Buy coal and act strategically on the fuel market*

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Abstract

A coalition of given size fights climate change by a policy of purchasing fossil fuel deposits, and it seeks to manipulate the fuel price in its favor. Assuming that non-signatories are price takers in the fuel market, Harstad (2012) designs a policy of trading deposits that attains efficiency despite the coalition's option to act strategically in the fuel market. The deposit transactions constituting that policy include the trade of deposits which the non-signatories would have exploited and the coalition will exploit. The present paper shows that in a proper subset of economies a simpler policy is (also) efficient that consists of deposit purchases for preservation only. In these economies the coalition is unable to raise its welfare above the level in the benchmark case of fuel price taking. In the economies, where the efficient policy requires deposit transactions for exploitation, the coalition is better off and the non-signatories are worse off than in case of price taking.

JEL classification: Q31, Q38, Q55
Key words: climate coalition, fossil fuel, deposits, extraction, fuel caps

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1 Introduction

During the last decades, scientific evidence has accumulated on severe negative climate externalities generated by greenhouse gas emissions, notably carbon emissions. Since the Rio de Janeiro summit of 1992, little progress has been made in international climate negotiations towards an effective international climate agreement. That gives rise to the questions of what the chances are of a sub-global climate coalition to reduce carbon emissions efficiently and which policy instruments are most effective. Climate policies in practice as well as the bulk of extant theoretical mitigation literature focus on demand-side instruments. If they are unilateral, such policies cause carbon leakage that curbs the net effectiveness of emissions reductions and leads to excessive global emissions. The inefficiency aggravates, if countries set their climate policies strategically by manipulating the terms of trade (e.g. Markusen 1975, Hoel 1994, Copeland 1996).[1] Supply-side mitigation policies are much less analyzed. This paper aims to contribute to the small literature on sub-global supply-side climate policies.

Specifically, we consider a coalition suffering from climate damage caused by burning fossil energy, denoted fuel for short. There is an international market for trading (the right to exploit or preserve) fuel deposits and an international market for fuel. The coalition seeks to internalize the climate damage by purchasing some of the non-signatories' deposits for the purpose to prevent their exploitation. This kind of climate policy follows the pollutee-pays principle. It is efficient, if all market participants refrain from exerting market power. However, the efficiency implications are less straightforward under Harstad's (2012) assumptions that the deposit prices are subject to bilateral bargaining, that the deposit market clears prior to the fuel market, and that the coalition has the option to manipulate the fuel price via the choice of its fuel demand and supply. Our paper adopts this framework and complements Harstad's investigation of trade in deposits as an efficient instrument of unilateral climate policy. We focus on the pattern of deposit transactions required by such a policy and on its impact on the distribution of welfare among the coalition and the non-signatories.

To our knowledge, Bohm (1993) is the first who investigates analytically that kind of deposit preservation policy. He shows that a special policy mix of deposit purchases and a fuel-demand cap implements an emissions cap at lower costs than the stand-alone fuel-demand-cap policy. Asheim (2013) makes the case for deposit purchase policies as a distributional instrument in a growth model. Harstad (2012) follows Hoel (1994) in consid-

[1] Environmental demand-side policy is inefficient not only if implemented by a sub-global coalition, but also if implemented by non-cooperative individual countries (Ludema and Wooton 1994, Copeland and Taylor 1995, Kiyono and Ishikawa 2013) or by signatories of a self-enforcing environmental agreement (Barrrett 1994, Rubio and Ulph 2006, Eichner and Pethig 2013).

ering a sub-global climate coalition that sets its fuel demand and fuel supply strategically. He extends Hoel's (1994) setup by a more elaborate international deposit market and a sequential structure of the game and finds that trade in deposits may fully internalize the climate externalities despite the coalition's option to act strategically in the fuel market. Eichner and Pethig (2017) apply Harstad's analytical framework but they replace his deposit market of bilateral deals by a market with uniform per-unit price of deposits. They demonstrate that Harstad's efficiency result depends on the unconventional structure of *his* deposit market by showing that the outcome is inefficient, if the coalition acts strategically in *their* deposit market and in the fuel market.

The present paper relates to Harstad (2012) even closer than Eichner and Pethig (2017), because it takes up his analytical framework including the deposit market concept, and it seeks to assess the potential, implications, and limits of Harstad's policy proposal. His deposit market consists of a set of bilateral trades at prices that may differ between each pair of traders and 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).[2] Our focus is on that version of Harstad's (2012) Theorem 1, which presupposes that all non-signatories are price takers on the fuel market while the coalition has the option to choose the fuel demand and supply strategically.[3] His theorem states that if the deposit market is in equilibrium, the coalition implements the first best.[4] That theorem is remarkable, because when terms-of-trade manipulations are added to climate externalities, one would expect an inefficient outcome, as is shown, e.g., by Copeland and Taylor (1995) or Kiyono and Ishikawa (2013). One would also expect that the deposit transactions, which constitute Harstad's efficient policy, exclusively relate to deposits the coalition buys to prevent their exploitation. Surprisingly, in all but exceptional cases[5] the deposit transactions constituting Harstad's policy include certain deposits which the seller would have exploited and the buyer will exploit. For convenience, we refer to that policy as *extended deposit policy.* Its puzzling requirement of deposit transactions for exploitation in addition to deposit purchases for preservation calls for closer inspection.

To get insights into that puzzle we will deviate from Harstad's (2012) policy design by investigate the outcome of the game under the assumption that the coalition implements

[2]"The absence of mutually advantageous bargains is precisely what one means by efficiency" (Usher 1998, p. 9).

[3]Harstad (2012) derives efficiency results under different sets of assumptions. Here, we restrict our attention to the case of price-taking non-signatories, which Harstad (2012, p. 103n.) briefly discusses in his section on extensions.

[4]Harstad (2012, p. 104). That result crucially hinges on his assumption that the non-signatories do not suffer from climate damage. To secure comparability, we stick to this assumption throughout this paper.

[5]Exceptional cases are those where the fuel market clears without exports and imports.

what appears to be the natural 'internalization policy', namely the purchase of deposits for preservation only. We refer to that policy as *deposit preservation policy*. Surprisingly, we identify a significant proper subset of economies beyond the set of exceptional cases referred to above, in which the deposit preservation policy is efficient. That is, the extended deposit policy (in Harstad 2012) is sufficient for attaining efficiency in all economies, but it is not necessary in a non-trivial subset of economies. Harstad (2012) failed to realize that in some non-trivial subset of economies the coalition has at its disposal a policy that is efficient without involving deposit transactions for exploitation. Another significant difference relates to the distribution of welfare among the coalition and the non-signatories. We show that if the deposit preservation policy is efficient, the welfares of all countries are as in the efficient Coaseian benchmark case, in which the coalition and the non-signatories take the fuel price as given. In these economies the coalition is not able to enhance welfare through strategic action in the fuel market. In all other economies, the extended deposit policy makes the coalition better off and the non-signatories worse off than in the benchmark case.

The paper is organized as follows. Section 2 briefly presents the model and characterizes the social optimum with deposit trading. The main Section 3 takes up Harstad's sequential structure of the game, but analyzes the deposit preservation policy and concludes, as indicated above, that this policy is efficient under certain meaningful conditions. Section 4 focuses on the modifications of the analysis of Section 3 that are necessary to replace the deposit preservation policy with the extended deposit policy. We show that in the latter policy the deposit transactions for exploitation serve the role to offset exactly the terms-of-trade effect of the coalition's fuel price manipulation (rather than, as Harstad (2012) argues, to eliminate fuel exports and imports in all countries). Section 4 also investigates the distribution of welfares among the coalition and the non-signatories. Section 5 concludes.

2 The model

The basic assumptions. Throughout the paper, we adopt Harstad's (2012) analytical framework. There is an economy with two groups of countries, M and N. Group M is a climate coalition that acts as one agent and all non-signatories are in group N. To ease the exposition, we restrict our analysis to a representative non-signatory, called country N. It derives the benefit $B_i(y_i)$ from consuming y_i units of fuel (with $B_i' > 0$ and $B_i'' < 0$) and produces the quantity x_i of fuel from domestic fossil energy deposits. The cost of extracting is $C_i(x_i)$, where $C_i' > 0$ and $C_i'' > 0$.

A fossil fuel deposit in the ground is characterized by the amount of fuel it stores and the costs of extracting that fuel. Country i's initial endowment of deposits is analytically captured by a (re)interpretation of the marginal extraction cost function C_i'. To avoid lumpiness we assume that each deposit stores a (very small) unit of fuel, and that these small deposits are ordered according to their extraction costs. That gives us a step function of increasing extraction costs per deposit. Finally, we apply the real number approximation and say with some abuse of notation[6] that the cost of extracting the (infinitesimally small) unit of fuel contained in the x_i^{th} deposit is $C_i'(x_i)$. We find it also convenient to denote country i's total endowment of deposits by $\big[0,\infty\big[_{C_i'}$ to indicate the link between fuel stored in the ground and the cost of extracting it. Correspondingly, the cost of extracting all deposits in some interval $\big[\underline{x},\overline{x}\big]_{C_i'} \subset \big[0,\infty\big[_{C_i'}$ is $\int_{\underline{x}}^{\overline{x}} C_i'(x)\mathrm{d}x = C_i(\overline{x}) - C_i(\underline{x})$. Country i is the initial owner of the deposits $\big[0,\infty\big[_{C_i'}$. It has the right to extract the fossil fuel stored in its deposits, but it can also choose to sell that right on an international deposit market. We will describe that unconventional market in the next section. The market for fuel is standard and analytically straightforward. Fuel is internationally traded at the uniform price p so that country i's representative consumer receives the profit income $px_i - C_i(x_i)$ and enjoys the utility

$$u_i = B_i(y_i) - C_i(x_i) - p(y_i - x_i) - \delta(i)H\left(x_M + x_N\right) \quad \text{with } \delta(i) = \begin{cases} 1, & \text{if } i = M, \\ 0, & \text{if } i = N. \end{cases} \tag{1}$$

$H\left(x_M + x_N\right)$ (with $H' > 0$ and $H'' \geq 0$) is the climate damage suffered by the coalition. Carbon emissions from burning fossil fuel generate climate damage. Since emissions are proportional to fuel output and consumption, x_i denotes both fuel supply and emissions. The condition for clearing the fuel market

$$x_M + x_N = y_M + y_N \tag{2}$$

completes the description of the analytical framework.

Efficiency with tradable deposits. In order to characterize an efficient allocation in case of tradable deposits, imagine a social planner who takes away from country N's initial deposit endowment $\big[0,\infty\big[_{C_N'}$ all deposits in some interval $\big[\underline{\xi},\overline{\xi}\big]_{C_N'} \neq \emptyset$ and transfers them to the coalition obliging it to preserve the deposits it receives. Then the question arises how to choose the boundary points $\underline{\xi}$ and $\overline{\xi}$ of the interval $\big[\underline{\xi},\overline{\xi}\big]_{C_N'}$ that maximize global welfare. Denote the 'number' of deposits in the interval $\big[\underline{\xi},\overline{\xi}\big]_{C_N'}$ by $z_N^s := \overline{\xi} - \underline{\xi}$ and the total 'size' of deposits transferred to the coalition by

$$z_M^d = z_N^s. \tag{3}$$

[6]See also Harstad's (2012, p. 85) definition and explanation.

The social planner maximizes with respect to x_M, y_M, y_N, z_M^d, z_N^s and $\overline{\xi}$ the Lagrangean

$$\begin{aligned}\mathcal{L} &= B_M(y_M) + B_N(y_N) - C_M(x_M) - C_N(\overline{\xi} - z_N^s) - H\left(x_M + \overline{\xi} - z_M^d\right) \\ &\quad +\lambda_f\left(x_M + \overline{\xi} - z_N^s - y_M - y_N\right) + \lambda_z\left(z_N^s - z_M^d\right). \qquad (4)\end{aligned}$$

Attach an asterisk superscript to the solution values of (4), restrict attention to interior solutions and characterize the social optimum by

$$B_M'(y_M^*) = B_N'(y_N^*), \qquad (5a)$$

$$B_i'(y_i^*) = C_i'(x_i^*) + H'\left(x_M^* + x_N^*\right) \qquad i = M, N, \qquad (5b)$$

$$z_N^{s*} = z_M^{d*} = \overline{\xi}^* - \underline{\xi}^* = \overline{\xi}^* - x_N^*. \qquad (5c)$$

Equation (5a) represents the rule for efficient fuel consumption. Equation (5b) requires that the marginal benefit of consuming fuel equals marginal costs, which consist of the marginal extraction costs and the coalition's marginal climate damage. (5a) and (5b) imply production efficiency, formally $C_M'(x_M^*) = C_N'(x_N^*)$. It is easy to see that the equations (5a) and (5b) also result from the standard solution of the social planner we obtain when solving the Lagrangean (4) after setting $z_N^s = 0$ and $\overline{\xi} = x_N$.

3 The policy of purchasing deposits for preservation

Like Harstad (2012) we model purchases and sales of (the right to exploit or preserve) deposits as transactions in a deposit market. The deposits need not be traded at a uniform price (per unit) in that market;[7] instead, our only requirement - and assumption - is that the parties select mutually beneficial bilateral deposit trades and agree on how to share the surplus of these trades among them.[8] Since emissions are excessive in the no-policy scenario, the coalition's willingness-to-pay is positive for buying and preserving some of those deposits, which N would have exploited otherwise. In this section, we aim to investigate to which extent the coalition succeeds in internalizing the climate damage externality imposed by country N, when it pursues a policy of buying deposits for preservation. Under the assumption that all parties take the fuel price as given we rightly expect, and will confirm below, that full internalization - and hence efficiency - is achieved, which is the Coaseian solution implemented via the pollutee-pays-principle. However, we are primarily interested in the scenario in which the coalition has the option to exert market power in the fuel market

[7]For the analysis of a deposit market with a uniform price, see Eichner and Pethig (2017).

[8]Harstad's (2012, p. 86) requires in addition that the deposit market "... is cleared if and only if there exists no pair of countries ... and no price of deposits such that both ... [countries] strictly benefit from transferring the right to exploit a deposit ... at that price."

via manipulation of the equilibrium fuel price (while country N continues to take the fuel price as given). Economic intuition suggests that then the solution is inefficient because the coalition distorts the equilibrium fuel price. However, we will show that this conjecture fails to be correct for some non-trivial subset of economies.

In the subsequent formal analysis, we adopt Harstad's (2012) three-stage structure of the game. The market for deposits clears at stage 1, the coalition determines its fuel supply and demand at stage 2, and the fuel market clears at stage 3. The coalition analyzes the game via backward induction as follows.

Stage 3 (Fuel market equilibrium). At stage 3, M has already chosen its fuel supply and demand, x_M and y_M. The representative consumer of country N determines its fuel demand by maximizing with respect to y_N

$$B_N(y_N) - K(x_N, \underline{\xi}, \overline{\xi}) - p(y_N - x_N) + \theta. \tag{6}$$

In (6) p is the fuel price, K is country N's extraction cost function after M bought from N the deposits in the interval $\left[\underline{\xi}, \overline{\xi}\right]_{C'_N}$ for the purpose to prevent their exploitation, and θ is N's revenue from selling deposits at stage 1. The first-order condition readily yields

$$B'_N(y_N) = p \quad \text{and hence} \quad y_N = B_N'^{-1}(p) =: D(p), \tag{7}$$

where $B_N'^{-1}$ is the inverse of the marginal benefit function B'_N. Next, consider the fuel supply of country N, the derivation of which is quite complex because at stage 1 country N sold the deposits $\left[\underline{\xi}, \overline{\xi}\right]_{C'_N}$ for preservation. The deposit sale at stage 1 changed N's endowment of deposits such that N's initial marginal cost function C'_N turned into the marginal cost function K' defined by

$$K'(x_N, \underline{\xi}, \overline{\xi}) := \begin{cases} C'_N(x_N) & \text{for } x_N \leq \underline{\xi}, \\ C'_N\left(x_N + \overline{\xi} - \underline{\xi}\right) & \text{for } x_N \geq \underline{\xi}. \end{cases} \tag{8}$$

Figure 1 illustrates the marginal cost functions C'_N and K'. The straight line $0D$ is the graph of C'_N. After having sold the deposits $[\underline{\xi}, \overline{\xi}]_{C'_N}$ at stage 1, country N's marginal cost function K' is represented by the line $0BEF$ which is constructed as in Harstad's (2012) Figure 1. We derive that line from $0D$ by shifting the line segment CD to the left by the amount $\overline{\xi} - \underline{\xi}$ such that CD becomes EF. Thus, country N's endowment of deposits changed from $0BCD$ to $0BEF$. The function K' is discontinuous at $x = \underline{\xi}$, as reflected in the gap BE of the graph $0BEF$.

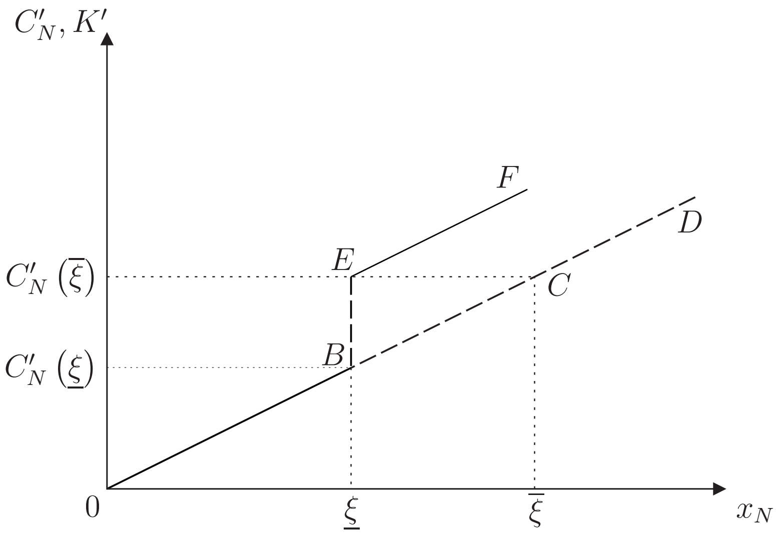

Figure 1: Marginal cost curves of country N before and after deposit trading $[\underline{\xi}, \overline{\xi}]_{C'_N}$ at stage 1

The Appendix A shows that maximizing with respect to x_N the welfare (6) yields country N's fuel supply function S with the properties

$$S\left(p, \underline{\xi}, \overline{\xi}\right) = \begin{cases} C_N'^{-1}(p) & \text{for } p \leq C'_N\left(\underline{\xi}\right), \\ \underline{\xi} & \text{for } p \in [C'_N\left(\underline{\xi}\right), C'_N\left(\overline{\xi}\right)], \\ C_N'^{-1}(p) - \overline{\xi} + \underline{\xi} & \text{for } p \geq C'_N\left(\overline{\xi}\right). \end{cases} \tag{9}$$

The fuel supply function (9) is illustrated by the inverse supply curve $0BEF$ in Figure 1 that we create by simply assigning the fuel price p to the vertical axis of Figure 1. In view of (7) and (9), the fuel market clearing condition is

$$x_M + S\left(p, \underline{\xi}, \overline{\xi}\right) = y_M + D(p). \tag{10}$$

Equation (10) yields the equilibrium fuel price as a function of x_M, y_M, $\underline{\xi}$ and $\overline{\xi}$, all of which have been determined earlier in the game. We denote that price function by

$$p = P(x_M, y_M, \underline{\xi}, \overline{\xi}). \tag{11}$$

Stage 2 (Determination of M's fuel supply and demand). The deposits M bought at stage 1 do not change M's initial extraction cost function C'_M since by presupposition the coalition pursues a policy of buying deposits for preservation. M chooses its fuel supply and demand by maximizing with respect to x_M and y_M its welfare

$$U_M(x_M, y_M, \underline{\xi}, \overline{\xi}) = B_M(y_M) - C_M(x_M) - p(y_M - x_M) - H\left[x_M + S\left(p, \underline{\xi}, \overline{\xi}\right)\right] - \theta \tag{12}$$

subject to (11). The first-order conditions

$$\frac{\partial U_M}{\partial y_M} = B_M' - p - (y_M - x_M + H'S') \frac{\partial P}{\partial y_M} = 0, \tag{13}$$

$$\frac{\partial U_M}{\partial x_M} = -C_M' + p - H' - (y_M - x_M + H'S') \frac{\partial P}{\partial x_M} = 0, \tag{14}$$

determine M's optimal choice of x_M and y_M as functions of $\underline{\xi}$ and $\overline{\xi}$. We denote the solution of (13) and (14) by

$$x_M = X_M(\underline{\xi}, \overline{\xi}) \quad \text{and} \quad y_M = Y_M(\underline{\xi}, \overline{\xi}). \tag{15}$$

We consider (15) in (11) and conclude that at stage 2 the equilibrium fuel price depends on $\underline{\xi}$ and $\overline{\xi}$ only,

$$p = \hat{P}\left(\underline{\xi}, \overline{\xi}\right). \tag{16}$$

Stage 1 (Deposit market transaction). Since M suffers from climate damage, it has a positive willingness-to-pay for purchasing some of N's deposits to prevent their exploitation. Suppose M buys the deposits in the interval $[\underline{x}, \overline{x}]_{C_N'}$. As both countries seek to secure some share of the gains from trade, it is in their common interest to choose that interval $[\underline{x}, \overline{x}]_{C_N'}$ which yields the largest aggregate welfare gain, or equivalently, which fully internalizes the coalition's climate damage. To determine that interval, observe first that M only buys some of those deposits, country N would have extracted in the absence of deposit trading. Given the fuel price p, the interval with such profitable deposits is $[0, \overline{\xi}]_{C_N'}$, where $\overline{\xi} = C_N'^{-1}(p) =: \overline{\xi}(p)$. Hence M's purchase and subsequent preservation of $[\underline{x}, \overline{x}]_{C_N'}$ reduces the climate damage only if $[\underline{x}, \overline{x}]_{C_N'} \subset \left[0, \overline{\xi}(p)\right]_{C_N'}$. Moreover, the inequality $\overline{x} \leq \overline{\xi}(p)$ must hold as an equality, because there is no other interval of deposits in $\left[0, \overline{\xi}(p)\right]_{C_N'}$ of the same size as $\left[\underline{x}, \overline{\xi}(p)\right]_{C_N'}$, whose economic value is smaller than that of $\left[\underline{x}, \overline{\xi}(p)\right]_{C_N'}$.[9] These considerations make the surplus maximizing trade in deposits equivalent to the choice of $\underline{x}$. To put it differently, we have to determine the number of deposits $z_M^d = z_N^s = \overline{\xi}(p) - \underline{x}$ the coalition needs to buy and will buy to internalize fully the climate damage. In the Appendix A we prove

Lemma 1. *Contingent on the fuel price p, the climate damage is fully internalized, if and only if M purchases the deposits $\left[\underline{\xi}(p), \overline{\xi}(p)\right]_{C_N'}$ for preservation, where $\underline{x} = \underline{\xi}(p)$ is implicitly defined by $\underline{\xi} = C_N'^{-1}(p - \lambda_z)$ and $\lambda_z = H'\left[X_M\left(\underline{\xi}, \overline{\xi}(p)\right) + \underline{\xi}\right]$.*[10]

[9] The economic value of the deposits in the interval $\left[\underline{x}, \overline{\xi}(p)\right]_{C_N'}$ is the profit $p\left[\overline{\xi}(p) - \underline{x}\right] - C_N\left[\overline{\xi}(p)\right] + C_N(\underline{x})$ that would accrue to country N if it would extract and sell the fuel from these deposits instead of selling the unexploited deposits to M.

[10] λ_z is the shadow price of deposits that equals the marginal climate damage when that damage is internalized.

According to Lemma 1, the coalition secures full internalization subject to the prevailing fuel price. However, we cannot conclude from Lemma 1 that the deposit preservation policy is efficient, because the additional requirement for efficiency is an equilibrium fuel price that is undistorted. The deposit market is in equilibrium when the countries agree on some price θ that M pays for purchasing the deposits $\left[\underline{\xi}(p), \overline{\xi}(p)\right]_{C'_N}$. Since the set of prices is non-empty, at which the deal is beneficial for both countries, we assume that the countries do agree on some mutually advantageous price θ.

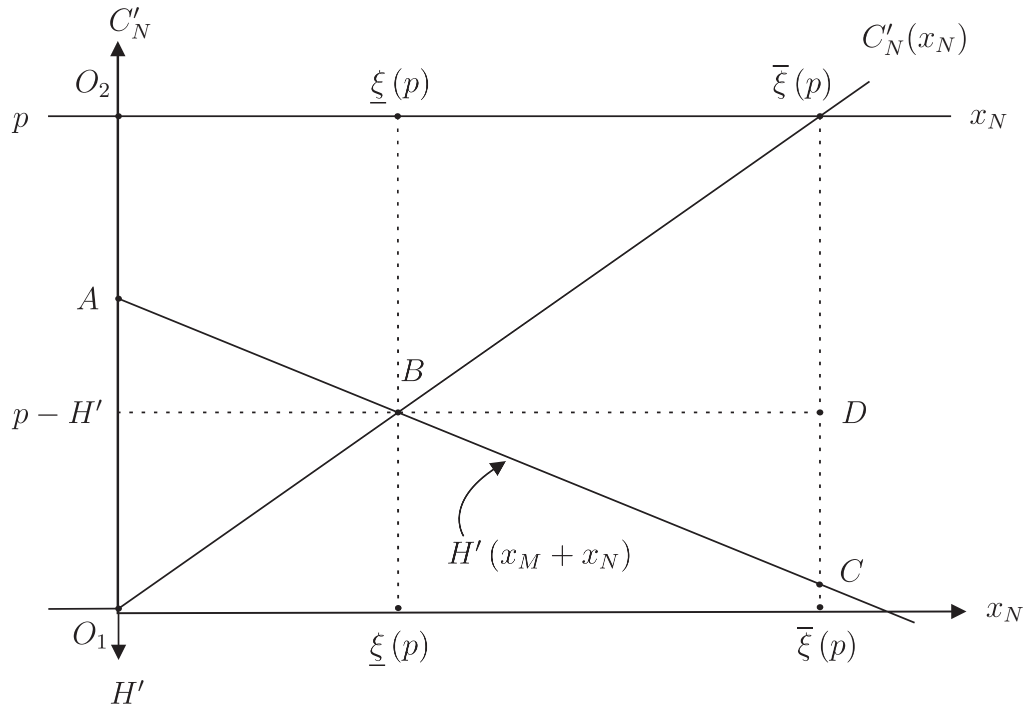

Figure 2: Bargaining over the purchase of deposits

Figure 2 illustrates the deposit market equilibrium characterized in Lemma 1. The coordinate systems with origin O_1 and O_2 depict the graph of $C'_N(x_N)$ and $H'(x_M + x_N)$, respectively. For given p and $H'(x_M+x_N)$, the coalition seeks to buy the deposits $\left[\underline{\xi}(p), \overline{\xi}(p)\right]_{C'_N}$ from country N. The minimum price country N demands for these deposits is the profits foregone which equals the triangle $B\underline{\xi}\overline{\xi}$ in Figure 2. The maximum price the coalition is willing to pay is the area $B\underline{\xi}\overline{\xi}C$ in Figure 2. The coalition knows that country N does not sell deposits unless the sales price exceeds the profits it could have made from exploiting instead of selling the deposits (profits foregone) and N knows that the coalition does not make a deal if the price exceeds the welfare gain from reduced carbon emissions. A bargain may be - and will be assumed to be - made at a price above the minimum and below the maximum, depending on the allocation of bargaining power.

The equations (15), (16) and Lemma 1 demonstrate the interdependence of the markets for deposits and fuel. Insertion of $\underline{\xi} = \underline{\xi}(p)$ and $\overline{\xi} = \overline{\xi}(p)$ in $p = \hat{P}\left(\underline{\xi}, \overline{\xi}\right)$ yields the equilibrium fuel price and thus establishes the equilibrium of the tree-stage game. It remains to examine the efficiency properties of the outcome. The efficiency condition (5b) is satisfied for N due to (7) and Lemma 1. In view of (13) and (14), the efficiency conditions (5a) and (5b) for M are also satisfied, if and only if

$$(y_M - x_M + H'S')\,\frac{\partial P}{\partial y_M} = 0. \tag{17}$$

(17) holds, in turn, if and only if either $\frac{\partial P}{\partial y_M} = 0$ or the bracketed term is is zero. This observation is of interest, because the condition $\frac{\partial P}{\partial y_M} = 0$ can readily be interpreted as characterizing the (benchmark) scenario, in which the coalition is a price taker on the fuel market along with country N. Technically speaking, we capture that special case by dropping the second stage of the game and by simply setting $\frac{\partial P}{\partial y_M} = -\frac{\partial P}{\partial x_M} = 0$ in (13) and (14) to obtain the efficiency conditions (5a) and (5b).

Proposition 1 . *Suppose the coalition implements the climate policy of purchasing deposits for preservation and assume that country N as well as the coalition take the fuel price as given. Then the coalition's policy is efficient.*

Proposition 1 presents the well-known efficient Coaseian solution according to the pollutee-pays principle. Its crucial precondition is that both countries are price takers on the fuel market. While the absence of fuel market power is a useful benchmark, in the following we focus on the scenario, in which country N takes the fuel price as given and the coalition acts strategically on the fuel market.

The case of strategic action in the fuel market is less straightforward. We now assume $\frac{\partial P}{\partial y_M} = -\frac{\partial P}{\partial x_M} > 0$ and conclude that (17) is satisfied if and only if

$$y_M - x_M + H'S' = 0. \tag{18}$$

For presentation of the results, which we proved in the Appendix A, it is useful to introduce the following notation:[11]

$$\begin{aligned}
\mathcal{E} &:= \left\{ \text{Economies } E \,\middle|\, E \text{ possesses an allocation } \left(x_M^*, x_N^*, y_M^*, y_N^*, z_M^{d*}, z_N^{s*}\right) \text{ satisfying (5)} \right\},\\
\mathcal{E}_{(=)} &:= \left\{ E \in \mathcal{E} \,\middle|\, E \text{ satisfies } x_i^* = y_i^* \text{ for } i = M, N \right\},\\
\mathcal{E}_{NO} &:= \left\{ E \in \mathcal{E} \,\middle|\, E \text{ satisfies } \left\langle y_M^* - x_M^* > 0 \right\rangle \text{ or } \left\langle y_M^* - x_M^* < 0 \text{ and } y_M^* - x_M^* + H'^* S'^* < 0 \right\rangle \right\},\\
\mathcal{E}_{O} &:= \left\{ E \in \mathcal{E} \,\middle|\, E \text{ satisfies } y_M^* - x_M^* < 0 \text{ and } y_M^* - x_M^* + H'^* S'^* \geq 0 \right\}.
\end{aligned}$$

[11]Since the socially optimal allocation is unique, that allocation unambiguously characterizes every individual economy.

Proposition 2. *Suppose the coalition implements the climate policy of purchasing deposits for preservation and assume that the coalition acts strategically in the fuel market while country N takes the fuel price as given. Then the equilibrium of the three-stage game is characterized as follows:*

(i) The coalition's policy is **inefficient**, *if and only if $E \in \mathcal{E}_{NO}$.*

(ii) The coalition's policy is **efficient**, *if and only if $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_{O}$.*

The striking message of Proposition 2 is that the coalition's strategic action on the fuel market is non-distortionary in a major subset of economies. It is not surprising, of course, that the coalition's deposit preservation policy is efficient in the subset $\mathcal{E}_{(=)}$ of economies, in which the socially optimal fuel exports and imports happen to be zero.[12] The interesting and remarkable result is that the deposit preservation policy is efficient in the non-marginal subset $\mathcal{E}_{O}$ of economies with non-zero socially optimal exports and imports. To get an intuition for the constraints defining the sets $\mathcal{E}_{NO}$ and $\mathcal{E}_{O}$, we investigate how the coalition's welfare changes when the fuel cap x_M is marginally increased[13]

$$\begin{aligned} \mathrm{d}U_M &= \frac{\partial U_M^*}{\partial x_M}\mathrm{d}x_M := -\left(y_M^* - x_M^* + H'^* S'^*\right)\frac{\partial P}{\partial x_M}\mathrm{d}x_M \\ &= \underbrace{-\left(y_M^* - x_M^*\right)\frac{\partial P}{\partial x_M}\mathrm{d}x_M}_{\mathrm{d}w_F}\underbrace{-\left(H'^* S'^*\right)\frac{\partial P}{\partial x_M}\mathrm{d}x_M}_{\mathrm{d}w_H}. \end{aligned} \tag{19}$$

The term $\mathrm{d}w_F$ in (19) represents the coalition's welfare change due to the change of fuel exports or imports induced by the coalition through the variation of its fuel supply ($\mathrm{d}x_M \neq 0$). dw_F is the *terms of trade effect of strategic action.* The term $\mathrm{d}w_H$ captures the welfare change due to the change in climate damage which is induced by the coalition through the variation of its fuel supply ($\mathrm{d}x_M \neq 0$). $\mathrm{d}w_H$ is the *climate damage effect of strategic action.*

We explain the welfare changes exemplarily for a fuel exporting coalition ($y_M^* < x_M^*$). If the coalition refrains from strategic action, the fuel supply and the marginal extraction costs of country N are characterized by point E in Figure 1. To figure out whether strategic action pays, the coalition marginally increases x_M. The consequence is a reduction of the fuel price $\left(\frac{\partial P}{\partial x_M} < 0\right)$ which yields the negative terms-of-trade effect of strategic action ($\mathrm{d}w_F < 0$). Reducing the fuel price (the movement from point E in the direction of point B in Figure 1) does not change the fuel supply of country N, formally $S' = 0$ due to $p \in \left[C_N'\left(\underline{\xi}\right), C_N'\left(\overline{\xi}\right)\right]$ in (9), and hence the climate damage effect of strategic action vanishes ($\mathrm{d}w_H = 0$). The total effect $\mathrm{d}w_F + \mathrm{d}w_H < 0$ shows that increasing x_M reduces the coalition's welfare and strategic action does not pay. Next, we investigate the welfare effects of reducing the fuel cap x_M.

[12]This condition is satisfied if, but not only if, the economy consists of identical countries.

[13]The corresponding effects of changes in $\mathrm{d}y_M$ are listed in Table 1 of the Appendix B.

Decreasing x_M raises the fuel price and the terms-of-trade effect of strategic action is positive ($\mathrm{d}w_F > 0$). Country N increases its fuel supply ($S' > 0$) when the fuel price rises (the movement from point E in Figure 1 in the direction of point F implies $p > C'_N\left(\bar{\xi}\right)$ in (9)). Thus the climate damage effect $\mathrm{d}w_H$ is negative. Reducing x_M diminishes the coalition's welfare, iff $\mathrm{d}w_F + \mathrm{d}w_H \leq 0$, i.e. iff the negative climate damage effect overcompensates the positive terms-of-trade effect. To conclude, if $y_M^* < x_M^*$ and $y_M^* - x_M^* + H'^*S'^* \geq 0$ or equivalently if the economy belongs to $\mathcal{E}_O$ the coalition's deviation $\mathrm{d}x_M$ from x_M^* does not pay. Analogous arguments apply to deviations $\mathrm{d}y_M$ from y_M^*. However, if $y_M^* < x_M^*$ and $y_M^* - x_M^* + H'^*S'^* < 0$ strategic action is distortionary and pays.

A detailed analysis of all cases in which the coalition does not export fuel ($y_M^* \geq x_M^*$) can be found in the Appendix B. The results are as follows: If the coalition neither imports nor exports fuel in the social optimum ($y_M^* = x_M^*$), its strategic action is non-distortionary, because all feasible strategic actions have a zero terms-of-trade effect ($\mathrm{d}w_F = 0$) and a non-positive climate damage effect ($\mathrm{d}w_H \leq 0$). If the coalition imports fuel in the social optimum ($y_M^* > x_M^*$), its strategic action is distortionary, since decreasing x_M has a positive terms-of-trade effect ($\mathrm{d}w_F > 0$) and a zero climate damage effect ($\mathrm{d}w_H = 0$).

To understand better the intuition and the economic relevance of the constraints defining the sets of economies $\mathcal{E}_{NO}$ and $\mathcal{E}_O$, we consider the parametric functions

$$B_i(y_i) = \alpha y_i - \frac{b}{2}y_i^2,\; C_i(x_i) = \frac{c_i}{2}x_i^2,\; H(x_M + x_N) = h(x_M + x_N) \quad i = M, N, \tag{20}$$

where α, b, c_M, c_N and h are positive parameters. It is easy to show (in the Appendix A) that the efficient allocation is characterized by

$$y_M^* - x_M^* \gtreqless 0 \quad \Longleftrightarrow \quad c_M \gtreqless c_N \quad \text{and} \quad y_M^* - x_M^* + H'^*S'^* \gtreqless 0 \quad \Longleftrightarrow \quad h \gtreqless \bar{h}, \tag{21}$$

where $\bar{h} := \frac{\alpha c_N(c_N - c_M)}{(b+c_N)c_M + c_N}$. The equivalences (21) demonstrate that in the parametric model (20), an economy's socially optimal allocation $\left(x_M^*, x_N^*, y_M^*, y_N^*, z_M^{d*}, z_N^{s*}\right)$ is uniquely determined by its parameters (α, b, c_M, c_N, h). Therefore the set of economies

$$\mathcal{M} := \left\{(\alpha, b, c_M, c_N, h)\middle|\langle c_M = c_N\rangle \;\vee\; \langle c_N > c_M \wedge h \geq \bar{h}\rangle\right\}$$

is the parametric equivalent of the set $\mathcal{E}_{(=)} \cup \mathcal{E}_O$ in the more general non-parametric model. Invoking (21) and the conditions defining the sets $\mathcal{E}_{(=)}$ and $\mathcal{E}_O$, we get

Proposition 3. *Suppose the coalition purchases deposits for preservation and acts strategically on the fuel market while country N takes the fuel price as given. In the game with the parametric functional forms (20),*

$$\text{the coalition's policy is} \left\{\begin{array}{c}\text{efficient}\\ \text{inefficient}\end{array}\right\}, \text{if and only if the economy } E \left\{\begin{array}{c}\in\\ \notin\end{array}\right\} \mathcal{M}.$$

The condition $\langle c_M = c_N \rangle$ in the definition of the set $\mathcal{M}$ makes all countries alike in the parametric model, and efficiency is the well-known result in the absence of fuel exports and imports. The other condition $\langle c_N > c_M \wedge h \geq \bar{h} \rangle$ in the set $\mathcal{M}$ is more interesting. It specifies in a straightforward way what is necessary for the deposit preservation policy to be efficient, if countries are asymmetric. First, the coalition's extraction costs must be lower than those of country N, which secures $x_N^* < x_M^*$ and $y_M^* < x_M^*$ because of $y_M^* = y_N^*$ in our parametric model. Second, the coalition's marginal climate damage (parameter) must exceed some threshold value such that the climate damage effect $H'^*S'^* > 0$ overcompensates the terms-of-trade effect induced by $y_M^* - x_M^* < 0$.

4 An efficient deposit policy in the economies $E \in \mathcal{E}_{NO}$ (Harstad 2012)

Section 3 has established that in all economies $E \in \mathcal{E}_{NO}$ the coalition's policy of purchasing deposits for preservation distorts the allocation, if the coalition acts strategically in the deposit market. This section briefly reconstructs the deposit policy suggested by Harstad (2012) that achieves efficiency in the economies belonging to $\mathcal{E}_{NO}$ despite the coalition's option to manipulate the fuel price in its own favor. Essentially, Harstad suggests a modification of the deposit preservation policy analyzed in the last section. The crucial difference is that his policy requires not only trade in deposits for preservation, but also some specific trade in those deposits, which the seller would have exploited and the buyer does exploit. In the sequel, we go through the three-stage game of the previous section focusing on the modifications necessary to implement the policy suggested by Harstad. We describe the implementation for economies in $\mathcal{E}_{NO}$ that are characterized by $y_M^* > x_M^*$, and after that we briefly indicate how an analogous procedure can be applied to those economies in $\mathcal{E}_{NO}$ that satisfy the condition $\langle y_M^* - x_M^* < 0 \text{ and } y_M^* - x_M^* + H'^*S'^* < 0 \rangle$.

Stage 3. M and N know that at stage 1 N sold to M the deposits in the interval $[\underline{\xi}, \overline{\xi}]_{C_N'}$ for preservation and the deposits in some interval $[\underline{\chi}, \overline{\chi}]_{C_N'} \subset [0, \underline{\xi}]_{C_N'}$ for exploitation. M and N have also agreed at stage 1 that N's extraction firm extracts and sells the fuel from $[\underline{\chi}, \overline{\chi}]_{C_N'}$ and then transfers the profits $p(\overline{\chi} - \underline{\chi}) - \left[C_N(\overline{\chi}) - C_N(\underline{\chi})\right]$ to M. These actions and decisions at the earlier stages of the game imply that N's extraction cost function $C_N(x_N)$ turns into the function $K(x_N, \underline{\xi}, \overline{\xi})$ (see also (8)) after the deposit sale for preservation at stage 1. It follows that at stage 3 the representative consumer of country N determines her fuel demand by maximizing with respect to y_N her welfare

$$B_N(y_N) - K(x_N, \underline{\xi}, \overline{\xi}) - p(y_N - x_N) + \theta - \left\{p(\overline{\chi} - \underline{\chi}) - \left[C_N(\overline{\chi}) - C_N(\underline{\chi})\right]\right\}. \tag{22}$$

The welfare (22) differs from (6) by the term $\{\cdot\}$ that represents the profit of selling the fuel from the deposits $[\underline{\chi}, \overline{\chi}]_{C'_N}$, which N agreed to transfer to M. Although the trade in deposits differs from that in the last section, the conclusions at stage 3 about N's demand and supply of fuel and about the fuel market equilibrium remain unchanged.

Stage 2. Next we investigate how M determines its fuel supply and demand at stage 2. As described above, M bought the deposits $[\underline{\xi}, \overline{\xi}]_{C'_N}$ for preservation and the deposits $[\underline{\chi}, \overline{\chi}]_{C'_N}$ for exploitation. Since M 'delegated' the extraction and sale of the fuel from the deposits $[\underline{\chi}, \overline{\chi}]_{C'_N}$ to N's extraction firm, M's deposit purchases at stage 1 do not change its initial extraction cost function C_M. However, M's welfare is now given by

$$\begin{aligned} U_M(\cdot) &= B_M(y_M) - C_M(x_M) - p(y_M - x_M) - H\left[x_M + S(p, \underline{\xi}, \overline{\xi})\right] - \theta \\ &\quad + \left\{p(\overline{\chi} - \underline{\chi}) - \left[C_N(\overline{\chi}) - C_N(\underline{\chi})\right]\right\}, \end{aligned} \tag{23}$$

which differs from (12) by the profit transfer $p(\overline{\chi} - \underline{\chi}) - \left[C_N(\overline{\chi}) - C_N(\underline{\chi})\right]$ that M receives from N. M chooses its fuel supply and demand by maximizing with respect to x_M and y_M its welfare (23) subject to (11). The first-order conditions are

$$\frac{\partial U_M}{\partial y_M} = B'_M - p - \left[(y_M - x_M) - (\overline{\chi} - \underline{\chi}) + H'S'\right]\frac{\partial P}{\partial y_M} = 0, \tag{24}$$

$$\frac{\partial U_M}{\partial x_M} = -C'_M + p - H' - \left[(y_M - x_M) - (\overline{\chi} - \underline{\chi}) + H'S'\right]\frac{\partial P}{\partial x_M} = 0. \tag{25}$$

The conditions (24) and (25) differ significantly from (13) and (14), and this difference will turn out to be crucial.[14]

Stage 1. Finally, we have to investigate how the deposit market clears at stage 1. All considerations regarding the deposits $[\underline{\xi}, \overline{\xi}]_{C'_N}$ that M seeks to purchase for preservation, in particular Lemma 1, remain unchanged. In addition to their actions at the stage 1 in the last section, M and N must now reach an agreement (i) on the size of the interval $[\underline{\chi}, \overline{\chi}]_{C'_N}$, and (ii) on the total price θ of the package deal of transferring the ownership of the deposits $[\underline{\xi}, \overline{\xi}]_{C'_N}$ and $[\underline{\chi}, \overline{\chi}]_{C'_N}$ from N to M.[15] Observe first that whatever interval $[\underline{\chi}, \overline{\chi}]_{C'_N} \subset [0, \underline{\xi}]_{C'_N}$

[14]The first-order conditions (6) and (7) in Harstad (2012, p. 88) are equivalent to our conditions (13) and (14), which we proved to characterize the deposit preservation policy. Thus, they deviate from the first-order conditions (24) and (25), which we proved to characterize Harstad's extended deposit policy.

[15]We easily verify that mutually beneficial deals exist as follows. Let θ_o be the price M and N agreed upon in the game of the last section and suppose that M pays N for the package the price θ_o *plus* the profits foregone of extracting and selling the deposits $[\underline{\chi}, \overline{\chi}]_{C'_N}$. That deal clearly makes both countries better off.

is chosen, there exist prices θ for the package deal that are strictly beneficial for M and N. We assume that some mutually beneficial price is chosen, and we will be more specific about that price below. The interesting and decisive issue is the agreement on the size of the interval $[\underline{\chi}, \overline{\chi}]_{C'_N}$, because according to (24) and (25) the choice of $\overline{\chi} - \underline{\chi}$ influences M's incentive to manipulate the fuel price. In the Appendix A we prove

Lemma 2. *Suppose, at stage 1 of the game M and N agree on the package deal of selling/buying $[\underline{\xi}, \overline{\xi}]_{C'_N}$ for preservation and $[\underline{\chi}, \overline{\chi}]_{C'_N}$ with $\overline{\chi} - \underline{\chi} = y_M^* - x_M^*$ for exploitation. Then the outcome of the game is efficient.*

The intuition of Lemma 2 is clear. As the comparison of (13), (14) with (24), (25) shows, in both policies strategic action generates a terms-of-trade effect and a climate-damage effect that are specified in (19). When the extended deposit policy is applied, we have the additional effect $\left(\overline{\chi} - \underline{\chi}\right) \frac{\partial P}{\partial y_M}$ generated by the transfer of profits. The profit-transfer effect and the terms-of-trade effect work in opposite directions, and by design the extended deposit policy chooses the size of the interval of deposits for exploitation such that the associated profit-transfer effect exactly offsets the terms-of-trade effect.[16]

In the preceding analysis we focused on an economy in $\mathcal{E}_{NO}$ that satisfies the condition $y_M^* > x_M^*$. There is another subset of economies in $\mathcal{E}_{NO}$ that is characterized by $y_M^* < x_M^*$. We can modify the extended deposit policy described above such that it achieves an efficient outcome for all $E \in \mathcal{E}_{NO}$ satisfying $y_M^* < x_M^*$ as well. To that end, we specify the deposits for preservation as before, but let the coalition sell some of its profitable deposits to country N (rather than let it buy some profitable deposits from N). Specifically, if M sells the deposits in an interval $[\underline{\chi}, \overline{\chi}]_{C'_M} \subset [0, x_M^*]_{C'_M}$ of size $\overline{\chi} - \underline{\chi} = x_M^* - y_M^*$, it is then straightforward to prove along the lines of Lemma 2 that the outcome of the three-stage game is efficient. We summarize the results in

Proposition 4 *(Harstad 2012, Theorem 1)*.[17]
Consider the following **extended deposit policy**. *The coalition buys from country N for preservation those highest-cost profitable deposits, which internalize the climate damage for any given fuel price, as in the deposit preservation policy of Section 3. In addition, the coalition and country N trade profitable deposits for exploitation such that*

- *either N sells the deposits in an interval $[\underline{\chi}, \overline{\chi}]_{C'_N}$ of size $\overline{\chi} - \underline{\chi} = y_M^* - x_M^*$, if $y_M^* > x_M^*$*

[16] Harstad (2012, p. 92) incorrectly argues that if "... M buys a small deposit from i, which is such that any owner would exploit it ..., then M imports less afterward". Socially optimal fuel imports and exports are not affected by any trade in deposits.

[17] Some remarks to the exact relation of Proposition 4 and Harstad's (2012) Theorem 1 can be found in the Appendix B.

- *or M sells the deposits in an interval $[\underline{\chi}, \overline{\chi}]_{C'_M}$ of size $\overline{\chi} - \underline{\chi} = x^*_M - y^*_M$, if $x^*_M > y^*_M$.*

The outcome of the three-stage game with the extended deposit policy is efficient.

Proposition 4 reconstructs Harstad's (2012) Theorem 1 and covers all economies in the set $\mathcal{E}$ as does Harstad's theorem. However, in contrast to Harstad we showed in the previous section that the deposit preservation policy is efficient in all economies $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$ without trade in deposits for exploitation and hence without the extension that is constituent for Proposition 4. Consequently, the extended deposit policy removes an allocative distortion in the economies in $\mathcal{E}_{NO}$ only, and therefore its application is unnecessary in the economies $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$. We conclude that trade in deposits can be an efficient climate policy instrument in all economies $E \in \mathcal{E}$. In the economies $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$, efficiency is attained by a policy involving only trade in deposits for preservation as specified in Proposition 2(ii). In the economies $E \in \mathcal{E}_{NO}$, efficiency requires applying the extended deposit policy of Proposition 4.

The preceding analysis suggests to apply the deposit preservation policy in the economies $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$ and the extended deposit policy in the economies $E \in \mathcal{E}_{NO}$. We have shown above that both policies then secure efficiency but that they differ with respect to the deposit transactions they require. Since efficiency may go along with different distributions of welfares between the coalition and the country N, it is interesting to investigate whether or how the welfare implications of the two policies differ. That question can be conveniently investigated by means of Figure 3. The origin 0 in Figure 3 corresponds to the (normalized) welfares of M and N in the no-policy regime and the negatively sloped straight line WW is the welfare frontier. If M and N are price takers in the fuel market in any $E \in \mathcal{E}$, M's deposit preservation policy shifts the welfares (U_M, U_N) from the origin 0 to some point on the welfare frontier[18] such as the point D. Taking the point D as a benchmark, we now distinguish three different cases.

(i) Suppose first that M implements the deposit preservation policy with the option to manipulate the fuel price in an economy in $\mathcal{E}_{(=)} \cup \mathcal{E}_O$. According to Proposition 2(ii) M is not able in that case to raise its welfare by manipulating the fuel price above the level it enjoys as a fuel price taker. Hence, in all economies $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$ the welfares of M and N are the same as in case of price taking. That is, the point D in Figure 3 is attained in all $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$ without and with the option to act strategically, because terms-of-trade manipulations are ineffective.

[18]The position of the point D on the welfare frontier depends on how M and N share the surplus from the trade in deposits. For more details we refer to Figure 4 of the Appendix B.

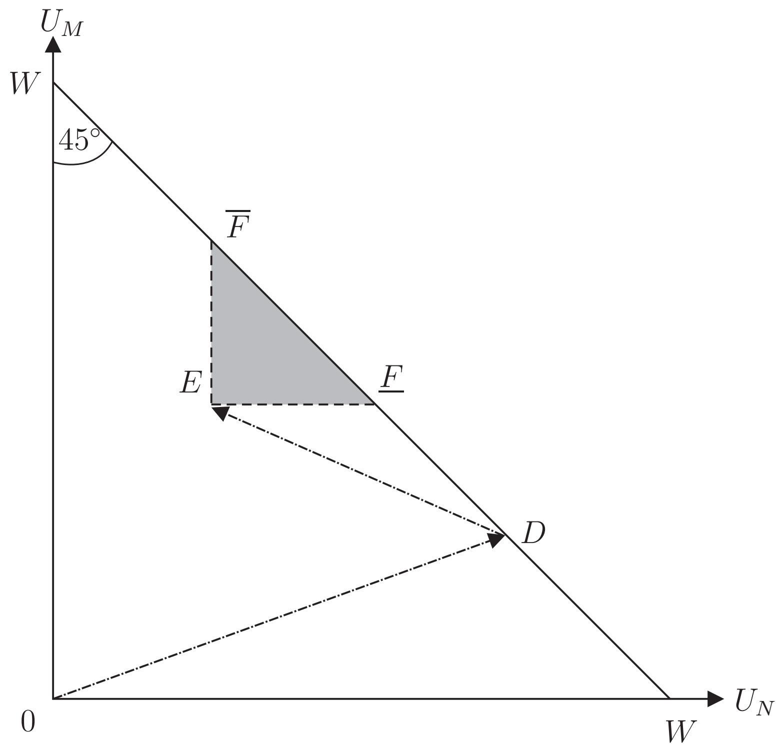

Figure 3: Welfare implications

(ii) Consider next an economy in $\mathcal{E}_{NO}$ in which M implements the deposit preservation policy with the option to manipulate the fuel price. According to Proposition 2(i), now M is able to raise its welfare above the 'price-taking level' via its choice of fuel demand and supply. Since the outcome is inefficient, the result corresponds to a point such as the point E in Figure 3 below the welfare frontier. The move from D to E is welfare increasing for the coalition, welfare reducing for country N, and it is wasteful.

(iii) Finally, consider an economy in $\mathcal{E}_{NO}$ in which M implements the extended deposit policy with the option to manipulate the fuel price. According to Proposition 4 the extended deposit policy is efficient in all economies $E \in \mathcal{E}_{NO}$. Hence, some point on the welfare frontier is realized in Figure 3. However, this point must differ from the point D for the following reason. The extended deposit policy requires M to buy or sell some deposits for exploitation in addition to purchasing the same deposits for preservation as in the deposit preservation policy of Proposition 2. Hence, the coalition rejects all those proposals of sharing the gains from implementing the extended deposit policy, which make it worse off than it would be in the point E in Figure 3. In other words, the point E is M's threat point. Country N is aware of the coalition's strong bargaining power and therefore it knows that M would only agree to implement the extended deposit policy if M's share of the surplus is so large that a welfare point on the line segment $\underline{F}\overline{F}$ is attained in Figure 3. Since there are deals (i.e. all points on the line segment $\underline{F}\overline{F}$ excluding the boundary points) that make M and N strictly better off under the extended deposit policy than under the deposit preservation policy (in point E), they will agree on the former.

We summarize these results as follows.

Proposition 5 .

(i) Suppose country N takes the fuel price as given, the coalition has the option to act strategically in the fuel market, and the **deposit preservation policy** *is implemented in an economy belonging to the set $\mathcal{E}_{(=)} \cup \mathcal{E}_O$ (Proposition 2(ii)). Then the welfare of the coalition and of country N does not differ from the level they enjoy when both of them take the fuel price as given.*[19]

(ii) Suppose country N takes the fuel price as given, the coalition has the option to act strategically in the fuel market, and the **extended deposit policy** *is implemented in an economy belonging to the set $\mathcal{E}_{NO}$ (Proposition 4). Then the welfare of the coalition and of country N differs from the levels they enjoy when both of them act as price takers in the fuel market. Compared to the price taking case, the welfare of country N is smaller and the coalition's welfare is larger.*

The difference in the welfare implications of efficient deposit policies stated in Proposition 5 is remarkable. If we relate the coalition's option to act strategically in the fuel market to the notion of market power in the fuel market, we may interpret Proposition 5 as follows. Under the conditions of Proposition 5(i), the coalition is not able to translate the option to act strategically into market power. In contrast, under the conditions of Proposition 5(ii) the option of strategic action gives the coalition market power. However, the coalition does not use that power to enhance its welfare by distorting the allocation, as the standard analysis of market power would suggest. Instead, here the market power is non-distortionary, but it shows up in the coalition's welfare gain that is even larger than it would be, if the coalition would use its strategic action to manipulate the terms-of-trade in its favor.

5 Concluding remarks

While most analytical studies on fighting climate change with demand-side policies are quite pessimistic with respect to international cooperation and the effectiveness of (sub-global) climate agreements, Harstad's (2012) message is that the perfect solution to the climate problem is a supply-side policy that consists of a set of transactions in an international

[19]Comparability requires assuming that the distribution of the trade surplus that M and N agree upon is the same in both scenarios.

market for fossil energy deposits. In general, the policy he suggests requires the coalition not only to buy deposits to prevent their exploitation, but also to buy or sell certain deposits that will then be exploited. Such an 'extended deposit policy' secures the first-best allocation, and more surprisingly, it does so even if a sub-global climate coalition is able to manipulate the fuel price.

The motivation for and the aim of the present paper is to understand better and to complement Harstad's 'extended deposit policy'. To that end, we investigate the outcome of the game under the assumption that the coalition applies what appears to be the natural internalization policy, namely that it purchases deposits exclusively for the purpose to prevent their exploitation (deposit preservation policy). The surprising result is that the deposit preservation policy is efficient in a non-trivial proper subset of economies. That is, the extended deposit policy is sufficient for attaining efficiency in all economies, but it is not necessary in a significant subset of economies. Another important difference relates to the distribution of welfare among the coalition and the non-signatories. If the deposit preservation policy is efficient, the welfares of all countries are as in the efficient Coaseian benchmark case, in which all countries take the fuel price as given. In the economies, in which the deposit preservation policy is inefficient, the (efficient) extended deposit policy makes the coalition better off and the non-signatories worse off than in the benchmark case.

The game model is based on a number of restrictive assumptions that may limit its relevance as a guide for policy. First, the assumption that only a subset of countries, called the coalition, suffers from climate damage is a simplification that is not harmless because it is unclear whether or how the first-best can be attained via an international market for deposits without that assumption. Second, even if one accepts that only the members of the sub-global coalition suffer from climate damage, the assumption that the coalition acts as one agent is strong. Essentially, it expresses a Coaseian optimism with respect to reaching an agreement on the distribution of costs and benefits among all signatories. Not least, the market power on the fuel market is asymmetric since the coalition has the option to act strategically, whereas the non-signatories take the fuel price as given. One may question the plausibility of such asymmetric fuel market power, when at the same time non-signatories are supposed to exert bargaining power in the deposit market in their deals with the coalition.

References

Asheim, G. (2013): A distributional argument for supply-side climate policies, *Environmental and Resource Economics* 56, 239-254.

Barrett, S. (1994): Self-enforcing international environmental agreements, *Oxford Economic Papers* 46, 878-894.

Bohm, P. (1993): Incomplete international cooperation to reduce CO_2 emissions: alternative policies, *Journal Environmental Economics and Management* 24, 258-271.

Copeland, B. (1996): Pollution content tariffs, environmental rent shifting, and the control of cross-border pollution, *Journal of International Economics* 40, 459-479.

Copeland, B. and S. Taylor (1995): Trade and transboundary pollution, *American Economic Review* 85, 716-737.

Eichner, T. and R. Pethig (2017): Trade in fossil fuel deposits and strategic action, *Journal of Public Economics*, forthcoming.

Eichner, T. and R. Pethig (2013): Self-enforcing environmental agreements and international trade, *Journal of Public Economics* 102, 37-50.

Harstad, B. (2012): Buy coal! A case for supply-side environmental policy, *Journal of Political Economy* 120, 77-115.

Hoel, M. (1994): Efficient climate policy in the presence of free riders, *Journal Environmental Economics and Management* 27, 259-274.

Kiyono, K. and J. Ishikawa (2013): Environmental management policy under international carbon leakage, *International Economic Review* 54, 1057-1083. Krugman, P. (Ed.) (1986). Strategic Trade Policy and International Economics. The MIT Press, Cambridge, Mass. London.

Ludema, R.D. and I. Wooton (1994): Cross-border externalities and trade liberalization: The strategic control of pollution, *Canadian Journal of Economics* 27, 950-966.

Markusen J.R. (1975): International externalities and optimal tax structure, *Journal of International Economics* 5, 15-29.

Rubio, S.J. and A. Ulph (2006): Self-enforcing international environmental agreements revisted, *Oxford Economic Papers* 58, 233-263.

Usher, D. (1998): The Coase theorem is tautological, incoherent or wrong. *Economics Letters* 61, 3-11.

Appendix

Appendix A: Proofs

Derivation of (9):

Maximizing (6) with respect to x_N yields

$$K'(x_N, \underline{\xi}, \overline{\xi}) = p.$$

Suppose that $x_N \leq \underline{\xi}$, then we obtain

$$C_N'(x_N) = p \quad \Longleftrightarrow \quad x_N = C_N'^{-1}(p).$$

Suppose that $x_N \geq \underline{\xi}$, then we get

$$C_N'\left(x_N + \overline{\xi} - \underline{\xi}\right) = p \quad \Longleftrightarrow \quad x_N = C_N'^{-1}(p) - \overline{\xi} + \underline{\xi}.$$

■

Proof of Lemma 1:

The coalition chooses that value of z_M^d and the lumpsum transfer θ under consideration of $z_M^d = z_N^s$ which maximizes its welfare subject to some given welfare $\bar{u}_N$ of N. In formal terms, it solves the Lagrangean

$$\begin{aligned}
&\mathcal{L}(z_N, z_M, \theta) = \\
&B_M(y_M) - C_M\left[X_M(\underline{\xi}, \overline{\xi})\right] - p\left[y_M - X_M(\underline{\xi}, \overline{\xi})\right] - H\left[X_M(\underline{\xi}, \overline{\xi}) + \overline{\xi} - z_M^d\right] - \theta \\
&+\lambda_N\{B_N(y_N) - C_N\left(\overline{\xi} - z_N^s\right) - p\left(y_N - \overline{\xi} + z_N^s\right) + \theta - \bar{u}_N\} + \lambda_z\left(z_N^s - z_M^d\right)
\end{aligned} \tag{A1}$$

with respect to z_M^d, z_N^s, θ, λ_N and λ_z for predetermined p, $\underline{\xi}$, $\overline{\xi} = \overline{\xi}(p) = C_N'^{-1}(p)$, y_M and y_N. The first-order conditions yield $\lambda_N = 1$,

$$C_N'(x_N) = p - \lambda_z \qquad \text{and hence} \qquad x_N = \underline{\xi} = \underline{\xi}(p) := C_N'^{-1}(p - \lambda_z) \tag{A2}$$

$$\text{and} \qquad \lambda_z = H'\left[X_M(\underline{\xi}, \overline{\xi}) + \underline{\xi}\right]. \tag{A3}$$

■

Proof of Proposition 2:

The efficiency condition (5b) is satisfied for N due to $B'_N(y_N) = p$ from (7) and $x_N = \underline{\xi} = C'^{-1}_N(p - H')$, which is equivalent to $C'_N(x_N) + H' = p$, from Lemma 1. To show that the efficiency conditions (5a) and (5b) for M do (not) hold, the partial derivatives of (12) with respect to y_M and x_M are evaluated at the first-best equilibrium values of the game

$$\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} = \underbrace{B'^*_M - p^*}_{=0} - \left(y_M^* - x_M^* + H'^* S'^*\right) \cdot \left.\frac{\partial P}{\partial y_M}\right|_{y_M^*}, \tag{A4}$$

where $\frac{\partial P}{\partial y_M} > 0$ and for all $i \in N$

$$S'^* = \left.\frac{\partial S}{\partial p}\right|_{p^*} = \begin{cases} S'^*_+ > 0, & \text{if } \mathrm{d}p = \frac{\partial P}{\partial y_M} \underbrace{\mathrm{d}y_M}_{(+)} > 0, \\ S'^*_- = 0, & \text{if } \mathrm{d}p = \frac{\partial P}{\partial y_M} \underbrace{\mathrm{d}y_M}_{(-)} < 0, \end{cases} \tag{A5}$$

and

$$\left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} = \underbrace{-C'^*_M + p^* - H'^*}_{=0} - \left(y_M^* - x_M^* + H'^* S'^*\right) \cdot \left.\frac{\partial P}{\partial x_M}\right|_{x_M^*}, \tag{A6}$$

where $\frac{\partial P}{\partial x_M} < 0$ and for all $i \in N$

$$S'^* = \left.\frac{\partial S}{\partial p}\right|_{p^*} = \begin{cases} S'^*_+ > 0, & \text{if } \mathrm{d}p = \frac{\partial P}{\partial x_M} \underbrace{\mathrm{d}x_M}_{(-)} > 0, \\ S'^*_- = 0, & \text{if } \mathrm{d}p = \frac{\partial P}{\partial x_M} \underbrace{\mathrm{d}x_M}_{(+)} < 0. \end{cases} \tag{A7}$$

Consider first the marginal welfare (A4) and distinguish the following four cases.

(a) Suppose that $y_M^* - x_M^* > 0$. If $\mathrm{d}y_M > 0$, (A5) yields $S'^* = S'^*_+ > 0$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} < 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M < 0$. If $\mathrm{d}y_M < 0$, (A5) yields $S'^* = S'^*_- = 0$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} < 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M > 0$.

(b) Suppose that $y_M^* - x_M^* < 0$ and $y_M^* - x_M^* + H'^* S'^*_+ < 0$. If $\mathrm{d}y_M > 0$, (A5) yields $S'^* = S'^*_+$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} > 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M > 0$. If $\mathrm{d}y_M < 0$, (A5) yields $S'^* = S'^*_- = 0$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} > 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M < 0$.

(c) Suppose that $y_M^* - x_M^* < 0$ and $y_M^* - x_M^* + H'^* S'^*_+ \geq 0$. If $\mathrm{d}y_M > 0$, (A5) yields $S'^* = S'^*_+ > 0$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \leq 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M \leq 0$.

If $\mathrm{d}y_M < 0$, (A5) yields $S'^* = S'^*_- = 0$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} > 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M < 0$.

(d) Suppose $y_M^* - x_M^* = 0$. If $\mathrm{d}y_M > 0$, (A5) yields $S'^* = S'^*_+$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} < 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M < 0$. If $\mathrm{d}y_M < 0$, (A5) yields $S'^* = S'^*_-$ and $\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} = 0$ follows from (A4). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} \cdot \mathrm{d}y_M = 0$.

Next we investigate whether variations of x_M enhance welfare under the conditions specified in the cases (c) and (d).

(e) Suppose $y_M^* - x_M^* < 0$ and $y_M^* - x_M^* + H'^* S'^*_+ \geq 0$ (as in (c)). If $\mathrm{d}x_M > 0$, (A7) yields $S'^* = S'^*_- = 0$ and $\left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} < 0$ follows from (A6). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} \cdot \mathrm{d}x_M < 0$. If $\mathrm{d}x_M < 0$, (A7) yields $S'^* = S'^*_+ > 0$ and $\left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} \geq 0$ follows from (A6). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} \cdot \mathrm{d}x_M \leq 0$.

(f) Suppose $y_M^* - x_M^* = 0$ (as in (d)). If $\mathrm{d}x_M > 0$, (A7) yields $S'^* = S'^*_-$ and $\left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} = 0$ follows from (A6). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} \cdot \mathrm{d}x_M = 0$. If $\mathrm{d}x_M < 0$, (A7) yields $S'^* = S'^*_+$ and $\left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} > 0$ follows from (A6). Hence $\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} \cdot \mathrm{d}x_M < 0$.

In view of (a) - (b), the equilibrium of the three-stage game with the deposit preservation policy and strategic action on the fuel market is inefficient, if and only if $E \in \mathcal{E}_{NO}$.
In view of (c) - (f), the equilibrium of the three-stage game with the deposit preservation policy and strategic action on the fuel market is efficient, if and only if $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$. ■

Proof of Proposition 3:

The efficient allocation follows from solving

$$\alpha - by_M = \alpha b y_N, \tag{A8}$$
$$\alpha - by_M = c_M x_M + h, \tag{A9}$$
$$\alpha - by_N = c_N x_N + h, \tag{A10}$$
$$y_M + y_N = x_M + x_N, \tag{A11}$$

which yields

$$y_M^* = y_N^* = \frac{(c_M + c_N)(\alpha - h)}{b(c_M + c_N) + 2c_M c_N}, \quad x_M^* = \frac{2c_N(\alpha - h)}{b(c_M + c_N) + 2c_M c_N},$$
$$x_N^* = \frac{2c_M(\alpha - h)}{b(c_M + c_N) + 2c_M c_N}. \tag{A12}$$

From (A12) we infer

$$y_M^* - x_M^* \lesseqgtr 0 \quad \Longleftrightarrow \quad \frac{(\alpha - h)(c_M - c_N)}{b(c_M + c_N) + 2c_M c_N} \lesseqgtr 0 \quad \Longleftrightarrow \quad c_M \lesseqgtr c_N. \tag{A13}$$

In addition, observe that

$$K'(x_N, \underline{\xi}, \overline{\xi}) = \begin{cases} c_N x_N & \text{for } x_N \leq \underline{\xi}, \\ c_N\left(x_N + \overline{\xi} - \underline{\xi}\right) & \text{for } x_N \geq \underline{\xi}, \end{cases} \tag{A14}$$

$$S(p, \underline{\xi}, \overline{\xi}) = \begin{cases} \frac{p}{c_N} & \text{for } p \leq c_N \underline{\xi}, \\ \underline{\xi} & \text{for } p \in [c_N \underline{\xi}, c_N \overline{\xi}], \\ \frac{p}{c_N} - \overline{\xi} + \underline{\xi} & \text{for } p \geq c_N \overline{\xi}. \end{cases} \tag{A15}$$

Next, we calculate

$$y_M^* - x_M^* + H'^* S'^* = \frac{bh(c_M + c_N) + c_N[c_M(\alpha + h) - c_N(\alpha - h)]}{c_N[b(c_M + c_N) + 2c_M c_N]} =: G(\alpha, b, c_M, c_N, h), \tag{A16}$$

where $S'^* = \frac{1}{c_N}$ for $p \geq c_N \overline{\xi}$ and $H'^* = h$. Verify that $G_h > 0$ and

$$G(\alpha, b, c_M, c_N, \bar{h}) = 0 \quad \Longleftrightarrow \quad \bar{h} = \frac{\alpha c_N (c_N - c_M)}{(b + c_N)(c_M + c_N)}. \tag{A17}$$

Hence, we conclude

$$y_M^* - x_M^* + H'^* S'^* \lesseqgtr 0 \quad \Longleftrightarrow \quad h \lesseqgtr \bar{h}. \tag{A18}$$

Making use of (A13) and (A18) in the sets $\mathcal{E}_{(=)} \cup \mathcal{E}_O$ and $\mathcal{E}_{NO}$ establishes Proposition 3. ■

Proof of Lemma 2:

The efficiency condition (5b) is satisfied for N due to $B_N'(y_N) = p$ from (7) and $C_N'(x_N) + H' = p$ from Lemma 1. To show that the efficiency conditions (5a) and (5b) for M are satisfied, the partial derivatives of (23) with respect to y_M and x_M are evaluated at the first-best equilibrium values of the game

$$\left.\frac{\partial U_M}{\partial y_M}\right|_{y_M^*} = \underbrace{B_M'^* - p^*}_{=0} - \left[(y_M^* - x_M^*) - (\overline{\chi} - \underline{\chi}) + H'^* S'^*\right] \left.\frac{\partial P}{\partial y_M}\right|_{y_M^*}, \tag{A19}$$

$$\left.\frac{\partial U_M}{\partial x_M}\right|_{x_M^*} = \underbrace{-C_M'^* + p^* - H'^*}_{=0} - \left[(y_M^* - x_M^*) - (\overline{\chi} - \underline{\chi}) + H'^* S'^*\right] \left.\frac{\partial P}{\partial x_M}\right|_{x_M^*}. \tag{A20}$$

Suppose $(y_M^* - x_M^*) = (\overline{\chi} - \underline{\chi})$. If $\mathrm{d}y_M > 0$, (A5) yields $S'^* = S'^*_+$ and $\frac{\partial U_M}{\partial y_M}\Big|_{y_M^*} < 0$ follows from (A19). Hence $\mathrm{d}U_M = \frac{\partial U_M}{\partial y_M}\Big|_{y_M^*} \cdot \mathrm{d}y_M < 0$. If $\mathrm{d}y_M < 0$, (A5) yields $S'^* = S'^*_-$ and $\frac{\partial U_M}{\partial y_M}\Big|_{y_M^*} = 0$ follows from (A19). Hence $\mathrm{d}U_M = \frac{\partial U_M}{\partial y_M}\Big|_{y_M^*} \cdot \mathrm{d}y_M = 0$.
If $\mathrm{d}x_M > 0$, (A7) yields $S'^* = S'^*_-$ and $\frac{\partial U_M}{\partial x_M}\Big|_{x_M^*} = 0$ follows from (A20). Hence $\mathrm{d}U_M = \frac{\partial U_M}{\partial x_M}\Big|_{x_M^*} \cdot \mathrm{d}x_M = 0$. If $\mathrm{d}x_M < 0$, (A7) yields $S'^* = S'^*_+$ and $\frac{\partial U_M}{\partial x_M}\Big|_{x_M^*} > 0$ follows from (A20). Hence $\mathrm{d}U_M = \frac{\partial U_M}{\partial x_M}\Big|_{x_M^*} \cdot \mathrm{d}x_M < 0$. ■

Appendix B

An analysis of (19):

(i) $\mathrm{d}x_M > 0 \Longrightarrow \mathrm{d}p = \frac{\partial P}{\partial x_M}\mathrm{d}x_M < 0 \Longrightarrow S'^* = 0$

$$\Longrightarrow \mathrm{d}U_M = \frac{\partial U_M^*}{\partial x_M}\mathrm{d}x_M = \begin{cases} -(y_M^* - x_M^*)\frac{\partial P}{\partial x_M}\mathrm{d}x_M \geq 0, & \text{if } y_M^* \geq x_M^* \\ -(y_M^* - x_M^*)\frac{\partial P}{\partial x_M}\mathrm{d}x_M < 0, & \text{if } y_M^* < x_M^* \end{cases}$$

(ii) $\mathrm{d}x_M < 0 \Longrightarrow \mathrm{d}p = \frac{\partial P}{\partial x_M}\mathrm{d}x_M > 0 \Longrightarrow S'^* > 0$

$$\Longrightarrow \mathrm{d}U_M = \frac{\partial U_M^*}{\partial x_M}\mathrm{d}x_M =$$

$$\begin{cases} \underbrace{-(y_M^* - x_M^*)\frac{\partial P}{\partial x_M}\mathrm{d}x_M}_{(-,0)} \underbrace{-H'^*S'^*\frac{\partial P}{\partial x_M}\mathrm{d}x_M}_{(-)} \leq 0, & \text{if} \quad y_M^* \geq x_M^* \\ \underbrace{-(y_M^* - x_M^*)\frac{\partial P}{\partial x_M}\mathrm{d}x_M}_{(+)} \underbrace{-H'^*S'^*\frac{\partial P}{\partial x_M}\mathrm{d}x_M}_{(-)} \gtreqless 0, & \text{if} \quad y_M^* < x_M^* \end{cases}$$

(iii) $\mathrm{d}y_M > 0 \Longrightarrow \mathrm{d}p = \frac{\partial P}{\partial y_M}\mathrm{d}y_M > 0 \Longrightarrow S'^* > 0$

$$\Longrightarrow \mathrm{d}U_M = \frac{\partial U_M^*}{\partial y_M}\mathrm{d}y_M =$$

$$\begin{cases} \underbrace{-(y_M^* - x_M^*)\frac{\partial P}{\partial y_M}\mathrm{d}y_M}_{(-)} \underbrace{-H'^*S'^*\frac{\partial P}{\partial y_M}\mathrm{d}y_M}_{(-)} < 0, & \text{if} \quad y_M^* > x_M^* \\ -H'^*S'^*\frac{\partial P}{\partial y_M}\mathrm{d}y_M < 0, & \text{if} \quad y_M^* = x_M^* \\ \underbrace{-(y_M^* - x_M^*)\frac{\partial P}{\partial y_M}\mathrm{d}y_M}_{(+)} \underbrace{-H'^*S'^*\frac{\partial P}{\partial y_M}\mathrm{d}y_M}_{(-)} \gtreqless 0, & \text{if} \quad y_M^* < x_M^* \end{cases}$$

(iv) $\mathrm{d}y_M < 0 \Longrightarrow \mathrm{d}p = \frac{\partial P}{\partial y_M}\mathrm{d}y_M < 0 \Longrightarrow S'^* = 0$

$$\Longrightarrow \mathrm{d}U_M = \frac{\partial U_M^*}{\partial y_M}\mathrm{d}y_M = \begin{cases} -(y_M^* - x_M^*)\frac{\partial P}{\partial y_M}\mathrm{d}y_M \geq 0, & \text{if } y_M^* \geq x_M^* \\ -(y_M^* - x_M^*)\frac{\partial P}{\partial y_M}\mathrm{d}y_M < 0, & \text{if } y_M^* < x_M^* \end{cases}$$

We summarize the results (i)-(iv) in Table 1.

	$y_M^* > x_M^*$	$y_M^* = x_M^*$	$y_M^* < y_M^*$
$\mathrm{d}x_M > 0$	$\mathrm{d}w_F > 0, \mathrm{d}w_H = 0$	$\mathrm{d}w_F = \mathrm{d}w_H = 0$	$\mathrm{d}w_F < 0, \mathrm{d}w_H = 0$
$\mathrm{d}x_M < 0$	$\mathrm{d}w_F < 0, \mathrm{d}w_H < 0$	$\mathrm{d}w_F = 0, \mathrm{d}w_H < 0$	$\mathrm{d}w_F > 0, \mathrm{d}w_H < 0$
$\mathrm{d}y_M > 0$	$\mathrm{d}w_F < 0, \mathrm{d}w_H < 0$	$\mathrm{d}w_F = 0, \mathrm{d}w_H < 0$	$\mathrm{d}w_F > 0, \mathrm{d}w_H < 0$
$\mathrm{d}y_M < 0$	$\mathrm{d}w_F > 0, \mathrm{d}w_H = 0$	$\mathrm{d}w_F = \mathrm{d}w_H = 0$	$\mathrm{d}w_F < 0, \mathrm{d}w_H = 0$
$\mathrm{d}U_M$	$\mathrm{d}U_M > 0$	$\mathrm{d}U_M = 0$	$\mathrm{d}U_M \gtreqless 0$

Table 1: Comparative statics of the fuel caps

Our Proposition 4 and Theorem 1 of Harstad (2012)

The proof Harstad (2012) offers for his Theorem 1 is incorrect in two points. First, Harstad's first-order conditions (6) and (7) are incorrect. They coincide with our conditions (13) and (14) but they should equal our first-order conditions (24) and (25). Second, Harstad's Lemma 2, which is an indispensable part of his proof of his Theorem 1, is incorrect. Lemma 2 claims that $x_i = y_i$ for $i = M, N$ in every equilibrium. In our proof of our Proposition 4 we show that neither $x_i = y_i$ holds in every equilibrium nor is that necessary for reaching efficiency. The proof of our Proposition 5 demonstrates that the two flaws in Harstad's proof can be fixed.

Generalization of Figure 3:

Figure 3 is drawn for a specific distribution of the surplus from trade in deposits. That surplus may be bargained as explained in the context of Figure 2. Figure 4 generalizes Figure 3 without changing the principal outcome. The three cases following Figure 3 are then captured by the three games

Game $G(A_O)$: Deposit preservation policy in the economy $E \in \mathcal{E}_{(=)} \cup \mathcal{E}_O$ (Proposition 2(ii), case (i))

Game $G(A_{NO})$: Deposit preservation policy in the economy $E \in \mathcal{E}_{NO}$ (Proposition 2(i), case (ii))

Game $G(B)$: Extended deposit policy in the economy $E \in \mathcal{E}_{NO}$ (Proposition 4, case (iii))

In the game $G(A_O)$ the deposit preservation policy leads to the welfare $\overline{D}$ [$\underline{D}$], if all gains from trade in deposits accrue to the coalition [country N]. The result of deposit preservation policy in game $G(A_{NO})$ is the move from $\underline{D}$ to $\underline{E}$ and from $\overline{D}$ to $\overline{E}$, respectively, in Figure 4. Finally, the result of the extended deposit policy in the game $G(B)$ is some point on the segment $\overline{F}\underline{G}$ on the welfare frontier. The closer that equilibrium point is to the point $\overline{F}$ [$\underline{G}$],

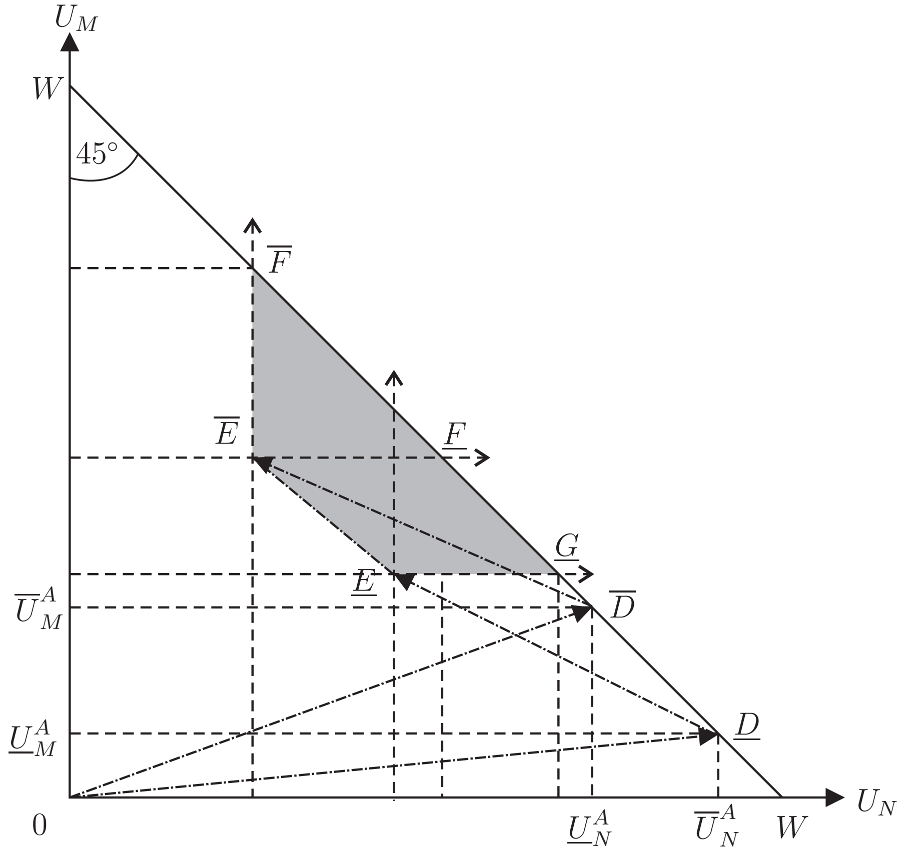

Figure 4: Welfare implications of different games

the larger is the climate coalition's [country N's] share of the gains from bargaining. The associated welfare levels of the three games are listed in Table 2.

			Coalition	Country N
Game $G(A_O)$	Best for coalition	1	$U_M(A_O) = \overline{U}_M^A$	$U_N(A_O) = \underline{U}_N^A$
	Worst for coalition	2	$U_M(A_O) = \underline{U}_M^A$	$U_N(A_O) = \overline{U}_N^A$
	Intermediate	3	$U_M(A_O) = U_M^A(\lambda) = \lambda\overline{U}_M^A + (1-\lambda)\underline{U}_M^A$	$U_N(A_O) = U_N^A(\lambda) = \lambda\underline{U}_N^A + (1-\lambda)\overline{U}_N^A$
Game $G(A_{NO})$	Best for coalition	4	$U_M(A_{NO}) = \overline{U}_M^A + \Delta U_M$	$U_N(A_{NO}) = \underline{U}_N^A - \Delta U_M^{NO} - \Delta U_N^{NO}$
	Worst for coalition	5	$U_M(A_{NO}) = \underline{U}_M^A + \Delta U_M^s$	$U_N(A_{NO}) = \overline{U}_N^A - \Delta U_M^{NO} - \Delta U_N^{NO}$
	Intermediate	6	$U_M(A_{NO}) = U_M^A(\lambda) + \Delta U_M^{NO}$	$U_N(A_{NO}) = U_N^A(\lambda) - \Delta U_M^{NO} - \Delta U_N^{NO}$
Game $G(B)$	Best for coalition	7	$U_M(B) = \overline{U}_M^A + \Delta U_M^{NO} + \Delta U_N^{NO}$	$U_N(B) = \underline{U}_N^A - \Delta U_M^{NO} - \Delta U_N^{NO}$
	Worst for coalition	8	$U_M(B) = \underline{U}_M^A + \Delta U_M^{NO}$	$U_N(B) = \overline{U}_N^A - \Delta U_M^{NO}$
	Intermediate	9	$U_M(B) = U_M(\lambda) + \Delta U_M^{NO} + \mu\Delta U_N^{NO}$	$U_N(B) = U_N^A(\lambda) - \Delta U_M^{NO} + (1-\mu)\Delta U_N^{NO}$

Table 2: Welfare implications of three different games in comparison (based on the Figures 3 and 4)

($\overline{U}_M^A + \underline{U}_N^A = \underline{U}_M^A + \overline{U}_N^A =$ first best; $\lambda \in [0,1]; \mu \in [0,1]$)