With climate damage in non-coalition countries and deposit policy, free-rider incentives also jeopardize the formation of self-enforcing climate coalitions, similar as the free-rider incentives in the context of fuel-demand-cap policies studied e.g. by Eichner and Pethig (2013).

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³⁵As suggested by Harstad (2012) it is also possible that non-coalition countries suffer from climate damage but do not take action for some reason of policy failure. In that case, our analysis would still apply except that the allocation of the perfectly competitive economy of Section 2 is not efficient any more.

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Appendix

Appendix A

Derivation of (14):

Differentiating (7) and (13) yields

$$\sum_{\{M\} \cup N} E_{p_e}^{dj} dp_e = \sum_{\{M\} \cup N} E_{\sigma}^{sj} (dp_e - dp_z), \quad (\text{A1})$$

$$dz_M^d = \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} dp_e - \sum_{\{M\} \cup N} E_{\sigma}^{sj} (dp_e - dp_z), \quad (\text{A2})$$

where $\sigma := p_e - p_z$. Subtraction of (A1) from (A2) leads to

$$dz_M^d = \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} dp_e - \sum_{\{M\} \cup N} E_{p_e}^{dj} dp_e \iff \frac{dp_e}{dz_M^d} = P_{z_M}^e = \frac{1}{\sum_{\{M\} \cup N} (\mathcal{E}_{p_e}^{sj} - E_{p_e}^{dj})} > 0. \quad (\text{A3})$$

Combine (A1) and (A3) to obtain

$$\frac{dp_z}{dz_M^d} = P_{z_M}^z = \frac{\sum_{\{M\} \cup N} (E_{\sigma}^{sj} - E_{p_e}^{dj})}{\sum_{\{M\} \cup N} (\mathcal{E}_{p_e}^{sj} - E_{p_e}^{dj}) \cdot \sum_{\{M\} \cup N} E_{\sigma}^{sj}} > 0. \quad (\text{A4})$$

From (A3) and (A4) we infer

$$\frac{d(p_e - p_z)}{dz_M^d} = P_{z_M}^e - P_{z_M}^z = \frac{\sum_{\{M\} \cup N} E_{p_e}^{dj}}{\sum_{\{M\} \cup N} (\mathcal{E}_{p_e}^{sj} - E_{p_e}^{dj}) \cdot \sum_{\{M\} \cup N} E_{\sigma}^{sj}} < 0. \quad (\text{A5})$$

The signs in (A3) - (A5) follow from $E_{p_e}^{dj} = \frac{1}{B_j''} < 0$, $E_{\sigma}^{sj} = \frac{1}{C_j''[E^{sj}(\sigma)]} > 0$ and $\mathcal{E}_{p_e}^{sj} = \frac{1}{C_j''[\mathcal{E}^{sj}(p_e)]} > 0$.

Derivation of (16):

Maximizing (15) w.r.t. z_M^d yields the first-order condition

$$\begin{aligned} \frac{du_M}{dz_M^d} &= D_e - p_z + \underbrace{(B'_M - p)}_{=0} E_{p_e}^{dM} P_{z_M^d}^e + \underbrace{(C'_M - p_e + p_z)}_{=0} E_{\sigma}^{sM} \left(P_{z_M^d}^e - P_{z_M^d}^z \right) \\ &- (z_M^d - z_M^s) P_{z_M^d}^z - \left[D_e \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} + e_M^d - e_M^s - p_z \mathcal{E}_{p_e}^{sM} \right] P_{z_M^d}^e = 0. \end{aligned} \quad (\text{A6})$$

Accounting for

$$D_e \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} + e_M^d - e_M^s - p_z \mathcal{E}_{p_e}^{sM} = (D_e - p_z) \mathcal{E}_{p_e}^{sM} + D_e \sum_N \mathcal{E}_{p_e}^{sj} + e_M^d - e_M^s \quad (\text{A7})$$

in (A6) establishes (16).

Observe also that $\mathcal{E}_{p_e}^{sM} P_{z_M^d}^e = \frac{\mathcal{E}_{p_e}^{sM}}{\sum_{\{M\} \cup N} (\mathcal{E}_{p_e}^{sj} - E_{p_e}^{dj})} \in [0, 1]$ and that (9) implies $e_M^s = e_M^d$ in case of identical benefit and cost functions.

Appendix B

Proof of (30) and (31):

The coalition purchases that amount of deposits which maximizes w.r.t. z_M^d the welfare

$$\begin{aligned} u_M &= B^M(\bar{e}_M^d) - C^M(\bar{e}_M^s) - p_e(\bar{e}_M^d - \bar{e}_M^s) - D \left[\sum_{\{M\} \cup N} \mathcal{E}^{sj}(p_e) - \hat{z}_M^d \right] \\ &- p_z [\hat{z}_M^d - \mathcal{E}^{sj}(p_e) + \bar{e}_M^s], \end{aligned} \quad (\text{B1})$$

subject to

$$p_e = P^e(\bar{e}_M^d, \hat{z}_M^d), \quad (\text{B2})$$

$$\bar{e}_M^d = \bar{E}^{dM}(p_e, p_z) \quad \text{and} \quad \bar{e}_M^s = \bar{E}^{sM}(p_e, p_z). \quad (\text{B3})$$

$$p_z = P^z(p_e, \hat{z}_M^d). \quad (\text{B4})$$

The equations (B2), (B3) and (B4) characterize the joint equilibria on the markets for fuel and deposits as a function of the coalition's policy parameters. In order to observe these equations, the coalition determines the equilibrium displacement effects of small changes in its policy parameters by totally differentiating (B2), (B3) and (B4). (B2) and (B3) yield

$$p_e = P^e[\bar{E}^{dM}(p_e, p_z), \hat{z}_M^d]. \quad (\text{B5})$$

Total differentiation of (B4) and (B5) leads to

$$P_{p_e}^z dp_e - dp_z = -P_{\hat{z}_M^d}^z d\hat{z}_M^d, \quad (\text{B6})$$

$$\left(P_{\bar{e}_M^d}^e \bar{E}_{p_e}^{dM} - 1 \right) dp_e + P_{\bar{e}_M^d}^e \bar{E}_{p_z}^{dM} dp_z = -P_{\hat{z}_M^d}^e d\hat{z}_M^d, \quad (\text{B7})$$

or in matrix notation

$$\begin{bmatrix} P_{p_e}^z & -1 \\ \left(P_{\bar{e}_M^d}^e \bar{E}_{p_e}^{dM} - 1 \right) & P_{\bar{e}_M^d}^e \bar{E}_{p_z}^{dM} \end{bmatrix} \cdot \begin{bmatrix} dp_e \\ dp_z \end{bmatrix} = \begin{bmatrix} -P_{\hat{z}_M^d}^z d\hat{z}_M^d \\ -P_{\hat{z}_M^d}^e d\hat{z}_M^d \end{bmatrix}. \quad (\text{B8})$$

Solving (B8) yields (31).

The first-order condition of maximizing (B1) subject to $\bar{e}_M^d = \bar{E}^{dM}(p_e, p_z)$, $\bar{e}_M^s = \bar{E}^{sM}(p_e, p_z)$ and (31) is

$$\begin{aligned} \frac{du_M}{d\hat{z}_M^d} &= D_e - p_z + \left(B_{\bar{e}_M^d}^M - p_e \right) \mu_d - \underbrace{\left(C_{\bar{e}_M^s}^M - p_e + p_z \right)}_{=0} \mu_s - \left[\hat{z}_M^d - \mathcal{E}^{sj}(p_e) + \bar{e}_M^s \right] \frac{dp_z}{d\hat{z}_M^d} \\ &\quad - \left(\bar{e}_M^d - \bar{e}_M^s + D_e \sum_{\{M\} \cup N} \mathcal{E}_{p_e}^{sj} - p_z \mathcal{E}_{p_e}^{sM} \right) \frac{dp_e}{d\hat{z}_M^d}, \end{aligned} \quad (\text{B9})$$

where $\mu_h := \bar{E}_{p_e}^{hM} \frac{dp_e}{d\hat{z}_M^d} + \bar{E}_{p_z}^{hM} \frac{dp_z}{d\hat{z}_M^d}$ with $h = d, s$. Finally, accounting for (24) and $\hat{z}_M^d = z_M^d + \bar{z}_M^s$ establishes (30).

Proof of Proposition 4(iii):

$P_{\bar{e}_M^d}^e = 0$ in (23) yields $B_{\bar{e}_M^d}^M = p_e$ or equivalently $\bar{e}_M^d = E^{dM}(p_e)$. From (24) we infer $\bar{e}_M^s = E^{sM}(p_e - p_z)$. Making use of $\bar{e}_M^d = E^{dM}(p_e)$ and $\bar{e}_M^s = E^{sM}(p_e - p_z)$ in the fuel market equilibrium condition (19) proves the equivalence of (7) and (19). Next, observe that (29) coincides with (15) when z_M^d in the two-stage game is set equal to \hat{z}_M^d in the four-stage game. To sum up, both the fuel market and deposit market equilibrium condition are the same in the two-stage game as in the four-stage game if the coalition sets caps non-strategically and buys deposits strategically. To put it differently, the price functions

$$p_e = P^e \left[E^{dM}(p_e), \hat{z}_M^d \right], \quad p_z = P^z \left(p_e, \hat{z}_M^d \right)$$

from (B6) and (B7) yield the price functions

$$p_e = \tilde{P}^e \left(\hat{z}_M^d \right), \quad p_z = \tilde{P}^z \left(\hat{z}_M^d \right)$$

from (14), where

$$\frac{dp_e}{d\hat{z}_M^d} = \tilde{P}_{\hat{z}_M^d}^e, \quad \frac{dp_z}{d\hat{z}_M^d} = \tilde{P}_{\hat{z}_M^d}^z. \quad (\text{B10})$$

Accounting for (B10) it is straightforward to show that the first-order conditions of deposit purchase in the two-stage game (A6) is equivalent to the associated first-order condition in the four-stage game (30).

Appendix C: Parametric functions

Efficiency. Inserting

$$e_j^d = E^{dj}(p_e) = \frac{a - p_e}{b}, \quad e_j^s = E^{sj}(p_e - p_z) = \frac{p_e - p_z}{c}, \quad \mathcal{E}^{sj}(p_e) = \frac{p_e}{c} \quad \text{and} \quad D_e = \delta \quad (\text{C1})$$

into (9a) yields³⁶ $p_z^* = \delta$. Using this information in (7) we get $p_e^* = \frac{ac+b\delta}{b+c}$. Next, we obtain $z_i^{s*} = \frac{\delta}{c} = \frac{z_M^d}{n+1}$ from (6). The associated allocation and welfare levels follow from inserting (p_e^*, p_z^*, z_M^d) into (C1) and into the welfare function (8), and are listed in column 2 of Table 1.

Strategic deposit policy. Inserting (C1) into (7) and (13) leads to

$$\frac{a - p_e}{b} = \frac{p_e - p_z}{c}, \quad z_M^d = \frac{(n+1)p_z}{c}. \quad (\text{C2})$$

Solve (C2) with respect to p_e and p_z to get

$$P^e(z_M^d) = \frac{c[a(n+1) + bz_M^d]}{(n+1)(b+c)}, \quad P^z(z_M^d) = \frac{cz_M^d}{n+1}. \quad (\text{C3})$$

Inserting (C1) and (C3) in (16) yields after rearrangement of terms,

$$\begin{aligned} \frac{du_M}{dz_M^d} &= \delta - p_z - \left(z_M^d - \frac{z_M^d}{n+1} \right) P_{z_M^d}^z - \left[\frac{(n+1)\delta}{c} - \frac{p_z}{c} \right] P_{z_M^d}^e \\ &= -\frac{c[2n(b+c) + c]z_M^d - (n+1)^2\delta}{(b+c)(n+1)^2} = 0. \end{aligned} \quad (\text{C4})$$

The derivative of (C4) is

$$\frac{d^2u_M}{d(z_M^d)^2} = -\frac{c[2n(b+c) + c]}{(b+c)(n+1)^2} < 0. \quad (\text{C5})$$

Solving (C4) with respect to z_M^d results in

$$\tilde{z}_M^d = \frac{(n+1)^2\delta}{2n(b+c) + c}. \quad (\text{C6})$$

After substituting (C6) into (C1), (C3) and u_M we obtain the allocation and prices listed in column 1 of Table 1.

Deposit policy combined with fuel caps regulation.

³⁶The efficient allocation is marked by an asterisk.

	strategic	efficiency (non-strategic)
column	1	2
z_M^d	$\frac{(n+1)^2\delta}{2n(b+c)+c}$	$\frac{(n+1)\delta}{c}$
p_e	$\frac{c[a[c+(b+c)2n+(n+1)b\delta]]}{(b+c)[c+(b+c)2n]}$	$\frac{ac+b\delta}{b+c}$
p_z	$\frac{c(n+1)\delta}{(b+c)[c+(b+c)2n]}$	δ
e_M^d	$\frac{a[c+(b+c)2n]-(n+1)c\delta}{(b+c)[c+(b+c)2n]}$	$\frac{a-\delta}{b+c}$
e_M^s	$\frac{a[c+(b+c)2n]-(n+1)c\delta}{(b+c)[c+(b+c)2n]}$	$\frac{a-\delta}{b+c}$
$e_M^s - e_M^d$	0	0
u_M	$\frac{a[c+(b+c)2n][a-(n+1)\delta]+(n+1)^2c\delta^2}{2(b+c)[c+(b+c)2n]}$	$\frac{ac[a-2(n+1)\delta]+(c-2bn)\delta^2}{2c(b+c)}$
v_M	$\frac{a^2[c+(b+c)2n]-(n+1)^2c\delta^2}{2(b+c)[c+(b+c)2n]}$	$\frac{a^2c[2n(b+c)+c]\delta}{2c(b+c)}$
D	$\frac{(n+1)\delta[a[c+(b+c)2n]-(n+1)c\delta]}{2(b+c)[c+(b+c)2n]}$	$\frac{(n+1)(a-\delta)\delta}{b+c}$

Table 1: deposit policy in the 2 stage game: allocation, prices and welfare

[1] *Strategic deposit policy and caps policy.* In that case (B2) - (B4) are specified by

$$P^e(\bar{e}_M^d, z_M^d) = \frac{c[an + b(e_M^d + \hat{z}_M^d)]}{b(n+1) + cn}, \quad (C7)$$

$$\bar{E}^{dM}(p_e, p_z) = \frac{a[b(n+1) + cn] - cnp_e - b[\delta + (p_e + \delta)n]}{b(b+c)(n+1)}, \quad (C8)$$

$$\bar{E}^{sM}(p_e, p_z) = \frac{p_e - p_z}{c}, \quad (C9)$$

$$P^z(p_e, z_M^d) = \frac{c\hat{z}_M^d}{n+1}. \quad (C10)$$

Solving (B4) and (B5) with respect to p_e and p_z yields

$$p_e = \frac{c[a[b(n+1)^2 + cn(n+2)] + b(n+1)[(b+c)\hat{z}_M^d - \delta]}{(b+c)[b(n+1)^2 + cn(n+2)]}, \quad (C11)$$

$$p_z = \frac{c\hat{z}_M^d}{n+1}. \quad (C12)$$

with

$$\frac{dp_e}{d\hat{z}_M^d} = \frac{bc}{(b+c)(n+1)} > 0 \quad \text{and} \quad \frac{dp_z}{d\hat{z}_M^d} = \frac{c}{n+1} > 0. \quad (C13)$$

We invoke p_e and p_z from (C11) and (C12), $\bar{E}^{dM}(p_e, p_z)$ and $\bar{E}^{sM}(p_e, p_z)$ from (C9) and

(C10), and (C13) to turn (30) into

$$\begin{aligned} \frac{du_M}{d\hat{z}_M^d} &= \delta - p_z + (a - b\bar{e}_M^d)\bar{E}_{p_e}^{dM} \frac{dp_e}{d\hat{z}_M^d} - \left(\hat{z}_M^d - \frac{p_e}{c} + \bar{e}_M^s \right) \frac{dp_z}{d\hat{z}_M^d} \\ &\quad - \left[\bar{e}_M^d - \bar{e}_M^s + \frac{\delta(n+1)}{c} - \frac{p_z}{c} \right] \frac{dp_e}{d\hat{z}_M^d} = 0. \end{aligned} \quad (\text{C14})$$

Solving (C14) for z_M^d yields:

$$\hat{z}_M^d = \frac{(n+1)^2(n+2)\delta}{\hat{b} + \hat{c}}, \quad (\text{C15})$$

where $\hat{b} := 2(n+1)^2b$ and $\hat{c} := (2n^2 + 5n + 2)c$. The associate equilibrium quantities, prices and welfare levels are listed in column 1 of Table 2.

- [2] *Non-strategic deposit policy and strategic caps policy.* Observe that (C11) and (C13) still hold. We now deviate from [1] by setting $\frac{dp_z}{d\hat{z}_M^d} = 0$ in (C14) and solve that equation with respect to \hat{z}_M^d to get

$$\hat{z}_M^d = \frac{(n+1)(n+2)\delta}{\check{b} + \check{c}}, \quad (\text{C16})$$

where $\check{b} := (n+1)b$ and $\check{c} := (n+2)c$. The associated equilibrium quantities, prices, and welfare levels are listed in column 2 of Table 2.

	strategic deposits and strategic caps	strategic deposits, non-strategic caps
column	1	2
\hat{z}_M^d	$\frac{(n+1)^2(n+2)\delta}{\hat{b}+\hat{c}}$	$\frac{(n+1)(n+2)\delta}{\check{b}+\check{c}}$
p_e	$\frac{c[a(\hat{b}+\hat{c})+bn(n+1)]\delta}{(b+c)(\hat{b}+\hat{c})}$	$\frac{c[a(\check{b}+\check{c})+\check{b}\delta]}{(b+c)(\check{b}+\check{c})}$
p_z	$\frac{c(n+1)(n+2)\delta}{\hat{b}+\hat{c}}$	$\frac{\check{c}\delta}{\check{b}+\check{c}}$
e_M^d	$\frac{a(\hat{b}+\hat{c})-(n+1)[2b+(n+2)c]\delta}{(b+c)(\hat{b}+\hat{c})}$	$\frac{a(\check{b}+\check{c})-(n+1)(b+2c)\delta}{(b+c)(\check{b}+\check{c})}$
e_M^s	$\frac{a(\hat{b}+\hat{c})-(n+1)[2b(n+1)+(3n+2)c]\delta}{(b+c)(\hat{b}+\hat{c})}$	$\frac{a(\check{b}+\check{c})-[b+(n+2)c]\delta}{(b+c)(\check{b}+\check{c})}$
$e_M^s - e_M^d$	$\frac{2n(n+1)\delta}{\hat{b}+\hat{c}}$	$\frac{n\delta}{\check{b}+\check{c}}$
u_M	$\frac{a(\hat{b}+\hat{c})[\hat{a}-2(n+1)\delta]+(n+1)^2[2b+(n+2)c]\delta^2}{2(b+c)(\hat{b}+\hat{c})}$	$\frac{a(\check{b}+\check{c})[a-2(n+1)\delta]+[\check{b}^2+b\check{c}(n+2)+\check{c}^2]\delta^2}{2(b+c)(\check{b}+\check{c})}$
v_M	$\frac{a^2(\hat{b}+\hat{c})-(n+1)^2[2b+(n+2)c]\delta^2}{2(b+c)(\hat{b}+\hat{c})}$	$\frac{a^2(\check{b}+\check{c})^2-[\check{b}^2+b\check{c}(n+2)(2n+1)+\check{c}^2(2n+1)]\delta^2}{2(b+c)(\check{b}+\check{c})^2}$
D	$\frac{(n+1)(\hat{b}+\hat{c})\delta-(n+1)[2b+(n+2)c]\delta}{(b+c)(\hat{b}+\hat{c})}$	$\frac{(n+1)\delta[a(\check{b}+\check{c})-[b+(n+2)c]\delta]}{(b+c)(\check{b}+\check{c})}$

Table 2: deposit policy and caps policy in the four stage game: allocation, prices and welfare

	strategic deposits and caps	strategic deposits, non-strategic caps
column	1	2
$\hat{z}_M^d - z_M^{d*}$	$-\frac{(n+1)[\hat{b}+(n+2)nc]\delta}{(\hat{b}+\hat{c})c} < 0$	$-\frac{(n+1)\check{b}\delta}{(\check{b}+\check{c})\delta} < 0$
$p_e - p_e^*$	$-\frac{b[\hat{b}+c(n^2+4n+2)]\delta}{(b+c)(\hat{b}+\hat{c})} < 0$	$-\frac{b(\check{b}+c)\delta}{(b+c)(\check{b}+\check{c})} < 0$
$p_z - p_z^*$	$-\frac{[\hat{b}+(n+2)nc]\delta}{\hat{b}+\hat{c}}$	$-\frac{\check{b}\delta}{\check{b}+\check{c}} < 0$
$e_M^d - e_M^{d*}$	$-\frac{cn^2\delta}{(b+c)(\hat{b}+\hat{c})} < 0$	$-\frac{cn\delta}{(b+c)(\check{b}+\check{c})} < 0$
$e_M^s - e_M^{s*}$	$\frac{n[(n+1)2b+(n+2)c]\delta}{(b+c)(\hat{b}+\hat{c})} > 0$	$\frac{bn\delta}{(b+c)(\check{b}+\check{c})} > 0$
$u_M - u_M^*$	$\frac{n[4b\hat{b}+(n+2)nc^2+2bc\hat{c}]\delta^2}{2(b+c)c(\hat{b}+\hat{c})} > 0$	$\frac{bn[2\check{b}^2+4bc(n^2+3n+2)+c^2(2n^2+7n+6)]\delta^2}{2(b+c)c(\check{b}+\check{c})^2} > 0$
$v_M - v_M^*$	$\frac{n[4b\hat{b}+(3n^2+8n+4)c^2+(4n^2+9n+4)2bc]\delta^2}{2(b+c)c(\hat{b}+\hat{c})} > 0$	$\frac{bn[2\check{b}^2+2bc(3n^2+8n+5)+c^2(4n^2+13n+10)]\delta^2}{2(b+c)c(\check{b}+\check{c})^2} > 0$
$D - D^*$	$\frac{n(n+1)[(n+1)2b+(n+2)c]\delta^2}{(b+c)(\hat{b}+\hat{c})} > 0$	$\frac{n\check{b}\delta^2}{(b+c)(\check{b}+\check{c})}$

Table 3: deposit policy and caps policy: deviation from first-best

column	$MI - DS$
$\hat{z}^d(MI) - z^d(DS)$	$-\frac{2b(n+1)^2\delta}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$
$p_e(MI) - p_e(DS)$	$-\frac{2bc(2n^2+3n+1)\delta}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$
$p_z(MI) - p_z(DS)$	$-\frac{2bc(n+1)\delta}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$
$e_M^d(MI) - e_M^d(DS)$	$-\frac{2n(n+1)[2b(n+1)+c(2n+1)]}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$
$e_M^s(MI) - e_M^s(DS)$	$-\frac{4bn(n+1)\delta}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$
$u_M(MI) - u_M(DS)$	$\frac{2bn(n+1)^2\delta^2}{[2n(b+c)+c](\hat{b}+\hat{c})} > 0$
$v_M(MI) - v_M(DS)$	$-\frac{2bn(n+1)^2\delta^2}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$
$D(MI) - D(DS)$	$-\frac{4bn(n+1)^2\delta^2}{[2n(b+c)+c](\hat{b}+\hat{c})} < 0$

Table 4: Comparison MI and DS

Proof of Proposition 4(iv):

Below we use the following acrynoms:

DS = stand-alone strategic deposit policy.

MI = policy mix consisting of the strategic deposit policy, the strategic fuel-demand-cap policy and the strategic fuel-supply-cap policy.

$MIII$ = policy mix consisting of the non-strategic deposit policy, the strategic fuel-demand-cap policy and the strategic fuel-supply-cap policy.

Comparing MI and DS yields Table 4.

Finally, comparing the welfare levels under DS , MI and $MIII$ we get:

$$\begin{aligned}
u(MI) - u(DS) &= \frac{2bn(n+1)^2\delta^2}{[c+(b+c)2n](\hat{b}+\hat{c})} > 0, \\
u(MI) - u(MIII) &= \frac{\check{c}n(n+2)[\check{b}(n+1)+\check{c}n]\delta^2}{2(\check{b}+\check{c})^2(\check{b}+\check{c})} > 0, \\
u(DS) - u(MIII) &= \frac{n[-2\check{b}+n\check{c}^2+bc(n^3+2n^2-3n-6)]\delta}{2[c+(b+c)2n](\check{b}+\check{c})^2}.
\end{aligned}$$