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Buying versus leasing fuel deposits for preservation

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Abstract

In a two-period model with two groups of countries that extract, trade and consume fossil fuel, a climate coalition fights against climate damage by purchasing or leasing deposits to prevent their extraction, and seeks to manipulate the fuel prices in its favor. The deposit-purchase policy is inefficient since it leaves the first-period climate damage externality non-internalized, which is in stark contrast to the efficiency of the deposit-purchase policy in static models. However, for a subset of economies the deposit-lease policy turns out to be efficient. It internalizes the climate damage externalities and makes strategic action in the fuel markets ineffective. Finally, we compare the deposit-lease policy and the deposit-purchase policy in an empirically calibrated economy. If strategic action pays in the fuel markets, a transition from the deposit-purchase policy to the deposit-lease policy increases the coalition's welfare if the discount rate is small.

JEL classification: F55, H23, Q54, Q58

Key words: fossil fuel, deposit, deposit-lease policy, deposit-purchase policy, fuel cap

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1 Introduction

The climate problem is one of the most important challenges facing the world today. To stabilize the world climate at safe levels the world global warming should be kept below 2°C. At the Paris Agreement governments agreed to pursue efforts to limit the temperature increase to 1.5°C. Allen et al. (2009) have shown that there is a strong correlation between the maximum level of global warming and cumulative greenhouse gas emissions. Rogelj et al. (2011) and Walsh et al. (2017) have pointed out that staying below the 2°C global temperature limit not only depends on cumulative emissions but also on the emissions path. However, the recent withdraw of the U.S at the Paris Agreement impressively shows that global cooperation is hard to achieve due to strong free-rider incentives. That raises the question whether unilateral action of a (sub-global) climate coalition is able to achieve first-best solutions.

The economic literature has mainly analyzed demand-side climate policies. The problem inherent in demand-side policies is that they cause carbon leakage and may lead to a green paradox. Carbon leakage occurs when a country's unilateral emission reductions are offset by increased emissions in other countries. If the unilateral reductions are more than offset then a green paradox arises. Felder and Rutherford (1993), Hoel (1996), Babiker (2005), Copeland and Taylor (2005), Gerlagh (2011), Burniaux and Martins (2012) and Baylis et al. (2014) provide interesting insights into various channels and determinants of carbon leakage. Unilateral demand-side policies in intertemporal models with fossil fuel supply have been studied by Hoel (2011), Eichner and Pethig (2011), Grafton et al. (2012), van der Meijden et al. (2015) and van der Ploeg (2016). In different models with alternative assumptions (renewable resource as a perfect substitute, homothetic preferences, extraction costs, exploration investments etc.) these papers show that unilateral demand-side policies are always second-best and hence the efficient allocation is missed.

Whereas the economic literature on demand-side policies is large there are only few papers dealing with supply-side policies, and hence up to date supply-side policies are under-researched and not well understood. Bohm (1993) pointed out that carbon leakage could be reduced if a climate coalition would buy or lease deposits from non-signatories and preserve them from extraction. Hoel (1994) determines the second-best mix of demand-side and supply-side caps (or taxes). In numerical analyses Golombek et al. (1995) and Fæhn et al. (2017) further illustrate the second-best mix of demand-side and supply-side policies. Bohm (1993), Hoel (1994), Golombek et al. (1995) and Fæhn et al. (2017) apply static models.

Harstad (2012) extends Hoel's (1994) analysis by trading fossil fuel deposits. Especially, he shows that a (sub-global) climate coalition can buy deposits such that the first-best allocation is implemented. The deposit transactions kill two birds with one stone. They internalize the climate damage externality and eliminate strategic action in the fuel market. The internalization of the climate damage externality requires purchasing deposits for preservation, and to eliminate strategic action deposits are purchased and extracted by the coalition which anyway would have been extracted by the deposit sellers. Since it is questionable whether in the real world a climate coalition purchases deposits for extraction (to eliminate strategic effects), Eichner and Pethig (2017a) have investigated in a static setting whether purchasing deposits with the only purpose to prevent them from exploitation is sufficient to achieve first-best. They have shown that there exist a subset of economies at which deposit purchases for preservation implement efficiency, and other economies at which efficiency is missed.

Since the climate damages not only depend on cumulative emissions but also on the emissions path (Rogelj et al. 2011 and Walsh et al. 2017) the starting point of the present paper is a two-period model. Throughout the paper we assume that deposits are purchased (or leased) for preservation and not for extraction.[1] We consider a world with two (groups of) countries all of which extract, trade, and consume fossil fuel. All countries' carbon emissions from fuel extraction generate climate damage. However, only one group of countries makes use of policies to mitigate climate damage. This climate coalition caps fuel demand and supply in each period and purchases fossil fuel deposits to prevent their exploitation. The coalition may behave as price-taker or may strategically act in the fuel markets. Harstad (2012) 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).[2] In our paper these deposit transactions are implemented by a Nash bargaining solution. Our analysis reveals that the policy of purchasing deposits for preservation (*deposit-purchase policy*) is inefficient both for price-taking and strategic action in the fuel market (Proposition 1 and 2) which is in stark contrast to its performance in static models (Eichner and Pethig 2017a). The economic rationale lies in a non-internalized first-period climate damage externality. The group of non-signatories "extracts too much too early".

[1] Harstad (2012, Section IV.B.) shows that his deposit purchases for preservation combined with deposit purchases for extraction also achieve efficiency in a two-period model.

[2] On the consequences of market power at the deposit market in a static model we refer to Eichner and Pethig (2017b).

To address the inefficiency we extend the coalition's policy space by leasing deposits for preservation. The *deposit-lease policy* turns out to be efficient if the coalition takes prices as given in the fuel markets (Proposition 3). In case of strategic action the deposit-lease policy is efficient for a subset of economies which is characterized in Proposition 4. Next, we compare the allocations and welfare levels in the games with deposit-purchase policy and deposit-lease policy when the coalition behaves strategically in the fuel markets and strategic action pays. For parametric functions we show that the deposit-lease policy decreases first-period extraction, increases second-period extraction and reduces total climate damage compared to the deposit-purchase policy. In an empirically calibrated economy the deposit-lease policy results in larger (total and coalition's) welfare if the discount rate is small. At small discount rates, the climate damage is large and the non-internalization of the first-period climate externality becomes more pronounced at the deposit-purchase policy, which makes the deposit-lease policy more favorable (Proposition 5). Propositions 1-5 rest on the assumption that the coalition can commit to future policies. However, we also employ that these Proposition 1-4 remain true if the coalition cannot commit to future policies (Proposition 6).

The paper is organized as follows: Section 2 outlines the model and characterizes the efficient allocation. Section 3 analyzes the game with the deposit-purchase policy. Section 4 investigates the game with the deposit-lease policy. Section 5 turns to a comparison of the deposit-lease policy with the deposit-purchase policy in an empirically calibrated economy. Section 6 assumes that the coalition cannot commit to future policies and studies time consistent policies. Section 7 concludes.

2 The model

Consider a two-period model with two (groups of) countries M and N, where M is the climate coalition that acts as one agent and N is a representative non-signatory. Each country $i = M, N$ derives the benefit $B_{it}(y_{it})$ from consuming y_{it} units of fuel in period $t = 1, 2$. The benefit function is increasing and concave ($B'_{it} > 0$ and $B''_{it} < 0$). In each period each country produces the quantity x_{it} of fuel from domestic energy deposits. The cost of extracting x_{i1} in period 1 is $C_i(x_{i1})$ and the cost of extracting x_{i2} in period 2 is $C_i(x_{i1} + x_{i2}) - C_i(x_{i1})$ (with $C'_i > 0$ and $C''_i > 0$). Emissions are proportional to fuel extraction and hence x_{it} denotes both fuel supply and emissions. The coalition suffers the climate damage[3] $H\left[x_{M1}+x_{N1}+\psi\left(x_{M1}+x_{N1}+x_{M2}+x_{N2}\right)\right]$ (with $H'>0$ and $H''\geq 0$), where $\psi\in[0,1]$ is the ecological discount factor. The model is closed by the fuel market conditions

$$x_{Mt}+x_{Nt}=y_{Mt}+y_{Nt} \quad t=1,2. \tag{1}$$

As a benchmark, we characterize the efficient allocation which follows from maximizing

$$\begin{aligned} & B_{M1}(y_{M1})+B_{N1}(y_{N1})-C_M(x_{M1})-C_N(x_{N1}) \\ & \quad +\delta\left[B_{M2}(y_{M2})+B_{N2}(y_{N2})-C_M(x_{M1}+x_{M2})+C_M(x_{M1})-C_N(x_{N1}+x_{N2})+C_N(x_{N1})\right] \\ & \quad -H\left[x_{M1}+x_{N1}+\psi\left(x_{M1}+x_{N1}+x_{M2}+x_{N2}\right)\right] \end{aligned} \tag{2}$$

subject to (1). In (2), $\delta\in[0,1]$ is the discount factor. Restricting our attention to an interior solution and attaching an asterisk to the solution values of (2) the first-order conditions are

$$B'_{Mt}(y^*_{Mt}) = B'_{Nt}(y^*_{Nt}) \qquad t=1,2, \tag{3a}$$

$$B'_{i1}(y^*_{i1}) = C'_i(x^*_{i1})+\delta\left[C'_i(x^*_{i1}+x^*_{i2})-C'_i(x^*_{i1})\right]+(1+\psi)H' \quad i=M,N, \tag{3b}$$

$$\delta B'_{i2}(y^*_{i2}) = \delta C'_i(x^*_{i1}+x^*_{i2})+\psi H' \quad i=M,N. \tag{3c}$$

The allocation rules (3a) require consumption efficiency in both periods. The rules (3b) and (3c) reflect overall efficiency in period 1 and 2, respectively. Extraction in period t should be increased until its marginal consumption benefits equal its marginal costs. In period 1 the marginal costs of x_{i1} consists of four components. Enhancing x_{i1} increases first the extraction costs in period 1, $C'_i(x_{i1})$, second the discounted extraction costs in period 2, $\delta\left[C'_i(x_{i1}+x_{i2})-C'_i(x_{i1})\right]$, third the marginal climate damage in period 1, H', and fourth the discounted marginal climate damage in period 2, $\psi H'$. According to (3c) expanding extraction in period 2 increases the discounted extraction costs in period 2, $\delta C'_i(x_{i1}+x_{i2})$, and the discounted marginal climate damage in period 2, $\psi H'$.

3 Deposit-purchase policy

In this section we assume that the coalition buys deposits to prevent their extraction, *deposit-purchase policy* for short. To be more precise, a fossil fuel deposit in the ground is described

[3]The climate damage function which depends on both first-period and second-period emissions stock is in line with Michielsen (2014), van der Meijden et al. (2015) and van der Ploeg (2016).

by the fuel it stores and the cost of extracting the fuel. Each deposit stores a very small unit of fuel and these deposits are ordered according to their extraction costs. In formal terms, the cost of extracting the infinitesimally small unit of fuel in the x_i^{th} deposit is $C_i'(x_i)$. We denote country i's total endowment of deposits by $\left[0, \infty\right[_{C_i'}$ and the cost of extracting the deposits in some interval $[\underline{x}, \overline{x}]_{C_i'} \subset \left[0, \infty\right[_{C_i'}$ is $C_i(\overline{x}) - C_i(\underline{x})$. Country N is the owner of the deposits $\left[0, \infty\right[_{C_N'}$ and can extract the fuel stored in the deposits or can sell the deposits to the coalition.

3.1 The game

In the sequel we analyze the game. In Section 3-5 we assume that the coalition commits to its future policies.[4] At the beginning of period $t = 1$ the coalition and the non-signatory contract. They bargain over deposits purchased for preservation in some interval $[\underline{\xi}, \overline{\xi}]_{C_N'}$ and the deposit price p_z. In period $t = 1$ the coalition chooses its first- and second-period fuel demand and supply caps, and the first-period fuel market clears. In period $t = 2$ the second-period fuel market clears. The non-signatory is price taker in the fuel markets, whereas the coalition may either take prices as given or behave strategically in the fuel markets.[5] Fuel is internationally traded, and in each period $t = 1, 2$ the fuel market equilibrates at the fuel price p_t. The game is solved by backward induction.

Fuel market equilibria in the first and second period. To derive the first- and second-period fuel market equilibria we determine country N's first- and second-period fuel demand and supply. Country N's fuel demand follows from maximizing the intertemporal utility of its representative consumer

$$\begin{aligned} U_N &= B_{N1}(y_{N1}) - K(x_{N1}, \underline{\xi}, \overline{\xi}) - p_1(y_{N1} - x_{N1}) + p_z z \\ &\quad + \delta[B_{N2}(y_{N2}) - K(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi}) + K(x_{N1}, \underline{\xi}, \overline{\xi}) - p_2(y_{N2} - x_{N2})] \end{aligned} \tag{4}$$

with respect to y_{Nt} for $t = 1, 2$. In (4), $K(x_{N1}, \underline{\xi}, \overline{\xi})$ and $K(x_{N1}+x_{N2}, \underline{\xi}, \overline{\xi}) - K(x_{N1}, \underline{\xi}, \overline{\xi})$ are country N's extraction costs in period 1 and 2, respectively, after having sold the deposits $[\underline{\xi}, \overline{\xi}]_{C_N'}$ to country M, p_t is the fuel price in period $t = 1, 2$, $z := \overline{\xi} - \underline{\xi}$ is the number of sold deposits, and $p_z z$ is N's revenue from selling the deposits. The first-order conditions of

[4] The case that the coalition cannot commit to its future policies is discussed in Section 6.

[5] Strategic action of country N would not qualitatively change our results. For a further discussion of these assumptions we refer to Harstad (2012, p. 103 ff).

maximizing (4) yield $B'_{Nt}(y_{Nt}) = p_t$ and country N's fuel demand in period $t = 1, 2$ is[6]

$$y_{Nt} = B'^{-1}_{Nt}(p_t) =: D_t(p_t). \tag{5}$$

Next, we turn to country N's fuel supply. The sale of deposits $[\underline{\xi}, \overline{\xi}]_{C'_N}$ for preservation changed N's endowment of deposits such that N's initial marginal extraction cost function C'_N turned into the marginal extraction cost function K'. To avoid the corner solution $x_{N2} = 0$ we assume $x_{N1} < \underline{\xi}$ such that the first-period marginal extraction cost is not affected by the deposit transactions and $K'(x_{N1}, \underline{\xi}, \overline{\xi}) = C'_N(x_{N1})$ holds.[7] The overall marginal extraction cost function is given by

$$K'(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi}) := \begin{cases} C'_N(x_{N1} + x_{N2}) & \text{for} \quad x_{N1} + x_{N2} \leq \underline{\xi}, \\ C'_N(x_{N1} + x_{N2} + \overline{\xi} - \underline{\xi}) & \text{for} \quad x_{N1} + x_{N2} \geq \overline{\xi}. \end{cases} \tag{6}$$

Taking advantage of the marginal cost functions $C'_N(x_{N1})$ and $K'(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi})$, maximizing (4) with respect to x_{N1} and x_{N2} yields

$$\frac{\partial U_N}{\partial x_{N1}} = p_1 - (1 - \delta)C'_N(x_{N1}) - \delta K'(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi}) = 0, \tag{7}$$

$$\frac{\partial U_N}{\partial x_{N2}} = \delta \left[p_2 - K'(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi}) \right] = 0. \tag{8}$$

The first-order conditions (7) and (8) determine country N's first-period fuel supply[8]

$$x_{N1} = S_1 \left(\frac{p_1 - \delta p_2}{1 - \delta} \right) := C'^{-1}_N \left(\frac{p_1 - \delta p_2}{1 - \delta} \right), \tag{9}$$

and country N's total fuel supply

$$x_{N1} + x_{N2} = S(p_2, \underline{\xi}, \overline{\xi}) := \begin{cases} C'^{-1}_N(p_2) & \text{for} \quad p_2 \leq C'_N(\underline{\xi}), \\ \underline{\xi} & \text{for} \quad p_2 \in [C'_N(\underline{\xi}), C'_N(\overline{\xi})], \\ C'^{-1}_N(p_2) - \overline{\xi} + \underline{\xi} & \text{for} \quad p_2 \geq C'_N(\overline{\xi}). \end{cases} \tag{10}$$

Combining (7) and (8) we obtain the Hotelling rule for country N's optimal first- and second-period extraction. In the sequel we refer to $\frac{p_1 - \delta p_2}{1 - \delta}$ as Hotelling price.

Accounting for (5), (9) and (10) the fuel market clearing conditions in the first and second period, respectively, are

$$x_{M1} + S_1 \left(\frac{p_1 - \delta p_2}{1 - \delta} \right) = y_{M1} + D_1(p_1), \tag{11}$$

$$x_{M2} + S \left(p_2, \underline{\xi}, \overline{\xi} \right) - S_1 \left(\frac{p_1 - \delta p_2}{1 - \delta} \right) = y_{M2} + D_2(p_2). \tag{12}$$

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[6] B'^{-1}_{Nt} is the inverse of the marginal benefit function B'_{Nt}.

[7] The inefficiency of the deposit-purchase policy (see Propositions 1 and 2) is not affected by that assumption.

[8] C'^{-1}_N is the inverse of the marginal extraction function C'_N.

(11) and (12) determine the fuel prices p_1 and p_2 as functions of $y_{M1}, x_{M1}, y_{M2}, x_{M2}$, $\underline{\xi}$ and $\overline{\xi}$, formally

$$\begin{aligned} p_1 &= P^1(y_{M1}, x_{M1}, y_{M2}, x_{M2}, \underline{\xi}, \overline{\xi}), & (13) \\ p_2 &= P^2(y_{M1}, x_{M1}, y_{M2}, x_{M2}, \underline{\xi}, \overline{\xi}). & (14) \end{aligned}$$

The properties of (13) and (14) with respect to y_{M1}, x_{M1}, y_{M2} and x_{M2} are derived in the Appendix A1.

It remains to specify the coalition's choice of its first- and second-period fuel caps. The coalition maximizes with respect to $y_{M1}, x_{M1}, y_{M2}, x_{M2}$ its welfare

$$\begin{aligned} U_M &= B_{M1}(y_{M1}) - C_M(x_{M1}) - p_1(y_{M1} - x_{M1}) \\ &\quad + \delta[B_{M2}(y_{M2}) - C_M(x_{M1} + x_{M2}) + C_M(x_{M1}) - p_2(y_{M2} - x_{M2}) \\ &\quad - H\left[x_{M1} + S_1\left(\frac{p_1 - \delta p_2}{1-\delta}\right) + \psi\left(x_{M1} + x_{M2} + S(p_2, \underline{\xi}, \overline{\xi})\right)\right] \end{aligned} \tag{15}$$

subject to (13) and (14). The first-order conditions are

$$\begin{aligned} \frac{\partial U_M}{\partial y_{M1}} &= B'_{M1} - p_1 \\ &\quad - \left(I_1 + \frac{H'S'_1}{1-\delta}\right) P^1_{y_{M1}} - \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right] P^2_{y_{M1}} = 0, & (16a) \\ \frac{\partial U_M}{\partial x_{M1}} &= p_1 - (1-\delta)C'_M(x_{M1}) - \delta C'_M(x_{M1} + x_{M2}) - (1+\psi) H' \\ &\quad + \left(I_1 + \frac{H'S'_1}{1-\delta}\right) P^1_{x_{M1}} + \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right] P^2_{x_{M1}} = 0, & (16b) \\ \frac{\partial U_M}{\partial y_{M2}} &= \delta\left(B'_{M2} - p_2\right) \\ &\quad - \left(I_1 + \frac{H'S'_1}{1-\delta}\right) P^1_{y_{M2}} - \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right] P^2_{y_{M2}} = 0, & (16c) \\ \frac{\partial U_M}{\partial x_{M2}} &= \delta\left(p_2 - C'_M(x_{M1} + x_{M2}) - \frac{\psi}{\delta} H'\right) \\ &\quad + \left(I_1 + \frac{H'S'_1}{1-\delta}\right) P^1_{x_{M2}} + \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right] P^2_{x_{M2}} = 0, & (16d) \end{aligned}$$

where $I_t := y_{Mt} - x_{Mt}$, $P^t_{x_{Mt}} := \frac{\partial P^t}{\partial x_{Mt}}$, $P^t_{y_{Mt}} := \frac{\partial P^t}{\partial y_{Mt}}$ for $t = 1, 2$, $S'_1 := \frac{\partial S_1}{\partial\left(\frac{p_1 - \delta p_2}{1-\delta}\right)}$ and $S' := \frac{\partial S}{\partial p_2}$.

Deposit contract. Finally, we turn to the deposit contract. The coalition wants to buy deposits for preservation. The two groups negotiate over the number of deposits $z = \overline{\xi} - \underline{\xi}$

from the interval $[\underline{\xi}, \overline{\xi}]_{C'_N}$ and the deposit price p_z. The outcome of negotiations is efficient. That is, once an agreement is reached there is no room for re-negotiations such that both parties can be made better off. As is well known the efficient contract can be implemented by Nash bargaining.[9]

The coalition buys only deposits that country N would have extracted in the absence of deposit trading. The highest-cost deposit, $\overline{\xi}$, that country N would have exploited in the absence of deposit trade follows from maximizing country N's welfare

$$B_{N1}(y_{N1}) - C_N(x_{N1}) - p_1(y_{N1} - x_{N1}) + \delta[B_{N2}(y_{N2}) - C_N(\overline{\xi}) + C_N(x_{N1}) - p_2(y_{N2} - \overline{\xi} + x_{N1})]$$

with respect to $\overline{\xi}$. The associated first-order condition yields

$$C'_N(\overline{\xi}) = p_2 \quad \Longleftrightarrow \quad \overline{\xi} = C_N'^{-1}(p_2). \tag{17}$$

Without deposit trading country N extracts all profitable deposits from the interval $[0, \overline{\xi}]_{C'_N}$.

Allowing for deposit trade country N keeps extracting its low-cost deposits and sells only its highest-cost profitable deposits. Formally, with deposit trade its total fuel supply $x_{N1} + x_{N2}$ is given by

$$x_{N1} + x_{N2} = \overline{\xi} - z, \tag{18}$$

where z is the number of sold deposits. Denoting by p_z the deposit price, the welfare of country N and M, respectively, is

$$\begin{aligned} U_N &= B_{N1}(y_{N1}) - C_N(x_{N1}) - p_1(y_{N1} - x_{N1}) + p_z z \\ &\quad +\delta\left[B_{N2}(y_{N2}) - C_N(\overline{\xi} - z) + C_N(x_{N1}) - p_2(y_{N2} - \overline{\xi} + z + x_{N1})\right], \end{aligned} \tag{19}$$

$$\begin{aligned} U_M &= B_{M1}(y_{M1}) - C_M(x_{M1}) - p_1(y_{M1} - x_{M1}) - p_z z \\ &\quad +\delta\left[B_{M2}(y_{M2}) - C_M(x_{M1} + x_{M2}) - C_M(x_{M1}) - p_2(y_{M2} - x_{M2})\right] \\ &\quad -H\left[x_{M1} + S_1\left(\frac{p_1 - \delta p_2}{1 - \delta}\right) + \psi\left(x_{M1} + x_{M2} + \overline{\xi} - z\right)\right]. \end{aligned} \tag{20}$$

The coalition and the non-signatory simultaneously bargain over the number of deposits z and the price p_z. The Nash bargaining solves the following maximization problem

$$\max_{z, p_z} S := \left(U_M - U_M^o\right)^b \left(U_N - U_N^o\right)^{1-b} \tag{21}$$

[9] Harstad (2012) also considers efficient deposit trade but leaves the bargaining process unspecified. For the sake of more specific results we restrict our attention to the (cooperative) Nash bargaining.

subject to (19) and (20). In (21), $b \in [0, 1]$ represents the coalition's bargaining power, and U^o_M and U^o_N are the disagreement welfares of M and N, i.e. the welfare levels the countries achieve in the equilibrium without deposit trading. The first-order conditions of (21) yield[10]

$$\delta p_2 = \delta C'_N(\overline{\xi} - z) + \psi H'. \tag{22}$$

To sum up, the coalition purchases the number of deposits $z = \overline{\xi} - \underline{\xi}$ from the interval $[\underline{\xi}, \overline{\xi}]_{C'_N}$, where $\overline{\xi} = C'^{-1}_N(p_2)$ and $\underline{\xi} \equiv \overline{\xi} - z = C'^{-1}_N\left(p_2 - \frac{\psi H'}{\delta}\right)$. Inserting $\underline{\xi}$ and $\overline{\xi}$ in (13) and (14) determines the fuel prices, and solving (16) establishes the equilibrium of the game.

3.2 Allocative inefficiency

In this subsection we investigate whether the deposit-purchase policy implements the efficient allocation. Before we discuss the impact of strategic action in the fuel markets, we consider the special case of perfect competition, i.e. the coalition behaves as price taker, in the fuel markets. In formal terms, the absence of strategic action is readily established by $P^1_{y_{Mt}} = P^1_{x_{Mt}} = P^2_{y_{Mt}} = P^2_{x_{Mt}} \equiv 0$ for $t = 1, 2$ in (16). In view of (5), (7), (8), (16) and (22), the equilibrium of the game is characterized by

$$B'_{Mt}(y_{Mt}) = B'_{Nt}(y_{Nt}) \qquad t = 1, 2, \tag{23a}$$

$$\underbrace{B'_{M1}(y_{M1})}_{=p_1} = C'_M(x_{M1}) + \delta\left[C'_M(x_{M1} + x_{M2}) - C'_M(x_{M1})\right] + (1 + \psi)H', \tag{23b}$$

$$\underbrace{B'_{N1}(y_{N1})}_{=p_1} = C'_N(x_{N1}) + \delta\left[C'_N(x_{N1} + x_{N2}) - C'_N(x_{N1})\right] + \psi H', \tag{23c}$$

$$\underbrace{\delta B'_{M2}(y_{M2})}_{=\delta p_2} = \delta C'_M(x_{M1} + x_{M2}) + \psi H', \tag{23d}$$

$$\underbrace{\delta B'_{N2}(y_{N2})}_{=\delta p_2} = \delta C'_N(x_{N1} + x_{N2}) + \psi H'. \tag{23e}$$

Comparing (23a)-(23e) with the efficiency conditions (3a)-(3c) shows that the deposit-purchase policy leads to consumption efficiency and overall efficiency in both periods for the coalition. Whereas the deposit-purchase policy also attains overall efficiency for country N's second-period extraction ((3c) for $i = N$ is equal to (23e)), the allocation rule for country N's first-period extraction (23c) does not match with the efficient one ((3b) for $i = N$) and hence the overall efficiency of country N's first-period extraction is missed. To put it differently, the deposit purchases for preservation induce country N to account for the

[10] The derivation of (22) can be found in the Appendix A2.

coalition's climate damage when extracting in period 2. In contrast, the deposit purchases do not provide the appropriate incentives for country N's first-period extraction.

In the Appendix A3 we proof the differences between the efficient allocation, marked by an asterix *, and the (inefficient) equilibrium of the game with deposit-purchase policy, marked by a star *, and compare them in Table 1.

Table 1: Social optimum versus deposit-purchase policy (non-strategic action in the fuel markets)

$x^*_{M1} - x^\star_{M1}$	$x^*_{N1} - x^\star_{N1}$	$x^*_{N2} - x^\star_{N2}$	$y^*_{i1} - y^\star_{i1}$	$y^*_{i2} - y^\star_{i2}$	$H^* - H^\star$
> 0	< 0	> 0	< 0	> 0	< 0

The main difference between the efficient allocation and the allocation with deposit-purchase policy is that the first-period climate damage externality is internalized in the former case whereas it is non-internalized in the latter case. Table 1 reveals that in the transition from the deposit-purchase policy to the social optimum country N's first-period fuel extraction decreases ($x^*_{N1} < x^\star_{N1}$) and first-period total extraction reduces[11] ($x^*_{M1} + x^*_{N1} < x^\star_{M1} + x^\star_{N1}$) which internalizes the first-period climate damage externality. When moving from the deposit-purchase policy to the social optimum, country N expands its second-period fuel extraction ($x^*_{N2} > x^\star_{N2}$) and total second-period fuel extraction rises ($x^*_{M2} + x^*_{N2} > x^\star_{M2} + x^\star_{N2}$). Extraction is shifted from the first to the second period. In sum, the climate damage is increased ($H^* > H^\star$). At the deposit-purchase policy the coalition reduces first-period extraction ($x^\star_{M1} < x^*_{M1}$) to undertake part of (country N's) non-internalized first-period climate damage externality which results in inefficiently low first-period fuel extraction of the coalition. We summarize our results in

Proposition 1. *Suppose the coalition implements the climate policy of purchasing deposits for preservation and suppose the coalition takes the fuel prices as given. Then the equilibrium of the game is inefficient. The transition from the social optimum to the deposit-purchase policy increases first-period extraction, reduces second-period extraction and increases the climate damage.*

Next, the coalition acts strategically in the fuel markets and manipulates the fuel prices in its favor, formally $P^1_{y_{Mt}} = -P^1_{x_{Mt}} > 0$, $P^2_{y_{Mt}} = -P^2_{x_{Mt}} > 0$ for $t = 1, 2$ in (16). Then the

[11] $x^*_{M1} + x^*_{N1} < x^\star_{M1} + x^\star_{N1}$ follows from $y^*_{i1} < y^\star_{i1}$ for $i = M, N$.

equilibrium of the game is characterized by

$$B'_{M1}(y_{M1}) - \text{SE}_{B1} = \underbrace{B'_{N1}(y_{N1})}_{=p_1}, \tag{24a}$$

$$B'_{M2}(y_{M2}) - \frac{\text{SE}_{B2}}{\delta} = \underbrace{B'_{N2}(y_{N2})}_{=p_2}, \tag{24b}$$

$$B'_{M1}(y_{M1}) = C'_M(x_{M1}) + \delta\left[C'_M(x_{M1}+x_{M2}) - C'_M(x_{M1})\right] + (1+\psi)H', \tag{24c}$$

$$\underbrace{B'_{N1}(y_{N1})}_{=p_1} = C'_N(x_{N1}) + \delta\left[C'_N(x_{N1}+x_{N2}) - C'_N(x_{N1})\right] + \psi H', \tag{24d}$$

$$\delta B'_{M2}(y_{M2}) = \delta C'_M(x_{M1}+x_{M2}) + \psi H', \tag{24e}$$

$$\underbrace{\delta B'_{N2}(y_{N2})}_{=\delta p_2} = \delta C'_N(x_{N1}+x_{N2}) + \psi H', \tag{24f}$$

where

$$\text{SE}_{Bt} := \left(I_1 + \frac{H'S'_1}{1-\delta}\right)P^1_{y_{Mt}} + \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right]P^2_{y_{Mt}} \qquad t = 1, 2.$$

In addition to the inefficiency discussed at price-taking there are additional distortions stemming from the strategic effects SE_{B1} and SE_{B2}. Comparing (24a)-(24f) with (3a)-(3c) reveals that the coalition's strategic action destroys consumption efficiency in both periods which aggravates the prevailing inefficiency of the game. Hence, we get

Proposition 2. *Suppose the coalition implements the climate policy of purchasing deposits for preservation and suppose the coalition acts strategically in the fuel markets. Then the equilibrium of the game is inefficient.*

The performance of the deposit-purchase policy in the present two-period model is in stark contrast to its performance in a static (one-period) model. Whereas the deposit-purchase policy is able to achieve efficiency for a subset of economies in a static model (Eichner and Pethig 2017a, Proposition 2), the extension to two (or more) periods leaves the deposit-purchase policy inefficient. In a two-period model the deposit-purchase policy is inefficient due to a non-internalized first-period climate damage externality and due to (possibly prevailing) strategic effects.

4 Deposit-lease policy

In this section, we extend country M's deposit policy. In particular, the coalition and the non-signatory still bargain over purchased deposits, which are then permanently preserved from extraction, but they also bargain over leased deposits in some interval $[\underline{\xi}_1, \overline{\xi}_1]_{C'_N}$ and the leased deposits' price p_{z1}. These deposits are preserved in period 1 and can be extracted by the non-signatory in period 2. We denote the number of leased deposits by $z_1 := \overline{\xi}_1 - \underline{\xi}_1$, and refer to the deposit policy of the present section as *deposit-lease policy.*[12]

4.1 The game

Fuel market equilibria in the first and second period. With the possibility of leasing deposits and assuming $x_{N1} < \underline{\xi}$, (4) becomes

$$\begin{aligned} U_N &= B_{N1}(y_{N1}) - K(x_{N1}, \underline{\xi}_1, \overline{\xi}_1) - p_1(y_{N1} - x_{N1}) + p_{z1}z_1 + p_z z \\ &\quad + \delta[B_{N2}(y_{N2}) - K(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi}) + K(x_{N1}, \underline{\xi}_1, \overline{\xi}_1) - p_2(y_{N2} - x_{N2})], \end{aligned} \quad (25)$$

where $K(x_{N1}, \underline{\xi}_1, \overline{\xi}_1)$ and $K(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi}) - K_N(x_{N1}, \underline{\xi}_1, \overline{\xi}_1)$ are country N's extraction costs in period 1 and 2 after having leased and sold the deposits $[\underline{\xi}_1, \overline{\xi}_1]_{C'_N}$ and $[\underline{\xi}, \overline{\xi}]_{C'_N}$ to country M, respectively, and $p_{z1}z_1$ is N's revenue from leasing the deposits. Maximizing (25) with respect to y_{N1} and y_{N2} yields country N's fuel demand (5).

Turning to country N's fuel supply, leasing deposits $[\underline{\xi}_1, \overline{\xi}_1]_{C'_N}$ for temporal preservation does not change N's total endowment of deposits, because these deposits are returned to N in period 2. Thus, neither the total marginal cost function $K'(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi})$ nor the total fossil fuel supply function $S(p_2, \underline{\xi}, \overline{\xi})$ are affected by the extension of country M's deposit policy. However, the lease of deposits does change N's first-period endowment of deposits such that N's first-period marginal cost function is given by

$$K'(x_{N1}, \underline{\xi}_1, \overline{\xi}_1) := \begin{cases} C'_N(x_{N1}) & \text{for} \quad x_{N1} \leq \underline{\xi}_1, \\ C'_N(x_{N1} + \overline{\xi}_1 - \underline{\xi}_1) & \text{for} \quad x_{N1} \geq \underline{\xi}_1. \end{cases} \quad (26)$$

Figure 1 illustrates the marginal cost functions $C'_N(x_{N1})$, $K'(x_{N1}, \underline{\xi}_1, \overline{\xi}_1)$, $C'_N(x_{N1} + x_{N2})$ and $K(x_{N1} + x_{N2}, \underline{\xi}, \overline{\xi})$. The straight line $0C$ represents the graph of $C'_N(x_{N1})$ and $C'_N(x_{N1} + x_{N2})$. After having leased the deposits $[\underline{\xi}_1, \overline{\xi}_1]_{C'_N}$ and sold the deposits $[\underline{\xi}, \overline{\xi}]_{C'_N}$, country N's first-period marginal cost function $K'(x_{N1})$ is captured by the line $0ADE$. Since the leased deposit are given back to N in the second period, its total marginal cost function $K'(x_{N1} + x_{N2})$ is represented by the graph $0BFG$. The marginal cost function $K'(x_{N1})$ $[K'(x_{N1} + x_{N2})]$ is discontinuous at $x_{N1} = \underline{\xi}_1$ $[x_{N1} + x_{N2} = \underline{\xi}]$.

[12]Since our model ends after the second period, the deposit purchases for preservation can also be interpreted as deposit leasing in the second period.

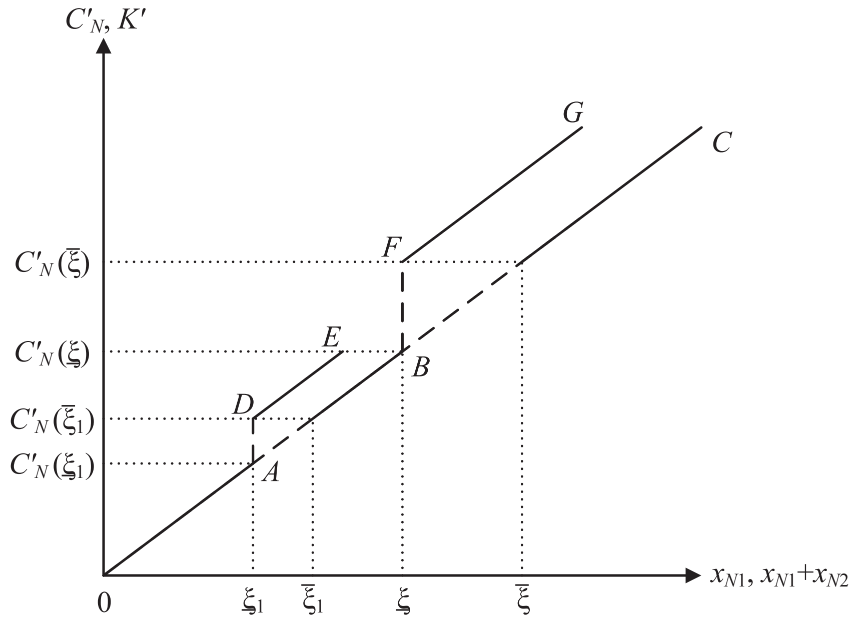

Figure 1: Marginal cost curves of country N before and after deposit transactions

Making use of the marginal cost functions (6) and (26), and maximizing the welfare (25) with respect to x_{N1} and x_{N2} yields N's first-period fuel supply

$$x_{N1} = S_1\left(\frac{p_1 - \delta p_2}{1-\delta}, \underline{\xi}_1, \overline{\xi}_1\right) := \begin{cases} C_N'^{-1}\left(\frac{p_1-\delta p_2}{1-\delta}\right) & \text{for } \frac{p_1-\delta p_2}{1-\delta} \leq C_N'(\underline{\xi}_1), \\ \underline{\xi}_1 & \text{for } \frac{p_1-\delta p_2}{1-\delta} \in [C_N'(\underline{\xi}_1), C_N'(\overline{\xi}_1)], \\ C_N'^{-1}\left(\frac{p_1-\delta p_2}{1-\delta}\right) - \overline{\xi}_1 + \underline{\xi}_1 & \text{for } \frac{p_1-\delta p_2}{1-\delta} \geq C_N'(\overline{\xi}_1). \end{cases} \quad (27)$$

From (5), (10) and (27) the fuel market equilibria are given by

$$x_{M1} + S_1\left(\frac{p_1 - \delta p_2}{1-\delta}, \underline{\xi}_1, \overline{\xi}_1\right) = y_{M1} + D_1(p_1), \quad (28)$$

$$x_{M2} + S\left(p_2, \underline{\xi}, \overline{\xi}\right) - S_1\left(\frac{p_1 - \delta p_2}{1-\delta}, \underline{\xi}_1, \overline{\xi}_1\right) = y_{M2} + D_2(p_2). \quad (29)$$

(28) and (29) determine the fuel prices p_1 and p_2 as functions of $y_{M1}, x_{M1}, y_{M2}, x_{M2}, \underline{\xi}_1, \overline{\xi}_1, \underline{\xi}$ and $\overline{\xi}$, formally[13]

$$p_1 = P^1(y_{M1}, x_{M1}, y_{M2}, x_{M2}, \underline{\xi}_1, \overline{\xi}_1, \underline{\xi}, \overline{\xi}), \quad (30)$$

$$p_2 = P^2(y_{M1}, x_{M1}, y_{M2}, x_{M2}, \underline{\xi}_1, \overline{\xi}_1, \underline{\xi}, \overline{\xi}). \quad (31)$$

[13]The properties of (30) and (31) with respect to I_1 and I_2 are equivalent to those of (13) and (14).

The coalition's fuel caps $y_{M1}, x_{M1}, y_{M2}, x_{M2}$ follow from maximizing its welfare

$$\begin{aligned} U_M &= B_{M1}(y_{M1}) - C_M(x_{M1}) - p_1(y_{M1} - x_{M1}) - p_{z1}z_1 - p_z z \\ &\quad +\delta[B_{M2}(y_{M2}) - C_M(x_{M1} + x_{M2}) + C_M(x_{M1}) - p_2(y_{M2} - x_{M2})] \\ &\quad -H\left[x_{M1} + S_1\left(\frac{p_1 - \delta p_2}{1-\delta}, \underline{\xi}_1, \overline{\xi}_1\right) + \psi\left(x_{M1} + x_{M2} + S\left(p_2, \underline{\xi}, \overline{\xi}\right)\right)\right] \end{aligned} \tag{32}$$

subject to (30) and (31). The resulting first-order conditions are

$$\frac{\partial U_M}{\partial y_{M1}} = B'_{M1} - p_1 - \mathrm{SE}_{L1} = 0, \tag{33a}$$

$$\frac{\partial U_M}{\partial x_{M1}} = p_1 - (1-\delta)C'_M(x_{M1}) - \delta C'_M(x_{M1} + x_{M2}) - (1+\psi)\, H' + \mathrm{SE}_{L1} = 0, \tag{33b}$$

$$\frac{\partial U_M}{\partial y_{M2}} = \delta\left(B'_{M2} - p_2\right) - \mathrm{SE}_{L2} = 0, \tag{33c}$$

$$\frac{\partial U_M}{\partial x_{M2}} = \delta\left(p_2 - C'_M(x_{M1} + x_{M2}) - \frac{\psi}{\delta}H'\right) + \mathrm{SE}_{L2} = 0, \tag{33d}$$

where

$$\mathrm{SE}_{Lt} := \left(I_1 + \frac{H'S'_1}{1-\delta}\right) P^1_{y_{Mt}} + \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right] P^2_{y_{Mt}} \qquad t = 1, 2.$$

Deposit contract. The deposit transactions now consist of the number of leased deposits, z_1, and the number of purchased deposits for preservation, z. The negotiated deposit prices are p_{z1} and p_z. Again, the bargaining problem is solved by applying the Nash solution.

To determine the deposit transactions z_1 and z, we need to know how much country N would extract in period 1 and 2, if there were no deposit trade. N's fuel extraction in the absence of deposit trading $\overline{\xi}_1$ and $\overline{\xi} - \overline{\xi}_1$, respectively, follows from maximizing

$$B_{N1}(y_{N1}) - C_N(\overline{\xi}_1) - p_1(y_{N1} - \overline{\xi}_1) + \delta\left[B_{N2}(y_{N2}) - C_N(\overline{\xi}) + C_N(\overline{\xi}_1) - p_2(y_{N2} - \overline{\xi} + \overline{\xi}_1)\right] \tag{34}$$

with respect to $\overline{\xi}_1$ and $\overline{\xi}$. The first-order conditions yield

$$C'_N(\overline{\xi}_1) = \frac{p_1 - \delta p_2}{1-\delta} \quad \Longleftrightarrow \quad \overline{\xi}_1 = C'^{-1}_N\left(\frac{p_1 - \delta p_2}{1-\delta}\right), \tag{35}$$

$$C'_N(\overline{\xi}) = p_2 \quad \Longleftrightarrow \quad \overline{\xi} = C'^{-1}_N(p_2). \tag{36}$$

The welfare levels U^o_M and U^o_N that M and N achieve in the game without deposit transactions serve as disagreement point of the Nash bargaining game.

With deposit trading country N keeps extracting its low-cost deposits in each period, leases the highest-cost deposits that would otherwise have been extracted in period 1 and sells the highest-cost deposits that would otherwise have been extracted in period 2, formally

$$\begin{aligned} x_{N1} &= \overline{\xi}_1 - z_1, && (37) \\ x_{N1} + x_{N2} &= \overline{\xi} - z. && (38) \end{aligned}$$

The welfare of N and M is then given by

$$\begin{aligned} U_N &= B_{N1}(y_{N1}) - C_N(\overline{\xi}_1 - z_1) - p_1(y_{N1} - \overline{\xi}_1 + z_1) + p_{z1}z_1 + p_z z \\ &\quad +\delta \left[B_{N2}(y_{N2}) - C_N(\overline{\xi} - z) + C_N(\overline{\xi}_1 - z_1) - p_2(y_{N2} - \overline{\xi} + z + \overline{\xi}_1 - z_1)\right], && (39) \\ U_M &= B_{M1}(y_{M1}) - C_M(x_{M1}) - p_1(y_{M1} - x_{M1}) - p_{z1}z_1 - p_z z \\ &\quad +\delta \left[B_{M2}(y_{M2}) - C_M(x_{M1} + x_{M2}) + C_M(x_{M1}) - p_2(y_{M2} - x_{M2})\right] \\ &\quad -H \left[x_{M1} + \overline{\xi}_1 - z_1 + \psi \left(x_{M1} + x_{M2} + \overline{\xi} - z\right)\right]. && (40) \end{aligned}$$

The deposit contract negotiated by the Nash bargaining solution follows from

$$\max_{z, p_z, z_1, p_{z1}} \quad S := (U_M - U_M^o)^b \, (U_N - U_N^o)^{1-b} \qquad (41)$$

subject to (39) and (40). In the Appendix A4 we show that the first-order conditions imply

$$\begin{aligned} \delta p_2 &= \delta C_N'(\overline{\xi} - z) + \psi H', && (42) \\ p_1 - \delta p_2 &= (1-\delta)C_N'(\overline{\xi}_1 - z_1) + H'. && (43) \end{aligned}$$

The coalition leases the number of deposits $z_1 = \overline{\xi}_1 - \underline{\xi}_1$ from the interval $[\underline{\xi}_1, \overline{\xi}_1]_{C_N'}$, where $\overline{\xi}_1 = C_N'^{-1}\left(\frac{p_1 - \delta p_2}{1-\delta}\right)$ and $\underline{\xi}_1 = C_N'^{-1}\left(\frac{p_1 - \delta p_2 - H'}{1-\delta}\right)$, and purchases the number of deposits $z = \overline{\xi} - \underline{\xi}$ from the interval $[\underline{\xi}, \overline{\xi}]_{C_N'}$, where $\overline{\xi} = C_N'^{-1}(p_2)$ and $\underline{\xi} = C_N'^{-1}\left(p_2 - \frac{\psi H'}{\delta}\right)$. Accounting for $\underline{\xi}_1$, $\overline{\xi}_1$, $\underline{\xi}$ and $\overline{\xi}$ in (30) and (31) determines the fuel prices p_1 and p_2, and solving (33) establishes the equilibrium of the game.

4.2 Allocative (in)efficiency

In this subsection, we wish to answer the question whether the deposit-lease policy leads to efficient equilibria. Again, we begin with assuming that the coalition behaves as price taker in the fuel markets. Making use of $\mathrm{SE}_{L1} = \mathrm{SE}_{L2} \equiv 0$, (42) and (43) in (5) and (33), the equilibrium of the game is characterized by

$$\begin{aligned} B_{Mt}'(y_{Mt}) &= B_{Nt}'(y_{Nt}) \quad t = 1, 2, && (44a) \\ B_{i1}'(y_{i1}) &= C_i'(x_{i1}) + \delta\left[C_i'(x_{i1} + x_{i2}) - C_i'(x_{i1})\right] + (1+\psi)H' \quad i = M, N, && (44b) \\ \delta B_{i2}'(y_{i2}) &= \delta C_i'(x_{i1} + x_{i2}) + \psi H' \quad i = M, N. && (44c) \end{aligned}$$

(44a)-(44c) are equivalent to the efficiency conditions (3a)-(3c). The deposit-lease policy enables the coalition to internalizes the climate damage externalities of country N's fuel extraction. The deposit contract is designed such that country N accounts for the climate damage its first-period and second-period extraction imposes on the coalition. Thus, we conclude

Proposition 3. *Suppose the coalition implements the climate policy of leasing deposits for preservation and suppose the coalition takes the fuel prices as given. Then the equilibrium of the game is efficient.*

If the coalition acts strategically in the fuel markets, the equilibrium of the game is characterized by

$$B'_{M1}(y_{M1}) - \mathrm{SE}_{L1} = B'_{N1}(y_{N1}), \tag{45a}$$
$$B'_{M2}(y_{M2}) - \frac{\mathrm{SE}_{L2}}{\delta} = B'_{N1}(y_{N1}), \tag{45b}$$
$$B'_{i1}(y_{i1}) = C'_i(x_{i1}) + \delta\left[C'_i(x_{i1}+x_{i2}) - C'_i(x_{i1})\right] + (1+\psi)H' \quad i = M, N, \tag{45c}$$
$$\delta B'_{i2}(y_{i2}) = \delta C'_i(x_{i1}+x_{i2}) + \psi H' \quad i = M, N. \tag{45d}$$

In contrast to (24a)-(24f) that violate overall efficiency for country N in case of the deposit-purchase policy, the possibility of leasing deposits leads to overall efficiency for both countries. However, consumption efficiency may be destroyed depending on whether the coalition may improve or not by strategic action. Defining[14]

$$\mathcal{E} := \left\{ \text{Economies } E \,\middle|\, E \text{ possesses an allocation } (x^*_{Mt}, x^*_{Nt}, y^*_{Mt}, y^*_{Nt}) \text{ for } t = 1,2 \text{ satisfying (3)} \right\},$$
$$\mathcal{E}_O := \left\{ E \in \mathcal{E} \,\middle|\, E \text{ satisfies } 0 \geq I^*_1 \geq \underline{I}^*_1 \wedge \overline{I}^*_2 \geq I^*_2 \geq -\frac{H'^* S'^*}{\delta/\psi} \right\},$$

we prove in the Appendix A5

Proposition 4. *Suppose the coalition implements the climate policy of leasing and purchasing deposits for preservation and suppose the coalition acts strategically in the fuel markets. Then the equilibrium of the game is efficient if and only if $E \in \mathcal{E}_O$.*

To grasp an intuition for Proposition 4 we analyze how the coalition's welfare changes when starting from price taking in the fuel markets, which is tantamount to the efficient allocation

[14] The definition of $\underline{I}^*_1$ and $\overline{I}^*_2$ is given in the Appendix A5.

according to Proposition 3, the fuel caps x_{M1} and x_{M2} are marginally decreased or increased

$$\begin{aligned}
\mathrm{d}U_M &= \frac{\partial U_M}{\partial x_{M1}}\mathrm{d}x_{M1} \\
&= -\left[I_1^* P^1_{x_{M1}} + I_2^*\delta P^2_{x_{M1}} + \frac{H'^* S_1'^*}{1-\delta}\left(P^1_{x_{M1}} - \delta P^2_{x_{M1}}\right) + \psi H'^* S'^* P^2_{x_{M1}}\right]\mathrm{d}x_{M1} \\
&= \underbrace{-\left(I_1^* P^1_{x_{M1}} + I_2^*\delta P^2_{x_{M1}}\right)\mathrm{d}x_{M1}}_{\mathrm{d}w_{F1}} \underbrace{-\left[\frac{H'^* S_1'^*}{1-\delta}\left(P^1_{x_{M1}} - \delta P^2_{x_{M1}}\right) + \psi H'^* S'^* P^2_{x_{M1}}\right]\mathrm{d}x_{M1}}_{\mathrm{d}w_{H1}}, \qquad (46a)
\end{aligned}$$

$$\begin{aligned}
\mathrm{d}U_M &= \frac{\partial U_M}{\partial x_{M2}}\mathrm{d}x_{M2} \\
&= -\left[I_1^* P^1_{x_{M2}} + I_2^*\delta P^2_{x_{M2}} + \frac{H'^* S_1'^*}{1-\delta}\left(P^1_{x_{M2}} - \delta P^2_{x_{M2}}\right) + \psi H'^* S'^* P^2_{x_{M2}}\right]\mathrm{d}x_{M2} \\
&= \underbrace{-\left(I_1^* P^1_{x_{M2}} + I_2^*\delta P^2_{x_{M2}}\right)\mathrm{d}x_{M2}}_{\mathrm{d}w_{F2}} \underbrace{-\left[\frac{H'^* S_1'^*}{1-\delta}\left(P^1_{x_{M2}} - \delta P^2_{x_{M2}}\right) + \psi H'^* S'^* P^2_{x_{M2}}\right]\mathrm{d}x_{M2}}_{\mathrm{d}w_{H2}}. \qquad (46b)
\end{aligned}$$

The comparative static effects of $\mathrm{d}x_{M1}$ and $\mathrm{d}x_{M2}$ result in welfare changes that trace back to changes of export revenues or import payments in both periods. $\mathrm{d}w_{Ft}$ captures this *terms of trade effect* of $\mathrm{d}x_{Mt}$. In addition, there is a welfare effect that goes back to changes of the climate damage. $\mathrm{d}w_{Ht}$ represents the *climate damage effect* of $\mathrm{d}x_{Mt}$.

We study the welfare changes exemplarily for a coalition that exports fuel in both periods ($I_1^* < 0$ and $I_2^* < 0$). Note that at the social optimum the points D and F in Figure 1 are country N's marginal extraction costs of the efficient fuel quantities x^*_{N1} and $x^*_{N1}+x^*_{N2}$, respectively. We begin with checking whether $\mathrm{d}x_{M1} > 0$ increases welfare. Increasing x_{M1} reduces the first-period fuel price ($P^1_{x_{M1}} < 0$) and hence N moves from point D in direction to point A in Figure 1. As a consequence, country N's first-period fuel supply, total fuel supply and the second-period fuel price do not change ($S_1'^* = S'^* = P^2_{x_{M1}} = 0$). Making use of this information in (46a) the terms of trade effect is negative ($\mathrm{d}w_{F1} < 0$) and the climate damage effect vanishes ($\mathrm{d}w_{H1} = 0$) such that total welfare decreases and a strategic increase of x_{M1} does not pay.

Next, consider the welfare effects of $\mathrm{d}x_{M1} < 0$. In that case the first-period fuel price, the second-period fuel price and the Hotelling price $\frac{p_1-\delta p_2}{1-\delta}$ increase ($P^1_{x_{M1}}\mathrm{d}x_{M1} > 0, P^2_{x_{M1}}\mathrm{d}x_{M1} > 0$ and $\frac{1}{1-\delta}(P^1_{x_{M1}} - \delta P^2_{x_{M1}})\mathrm{d}x_{M1} > 0$) and country N moves from point D to point E in period 1 and from point F to point G in period 2 (see Figure 1). The price increases induce country N to expand its first-period fuel supply and total fuel supply ($S_1'^* > 0, S'^* > 0$). In view of (46a) the terms of trade effect is positive $\mathrm{d}w_{F1} > 0$ and the climate damage effect is negative. Reducing x_{M1} is advantageous and hence strategic action pays for the coalition if the positive terms of trade effect overcompensates the negative climate damage effect.

It remains to investigate the welfare effects of changing the coalition's second-period fuel cap. $\mathrm{d}x_{M2} < 0$ increases the second-period fuel price p_2 and does not affect the first-period fuel price, which induces country N to leave its first-period fuel supply unaltered ($S_1' = 0$, remaining at point D) and to expand its total fuel supply ($S' > 0$, movement from point F to point G). Here, we get a positive terms of trade effect and a negative climate damage effect. Strategic action does not pay if the negative climate damage effect overcompensates the positive terms of trade effect. For $\mathrm{d}x_{M2} > 0$ prices in both periods decline, such that export revenues decline and $dw_{F2} < 0$ (movements from point D to point A and from point F to point B). Furthermore, the Hotelling price increases such that extraction is shifted from the second to the first period, which implies $dw_{H2} < 0$. Thus, a strategic increase of x_{M2} does not pay. A rigorous analysis of all cases can be found in the proof of Proposition 4 in the Appendix A5.

Two remarks are in order with respect to Proposition 4. First, if countries are identical which implies no exports and imports, then the equilibrium is efficient, i.e. $I_1^* = I_2^*$ constitutes an economy $E \in \mathcal{E}_O$. Second, the deposit-lease policy does not always implement the efficient allocation. In all feasible economies $E \notin \mathcal{E}_O$ strategic action pays and the equilibrium of the game is inefficient.

5 Deposit-lease versus deposit-purchase policy

In the previous sections we pointed out that the deposit-purchase policy cannot implement the efficient allocation, whereas the deposit-lease policy implements the efficient allocation if the coalition takes the fuel prices as given and *can* implement the efficient allocation if the coalition acts strategically in the fuel markets. In our view the most interesting and most relevant comparison, which is conducted in the present section, is between the deposit-purchase and deposit-lease policy when the coalition behaves strategically in the fuel markets, strategic action pays, and both policies result in inefficient outcomes.

For the sake of specific results, we turn to the parametric functions

$$B_{it}(y_{it}) = \alpha y_{it} - \frac{b}{2} y_{it}^2,\ C_i(x_i) = \frac{c_i}{2} x_i^2,\ H\left(x_1 + \psi x\right) = h\left(x_1 + \psi x\right) \tag{47}$$

for $i = M, N$, $t = 1, 2$, where α, b, c_M, c_N, h are positive parameters and where $x_t := x_{Mt} + x_{Nt}$

is total extraction in period $t = 1, 2$ and $x := x_1 + x_2$ is total extraction in both periods. For the parametric functions we define the sets[15]

$$\mathcal{M}_L := \left\{ (\alpha, b, c_M, c_N, h, \delta, \psi) \middle| \langle c_M = c_N \rangle \vee \langle c_N > c_M \wedge h > \underline{h}_L \rangle \right\}, \tag{48}$$

$$\mathcal{M}_B := \left\{ (\alpha, b, c_M, c_N, h, \delta, \psi) \middle| c_N > c_M \wedge \overline{h}_B > h > \underline{h}_B \right\} \tag{49}$$

and denote the set of feasible parameters by $\mathcal{M}$. At the deposit-lease policy the set $\mathcal{M}_L$ is the parametric version of the set $\mathcal{E}_O$ introduced before Proposition 4. Strategic action in the fuel market pays for the coalition if and only if $E \in \mathcal{M} \setminus \mathcal{M}_L$. At the deposit-purchase policy the coalition manipulates the fuel prices if and only $E \in \mathcal{M} \setminus \mathcal{M}_B$. The (inefficient) equilibrium of the game with deposit-lease [-purchase] policy is indicated by a hat [tilde]. In the Appendix B we calculate the equilibrium allocation of both games and compare them in Table 2.

Table 2: Deposit-lease versus deposit-purchase policy (strategic action in the fuel market)

$\hat{x}_{M1} - \tilde{x}_{M1}$	$\hat{x}_{N1} - \tilde{x}_{N1}$	$\hat{y}_{i1} - \tilde{y}_{i1}$	$\hat{x}_{M2} - \tilde{x}_{M2}$	$\hat{x}_{N2} - \tilde{x}_{N2}$	$\hat{y}_{i2} - \tilde{y}_{i2}$	$\hat{x}_i - \tilde{x}_i$	$\hat{y}_i - \tilde{y}_i$
> 0	< 0	< 0	< 0	> 0	> 0	< 0	< 0

At the deposit-purchase policy the first-period climate damage externality remains non-internalized and there are additional distortions stemming from strategic action. As the third table of Table 2 shows when moving from the deposit-purchase policy to the deposit-lease policy fuel extraction is postponed from the first period to the second period and the climate damage is reduced.[16] This effects harks back to the internalization of the climate damage externality. The strategic effects destroy consumption efficiency since at both policies the coalition aims to manipulate the fuel prices in its favor. In the transition from the deposit-purchase policy to the deposit-lease policy the climate welfare (which equals the negative climate damage) raises, which ceteris paribus increases total welfare. Consumption welfare also changes.

If the coalition imports fuel ($c_M > c_N$) it aims to reduce the fuel price.[17] The transition from the deposit-purchase policy to the deposit-lease policy reduces total consumption welfare. The reason lies in the vertical segment AD of N's marginal cost curve which corresponds to a vertical segment of N's first-period fuel supply at the deposit-lease policy. At

[15] $\mathcal{M}_L$ and $\mathcal{M}_B$ are derived, and $\underline{h}_L$, $\overline{h}_B$ and $\underline{h}_B$ are defined in the Appendix B.

[16] $\widehat{H} < \widetilde{H}$ follows from $\hat{y}_{i1} < \tilde{y}_{i1}$ and $\hat{y}_i < \tilde{y}_i$ for $i = M, N$.

[17] Since $c_M > c_N$ is empirically relevant, we refrain from investigating $c_M \leq c_N$

that segment N's supply is price-inelastic and the coalition ceteris paribus achieves large price reductions without changing the total extraction. At the deposit-lease policy the coalition's strategic incentives (at the margin) are much stronger than at the deposit-purchase policy. Stronger incentives result in larger (consumption) distortions and hence the consumption welfare is smaller at the deposit-lease policy than at the deposit-purchase policy. The change of total welfare consists of two countervailing effects - the total consumption welfare declines and the climate welfare increases. If the difference of strategic benefits is small [large] and the gain of climate welfare at the deposit-lease policy is large [small] then the total welfare increases [decreases] when moving from the deposit-purchase policy to the deposit-lease policy. If the gain of climate welfare is sufficiently large, i.e. the climate damage is sufficiently high, then the deposit-lease policy becomes welfare-superior.

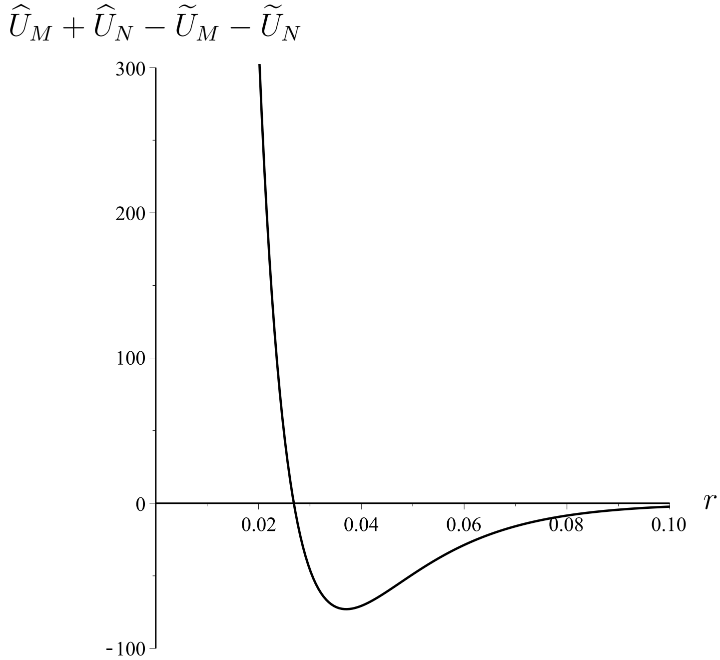

Figure 2: Welfare difference between deposit-lease policy and deposit-purchase policy ($\$b$).

To finally clarify the welfare changes in the transition from the deposit-purchase policy to the deposit-lease policy we have empirically calibrated the model. Period 1 lasts from 2011 to 2050 and period 2 from 2051 to 2090. The climate coalition comprises the OECD countries and country N consists of the non-OECD countries. The model is calibrated to an economy without any policies to real world oil quantities and production costs with data from IEA (2013) and EIA (2017, 2018). The discount rate ranges from $r = 2.5\%$ to $r = 5\%$. Delegating the technical details to the Appendix C, the main result is highlighted in Figure 2 that illustrates the welfare difference when moving from the deposit-lease policy to the deposit purchase policy. The total welfare increases in the transition from the deposit-purchase policy to the deposit-lease policy for discount rates smaller than $r = 2.7\%$. To get an intuition for that result, recall that consumption (climate) welfare declines (increases) in the transition from the deposit-purchase policy to the deposit-lease policy, and that the deposit-lease policy is advantageous if the climate damage is sufficiently high. As the Appendix C reveals, the marginal climate damage h is large at small discount rates, and hence the loss of consumption welfare is overcompensated by the gain in climate welfare when moving from the deposit-purchase to the deposit-lease policy. The marginal climate damage decreases in the discount rate which explains why the deposit-purchase policy becomes favorable for higher discount rates.

Moreover, the Appendix C shows that the transition from the deposit-purchase policy to the deposit-lease policy increases the coalition's welfare whenever total welfare rises. We summarize our results in

Proposition 5 . *Suppose the coalition acts strategically in the fuel markets and strategic action pays ($E \in (\mathcal{M} \setminus \mathcal{M}_L) \cap (\mathcal{M} \setminus \mathcal{M}_B)$).*

(i) In the parametric model the transition from the deposit-purchase policy to the deposit-lease policy reduces first-period extraction, increases second-period extraction, reduces total extraction and reduces the climate damage.

(ii) In the calibrated model the transition from the deposit-purchase policy to the deposit-lease policy increases the coalition's welfare and total welfare if and only if the discount rate r is smaller than 2.7%.

6 Time consistent second-period fuel caps

So far we assumed that the coalition can commit to its future policies. Now we dispense with that assumption. If the coalition cannot commit, the second-period fuel caps of Sections 3-5 are time inconsistent. To derive time consistent policies we modify the timing of the game as follows: At the beginning of period $t = 1$ the coalition and the non-signatory negotiate over deposits. Next, in period $t = 1$ the coalition and the non-signatory choose their first-period fuel demand and supply, and then the first-period fuel market clears. In period $t = 2$ the groups M and N choose their second-period fuel demand and supply, and the second-period fuel market clears. We go quickly through the game by backward induction.

In the second period the coalition maximizes with respect to y_{M2}, x_{M2} its welfare

$$\begin{aligned}U_M &= B_{M1}(y_{M1}) - C_M(x_{M1}) - p_1(y_{M1} - x_{M1}) \\ &\quad +\delta[B_{M2}(y_{M2}) - C_M(x_{M1} + x_{M2}) + C_M(x_{M1}) - p_2(y_{M2} - x_{M2})] \\ &\quad -H\left[x_{M1} + x_{N1} + \psi\left(x_{M1} + x_{M2} + S(p_2, \cdot)\right)\right] \qquad (50)\end{aligned}$$

subject to the price function $p_2 = \tilde{P}^2(x_{M2}, y_{M2}, x_{N1})$, which follows from the second-period fuel equilibrium condition (12).[18] The first-order conditions are

$$\frac{\partial U_M}{\partial y_{M2}} = \delta\left(B'_{M2} - p_2\right) - \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta}\right)\right]\tilde{P}^2_{y_{M2}} = 0, \qquad (51a)$$

$$\frac{\partial U_M}{\partial x_{M2}} = \delta\left(p_2 - C'_M(x_{M1} + x_{M2}) - \frac{\psi}{\delta}H'\right) - \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta}\right)\right]\tilde{P}^2_{x_{M2}} = 0. \qquad (51b)$$

In the first period the coalition maximizes with respect to x_{M1} and y_{M1} its welfare

$$\begin{aligned}U_M &= B_{M1}(y_{M1}) - C_M(x_{M1}) - p_1(y_{M1} - x_{M1}) \\ &\quad +\delta[B_{M2}(y_{M2}) - C_M(x_{M1} + x_{M2}) + C_M(x_{M1}) - p_2(y_{M2} - x_{M2}) \\ &\quad -H\left[x_{M1} + S_1\left(\frac{p_1 - \delta p_2}{1-\delta}, \cdot\right) + \psi\left(x_{M1} + x_{M2} + S(p_2, \cdot)\right)\right] \qquad (52)\end{aligned}$$

subject to $p_1 = P^1(x_{M1}, y_{M1})$, $p_2 = P^2(x_{M1}, y_{M1})$, $x_{M2} = X^{M2}(x_{M1}, y_{M1})$ and $y_{M2} = Y^{M2}(x_{M1}, y_{M1})$, which follow from $x_{N1} = S_1\left(\frac{p_1-\delta p_2}{1-\delta}, \cdot\right)$, the fuel equilibrium conditions (11) and (12), and the first-order conditions (51a) and (51b).[19] The first-order conditions are

$$\begin{aligned}\frac{\partial U_M}{\partial y_{M1}} &= B'_{M1} - p_1 - \left(I_1 + \frac{H'S'_1}{1-\delta}\right)P^1_{y_{M1}} - \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right]P^2_{y_{M1}} \\ &\quad +\delta\left(B'_{M2} - p_2\right)Y^{M2}_{y_{M1}} + \delta\left(p_2 - C'_M(x_{M1} + x_{M2}) - \frac{\psi}{\delta}H'\right)X^{M2}_{y_{M1}} = 0, \qquad (53a)\\ \frac{\partial U_M}{\partial x_{M1}} &= p_1 - (1-\delta)C'_M(x_{M1}) - \delta C'_M(x_{M1} + x_{M2}) - (1+\psi)H' \\ &\quad -\left(I_1 + \frac{H'S'_1}{1-\delta}\right)P^1_{x_{M1}} - \delta\left[I_2 + H'\left(\frac{\psi S'}{\delta} - \frac{S'_1}{1-\delta}\right)\right]P^2_{x_{M1}} \\ &\quad +\delta\left(B'_{M2} - p_2\right)Y^{M2}_{x_{M1}} + \delta\left(p_2 - C'_M(x_{M1} + x_{M2}) - \frac{\psi}{\delta}H'\right)X^{M2}_{x_{M1}} = 0. \qquad (53b)\end{aligned}$$

[18]In (12) we have replaced $S_1\left(\frac{p_1-\delta p_2}{1-\delta}, \cdot\right)$ by x_{N1}, since x_{N1} already has been chosen at period $t = 1$ and cannot be affected by the coalition at $t = 2$. The first-order conditions (7) and (8) also apply when N chooses x_{N1} in period 1 and x_{N2} in period 2.

[19]For more details we refer to the Appendix A7.

It is interesting to observe that the second-period fuel caps are used to influence only the second-period fuel price (and not the first-period fuel price), if M cannot commit. In contrast, the first-period fuel caps are used to manipulate both the first- and second-period fuel prices, and M takes into account that its first-period fuel caps affect its second-period fuel caps reflected by the terms $Y^{M2}_{y_{M1}}$, $Y^{M2}_{x_{M1}}$, $X^{M2}_{y_{M1}}$ and $X^{M2}_{x_{M1}}$ in (53a) and (53b).

At the beginning of period 1 M and N negotiate over deposits. The deposit contracts under commitment also apply here. For the deposit-purchase policy the contract is characterized by (22). In case of the deposit-lease policy the contract satisfies (42) and (43).

In the remainder of this section we investigate the (in)efficiency of the deposit policies, if M cannot commit. We begin with the deposit-purchase policy. If the coalition acts as price taker in the fuel markets ($\tilde{P}^2_{y_{M2}} = \tilde{P}^2_{x_{M2}} = P^1_{y_{M1}} = P^2_{y_{M1}} = P^1_{y_{M1}} = P^2_{y_{M1}} = 0$ in (51a), (51b), (53a), (53b)), it is straightforward to show that the allocation rules of the game coincide with (23a)-(23e) and the equilibrium of the game is inefficient. The reason for the inefficiency lies in a non-internalized first-period climate damage externality. If the coalition acts strategically in the fuel markets the inefficiency deteriorates. In case of the deposit-lease policy one can show that price taking ($\tilde{P}^2_{y_{M2}} = \tilde{P}^2_{x_{M2}} = P^1_{y_{M1}} = P^2_{y_{M1}} = P^1_{y_{M1}} = P^2_{y_{M1}} = 0$ in (51a), (51b), (53a), (53b)) leads to the allocation rules (44a) and (44c), and hence implements efficiency. Finally, for the deposit-lease policy and strategic action in the fuel markets we derive in Appendix A7 an analogue to Proposition 4. These results are summarized in

Proposition 6. *Suppose the coalition cannot commit to its future policies,*

(i) it pursues a deposit-purchase policy and suppose it takes the fuel prices as given. Then the equilibrium of the game is inefficient. The transition from the social optimum to the deposit-purchase policy increases first-period extraction, reduces second-period extraction and increases the climate damage.

(ii) it pursues a deposit-purchase policy and suppose it acts strategically in the fuel markets. Then the equilibrium of the game is inefficient.

(iii) it pursues a deposit-lease policy and suppose it takes the fuel prices as given. Then the equilibrium of the game is efficient.

(iv) it pursues a deposit-purchase policy and suppose it acts strategically in the fuel markets. Then the equilibrium of the game is efficient if and only if $E \in \tilde{\mathcal{E}}_O := \left\{ E \in \mathcal{E} \middle| E \text{ satisfies } 0 \geq I_1^* \geq \underline{\underline{I}}_1^* \wedge 0 \geq I_2^* \geq -\frac{H'^* S'^*}{\delta/\psi} \right\}$.

7 Summary and discussion

This paper compares the policies of leasing versus purchasing deposits to prevent their exploitation in a two-period model at which a (sub-global) climate coalition fights against climate damage and aims to manipulate the fuel prices in its favor. In that two-period model not only cumulative emissions but also the emissions path determines climate damages. It turns out that the deposit-purchase policy always leads to inefficiency which is in stark contrast to its performance in static models. The drawback of the deposit-purchase policy is a non-internalized first-period climate damage externality. The deposit-lease policy performs better. It implements efficiency, if the coalition is price taker in the fuel markets, and it achieves efficiency in a subset of economies, if the coalition acts strategically in the fuel markets. Our results are independent on whether the coalition can or cannot commit to future policies. So far our analysis provides an economic rationale for leasing instead of buying deposits for preservation.[20]

Next, we compare the economies that are inefficient for both the deposit-lease and the deposit-purchase policy. Presupposed the coalition imports fuel, the deposit-lease policy results in larger [smaller] (total and coalition's) welfare than the deposit-purchase policy, if the climate damage is large [small], because leasing improves the possibility to manipulate downward the fuel price in the first period. In an empirically calibrated economy the deposit-lease policy is welfare-superior to the deposit-purchase policy if the discount rate is small. In any case the transition from the deposit-purchase policy to the deposit-lease policy flattens the extraction path.

For the benefit of informative results we followed Harstad (2012) and Eichner and Pethig (2017a) in seeking analytical relief by employing additive, quasi-linear consumer preferences and, more importantly, by assuming that the non-signatory does suffer from climate damage. Furthermore, our analysis can be extended into other directions. First, one could introduce strategic action in the deposit market. Second, one could address aspects of incomplete information and moral hazard with respect to the deposits. Third, one could add a renewable resource. Fourth, a comprehensive comparison between leasing and buying deposits for preservation needs a computable general equilibrium model that is empirically calibrated. These issues are beyond the scope of the present paper but may be interesting and important tasks for future research.

[20]There is another argument for leasing, namely the threat of nationalization. As Harstad (2012) argues: "after selling a deposit located within its national boundary, a country may have a strong in incentive to nationalize the deposit and recapture its value."

References

Allen, M.R., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M. and N. Meinshausen (2009): Warming caused by cumulative carbon emissions towards the trillionth tonne, *Nature* 458, 1163-1166.

Babiker, M.H. (2005): Climate change policy, market structure and carbon leakage, *Journal of International Economics* 65, 421-445.

Baylis, K, Fullerton, D. and D. Karney (2014): Negative leakage, *Journal of the Association of Environmental and Resource Economists* 1, 51-73.

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

Burniaux, J.M. and J.O. Martins (2012): Carbon leakages: a general equilibrium view, *Economic Theory* 49, 473-495.

Copeland, B. and M.DS. Taylor (2005): free trade and global warming: a trade theory view of the Kyoto protocol, *Journal of Environmental Economics and Management* 49, 205-234.

Eichner, T. and R. Pethig (2017b): Buy coal and act strategically on the fuel market, *European Economic Review*, in press.

Eichner, T. and R. Pethig (2017a): Trade in fossil fuel deposits for preservation and strategic action, *Journal of Public Economics* 147, 50-61.

Eichner, T. and R. Pethig (2011): Carbon leakage, the green paradox and perfect future markets, *International Economic Review* 52, 767-805.

Energy Information Administration (EIA) (2017): International Energy Outlook.

Energy Information Administration (EIA) (2018): Crude Oil Proved Reserves. `https://www.eia.gov/beta/international/data/browser`.

Environmental Protection Agency (EPA) (2018): Greenhouse Gases Equivalencies Calculator. `https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references`.

Fæhn, T., Hagem, C., Lindholt, L., Mæland, S. and K.E. Rosendahl (2017): Climate policies in a fossil fuel producing country - demand versus supply side policies, *The Energy Journal* 38.

Gerlagh, R. and M. Liski (2017): Carbon prices for the next hundred years, *The Economic Journal*, forthcoming.

Gerlagh, R. (2011): Too much oil, *CESifo Economic Studies* 57, 79-102.

Golombek, R., Hagem, C. and M. Hoel (1995): Efficient incomplete international climate agreements, *Resource and Energy Economics* 17, 25-46.

Grafton, Q., Kompas, T. and N.V. Long (2012): Substitution between biofuels and fossil fuels: is there a green paradox, *Journal of Environmental Economics and Management* 64, 328-341.

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

Hoel, M. (2011): The supply side of CO_2 with country heterogeneity, *Scandinavian Journal of Economics* 113, 846-865.

Hoel, M. (1996): Should a carbon tax be differentiated across sectors?, *Journal of Public Economics* 59, 17-32.

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

Interagency Working Group on Social Cost of Greenhouse Gases (IWG) (2016): Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

International Energy Agency (IEA) (2013): Resources to Reserves.

Michielsen, T.O. (2014): Brown backstops versus the green paradox, *Journal of Environmental Economics and Management* 68(1), 87-110.

Rogelj, J., Hare, W., Lowe, J., van Vuuren, D.P., Riahi, K., Matthews, B., Hanaoka, T., Jiang, K. and M. Meinshausen (2011): Emission pathways consistent with a 2°C global temperature limit, *Nature Climate Change* 1, 413-418.

Van der Meijden, G. van der Ploeg, F. and C. Withagen (2015): International capital markets, oil producers and the green paradox, *European Economic Review* 76, 275-297.

Van der Ploeg, F. (2016): Second-best carbon taxation in the global economy: The green paradox and carbon leakage revisited, *Journal of Environmental Economics and Man-*

agement 78(4), 85-105.

Walsh B., Ciais, P., Janssens, I.A., Penuelas, J., Riahi, K., Rydzak, F., van Vuuren, D.P. and M. Obersteiner (2017): Pathways for balancing CO_2 emissions and sinks, *Nature Communications*.

Appendix A. Proofs

A1: The properties of P_1 and P_2 from (13) and (14): Total differentiation of (11) and (12) yields

$$S_1' \frac{\mathrm{d}p_1 - \delta \mathrm{d}p_2}{1-\delta} = \mathrm{d}y_{M1} - \mathrm{d}x_{M1} + D_1' \mathrm{d}p_1 \tag{A1}$$

$$S' \mathrm{d}p_2 - S_1' \frac{\mathrm{d}p_1 - \delta \mathrm{d}p_2}{1-\delta} = \mathrm{d}y_{M2} - \mathrm{d}x_{M2} + D_2' \mathrm{d}p_2. \tag{A2}$$

Solving (A1) and (A2) with respect to $\mathrm{d}p_1$ and $\mathrm{d}p_2$ we get

$$\frac{\mathrm{d}p_1}{\mathrm{d}y_{M1}} = -\frac{\mathrm{d}p_1}{\mathrm{d}x_{M1}} = \frac{\delta S_1' + (1-\delta)(S' - D_2')}{\Upsilon} > 0, \tag{A3}$$

$$\frac{\mathrm{d}p_1}{\mathrm{d}y_{M2}} = -\frac{\mathrm{d}p_1}{\mathrm{d}x_{M2}} = \frac{\delta S_1'}{\Upsilon} > 0, \tag{A4}$$

$$\frac{\mathrm{d}p_2}{\mathrm{d}y_{M1}} = -\frac{\mathrm{d}p_2}{\mathrm{d}x_{M1}} = \frac{S_1'}{\Upsilon} > 0, \tag{A5}$$

$$\frac{\mathrm{d}p_2}{\mathrm{d}y_{M2}} = -\frac{\mathrm{d}p_2}{\mathrm{d}x_{M2}} = \frac{S_1' - (1-\delta) D_1'}{\Upsilon} > 0, \tag{A6}$$

where $\Upsilon := (S' - D_2')S_1' - [(1-\delta)(S' - D_2') + \delta S_1']D_1' > 0$.

A2: Derivation of (22): Maximizing S from (21) with respect to p_z and z, we obtain the following first-order conditions

$$\frac{\partial S}{\partial p_z} = z \left[-b \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{1-b} + (1-b) \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{-b} \right] = 0, \tag{A7}$$

$$\frac{\partial S}{\partial z} = -\left(p_z - \psi H' \right) b \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{1-b} + \left(p_z + \delta C_N'(\overline{\xi} - z) - \delta p_2 \right) (1-b) \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{-b} = 0. \tag{A8}$$

Taking advantage of (A7) in (A8) we get

$$\delta p_2 = \delta C_N'(\overline{\xi} - z) + \psi H' \quad \Longleftrightarrow \quad \overline{\xi} - z = C_N'^{-1} \left(p_2 - \frac{\psi H'}{\delta} \right). \tag{A9}$$

Using $U_M\big|_{p_z=0} := U_M + p_z z$ and $U_N\big|_{p_z=0} := U_N - p_z z$ in (A7) yields

$$p_z z \;=\; (1-b)\left(U_M\big|_{p_z=0} - U_M^o\right) + b\left(U_N^o - U_N\big|_{p_z=0}\right). \tag{A10}$$

From $U := U_M + U_N$ and $U^o := U_M^o + U_N^o$ we then get

$$U_M = U_M^o + b(U - U^o) \quad \text{and} \quad U_N = U_N^o + (1-b)(U - U^o). \tag{A11}$$

A3: Proof of Proposition 1, equilibrium allocation of the social optimum compared to that of the deposit-purchase policy without strategic action: Using (3a) in (3c) as well as using (23a) in (23d) and (23e) yields

$$C_M'(x_{M1} + x_{M2}) = C_N'(x_{N1} + x_{N2}). \tag{A12}$$

Thus, $x_{M1}^\star + x_{M2}^\star \gtreqless x_{M1}^* + x_{M2}^* \iff x_{N1}^\star + x_{N2}^\star \gtreqless x_{N1}^* + x_{N2}^*$. Furthermore, using (3c) in (3b) as well as using (23d) and (23e) in (23b) and (23c) yields

$$(1-\delta)C_M'(x_{M1}) = B_{M1}'(y_{M1}) - \delta B_{M2}'(y_{M2}) - H', \tag{A13}$$

$$(1-\delta)C_N'(x_{N1}) = B_{N1}'(y_{N1}) - \delta B_{N2}'(y_{N2}) - \begin{cases} H' & \text{at the social optimum,} \\ 0 & \text{at the deposit-purchase policy.} \end{cases} \tag{A14}$$

In what follows, we distinguish between four cases concerning H' and $x_{i1} + x_{i2}$.

First, suppose that $H'^\star \leq H'^*$ and $x_{i1}^\star + x_{i2}^\star \leq x_{i1}^* + x_{i2}^*$. Then, (23d) and (23e) imply $y_{i2}^\star \geq y_{i2}^*$ and, since $x_{M2}+x_{N2} = y_{M2}+y_{N2}$, $x_{M2}^\star+x_{N2}^\star \geq x_{M2}^*+x_{N2}^*$. Since $x_{i1}^\star+x_{i2}^\star \leq x_{i1}^*+x_{i2}^*$, $x_{M1}^\star+x_{N1}^\star \leq x_{M1}^*+x_{N1}^*$ must hold. Then, (23a) and $x_{M1}+x_{N1} = y_{M1}+y_{N1}$ imply $y_{i1}^\star \leq y_{i1}^*$. All in all, the right-hand side of (A13) [(A14)] is not smaller [greater] at the deposit-purchase policy than at the social optimum, which implies $x_{M1}^\star \geq x_{M1}^*$ [$x_{N1}^\star > x_{N1}^*$], which contradicts $x_{M1}^\star + x_{N1}^\star \leq x_{M1}^* + x_{N1}^*$. Thus, this case cannot hold.

Second, suppose that $H'^\star \leq H'^*$ and $x_{i1}^\star + x_{i2}^\star > x_{i1}^* + x_{i2}^*$. This can only hold if $x_{M1}^\star + x_{N1}^\star < x_{M1}^* + x_{N1}^*$. Then, (23a) and $x_{M1} + x_{N1} = y_{M1} + y_{N1}$ imply $y_{i1}^\star < y_{i1}^*$. Since $x_{i1}^\star+x_{i2}^\star > x_{i1}^*+x_{i2}^*$, $x_{M2}^\star+x_{N2}^\star > x_{M2}^*+x_{N2}^*$ must hold. Then, (23a) and $x_{M2}+x_{N2} = y_{M2}+y_{N2}$ imply $y_{i1}^\star > y_{i1}^*$. All in all, the right-hand sides of (A13) and (A14) are greater at the deposit-purchase policy than at the social optimum, which implies $x_{i1}^\star > x_{i1}^*$, which contradicts $x_{M1}^\star + x_{N1}^\star \leq x_{M1}^* + x_{N1}^*$. Thus, this case cannot hold.

Third, suppose that $H'^\star > H'^*$ and $x_{i1}^\star + x_{i2}^\star \leq x_{i1}^* + x_{i2}^*$. This can only hold if $x_{M1}^\star + x_{N1}^\star > x_{M1}^* + x_{N1}^*$. Then, (23a) and $x_{M1} + x_{N1} = y_{M1} + y_{N1}$ imply $y_{i1}^\star > y_{i1}^*$. Since

$x^\star_{i1}+x^\star_{i2} \le x^*_{i1}+x^*_{i2}$, $x^\star_{M2}+x^\star_{N2} < x^*_{M2}+x^*_{N2}$ must hold. Then, (23a) and $x_{M2}+x_{N2} = y_{M2}+y_{N2}$ imply $y^\star_{i2} < y^*_{i2}$. All in all, the right-hand side of (A13) is smaller at the deposit-purchase policy than at the social optimum, which implies $x^\star_{M1} < x^*_{M1}$. Since $x^\star_{M1}+x^\star_{N1} > x^*_{M1}+x^*_{N1}$, $x^\star_{N1} > x^*_{N1}$ must hold. $x^\star_{N1} > x^*_{N1}$ and $x^\star_{N1} + x^\star_{N2} \le x^*_{N1} + x^*_{N2}$ imply $x^\star_{N2} < x^*_{N2}$.

Finally, suppose that $H'^\star > H'^*$ and $x^\star_{i1}+x^\star_{i2} > x^*_{i1}+x^*_{i2}$. Then, (23d) and (23e) imply $y^\star_{i2} < y^*_{i2}$ and, since $x_{M2}+x_{N2} = y_{M2}+y_{N2}$, $x^\star_{M2}+x^\star_{N2} < x^*_{M2}+x^*_{N2}$. Since $x^\star_{i1}+x^\star_{i2} > x^*_{i1}+x^*_{i2}$, $x^\star_{M1} + x^\star_{N1} > x^*_{M1} + x^*_{N1}$ must hold. Then, (23a) and $x_{M1} + x_{N1} = y_{M1} + y_{N1}$ imply $y^\star_{i1} > y^*_{i1}$. All in all, the right-hand side of (A13) is smaller at the deposit-purchase policy than at the social optimum, which implies $x^\star_{M1} < x^*_{M1}$. Since $x^\star_{M1} + x^\star_{M2} > x^*_{M1} + x^*_{M2}$ and $x^\star_{M1} + x^\star_{N1} > x^*_{M1} + x^*_{N1}$, $x^\star_{M2} > x^*_{M2}$ and $x^\star_{N1} > x^*_{N1}$ must hold. $x^\star_{M2} > x^*_{M2}$ and $x^\star_{M2} + x^\star_{N2} < x^*_{M2} + x^*_{N2}$ imply $x^\star_{N2} < x^*_{N2}$.

A4: Derivation of (42) and (43): Maximizing S from (41) with respect to p_z and z yields (A9). Maximizing it with respect to p_{z1} and z_1, we obtain the following first-order conditions

$$\frac{\partial S}{\partial p_{z1}} = z_1 \left[-b \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{1-b} + (1-b) \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{-b} \right] = 0, \tag{A15}$$

$$\begin{aligned} \frac{\partial S}{\partial z_1} &= -\left(p_{z1} - H'\right) b \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{1-b} \\ &\quad + \left(p_{z1} + (1-\delta) C_N'(\bar{\xi}_1 - z_1) - p_1 + \delta p_2\right) (1-b) \left(\frac{U_N - U_N^o}{U_M - U_M^o} \right)^{-b} = 0. \end{aligned} \tag{A16}$$

Taking advantage of (A15) in (A16) we get

$$p_1 - \delta p_2 = (1-\delta) C_N'(\bar{\xi}_1 - z_1) + H' \iff \bar{\xi}_1 - z_1 = C_N'^{-1} \left(\frac{p_1 - \delta p_2 - H'}{1-\delta} \right). \tag{A17}$$

Using $U_M\big|_{p_{z1},p_z=0} := U_M + p_{z1} z_1 + p_z z$ and $U_N\big|_{p_{z1},p_z=0} := U_N - p_{z1} z_1 - p_z z$ in (A16) yields

$$p_{z1} z_1 + p_z z = (1-b) \left(U_M\big|_{p_{z1},p_z=0} - U_M^o \right) + b \left(U_N^o - U_N\big|_{p_{z1},p_z=0} \right). \tag{A18}$$

From $U := U_M + U_N$ and $U^o := U_M^o + U_N^o$ we then get

$$U_M = U_M^o + b(U - U^o) \quad \text{and} \quad U_N = U_N^o + (1-b)(U - U^o). \tag{A19}$$

A5: Proof of Proposition 4, conditions for non-strategic action with a deposit-lease policy: Evaluating the partial derivatives of (40) with respect to y_{M1} and y_{M2} at the first-best equilibrium values yields

$$\left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^*_{M1}} = \underbrace{B'^*_{M1} - p^*_1}_{=0} - \left[I^*_1 P^1_{y_{M1}}\big|_{y^*_{M1}} + \frac{H'^* S'^*_1}{1-\delta}\left(P^1_{y_{M1}}\big|_{y^*_{M1}} - \delta P^2_{y_{M1}}\big|_{y^*_{M1}} \right) + \left(I^*_2 + \frac{H'^* S'^*}{\delta/\psi} \right) \delta P^2_{y_{M1}}\big|_{y^*_{M1}} \right], \tag{A20}$$

where $P^1_{y_{M1}} = \frac{\delta S'_1 + (1-\delta)(S' - D'_2)}{\Upsilon} > 0$, $P^2_{y_{M1}} = \frac{S'_1}{\Upsilon} \geq 0$, $P^1_{y_{M1}} - \delta P^2_{y_{M1}} = \frac{(1-\delta)(S' - D'_2)}{\Upsilon} > 0$,

$$S'^*_1 = \left.\frac{\partial S_1}{\partial \left(\frac{p_1 - \delta p_2}{1-\delta}\right)}\right|_{(p^*_1, p^*_2)} = \begin{cases} S'^*_{1+} > 0, & \text{if}\, \mathrm{d}\left(\frac{p_1 - \delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{y_{M1}} - \delta P^2_{y_{M1}} \right) \underbrace{\mathrm{d}y_{M1}}_{+} > 0, \\ S'^*_{1-} = 0, & \text{if}\, \mathrm{d}\left(\frac{p_1 - \delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{y_{M1}} - \delta P^2_{y_{M1}} \right) \underbrace{\mathrm{d}y_{M1}}_{-} \leq 0, \end{cases} \tag{A21}$$

$$S'^* = \left.\frac{\partial S}{\partial p_2}\right|_{p^*_2} = \begin{cases} S'^*_{+} > 0, & \text{if}\, \mathrm{d}p_2 = P^2_{y_{M1}} \underbrace{\mathrm{d}y_{M1}}_{+} > 0, \\ S'^*_{-} = 0, & \text{if}\, \mathrm{d}p_2 = P^2_{y_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-} \leq 0, \end{cases} \tag{A22}$$

and

$$\left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} = \delta \underbrace{\left[B'^*_{M2}(y^*_{M2}) - p^*_2 \right]}_{=0} - \left[I^*_1 P^1_{y_{M2}}\big|_{y^*_{M2}} + \frac{H'^* S'^*_1}{1-\delta}\left(P^1_{y_{M2}}\big|_{y^*_{M2}} - \delta P^2_{y_{M2}}\big|_{y^*_{M2}} \right) + \left(I^*_2 + \frac{H'^* S'^*}{\delta/\psi} \right) \delta P^2_{y_{M2}}\big|_{y^*_{M2}} \right], \tag{A23}$$

where $P^1_{y_{M2}} = \frac{\delta S'_1}{\Upsilon} \geq 0$, $P^2_{y_{M2}} = \frac{S'_1 - (1-\delta) D'_1}{\Upsilon} > 0$, $P^1_{y_{M2}} - \delta P^2_{y_{M2}} = \frac{\delta(1-\delta) D'_1}{\Upsilon} < 0$,

$$S'^*_1 = \left.\frac{\partial S_1}{\partial \left(\frac{p_1 - \delta p_2}{1-\delta}\right)}\right|_{(p^*_1, p^*_2)} = \begin{cases} S'^*_{1+} > 0, & \text{if}\, \mathrm{d}\left(\frac{p_1 - \delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{y_{M1}} - \delta P^2_{y_{M2}} \right) \underbrace{\mathrm{d}y_{M2}}_{-} > 0, \\ S'^*_{1-} = 0, & \text{if}\, \mathrm{d}\left(\frac{p_1 - \delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{y_{M2}} - \delta P^2_{y_{M2}} \right) \underbrace{\mathrm{d}y_{M2}}_{+} \leq 0. \end{cases} \tag{A24}$$

$$S'^* = \left.\frac{\partial S}{\partial p_2}\right|_{p^*_2} = \begin{cases} S'^*_{+} > 0, & \text{if}\, \mathrm{d}p_2 = P^2_{y_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} > 0, \\ S'^*_{-} = 0, & \text{if}\, \mathrm{d}p_2 = P^2_{y_{M2}} \underbrace{\mathrm{d}y_{M2}}_{-} \leq 0. \end{cases} \tag{A25}$$

Now we analyze how M's welfare changes if it alters its fuel policy. For $\mathrm{d}y_{M1} > 0$ ($\Longrightarrow$ $S_1^{\prime *} > 0 \quad \Rightarrow \quad P^2_{y_{M1}} > 0 \quad \Rightarrow \quad S^{\prime *} > 0$) we obtain

$$\begin{aligned}\mathrm{d}U_M &= \left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^*_{M1}} \underbrace{\mathrm{d}y_{M1}}_{+} = -\left[I_1^* P^1_{y_{M1}}\big|_{y^*_{M1}} + \frac{H^{\prime *} S^{\prime *}_{1+}}{1-\delta}\left(P^1_{y_{M1}}\big|_{y^*_{M1}} - \delta P^2_{y_{M1}}\big|_{y^*_{M1}} \right) \right. \\ &\quad \left. + \left(I_2^* + \frac{H^{\prime *} S^{\prime *}_{+}}{\delta/\psi} \right) \delta P^2_{y_{M1}}\big|_{y^*_{M1}} \right] \underbrace{\mathrm{d}y_{M1}}_{+}. \end{aligned} \tag{A26}$$

For $\mathrm{d}y_{M1} < 0$ ($\Longrightarrow \quad S_1^{\prime *} = 0 \quad \Rightarrow \quad P^2_{y_{M1}} = 0 \quad \Rightarrow \quad S^{\prime *} = 0$) we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^*_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-} = -I_1^* P^1_{y_{M1}}\big|_{y^*_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-}. \tag{A27}$$

For $\mathrm{d}y_{M2} > 0$ ($\Longrightarrow \quad S_1^{\prime *} = 0,\ P^1_{y_{M2}} = 0,\ S^{\prime *} > 0$) we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} = -\left(I_2^* + \frac{H^{\prime *} S^{\prime *}_{+}}{\delta/\psi} \right) \delta P^2_{y_{M2}}\big|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+}. \tag{A28}$$

For $\mathrm{d}y_{M2} < 0$ ($\Longrightarrow \quad S_1^{\prime *} > 0,\ P^1_{y_{M2}} > 0,\ S^{\prime *} = 0$) we obtain

$$\begin{aligned}\mathrm{d}U_M &= \left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{-} \\ &= -\left[I_1^* P^1_{y_{M2}}\big|_{y^*_{M2}} + \frac{H^{\prime *} S_1^{\prime *}}{1-\delta}\left(P^1_{y_{M2}}\big|_{y^*_{M2}} - \delta P^2_{y_{M2}}\big|_{y^*_{M2}} \right) + I_2^* \delta P^2_{y_{M2}}\big|_{y^*_{M2}} \right] \underbrace{\mathrm{d}y_{M2}}_{-} \end{aligned} \tag{A29}$$

From (A3) to (A6), $\frac{\mathrm{d}p_s}{\mathrm{d}y_{Mt}} = -\frac{\mathrm{d}p_s}{\mathrm{d}x_{Mt}}$ for $s, t = 1, 2$, such that $\left.\frac{\partial U_M}{\partial y_{Mt}}\right|_{y^*_{Mt}} \underbrace{\mathrm{d}y_{Mt}}_{+} = \left.\frac{\partial U_M}{\partial x_{Mt}}\right|_{x^*_{Mt}} \underbrace{\mathrm{d}x_{Mt}}_{-}$ and $\left.\frac{\partial U_M}{\partial y_{Mt}}\right|_{y^*_{Mt}} \underbrace{\mathrm{d}y_{Mt}}_{-} = \left.\frac{\partial U_M}{\partial x_{Mt}}\right|_{x^*_{Mt}} \underbrace{\mathrm{d}x_{Mt}}_{+}$ for $t = 1, 2$. Thus, (A26) to (A29) being smaller or equal to zero is necessary and sufficient for non-strategic action with a deposit-lease policy. (A27) and (A28) imply $I_1^* \leq 0$ and $I_2^* \geq -\frac{H^{\prime *} S^{\prime *}}{\delta/\psi}$, respectively. (A26) and (A29) imply a lower bound of I_1^* and an upper bound of I_2^*, which we define by $\underline{I}_1^*$ and $\overline{I}_2^*$, respectively. Substituting (A3) to (A6), these bounds read

$$\underline{I}_1^* := -\frac{H^{\prime *} S_1^{\prime *} (S^{\prime *} - D_2^{\prime *})}{S_1^{\prime *}\delta + (S^{\prime *} - D_2^{\prime *})(1-\delta)} - \frac{(I_2^*\delta + H^{\prime *} S^{\prime *}\psi) S_1^{\prime *}}{S_1^{\prime *}\delta + (S^{\prime *} - D_2^{\prime *})(1-\delta)}, \tag{A30}$$

$$\overline{I}_2^* := -\frac{S_1^{\prime *}(I_1^* + H^{\prime *} D_1^{\prime *})}{S_1^{\prime *} - D_1^{\prime *}(1-\delta)}, \tag{A31}$$

where $I_2^* \geq -\frac{H^{\prime *} S^{\prime *}}{\delta/\psi}$ and $I_1^* \leq 0$ imply $\underline{I}_1^* \leq 0$ and $\overline{I}_2^* \geq 0$, respectively.

A6: Conditions for non-strategic action with a deposit-purchase policy: For the comparison of the policies in Section 5, we need to know the conditions for non-strategic action with a deposit-purchase policy in the parametric model. We prepare this analysis by deriving the respective conditions in general. Denoting by $\star$ the deposit-purchase equilibrium values without strategic action and evaluating the partial derivatives of (20) with respect to y_{M1} and y_{M2} at these second-best equilibrium values yields

$$\left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^\star_{M1}} = \underbrace{B'^\star_{M1} - p^\star_1}_{=0} - \Bigg[I^\star_1 P^1_{y_{M1}}\big|_{y^\star_{M1}} + \frac{H'^\star S'^\star_1}{1-\delta}\left(P^1_{y_{M1}}\big|_{y^\star_{M1}} - \delta P^2_{y_{M1}}\big|_{y^\star_{M1}}\right) + \left(I^\star_2 + \frac{H'^\star S'^\star}{\delta/\psi}\right)\delta P^2_{y_{M1}}\big|_{y^\star_{M1}}\Bigg], \tag{A32}$$

where $P^1_{y_{M1}} = \frac{\delta S'_1 + (1-\delta)(S' - D'_2)}{\Upsilon} > 0$, $P^2_{y_{M1}} = \frac{S'_1}{\Upsilon} > 0$, $P^1_{y_{M1}} - \delta P^2_{y_{M1}} = \frac{(1-\delta)(S' - D'_2)}{\Upsilon} > 0$,

$$S'^\star_1 > 0, \tag{A33}$$

$$S'^\star = \left.\frac{\partial S}{\partial p_2}\right|_{p^\star_2} = \begin{cases} S'^\star_+ > 0, & \text{if } \mathrm{d}p_2 = P^2_{y_{M1}} \underbrace{\mathrm{d}y_{M1}}_{+} > 0, \\ S'^\star_- = 0, & \text{if } \mathrm{d}p_2 = P^2_{y_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-} \leq 0, \end{cases} \tag{A34}$$

and

$$\left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^\star_{M2}} = \delta \underbrace{\left[B'^\star_{M2}(y^\star_{M2}) - p^\star_2\right]}_{=0} - \Bigg[I^\star_1 P^1_{y_{M2}}\big|_{y^\star_{M2}} + \frac{H'^\star S'^\star_1}{1-\delta}\left(P^1_{y_{M2}}\big|_{y^\star_{M2}} - \delta P^2_{y_{M2}}\big|_{y^\star_{M2}}\right) + \left(I^\star_2 + \frac{H'^\star S'^\star}{\delta/\psi}\right)\delta P^2_{y_{M2}}\big|_{y^\star_{M2}}\Bigg], \tag{A35}$$

where $P^1_{y_{M2}} = \frac{\delta S'_1}{\Upsilon} > 0$, $P^2_{y_{M2}} = \frac{S'_1 - (1-\delta)D'_1}{\Upsilon} > 0$, $P^1_{y_{M2}} - \delta P^2_{y_{M2}} = \frac{\delta(1-\delta)D'_1}{\Upsilon} < 0$,

$$S'^\star_1 > 0, \tag{A36}$$

$$S'^\star = \left.\frac{\partial S}{\partial p_2}\right|_{p^\star_2} = \begin{cases} S'^\star_+ > 0, & \text{if } \mathrm{d}p_2 = P^2_{y_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} > 0, \\ S'^\star_- = 0, & \text{if } \mathrm{d}p_2 = P^2_{y_{M2}} \underbrace{\mathrm{d}y_{M2}}_{-} \leq 0. \end{cases} \tag{A37}$$

Now we analyze how M's welfare changes if it alters its fuel policy. For $\mathrm{d}y_{M1} > 0$ ($\Longrightarrow$ $S'^\star > 0$) we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^\star_{M1}} \underbrace{\mathrm{d}y_{M1}}_{+} = -\Bigg[I^\star_1 P^1_{y_{M1}}\big|_{y^\star_{M1}} + \frac{H'^\star S'^\star_1}{1-\delta}\left(P^1_{y_{M1}}\big|_{y^\star_{M1}} - \delta P^2_{y_{M1}}\big|_{y^\star_{M1}}\right) + \left(I^\star_2 + \frac{H'^\star S'^\star_+}{\delta/\psi}\right)\delta P^2_{y_{M1}}\big|_{y^\star_{M1}}\Bigg] \underbrace{\mathrm{d}y_{M1}}_{+}. \tag{A38}$$

For $\mathrm{d}y_{M1} < 0 \quad (\Longrightarrow \quad S'^{\star} = 0)$ we obtain

$$\begin{aligned}
\mathrm{d}U_M &= \left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^\star_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-} \\
&= -\left[I_1^\star P^1_{y_{M1}}\big|_{y^\star_{M1}} + \frac{H'^\star S_1'^\star}{1-\delta}\left(P^1_{y_{M1}}\big|_{y^\star_{M1}} - \delta P^2_{y_{M1}}\big|_{y^\star_{M1}} \right) + I_2^\star \delta P^2_{y_{M1}}\big|_{y^\star_{M1}} \right] \underbrace{\mathrm{d}y_{M1}}_{-} \qquad (A39)
\end{aligned}$$

For $\mathrm{d}y_{M2} > 0 \quad (\Longrightarrow \quad S'^{\star} > 0)$ we obtain

$$\begin{aligned}
\mathrm{d}U_M &= \left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^\star_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} = -\left[I_1^\star P^1_{y_{M2}}\big|_{y^\star_{M2}} + \frac{H'^\star S_1'^\star}{1-\delta}\left(P^1_{y_{M2}}\big|_{y^\star_{M2}} - \delta P^2_{y_{M2}}\big|_{y^\star_{M2}} \right) \right. \\
&\quad \left. + \left(I_2^\star + \frac{H'^\star S_+'^\star}{\delta/\psi} \right) \delta P^2_{y_{M2}}\big|_{y^\star_{M2}} \right] \underbrace{\mathrm{d}y_{M2}}_{+}. \qquad (A40)
\end{aligned}$$

For $\mathrm{d}y_{M2} < 0 \quad (\Longrightarrow \quad S'^{\star} = 0)$ we obtain

$$\begin{aligned}
\mathrm{d}U_M &= \left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^\star_{M2}} \underbrace{\mathrm{d}y_{M2}}_{-} \\
&= -\left[I_1^\star P^1_{y_{M2}}\big|_{y^\star_{M2}} + \frac{H'^\star S_1'^\star}{1-\delta}\left(P^1_{y_{M2}}\big|_{y^\star_{M2}} - \delta P^2_{y_{M2}}\big|_{y^\star_{M2}} \right) + I_2^\star \delta P^2_{y_{M2}}\big|_{y^\star_{M2}} \right] \underbrace{\mathrm{d}y_{M2}}_{-} \qquad (A41)
\end{aligned}$$

From (A3) to (A6), $\frac{\mathrm{d}p_s}{\mathrm{d}y_{Mt}} = -\frac{\mathrm{d}p_s}{\mathrm{d}x_{Mt}}$ for $s,t = 1,2$, such that $\left.\frac{\partial U_M}{\partial y_{Mt}}\right|_{y^\star_{Mt}} \underbrace{\mathrm{d}y_{Mt}}_{+} = \left.\frac{\partial U_M}{\partial x_{Mt}}\right|_{x^\star_{Mt}} \underbrace{\mathrm{d}x_{Mt}}_{-}$ and $\left.\frac{\partial U_M}{\partial y_{Mt}}\right|_{y^\star_{Mt}} \underbrace{\mathrm{d}y_{Mt}}_{-} = \left.\frac{\partial U_M}{\partial x_{Mt}}\right|_{x^\star_{Mt}} \underbrace{\mathrm{d}x_{Mt}}_{+}$ for $t = 1,2$. Thus, (A38) to (A41) being smaller or equal to zero is necessary and sufficient for non-strategic action with a deposit-purchase policy.

A7: Proof of Proposition 6, conditions for non-strategic action with a deposit-lease policy without commitment: First we analyze how M's welfare changes if it alters its second-period fuel policy. For this, we need to know $\tilde{P}^2_{y_{M2}}$ and $\tilde{P}^2_{x_{M2}}$. Total differentiation of (12) for $S_1\left(\frac{p_1-\delta p_2}{1-\delta}\right) = x_{N1}$ yields

$$S'\mathrm{d}p_2 + \mathrm{d}x_{N1} = \mathrm{d}I_2 + D_2'\mathrm{d}p_2 \qquad \Longrightarrow \qquad \tilde{P}^2_{y_{M2}} = -\tilde{P}^2_{x_{M2}} = \frac{1}{S' - D_2'} > 0. \qquad (A42)$$

Evaluating (50) at the first-best equilibrium values yields

$$\left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} = \underbrace{B'^*_{M2} - p^*_2}_{=0} - \left(I^*_2 + \frac{H'^* S'^*}{\delta/\psi} \right) \delta \tilde{P}^2_{y_{M2}}\big|_{y^*_{M2}}, \qquad (A43)$$

where

$$S'^{*} \;=\; \left.\frac{\partial S}{\partial p_2}\right|_{p_2^*} = \begin{cases} S'^{*}_{+} > 0, & \text{if } \mathrm{d}p_2 = \tilde{P}^2_{y_{M2}} \underbrace{\mathrm{d}y_{M1}}_{+} > 0, \\ S'^{*}_{-} = 0, & \text{if } \mathrm{d}p_2 = \tilde{P}^2_{y_{M2}} \underbrace{\mathrm{d}y_{M1}}_{-} \leq 0. \end{cases} \tag{A44}$$

For $\mathrm{d}y_{M2} > 0 \quad (\Longrightarrow \quad S'^{*} > 0)$ we obtain

$$\mathrm{d}U_M \;=\; \left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} = -\left(I_2^* + \frac{H'^{*}S'^{*}_{+}}{\delta/\psi}\right)\delta \tilde{P}^2_{y_{M2}}\big|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+}. \tag{A45}$$

For $\mathrm{d}y_{M2} < 0 \quad (\Longrightarrow \quad S'^{*} = 0)$ we obtain

$$\mathrm{d}U_M \;=\; \left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} = -I_2^*\delta \tilde{P}^2_{y_{M2}}\big|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{-}. \tag{A46}$$

From (A42), $\tilde{P}^2_{y_{M2}} = -\tilde{P}^2_{x_{M2}}$, such that $\left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{+} = \left.\frac{\partial U_M}{\partial x_{M2}}\right|_{x^*_{M2}} \underbrace{\mathrm{d}x_{M2}}_{-}$ and $\left.\frac{\partial U_M}{\partial y_{M2}}\right|_{y^*_{M2}} \underbrace{\mathrm{d}y_{M2}}_{-} = \left.\frac{\partial U_M}{\partial x_{M2}}\right|_{x^*_{M2}} \underbrace{\mathrm{d}x_{M2}}_{+}$. Thus, (A45) and (A46) being smaller or equal to zero is necessary and sufficient for non-strategic action in the second period with a deposit-lease policy without commitment.

Now we analyze how M's welfare changes if it alters its first-period fuel policy, given that the coalition refrains from strategic action in the second period. For this, we need to know the respective $P^1_{y_{M1}}$, $P^1_{x_{M1}}$, $P^2_{y_{M1}}$ and $P^2_{x_{M1}}$. Total differentiation of (51a) and (51b) for $x_{N1} = S_1\left(\frac{p_1-\delta p_2}{1-\delta}\right)$ and $\tilde{P}^2_{y_{M2}} = \tilde{P}^2_{x_{M2}} = 0$ and rearranging yields

$$\mathrm{d}y_{M2} \;=\; D'_M, \tag{A47}$$

$$\begin{aligned} \mathrm{d}x_{M2} \;=\; & -\frac{H''S'_1\psi}{(C''_M\delta + H''\psi^2)(1-\delta)}\mathrm{d}p_1 + \frac{(1-\delta)\delta - H''[S'(1-\delta)\psi - S'_1\delta]\psi}{(C''_M\delta + H''\psi^2)(1-\delta)}\mathrm{d}p_2 \\ & -\frac{C''_M\delta + H''\psi(1+\psi)}{C''_M\delta + H''\psi^2}\mathrm{d}x_{M1}, \end{aligned} \tag{A48}$$

where $D'_M := B'^{-1}_{M2}(p_2)$ and $C''_M := C''_M(x_{M1}+x_{M2})$. Substituting (A47) and (A48) into (A2) and afterwards solving (A1) and (A2) with respect to $\mathrm{d}p_1$ and $\mathrm{d}p_2$ we get

$$\begin{aligned} P^1_{y_{M1}} \;=\; & \frac{[1+(S'-D'_2-D'_M)C''_M]\delta(1-\delta) + S'_1C''_M\delta^2}{\Phi} \\ & + \frac{H''[S'_1\delta(1+\psi) + (D'_2+D'_M)(1-\delta)\psi]\psi}{\Phi} > 0, \end{aligned} \tag{A49}$$

$$P^1_{x_{M1}} \;=\; -\frac{[[1+(S'-D'_2-D'_M)C''_M]\delta - H''(D'_2+D'_M)\psi^2](1-\delta)}{\Phi} < 0, \tag{A50}$$

$$P^2_{y_{M1}} \;=\; \frac{S'_1[C''_M\delta + H''\psi(1+\psi)]}{\Phi} > 0, \tag{A51}$$

$$P^2_{x_{M1}} \;=\; \frac{-D'_1[C''_M\delta + H''\psi(1+\psi)](1-\delta)}{\Phi} > 0, \tag{A52}$$

where $\Phi := (S_1' - D_1')[1 + (S' - D_2' - D_M')C_M'']\delta(1-\delta) + S_1'[1 + (S' - D_1' - D_2' - D_M')C_M'']\delta^2 - H''[S_1'D_1'\delta(1+\psi) + (D_2' + D_M')[S_1' - D_1'(1-\delta)]\psi]\psi > 0$. From (A49) to (A52) we get

$$P^1_{y_{M1}} - \delta P^2_{y_{M1}} = \frac{[[1 + (S' - D_2' - D_M')C_M'']\delta + H''(D_2' + D_M')\psi^2](1-\delta)}{\Phi} > 0, \quad \text{(A53)}$$

$$P^1_{x_{M1}} - \delta P^2_{x_{M1}} = -\frac{[[1 + (S' - D_2' - D_M')C_M'']\delta - H''(D_2' + D_M')\psi^2](1-\delta)}{\Phi} - \frac{-D_1'[C_M''\delta + H''\psi(1+\psi)]\delta(1-\delta)}{\Phi} < 0. \quad \text{(A54)}$$

Evaluating (52) at the first best equilibrium yields

$$\left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^*_{M1}} = \underbrace{B'^*_{M1} - p^*_1}_{=0} + \delta \underbrace{\left(B'^*_{M2} - p^*_2\right)}_{=0} \left.Y^{M2}_{y_{M1}}\right|_{y^*_{M1}} + \delta \underbrace{\left(p^*_2 - C'^*_M(x_{M1} + x_{M2}) - \frac{\psi H'^*}{\delta}\right)}_{=0} \left.X^{M2}_{y_{M1}}\right|_{y^*_{M1}}$$
$$- \left(I^*_1 + \frac{H'^* S'^*_1}{1-\delta}\right) \left.P^1_{y_{M1}}\right|_{y^*_{M1}} - \left[I^*_2 + H'^*\left(\frac{\psi S'^*}{\delta} - \frac{S'^*_1}{1-\delta}\right)\right] \delta \left.P^2_{y_{M1}}\right|_{y^*_{M1}} \quad \text{(A55)}$$

where

$$S'^*_1 = \left.\frac{\partial S_1}{\partial\left(\frac{p_1 - \delta p_2}{1-\delta}\right)}\right|_{(p^*_1, p^*_2)} = \begin{cases} S'^*_{1+} > 0, & \text{if } \mathrm{d}\left(\frac{p_1 - \delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{y_{M1}} - \delta P^2_{y_{M1}}\right) \underbrace{\mathrm{d}y_{M1}}_{+} > 0, \\ S'^*_{1-} = 0, & \text{if } \mathrm{d}\left(\frac{p_1 - \delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{y_{M1}} - \delta P^2_{y_{M1}}\right) \underbrace{\mathrm{d}y_{M1}}_{-} \leq 0, \end{cases} \quad \text{(A56)}$$

$$S'^* = \left.\frac{\partial S}{\partial p_2}\right|_{p^*_2} = \begin{cases} S'^*_{+} > 0, & \text{if } \mathrm{d}p_2 = P^2_{y_{M1}} \underbrace{\mathrm{d}y_{M1}}_{+} > 0, \\ S'^*_{-} = 0, & \text{if } \mathrm{d}p_2 = P^2_{y_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-} \leq 0. \end{cases} \quad \text{(A57)}$$

For $\mathrm{d}y_{M1} > 0 \quad (\Longrightarrow \quad S'^*_1 > 0 \quad \Rightarrow \quad P^2_{y_{M1}} > 0 \quad \Rightarrow \quad S'^* > 0)$ we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^*_{M1}} \underbrace{\mathrm{d}y_{M1}}_{+} = -\left[I^*_1 \left.P^1_{y_{M1}}\right|_{y^*_{M1}} + \frac{H'^* S'^*_{1+}}{1-\delta}\left(\left.P^1_{y_{M1}}\right|_{y^*_{M1}} - \delta \left.P^2_{y_{M1}}\right|_{y^*_{M1}}\right) + \left(I^*_2 + \frac{H'^* S'^*_+}{\delta/\psi}\right) \delta \left.P^2_{y_{M1}}\right|_{y^*_{M1}}\right] \underbrace{\mathrm{d}y_{M1}}_{+}. \quad \text{(A58)}$$

For $\mathrm{d}y_{M1} < 0 \quad (\Longrightarrow \quad S'^*_1 = 0 \quad \Rightarrow \quad P^2_{y_{M1}} = 0 \quad \Rightarrow \quad S'^* = 0)$ we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial y_{M1}}\right|_{y^*_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-} = -I^*_1 \left.P^1_{y_{M1}}\right|_{y^*_{M1}} \underbrace{\mathrm{d}y_{M1}}_{-}. \quad \text{(A59)}$$

Evaluating (52) at the first best equilibrium yields

$$\left.\frac{\partial U_M}{\partial x_{M1}}\right|_{y^*_{M1}} = \underbrace{p^*_1 - (1-\delta)C'^*_M(x_{M1}) - \delta C'^*_M(x_{M1}+x_{M2}) - (1+\psi)\,H'^*}_{=0}$$
$$+\delta\underbrace{\left(B'^*_{M2} - p^*_2\right)}_{=0} \left.Y^{M2}_{x_{M1}}\right|_{x^*_{M1}} + \delta\underbrace{\left(p^*_2 - C'^*_M(x_{M1}+x_{M2}) - \frac{\psi H'^*}{\delta}\right)}_{=0} \left.X^{M2}_{x_{M1}}.\right|_{x^*_{M1}}$$
$$-\left(I^*_1 + \frac{H'^* S'^*_1}{1-\delta}\right) P^1_{x_{M1}}\big|_{x^*_{M1}} - \left[I^*_2 + H'^*\left(\frac{\psi S'^*}{\delta} - \frac{S'^*_1}{1-\delta}\right)\right] \delta P^2_{x_{M1}}\big|_{x^*_{M1}} \quad \text{(A60)}$$

where

$$S'^*_1 = \left.\frac{\partial S_1}{\partial\left(\frac{p_1-\delta p_2}{1-\delta}\right)}\right|_{(p^*_1,p^*_2)} = \begin{cases} S'^*_{1+} > 0, & \text{if } \mathrm{d}\left(\frac{p_1-\delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{x_{M1}} - \delta P^2_{x_{M1}}\right)\underbrace{\mathrm{d}x_{M1}}_{-} > 0, \\ S'^*_{1-} = 0, & \text{if } \mathrm{d}\left(\frac{p_1-\delta p_2}{1-\delta}\right) = \frac{1}{1-\delta}\left(P^1_{x_{M1}} - \delta P^2_{x_{M1}}\right)\underbrace{\mathrm{d}x_{M1}}_{+} \le 0, \end{cases} \quad \text{(A61)}$$

$$S'^* = \left.\frac{\partial S}{\partial p_2}\right|_{p^*_2} = \begin{cases} S'^*_+ > 0, & \text{if } \mathrm{d}p_2 = P^2_{x_{M1}}\underbrace{\mathrm{d}x_{M1}}_{+} > 0, \\ S'^*_- = 0, & \text{if } \mathrm{d}p_2 = P^2_{x_{M1}}\underbrace{\mathrm{d}x_{M1}}_{-} \le 0. \end{cases} \quad \text{(A62)}$$

For $\mathrm{d}x_{M1} > 0 \quad (\Longrightarrow \quad S'^*_1 = 0)$ we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial x_{M1}}\right|_{x^*_{M1}} \underbrace{\mathrm{d}x_{M1}}_{+} = -\left[I^*_1 P^1_{x_{M1}}\big|_{x^*_{M1}} + \left(I^*_2 + \frac{H'^* S'^*_+}{\delta/\psi}\right)\delta P^2_{x_{M1}}\big|_{x^*_{M1}}\right]\underbrace{\mathrm{d}x_{M1}}_{+} \quad \text{(A63)}$$

For $\mathrm{d}x_{M1} < 0 \quad (\Longrightarrow \quad S'^* = 0)$ we obtain

$$\mathrm{d}U_M = \left.\frac{\partial U_M}{\partial x_{M1}}\right|_{x^*_{M1}} \underbrace{\mathrm{d}x_{M1}}_{-} = -\left[I^*_1 P^1_{x_{M1}}\big|_{x^*_{M1}} + \frac{H'^* S'^*_{1+}}{1-\delta}\left(P^1_{x_{M1}}\big|_{x^*_{M1}} - \delta P^2_{x_{M1}}\big|_{x^*_{M1}}\right)\right.$$
$$\left. + I^*_2 \delta P^2_{x_{M1}}\big|_{x^*_{M1}}\right]\underbrace{\mathrm{d}x_{M1}}_{-}. \quad \text{(A64)}$$

Thus, (A45), (A46), (A58), (A59), (A63) and (A64) being smaller or equal to zero is necessary and sufficient for non-strategic action with a deposit-lease policy without commitment. (A45) and (A59) being smaller or equal to zero is sufficient for (A63) being smaller or equal to zero. (A45), (A46) and (A59) imply $I^*_2 \ge -\frac{H'^* S'^*_+}{\delta/\psi}$, $I^*_2 \le 0$ and $I^*_1 \le 0$, respectively. (A58) and (A64) imply lower bounds of I^*_1, which we define by $\underline{\underline{I}}^*_{1,1}$ and $\underline{\underline{I}}^*_{1,2}$, respectively.

Substituting (A49) to (A52), these bounds read

$$\underline{I}^*_{1,1} := -\frac{H'^* S_1'^* \{[1 + (S' - D_2' - D_M')C_M'']\delta - H''(D_2' + D_M')\psi^2\}}{\Theta} - \frac{(I_2'^*\delta + H'^* S'^* \psi) S_1'^* [C_M''\delta - H''\psi(1+\psi)]}{\Theta}, \tag{A65}$$

$$\underline{I}^*_{1,2} := -\frac{H'^* S_1'^*}{1-\delta} - \frac{[I_2'^*(1-\delta) - H'^* S_1'] D_1' [C_M''\delta + H''\psi(1+\psi)]\delta}{\{[1 - (D_2' + D_M')C_M'']\delta - H''(D_2' + D_M')\psi^2\}(1-\delta)}, \tag{A66}$$

where $\Theta := [1+(S'-D_2'-D_M')C_M'']\delta(1-\delta) + S_1'C_M''\delta^2 + H''[S_1'\delta(1+\psi) - (D_2'+D_M')(1-\delta)\psi]\psi$, and where $I_2^* \geq -\frac{H'^* S'^*}{\delta/\psi}$ and $I_2^* \leq 0$ imply $\underline{I}^*_{1,1} \leq 0$ and $\underline{I}^*_{1,2} \leq 0$, respectively. Finally, we define $\underline{I}_1^* := \max[\underline{I}^*_{1,1}, \underline{I}^*_{1,2}]$.

Appendix B. Parametric model (only for the referees)

B1: Equilibrium allocation of the deposit-lease policy without strategic action: Using (47) in (3), the first-order conditions with a deposit-lease policy without strategic action read

$$\alpha - by_{Mt} = \alpha - by_{Nt} \quad \text{for } t = 1, 2, \tag{B1}$$

$$\alpha - by_{i1} = c_i (x_{i1} + \delta x_{i2}) + (1 + \psi) h \quad \text{for } i = M, N, \tag{B2}$$

$$\alpha - by_{i2} = c_i (x_{i1} + x_{i2}) + \frac{\psi h}{\delta} \quad \text{for } i = M, N. \tag{B3}$$

Solving (1), (B1), (B2) and (B3) with respect to y_{i1}, x_{i1}, y_{i2} and x_{i2} for $i = M, N$ yields

$$y_{i1}^* = \frac{(c_M + c_N)[b(c_M + c_N)(\alpha - h(1+\psi)) + 2c_M c_N(\alpha(1-\delta) - h)]}{\Omega}, \tag{B4}$$

$$x_{i1}^* = \frac{2(c_M + c_N - c_i)[b(c_M + c_N)(\alpha - h(1+\psi)) + 2c_M c_N(\alpha(1-\delta) - h)]}{\Omega}, \tag{B5}$$

$$y_{i2}^* = \frac{(c_M + c_N)[b(c_M + c_N)(\alpha\delta - h\psi) - 2c_M c_N h(\psi(1-\delta) - \delta)]}{\Omega\delta}, \tag{B6}$$

$$x_{i2}^* = \frac{2(c_M + c_N - c_i)[b(c_M + c_N)(\alpha\delta - h\psi) - 2c_M c_N h(\psi(1-\delta) - \delta)]}{\Omega\delta}, \tag{B7}$$

where $\Omega := b^2(c_M + c_N)^2 + 4bc_M c_N(c_M + c_N) + 4c_M^2 c_N^2(1-\delta) > 0$. Taking the difference between (B4) and (B5) as well as between (B6) and (B7) for $i = M$ yields

$$y_{M1}^* - x_{M1}^* = \frac{(c_M - c_N)[b(c_M + c_N)(\alpha - h(1+\psi)) + 2c_M c_N(\alpha(1-\delta) - h)]}{\Omega}, \tag{B8}$$

$$y_{M2}^* - x_{M2}^* = \frac{(c_M - c_N)[b(c_M + c_N)(\alpha\delta - h\psi) + 2c_M c_N h(\psi(1-\delta) + \delta)]}{\Omega\delta}, \tag{B9}$$

so that $y_{Mt}^* - x_{Mt}^* \gtreqless 0 \iff c_M \gtreqless c_N$ for $t = 1, 2$ if (B4) to (B7) are greater than zero.

B2: Conditions for non-strategic action with a deposit-lease policy: With a deposit-lease policy, D_t, S_1 and S from (5), (10) and (27), respectively, are given by

$$D_t(p_t) = \frac{\alpha - p_t}{b} \quad \text{for } t = 1, 2 \tag{B10}$$

$$S_1\left(\frac{p_1 - \delta p_2}{1-\delta}, \underline{\xi}_1, \overline{\xi}_1\right) = \begin{cases} \frac{p_1-\delta p_2}{c_N(1-\delta)} & \text{for } \frac{p_1-\delta p_2}{1-\delta} \le c_N \underline{\xi}_1, \\ \underline{\xi}_1 & \text{for } \frac{p_1-\delta p_2}{1-\delta} \in [c_N\underline{\xi}_1, c_N\overline{\xi}_1], \\ \frac{p_1-\delta p_2}{c_N(1-\delta)} - \overline{\xi}_1 + \underline{\xi}_1 & \text{for } \frac{p_1-\delta p_2}{1-\delta} \ge c_N\overline{\xi}_1, \end{cases} \tag{B11}$$

$$S(p_2, \underline{\xi}, \overline{\xi}) = \begin{cases} \frac{p_2}{c_N} & \text{for } p_2 \le c_N\underline{\xi}, \\ \underline{\xi} & \text{for } p_2 \in [c_N\underline{\xi}, c_N\overline{\xi}], \\ \frac{p_2}{c_N} - \overline{\xi} + \underline{\xi} & \text{for } p_2 \ge c_N\overline{\xi}, \end{cases} \tag{B12}$$

so that $D'_{Nt} = -1/b$, $S'_{1-} = 0$, $S'_{1+} = 1/c_N$, $S'_{-} = 0$ and $S'_{+} = 1/c_N$. Then, the conditions for non-strategic action, (A26) to (A29), become

$$0 \le y^*_{M1} - x^*_{M1} + \frac{(y^*_{M2} - x^*_{M2})b\delta}{b + c_N(1-\delta)} + \frac{h[b(1+\psi) + c_N]}{c_N[b + c_N(1-\delta)]}, \tag{B13}$$

$$0 \ge y^*_{M1} - x^*_{M1}, \tag{B14}$$

$$0 \le y^*_{M2} - x^*_{M2} + \frac{h\psi}{c_N\delta}, \tag{B15}$$

$$0 \ge \frac{(y^*_{M1} - x^*_{M1})b}{b + c_N(1-\delta)} + y^*_{M2} - x^*_{M2} - \frac{h}{b + c_N(1-\delta)}. \tag{B16}$$

From (B8), $c_M - c_N \le 0$ is necessary and sufficient for (B14) to hold. From (B8) and (B9), $c_M - c_N \le 0$ implies $y^*_{M1} - x^*_{M1} \le 0$ and $y^*_{M2} - x^*_{M2} \le 0$, which is sufficient for (B16) to hold. The right-hand sides of (B13) and (B15) are increasing in h, which defines lower bounds of h for (B13) and (B15) to hold:

$$\underline{h}_{L1} := \frac{\alpha c_N(c_N - c_M)[b^2(c_M + c_N)(1+\delta) + bc_N(3c_M + c_N)(1-\delta) + 2c_M c_N^2(1-\delta)^2]}{(c_M + c_N)[b^2 + 2bc_N + c_N^2(1-\delta)][b(c_M + c_N)(1+\psi) + 2c_M c_N]}, \tag{B17}$$

$$\underline{h}_{L2} := \frac{\alpha b c_N(c_N - c_M)(c_M + c_N)\delta}{\psi(c_M + c_N)[b^2(c_M + c_N) + bc_N(3c_M + c_N) + 2c_M c_N^2(1-\delta)] - 2c_M c_N^2(c_N - c_M)\delta}. \tag{B18}$$

Taking the difference between (B17) and (B18) yields

$$\underline{h}_{L1} - \underline{h}_{L2} = \frac{\alpha c_N(c_N - c_M)(c_M + c_N)\Omega}{(c_M + c_N)[b^2 + 2bc_N + c_N^2(1-\delta)][b(c_M + c_N)(1+\psi) + 2c_M c_N](1-\delta)} \cdot \frac{[b + c_N(1-\delta)]^2(\psi(1-\delta) - \delta) + b^2\delta^2 + 2c_M c_N[b + c_N(1-\delta)]\delta(1-\delta)/(c_M + c_N)}{\psi(c_M + c_N)[b^2(c_M + c_N) + bc_N(3c_M + c_N) + 2c_M c_N^2(1-\delta)] - 2c_M c_N^2(c_N - c_M)\delta},$$

so that $c_M - c_N \le 0$ and $h \ge \underline{h}_L := \max[\underline{h}_{L1}, \underline{h}_{L2}]$ are necessary and sufficient for non-strategic action.

B3: Equilibrium allocation of the deposit-purchase policy without strategic action compared to that of the deposit-lease policy without strategic action: Using (47) in (23), the first-order conditions with a deposit-purchase policy without strategic action read

$$\alpha - by_{Mt} = \alpha - by_{Nt} \quad \text{for } t = 1, 2, \tag{B19}$$

$$\alpha - by_{M1} = c_M \left(x_{M1} + \delta x_{M2}\right) + (1 + \psi)\, h, \tag{B20}$$

$$\alpha - by_{N1} = c_N \left(x_{N1} + \delta x_{N2}\right) + \psi h, \tag{B21}$$

$$\alpha - by_{i2} = c_i \left(x_{i1} + x_{i2}\right) + \frac{\psi h}{\delta} \quad \text{for } i = M, N. \tag{B22}$$

Solving (1), (B19), (B20), (B21) and (B22) with respect to y_{i1}, x_{i1}, y_{i2} and x_{i2} for $i = M, N$ yields

$$y^\star_{i1} = y^*_{i1} + \frac{hc_M[b(c_M + c_N) + 2c_M c_N]}{\Omega}, \tag{B23}$$

$$x^\star_{M1} = x^*_{M1} - \frac{hb[b(c_M + c_N) + 2c_M c_N(1 + \delta)]]}{\Omega(1 - \delta)}, \tag{B24}$$

$$x^\star_{N1} = x^*_{N1} + \frac{h[b^2(c_M + c_N) + 2bc_M(2c_N + c_M(1 - \delta)) + 4c_M^2 c_N(1 - \delta)]}{\Omega(1 - \delta)}, \tag{B25}$$

$$y^\star_{i2} = y^*_{i2} - \frac{2hc_M^2 c_N}{\Omega}, \tag{B26}$$

$$x^\star_{M2} = x^*_{M2} + \frac{hb[b(c_M + c_N) + 4c_M c_N]}{\Omega(1 - \delta)}, \tag{B27}$$

$$x^\star_{N2} = x^*_{N2} - \frac{h[b^2(c_M + c_N) + 4bc_M c_N + 4c_M^2 c_N(1 - \delta)]}{\Omega(1 - \delta)}. \tag{B28}$$

Defining $y_t := y_{Mt} + y_{Nt} = x_{Mt} + x_{Nt}$ for $t = 1, 2$, we obtain from (B23) and (B26) $y^\star_1 > y^*_1$ and $y^\star_2 < y^*_2$, respectively. Furthermore, defining $y_i := y_{i1} + y_{i2}$ for $i = M, N$, we obtain from (B23) to (B28)

$$y^\star_i = y^*_i + \frac{hbc_M(c_M + c_N)}{\Omega}, \tag{B29}$$

$$x^\star_i = x^*_i + \frac{2hbc_M(c_M + c_N - c_i)}{\Omega}, \tag{B30}$$

$$\begin{aligned} y^\star_{M1} - x^\star_{M1} = {} & y^*_{M1} - x^*_{M1} \\ & + \frac{h[b^2(c_M + c_N) + bc_M[c_M(1 - \delta) + c_N(3 + \delta)] + 2c_M^2 c_N(1 - \delta)]}{\Omega}, \end{aligned} \tag{B31}$$

$$y^\star_{M2} - x^\star_{M2} = y^*_{M2} - x^*_{M2} - \frac{h[b^2(c_M + c_N) + 4bc_M c_N + 2c_M^2 c_N(1 - \delta)]}{\Omega}. \tag{B32}$$

Defining $y := y_1 + y_2 = x_1 + x_2$, we obtain from (B29) $y^\star > y^*$. Taking the sum of (B31) and (B32) yields

$$y^\star_M - x^\star_M = y^*_M - x^*_M + \frac{hbc_M(c_M - c_N)(1 - \delta)}{\Omega}, \tag{B33}$$

so that $y^\star_M - x^\star_M \gtreqless 0 \iff c_M \gtreqless c_N$ and $|y^\star_M - x^\star_M| > |y^*_M - x^*_M|$.

B4: Conditions for non-strategic action with a deposit-purchase policy: With a deposit-purchase policy, observe that D_t and S are given by (B10) and (B12), respectively, while $S_1 = (p_1 - \delta p_2)/[c_N(1-\delta)]$. Thus, $D'_{Nt} = -1/b$, $S'_1 = 1/c_N$, $S'_- = 0$ and $S'_+ = 1/c_N$. Then, the conditions for non-strategic action, (A38) to (A41), become

$$0 \le y^\star_{M1} - x^\star_{M1} + \frac{(y^\star_{M2} - x^\star_{M2})b\delta}{b + c_N(1-\delta)} + \frac{h[b(1+\psi) + c_N]}{bc_N + c_N^2(1-\delta)}, \tag{B34}$$

$$0 \ge y^\star_{M1} - x^\star_{M1} + \frac{(y^\star_{M2} - x^\star_{M2})b\delta}{b\delta + c_N(1-\delta)} + \frac{h}{b\delta + c_N(1-\delta)}, \tag{B35}$$

$$0 \le \frac{(y^\star_{M1} - x^\star_{M1})b}{b + c_N(1-\delta)} + y^\star_{M2} - x^\star_{M2} + \frac{h[b\psi + c_N((1-\delta)\psi - \delta)]}{c_N[b + c_N(1-\delta)]\delta}, \tag{B36}$$

$$0 \ge \frac{(y^\star_{M1} - x^\star_{M1})b}{b + c_N(1-\delta)} + y^\star_{M2} - x^\star_{M2} - \frac{h}{b + c_N(1-\delta)}. \tag{B37}$$

Using (B31) and (B32), we can modify these conditions to

$$\begin{aligned} 0 \le\ & y^*_{M1} - x^*_{M1} + \frac{(y^*_{M2} - x^*_{M2})b\delta}{b + c_N(1-\delta)} + \frac{h[b(1+\psi) + c_N]}{c_N[b + c_N(1-\delta)]} + \frac{2hc_M^2c_N^2(1-\delta)}{\Omega[b + c_N(1-\delta)]} \\ & + \frac{hb[b^2(c_M + c_N) + b[c_M^2 + 4c_Mc_N + c_N^2] + c_Mc_N[3c_M(1-\delta) + c_N(3+\delta)]]}{\Omega[b\delta + c_N(1-\delta)]}, \end{aligned} \tag{B38}$$

$$\begin{aligned} 0 \ge\ & y^*_{M1} - x^*_{M1} + \frac{(y^*_{M2} - x^*_{M2})b\delta}{b\delta + c_N(1-\delta)} + \frac{6hc_M^2c_N^2(1-\delta)}{\Omega[b\delta + c_N(1-\delta)]} \\ & + \frac{hb[b[c_M^2(1+\delta) + c_Mc_N(3-\delta) + 2c_N^2] + c_Mc_N[c_M(5-\delta) + c_N(7+\delta)]]}{\Omega[b\delta + c_N(1-\delta)]}, \end{aligned} \tag{B39}$$

$$\begin{aligned} 0 \le\ & \frac{(y^*_{M1} - x^*_{M1})b}{b + c_N(1-\delta)} + y^*_{M2} - x^*_{M2} + \frac{h\psi}{c_N\delta} \\ & - \frac{2c_Nh[b^2(2c_M + c_N) + 2bc_M(c_M + 2c_N) + 3c_M^2c_N(1-\delta)]}{\Omega[b + c_N(1-\delta)]}, \end{aligned} \tag{B40}$$

$$\begin{aligned} 0 \ge\ & \frac{(y^*_{M1} - x^*_{M1})b}{b + c_N(1-\delta)} + y^*_{M2} - x^*_{M2} - \frac{h}{b + c_N(1-\delta)} \\ & - \frac{2c_Nh[b^2(2c_M + c_N) + 2bc_M(c_M + 2c_N) + 3c_M^2c_N(1-\delta)]}{\Omega[b + c_N(1-\delta)]}. \end{aligned} \tag{B41}$$

From (B8) and (B9), $c_M - c_N < 0$ is necessary for (B39) to hold and sufficient for (B41) to hold. The right-hand side of (B39) is increasing in h, which defines an upper bound of h for (B39) to hold

$$\overline{h}_B := \frac{\alpha(c_N - c_M)[2b^2(c_M + c_N)\delta + bc_N(c_M(1+2\delta) + c_N)(1-\delta) + 2c_Mc_N^2(1-\delta)^2]}{b(c_N - c_M)[b[c_N + (c_M + c_N)\psi](1+\delta) + c_N[c_N + (3c_M + c_N)\psi](1-\delta)] + \Gamma}, \tag{B42}$$

where $\Gamma := \Omega + 2c_M c_N[b^2 + 2bc_N + c_N^2(1-\delta)] > 0$. The right-hand sides of (B38) and (B40) are increasing in h, which defines lower bounds of h for (B38) and (B40) to hold

$$\underline{h}_{B1} := \frac{\alpha c_N(c_N - c_M)[b^2(c_M + c_N)(1+\delta) + bc_N(3c_M + c_N)(1-\delta) + 2c_M c_N^2(1-\delta)^2]}{b[b^2 + 2bc_N + c_N^2(1-\delta)][c_N(c_N - c_M) + (c_M + c_N)^2\psi] + (b + c_N)\Gamma}, \tag{B43}$$

$$\underline{h}_{B2} := \frac{\alpha b c_N(c_N - c_M)[2b(c_M + c_N) + c_N(3c_M + c_N)(1-\delta)]\delta}{(c_M + c_N)[b^2 + 2bc_N + c_N^2(1-\delta)][b(c_M + c_N) + 2c_M c_N(1-\delta)]\psi - c_N\Gamma\delta}. \tag{B44}$$

Comparing (B38) with (B13) and (B40) with (B15) for $c_M - c_N < 0$, $\underline{h}_{L1} > \underline{h}_{B1}$ and $\underline{h}_{L2} < \underline{h}_{B2}$ hold, respectively. Taking the difference between (B43) and (B44) yields

$$\underline{h}_{B1} - \underline{h}_{B2} = \frac{\alpha c_N(c_N - c_M)[b^2 + 2bc_N + c_N^2(1-\delta)]\Omega}{b[b^2 + 2bc_N + c_N^2(1-\delta)][c_N(c_N - c_M) + (c_M + c_N)^2\psi] + (b + c_N)\Gamma} \cdot \frac{[(c_M + c_N)\psi(1-\delta) - (2c_M + c_N)\delta][b + c_N(1-\delta)] - 3bc_N\delta}{(c_M + c_N)[b^2 + 2bc_N + c_N^2(1-\delta)][b(c_M + c_N) + 2c_M c_N(1-\delta)]\psi - c_N\Gamma\delta},$$

so that $c_M - c_N < 0$ and $\overline{h}_B \geq h \geq \underline{h}_B := \max[\underline{h}_{B1}, \underline{h}_{B2}]$ are necessary and sufficient for non-strategic action.

B5: Equilibrium allocation of the deposit-purchase policy with strategic action compared to that of the deposit-lease policy with strategic action: With strategic action, (B1) and (B19) become

$$\alpha - by_{M1} - \mathrm{SE}_{j1} = \alpha - by_{N1}, \tag{B45}$$

$$\alpha - by_{M2} - \frac{\mathrm{SE}_{j2}}{\delta} = \alpha - by_{N2}, \tag{B46}$$

for $j = L, B$, respectively. Substituting (A3) to (A6) into SE_{Lt} and SE_{Bt} introduced before Propositions 4 and 2, respectively, and using $D'_t = -1/b$, $S'_1 = S' = 1/c_N$ and $H' = h$ yields

$$\mathrm{SE}_{j1} = \frac{(y_{M1} - x_{M1})bc_N[b + c_N(1-\delta)] + (y_{M2} - x_{M2})b^2 c_N\delta + hb[b(1+\psi) + c_N]}{b^2 + 2bc_N + c_N^2(1-\delta)},$$

$$\mathrm{SE}_{j2} = \frac{(y_{M1} - x_{M1})b^2 c_N\delta + (y_{M2} - x_{M2})bc_N[b + c_N(1-\delta)]\delta + hb[b\psi + c_N((1-\delta)\psi - \delta)]}{b^2 + 2bc_N + c_N^2(1-\delta)},$$

for $j = L, B$. Solving (1), (B45) and (B46) for $j = L$ as well as (B2) and (B3) with respect to y_{i1}, x_{i1}, y_{i2} and x_{i2} for $i = M, N$ yields the equilibrium quantities with the strategic deposit-lease policy. Solving (1), (B45) and (B46) for $j = B$ as well as (B20), (B21) and (B22) with respect to these variables yields the equilibrium quantities with the strategic deposit-purchase policy. Taking the differences of these quantities yields

$$\tilde{y}_{M1} = \hat{y}_{M1} + \frac{hc_M[b(c_M + 2c_N) + 3c_M c_N]}{\Lambda}, \tag{B47}$$

$$\tilde{y}_{N1} = \hat{y}_{N1} + \frac{hb^2[b(c_M + c_N)(c_M + 2c_N) + 2c_N(3c_M^2 + 5c_Mc_N + c_N^2)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda} + \frac{hc_Mc_N^2[b[6(c_M + c_N) + (5c_M + c_N)(1-\delta)] + 6c_Mc_N(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda}, \tag{B48}$$

$$\tilde{x}_{M1} = \hat{x}_{M1} - \frac{hb[b(c_M + 2c_N) + 3c_Mc_N(1+\delta)]}{\Lambda(1-\delta)}, \tag{B49}$$

$$\tilde{x}_{N1} = \hat{x}_{N1} + \frac{hb^3[b(c_M + 2c_N) + 4c_N(2c_M + c_N) + 2(c_M^2 + c_Mc_N + c_N^2)(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda(1-\delta)} + \frac{hb^2c_N[12c_Mc_N + (11c_M^2 + 9c_Mc_N + 4c_N^2)(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda(1-\delta)} + \frac{3hc_Mc_N^2[2b[2(c_M + c_N) + c_M(1-\delta)] + 3c_Mc_N(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda}, \tag{B50}$$

$$\tilde{y}_{M2} = \hat{y}_{M2} - \frac{3hc_M^2c_N}{\Lambda}, \tag{B51}$$

$$\tilde{y}_{N2} = \hat{y}_{N2} - \frac{2hc_N[b^2(c_M^2 + c_Mc_N + c_N^2) + 3bc_Mc_N(c_M + c_N) + 3c_M^2c_N^2(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda}, \tag{B52}$$

$$\tilde{x}_{M2} = \hat{x}_{M2} + \frac{hb[b(c_M + 2c_N) + 6c_Mc_N]}{\Lambda(1-\delta)}, \tag{B53}$$

$$\tilde{x}_{N2} = \hat{x}_{N2} - \frac{hb^2[b^2(c_M + 2c_N) + 4bc_N(c_M + 2c_N) + 12c_Mc_N^2]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda(1-\delta)} - \frac{hc_N[b^2(5c_M^2 + 3c_Mc_N + 4c_N^2) + 12bc_Mc_N(c_M + c_N) + 9c_M^2c_N^2(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda}, \tag{B54}$$

where $\Lambda := b^2(c_M + 2c_N)^2 + 6bc_Mc_N(c_M + 2c_N) + 9c_M^2c_N^2(1-\delta) > 0$. From (B47) and (B48), we obtain $\tilde{y}_1 > \hat{y}_1$, and from (B51) and (B52), we obtain $\tilde{y}_2 < \hat{y}_2$. Furthermore, from (B47) to (B54), we obtain

$$\tilde{y}_M = \hat{y}_M + \frac{hbc_M(c_M + 2c_N)}{\Lambda}, \tag{B55}$$

$$\tilde{y}_N = \hat{y}_N + \frac{hb[b^2(c_M + c_N)(c_M + 2c_N) + 4bc_Mc_N(c_M + 2c_N)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda} + \frac{hbc_Mc_N^2(5c_M + c_N)(1-\delta)}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda}, \tag{B56}$$

$$\tilde{x}_M = \hat{x}_M + \frac{3hbc_Mc_N}{\Lambda}, \tag{B57}$$

$$\tilde{x}_N = \hat{x}_N + \frac{2hb[b^2(c_M^2 + c_Mc_N + c_N^2) + 3bc_Mc_N(c_M + c_N) + 3c_M^2c_N^2(1-\delta)]}{[b(c_M + 2c_N) + c_N^2(1-\delta)]\Lambda}, \tag{B58}$$

$$\tilde{y}_{M1} - \tilde{x}_{M1} = \hat{y}_{M1} - \hat{x}_{M1} + \frac{h[b^2(c_M + 2c_N) + bc_M[c_M(1-\delta) + c_N(5+\delta)]]}{\Lambda(1-\delta)} + \frac{3hc_M^2c_N(1-\delta)}{\Lambda(1-\delta)}, \tag{B59}$$

$$\tilde{y}_{M2} - \tilde{x}_{M2} = \hat{y}_{M2} - \hat{x}_{M2} - \frac{h[b^2(c_M + 2c_N) + 6bc_Mc_N + 3c_M^2c_N(1-\delta)]]}{\Lambda(1-\delta)}. \tag{B60}$$

From (B55) and (B56), we obtain $\tilde{y} > \hat{y}$. Taking the sum of (B59) and (B60) yields

$$\tilde{y}_M - \tilde{x}_M = \hat{y}_M - \hat{x}_M + \frac{hbc_M(c_M - c_N)}{\Lambda}. \tag{B61}$$

B7: Total welfare of the deposit-purchase policy with strategic action compared to that of the deposit-lease policy with strategic action: Using (47) in (2), total welfare in general reads

$$\begin{aligned} U = {} & \alpha y_{M1} - \frac{b}{2}(y_{M1})^2 - \frac{c_M}{2}(x_{M1})^2 - p_1(y_{M1} - x_{M1}) \\ & + \delta[\alpha y_{M2} - \frac{b}{2}(y_{M2})^2 - \frac{c_M}{2}(x_M)^2 + \frac{c_M}{2}(x_{M1})^2 - p_2(y_{M2} - x_{M2})] - h(x_1 + \psi x) \\ & + \alpha y_{N1} - \frac{b}{2}(y_{N1})^2 - \frac{c_N}{2}(x_{N1})^2 - p_1(y_{N1} - x_{N1}) \\ & + \delta[\alpha y_{N2} - \frac{b}{2}(y_{N2})^2 - \frac{c_N}{2}(x_N)^2 + \frac{c_N}{2}(x_{N1})^2 - p_2(y_{N2} - x_{N2})], \end{aligned} \tag{B62}$$

where $p_t = \alpha - by_{Nt}$ for $t = 1, 2$ by (5). Substituting the respective quantities into (B62) yields total welfare of the deposit-lease [deposit-purchase] policy with strategic action $\widehat{U}$ [$\widetilde{U}$]. Taking the difference of these welfare values yields

$$\widehat{U} - \widetilde{U} = \widehat{U}_F - \widetilde{U}_F + \widehat{U}_H - \widetilde{U}_H, \tag{B63}$$

where the difference in consumption welfare is

$$\widehat{U}_F - \widetilde{U}_F = -h\left[\alpha(c_M - c_N)\Delta_\alpha + h\psi\Delta_\psi + h\Delta_h\right], \tag{B64}$$

with

$$\begin{aligned} \Delta_\alpha = {} & \frac{b^5 c_N(c_M + 2c_N)^2 + b^4 c_N(c_M + 2c_N)[(1+\delta)c_M^2 + (9 - 5\delta)c_M c_N + 2c_N^2(1-\delta)]}{[b^2 + 2bc_N + c_N^2(1-\delta)]\Lambda^2} \\ & + \frac{b^3 c_M c_N^2[7c_M^2 + 31c_M c_N + 16c_N^2](1-\delta) + 3b^2 c_M^2 c_N^3[5c_M(1-\delta) + c_N(7-\delta)](1-\delta)}{[b^2 + 2bc_N + c_N^2(1-\delta)]\Lambda^2} \\ & + \frac{9bc_M^3 c_N^4(1-\delta)^2}{[b^2 + 2bc_N + c_N^2(1-\delta)]\Lambda^2} > 0, \end{aligned} \tag{B65}$$

$$\begin{aligned} \Delta_\psi = {} & \frac{b^5[3c_M^4 + 12c_M^3 c_N + 20c_M^2 c_N^2 + 20c_M c_N^3 + 8c_N^4] + 10b^4 c_M^2 c_N(c_M + c_N)(2c_M + 5c_N)}{[b^2 + 2bc_N + c_N^2(1-\delta)]\Lambda^2} \\ & + \frac{56b^4 c_M c_N^3(c_M + c_N) + 2b^3 c_M^2 c_N^2[c_M^2(26 - 8\delta) + c_M c_N(85 - 31\delta) + c_N^2(76 - 22\delta)]}{[b^2 + 2bc_N + c_N^2(1-\delta)]\Lambda^2} \\ & + \frac{[4b^3 c_M c_N^5 + 18b^2 c_M^2 c_N^3(4c_M^2 + 9c_M c_N + c_N^2) + 9bc_M^3 c_N^4(5c_M + 2c_N)(1-\delta)](1-\delta)}{[b^2 + 2bc_N + c_N^2(1-\delta)]\Lambda^2} > 0, \end{aligned} \tag{B66}$$

$$\Delta_h = \frac{b^6(c_M+c_N)(c_M+2c_N)^2 + b^5(c_M+2c_N)[4c_M^3(1-\delta)+c_M^2c_N(22-8\delta)+c_Mc_N^2(25-7\delta)]}{2[b^2+2bc_N+c_N^2(1-\delta)]\Lambda^2(1-\delta)}$$
$$+\frac{b^5(c_M+2c_N)c_N^3(6-2\delta)+b^4c_M^2c_N[40c_M^2(1-\delta)+4c_Mc_N(46-31\delta)+3c_N^2(83-47\delta)]}{2[b^2+2bc_N+c_N^2(1-\delta)]\Lambda^2(1-\delta)}$$
$$+\frac{8b^4c_N^4[c_M(13-7\delta)+c_N(1-\delta)]+b^3c_M^3c_N^2[3c_M(51-5\delta)(1-\delta)+c_N(446-442\delta+68\delta^2)]}{2[b^2+2bc_N+c_N^2(1-\delta)]\Lambda^2(1-\delta)}$$
$$+\frac{b^3c_M^2c_N^2[c_N^2(335-298\delta+35\delta^2)+8c_M^2(7-\delta)]+3b^2c_M^3c_N^3[c_M(93-45\delta)+c_N(157-73\delta)]}{2[b^2+2bc_N+c_N^2(1-\delta)]\Lambda^2(1-\delta)}$$
$$+\frac{3b^2c_M^2c_N^5(50-26\delta)+9bc_M^3c_N^4[3c_M(9-\delta)+4c_N(5-\delta)](1-\delta)^2+81c_M^4c_N^5(1-\delta)^3}{2[b^2+2bc_N+c_N^2(1-\delta)]\Lambda^2(1-\delta)} > 0, \tag{B67}$$

and where the difference in climate welfare is

$$\widehat{U}_H - \widetilde{U}_H$$
$$= \frac{h^2\psi b[b^2(2c_M+c_N)(c_M+2c_N)+6bc_Mc_N(c_M+2c_N)+3c_Mc_N^2(2c_M+c_N)(1-\delta)]}{[b^2+2bc_N+c_N^2(1-\delta)]\Lambda}$$
$$+\frac{h^2[b(2c_M+c_N)+3c_Mc_N][b^2(c_M+2c_N)+2bc_N(2c_M+c_N)+3c_Mc_N^2(1-\delta)]}{[b^2+2bc_N+c_N^2(1-\delta)]\Lambda}. \tag{B68}$$

$\widehat{U}_F - \widetilde{U}_F$ is negative if $c_M - c_N \geq 0$, and $\widehat{U}_H - \widetilde{U}_H$ is positive.

Appendix C. Calibration

To calculate the marginal damages per barrel of oil, we use the three discount rates used by IWG (2016), namely 2.5%, 3% and 5%. Period 1 comprises 40 years, which implies discount factors of $\frac{1}{1.025^{40}} = 37\%$, 31% and 14%, respectively. In accordance with IWG (2016, p.16), marginal damages per ton of CO_2 for the years between 2010 and 2020, 2020 and 2030, 2030 and 2040, and 2040 and 2050 are calculated using linear interpolation. Afterwards, these damages are discounted and multiplied by 0.43 (EPA 2018) and 10^9 to get the real marginal damages per billion barrel of oil. $h(1+\psi)$ is the average of these damages for the years from 2011 to 2050. Dividing the real marginal damage in the year 2050 by the real marginal damage in the year 2011 yields the climate discount rate $\frac{\psi}{1+\psi}$.

We calibrate the economy without any policies to real world oil quantities and prices. The associated equilibrium is characterized by

$$\alpha - by_{Mt} = \alpha - by_{Nt} \quad \text{for } t = 1, 2, \tag{C1}$$
$$\alpha - by_{i1} = c_i\,(x_{i1} + \delta x_{i2}) \quad \text{for } i = M, N, \tag{C2}$$
$$\alpha - by_{i2} = c_i\,(x_{i1} + x_{i2}) \quad \text{for } i = M, N. \tag{C3}$$

Table 3: Parameter values (h, c_i, b in $\$b/bb$, α in $\$b$).

r	2.5%	3%	5%
δ	37%	31%	14%
h	8.904	6.487	1.699
ψ	1.169	0.870	0.646
c_M	0.248	0.248	0.248
c_N	0.070	0.070	0.070
α	117	117	117
b	0.060	0.060	0.060

From (C1), we get $y_{Mt} = y_{Nt} = \frac{y_t}{2}$ for $t = 1, 2$. Thus, the two country groups consume the same amount of fossil fuel in each period. According to EIA (2017), this is approximately the case for the OECD countries and the Non-OECD countries until the year 2050, such that we choose the OECD countries as country M and the Non-OECD countries as country N. Furthermore, we define period 1 as the years from 2011 to 2050, and period 2 as the years from 2051 to 2090. Concerning oil production in period 1, we use the projected data from EIA (2017) and find $x_{M1} = 280bb$ and $x_{N1} = 989bb$. From (C2) and (C3), we get $\frac{c_N}{c_M} = \frac{x_{Mt}}{x_{Nt}}$ for $t = 1, 2$, such that we use $\frac{c_N}{c_M} = \frac{280}{989}$. Concerning oil production in period 2, we assume that without policy intervention all proved reserves will be extracted until the year 2090. From EIA (2018), we find that the proved reserves were $1651bb$ in 2016 and from EIA (2017), we find that oil production in the years from 2016 to 2050 will be $1092bb$, such that we use $x_2 = 559bb$. From $\frac{c_N}{c_M} = \frac{x_{M2}}{x_{N2}}$, we then get $x_{M2} = 123bb$ and $x_{N2} = 436bb$. In accordance with IEA (2013, p.228), we use $100\$b$ for the production costs per billion barrel of oil in period 2. From $100\$b = c_i(x_{i1} + x_{i2})$ for $i = M, N$, we can then calculate c_M and c_N. Using these in (C2) and (C3), we find expressions of α and b depending on δ, where we choose $\delta = \frac{1}{1.03^{40}} = 37\%$ as reference case. We summarize all parameter values in Table 3.

Table 4 shows the allocation under the deposit-lease and deposit-purchase policy, respectively. Table 5 reports the differences in total welfare (U), consumption welfare (U_F) and climate welfare (U_H) at the policies. From (A11) and (A19), the differences in country M's welfare and country N's welfare at the policies are proportional to the differences in total welfare:

$$\widehat{U}_M - \widetilde{U}_M = b(\widehat{U} - \widetilde{U}) \quad \text{and} \quad \widehat{U}_N - \widetilde{U}_N = (1-b)(\widehat{U} - \widetilde{U}). \tag{C4}$$

Since the climate damage and the qualitative difference in total welfare depends on

Table 4: Quantities (bb).

r	$\hat{y}_1$	$\hat{y}_2$	$\hat{y}$	$\tilde{y}_1$	$\tilde{y}_2$	$\tilde{y}$	z_1	z
2.5%	1030	344	1374	1122	286	1408	398	202
3%	1122	403	1525	1187	362	1549	262	133
5%	1277	434	1711	1293	424	1717	110	028

Table 5: Welfare differences between deposit-lease policy and deposit-purchase policy ($\$b$).

	$\widehat{U} - \widetilde{U}$	$\widehat{U}_F - \widetilde{U}_F$	$\widehat{U}_H - \widetilde{U}_H$
2.5%	46	-1128	1174
3%	-45	-602	557
5%	-48	-81	33

the discount rate, we can find an expression for the latter deepening on the discount rate. Using the three values of h and ψ from Table 3, we first estimate functions of the climate damage parameters depending on r:[21]

$$h(r) = 46 \cdot 0.52^{100r} \quad \text{and} \quad \psi(r) = 0.64 + 33 \cdot 0.19^{100r}. \tag{C5}$$

Using these functions, we can then calculate the total welfare difference depending on r, which we plot in Figure 2. The function becomes negative at $r \approx 2.7\%$, declines monotonically until $r \approx 3.7\%$ and converges towards zero afterwards. For high discount rates, the climate damage becomes negligible, deposit purchases and leases converge to zero and the quantities coincide with both policies.

[21] For $\psi(r) = a_\psi + \beta_\psi(\gamma_\psi)^{100r}$, e.g., we have $\psi(2.5) = 1.169, \psi(3) = 0.870, \psi(5) = 0.646$. For $h(r) = a_h + \beta_h(\gamma_h)^{100r}$, we would get $h(r) = -0.32 + 42 \cdot 0.54^{100r}$, such that the climate damage would become negative for $r > 8\%$. Thus, we choose $h(r) = \beta_h(\gamma_h)^{100r}$ and minimize the sum of quadratic differences over β_h and γ_h.