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Conference Paper

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Beiträge zur Jahrestagung des Vereins für Socialpolitik 2016: Demographischer Wandel - Session: Bargaining and Participation Constraints, No. B04-V3

Provided in Cooperation with:

Verein für Socialpolitik / German Economic Association

Suggested Citation: Schopf, Mark; Voss, Achim (2016) : Bargaining over Natural Resources: Governments between Environmental Organizations and Extraction Firms, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2016: Demographischer Wandel - Session: Bargaining and Participation Constraints, No. B04-V3, ZBW - Deutsche Zentralbibliothek für Wirtschaftswissenschaften, Leibniz-Informationszentrum Wirtschaft, Kiel und Hamburg

This Version is available at:

<https://hdl.handle.net/10419/145496>

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Bargaining over Natural Resources: Governments between Environmental Organizations and Extraction Firms

Preliminary Version

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February 11, 2016

Abstract

In this article, we propose a sequential Nash bargaining solution and apply it to a dynamic bargaining game on exhaustible-resource extraction. The government and two agents bargain via the asymmetric Nash bargaining solution. Should the trilateral negotiation fail, the government chooses one agent for a bilateral negotiation. In this negotiation, the disagreement point is to bargain with the other agent. Finally, should this second bilateral negotiation break down, the government chooses the welfare maximizing policy.

In our dynamic bargaining game, the environmental organization is willing to pay for less extraction, because of stock-pollution effects, while the extraction firm is willing to pay for extraction per se. The government dislikes extraction, because of flow-pollution effects, but is willing to accept some if it is paid for it. It turns out that the disagreement point in the trilateral negotiation is always to bargain with the environmental organization. This is because there is no conflict of interest between the government and the environmental organization concerning extraction. However, as long as stock pollution is still low, it might be optimal for the environmental organization to let this bilateral negotiation break down. We demonstrate how these considerations shape the payments in case of agreement and disagreement, in total and over time.

Keywords: Nash Bargaining; Dynamic Bargaining; Lobbying; International Political Economy; Environmental Policy

JEL Codes: C71; C73; D72; F53; Q58

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1 Introduction

Natural-resource policy in many countries is the object of lobbying, bribery or simply auctioning off the usage rights. If both an environmental organization and an extraction firm are interested in taking influence on the policy, what will the political equilibrium look like, given that this equilibrium will depend on the stock of the resource, and that policy in turn changes the development of this stock?

As a step towards analyzing this question, we model this situation as a trilateral bargaining in which the government can threaten to bargain exclusively with one of the lobbies should the trilateral bargain break down. In the bilateral bargaining in turn, the disagreement point – that is, the behavior following a breakdown of the negotiation – is to bargain with the other lobby. The aim of this paper is to clarify which party would be chosen under which conditions and to demonstrate how this shapes the trilateral bargaining outcome. More specifically, we show how the transfer payments from the environmental organization and the extraction firm develop over time in a dynamic natural resource model.

In each negotiation, we apply the asymmetric Nash bargaining solution where the choice variables are resource extraction and transfer payments. Since we assume utilities to be linear in payments, each negotiation's equilibrium extraction does not depend on the disagreement points. Instead, it maximizes a weighted sum of non-transfer-payments utilities of the respective bargaining parties. The political weights decline with the respective marginal valuation of payments.

By contrast, the equilibrium transfer payments depend on the disagreement points. The better it is for the government or the worse it is for the other bargaining parties, the higher are the equilibrium payments. The disagreement points are determined endogenously by the government's choice of the bargaining order. After any failed bargaining, this choice has to be ex-post optimal. If the trilateral negotiation breaks down, the government can choose one of the parties for a (first) bilateral negotiation. Should this negotiation fail, the government starts a (second) bilateral negotiation with the remaining party. If this negotiation also breaks down, the government chooses the welfare-maximizing extraction. We refer to this game concept as sequential Nash bargaining solution.¹

It turns out that there is not always an agreement in the first bilateral negotiation. If the gains of cooperation are lower than the potential value of transfer payments in the second bilateral negotiation, there is no room for Pareto improvement. This happens if the first lobby's gain of keeping the government from bargaining with the other lobby is not high enough to compensate the government for the payments it would receive from that other lobby. In conclusion, we have to distinguish between four cases, agreement in the first bilateral negotiation with one, none or both of the parties. For each of these cases, we determine which party is chosen if the trilateral negotiation fails, depending on bargaining powers, political weights and non-transfer-payments utilities.

In a next step, we show that the results remain valid in a dynamic setting, where utilities and transfer payments have to be replaced by their intertemporal counterparts. Furthermore, we derive the payments in the periods by differentiating the intertemporal payments with respect to time. In the dynamic setting, we assume that if no agreement is reached in some bargaining constellation, cooperation in this bargaining constellation breaks down forever.²

For our explicit example, we apply an exhaustible-resource model with linear-quadratic functions. The extraction firm generates profits due to resource depletion, the government suffers from flow pollution due to resource extraction and the environmental organization dislikes stock pollution due to resource consumption.

¹ In the context of Nash bargaining, such a central role for one player in subsequent coalitions is also allowed by the models of Burguet and Caminal (2012) and Compte and Jehiel (2010). See Okada (2010) for an n-person Nash bargaining approach where there is no comparably central player.

² This assumption concept follows Petrosyan (1997) and is used by, e.g., Voss and Schopf (2015) in the context of bargaining over natural resources with two parties. See Sorger (2006) for an alternative approach.

There is no conflict of interest between the government and the environmental organization; both prefer zero extraction. This implies that the government would avoid to approach the environmental organization as its last bargaining partner; the environmental organization would pay nothing and let the government choose the welfare-maximizing policy. Instead, the government would invite the environmental organization to the bargaining table in the first bilateral negotiation, where both know that a breakdown would imply that the extraction firm influences policy.

It turns out that as long as the cumulative extraction is below some threshold, the environmental organization would not be willing to pay enough to keep the government from cooperating with the extraction firm. The reason is that the resource extractor's willingness to pay is high if stock-dependent extraction costs are still low. After the threshold has been crossed, a disagreement in the trilateral negotiation would imply that the government cooperates with the environmental organization, who pays to avoid further extraction. The disagreement extraction in the trilateral bargaining thus becomes zero.

In the recent literature, three papers deal with the conflict of interest between conservationists and harvesters.

In Harstad (2016), there are conservationists (who correspond to the environmental organization of the current article) who prefer a forest not to be harvested, and they also do not want to buy it, but they would buy it if it would otherwise be harvested. The harvesters, by contrast, would sell it, but if nobody wants to buy it, they would consider to harvest. The higher the bargaining power of the conservationists, the lower the price of the conservation good. This leads to less harvesting and more conservation in each period, because the conservationists can pay less to keep the harvesters from harvesting, and the harvesters only have to harvest a little to induce the conservationists to buy.

In Harstad and Mideksa (2015), the conservationists make a take-it-or-leave-it offer to (harvesting) governments. These governments can decide whether to centralize or decentralize. The take-it-or-leave-it offer from the conservationists can change this decision, which would be bad for themselves and could lead to more harvesting.

Finally, in Andrés-Domenech et al. (2015), forest owners and non-forest-owners maximize the sum of their profits. Depending on the time horizon, cooperation can lead to more afforestation, less deforestation and less production of the non-forest-owners. They apply the symmetric Nash bargaining solution to derive the intertemporal equilibrium profits, which are equal to the respective disagreement points plus half of the surplus due to cooperation. Finally, they demonstrate how the intertemporal equilibrium profits can be allocated over time so that the solution is time consistent, which results in a transfer payment path from the non-forest-owners to the forest owners.

Additionally, one paper in the recent literature deals with the influence of more than two parties on an environmental issue. In Eichner and Pethig (2015), a brown, a green and a consumer lobby with green preferences influence a green subsidy by making contribution payments to their government, which is not modeled explicitly. If the brown lobby is stronger than the green lobby, the green subsidy is inefficiently low. If the consumer lobby has only mild green preferences, the subsidy can even be negative.

Our contribution to this literature is to propose a framework in which we can analyze a trilateral conflict of interest over exhaustible resources. This captures the situation in many developing countries in which the government finds itself pressured (and possibly bribed) by environmental organizations and by natural-resource extraction firms (in both cases this includes organizations and firms from rich countries). We analyze the ensuing conflict of interest and derive policy, payments, and the development of both, taking into account that resource extraction increases both stock pollution (for instance, greenhouse gas concentration) and the cost to extract additional resources.

Our paper proceeds as follows. In Section 2, we introduce the sequential Nash bargaining solution

for three players and derive the bargaining order in equilibrium. Furthermore, we develop a dynamic version of the solution concept. Section 3 models our explicit example with a government between an environmental organization and an extraction firm and illustrates how policy and payments develop over time. Section 4 concludes.

2 Nash Bargaining Solution

2.1 Agents

There are three agents, the government and two lobbies. The government's utility g is a linear combination of its country's welfare $w(q)$ and payments m_i of lobbies $i = e, f$:

$$g(q, m_e, m_f) = w(q) + \gamma_e m_e + \gamma_f m_f. \quad (2.1a)$$

Welfare depends on the government's choice variable $q \in Q$. We assume $w(q)$ to have a unique interior maximum at some $q^w \equiv \arg\max_{q \in Q} w(q)$. The payments of the two lobbies may have different effects, so that the marginal-utility parameters γ_e and γ_f may differ. One possibility is that payments of a lobby could be completely transferred to the society; if utility of the population is linear in money, the marginal-utility parameter then is one. On the other hand, some of the money of a lobby group may be transferred to the private bank account of a corrupt government. The marginal utility parameter then exceeds one and would increase with the absorbed share of the money, and with the government's corruption level.³

Each of the lobbies $i = e, f$ has a gross profit $\pi_i(q)$. Like welfare, it depends on the choice variable $q \in Q$ and has a unique interior maximum at some $q_i^* \equiv \arg\max_{q \in Q} \pi_i(q)$. Subtracting the costs of paying contributions to the government, $\lambda_i m_i$ where $\lambda_i \geq 1$, yields net profit or – for brevity – utility l_i :

$$l_i(q, m_i) = \pi_i(q) - \lambda_i m_i \quad \text{for } i = e, f. \quad (2.1b)$$

If the lobby represents member firms and there are costs of raising contributions from them, or if there are adverse effects or moral disutility of paying money to a corrupt government, $\lambda_i > 1$.

2.2 Bargaining

Overview

We first outline the general approach of bargaining solutions in our model framework. For this we use a static framework, that is, everything happens within one time period (even though there may be more than one game stage in it). Bargaining may take place among different bargaining parties. The government always takes part as it can choose with whom to bargain. While the set of lobbies includes e and f , we denote the set of bargaining lobbies by B , which may, depending on the specific situation, include lobby e , f , or both. Bargaining is used to determine the variables (q, \mathbf{m}) , where $\mathbf{m} = \{m_i\}_{i \in B}$ is the profile of contributions from the bargaining lobbies. Lobbies that do not take part in the bargaining do not pay contributions, $m_i = 0$ for $i \notin B$, because the lobbies with whom the government does not negotiate cannot be forced to pay anything, and their payments will not have an effect on a negotiation of which they are no part. We let a superscript d denote the values of variables and functions in case of disagreement. Thus, g^d and l_i^d are the *disagreement utilities*, respectively.⁴ Likewise, a superscript a

³ The government's utility could also be written as $g = \omega + \gamma(y_e m_e + y_f m_f)$, where welfare is $\omega = w + (1 - y_e)m_e + (1 - y_f)m_f$. Then, $\gamma_i = 1 + y_i(\gamma - 1)$ for $i = e, f$. The interpretation would be that the government can keep a percentage y_i of the payments m_i from $i = e, f$ for itself. These payments are worth more than the payments to the society, $\gamma \geq 1$.

⁴ Other terms for these disagreement utilities in the literature are *threat utilities*, *outside-option utilities* and *breakdown utilities*; for "utility", "value" is used as well.

denotes the values of functions and variables if the bargaining parties agree; it is possible that they can only agree to disagree, which we discuss later. We refer to them as *agreement actions*, and *agreement utilities* etc. The agreement contributions from the bargaining lobbies and the agreement policy are determined by maximizing the Nash product:

$$N(q, \mathbf{m}) \equiv \left[w(q) + \sum_{i \in B} \gamma_i m_i - g^d \right]^\eta \cdot \prod_{i \in B} \left[\pi_i(q) - \lambda_i m_i - l_i^d \right]^{\eta_i}, \quad (2.2a)$$

$$(q^a, \mathbf{m}^a) \in \operatorname{argmax}_{q \in Q, \mathbf{m}} N(q, \mathbf{m}). \quad (2.2b)$$

where η_i denotes the bargaining weight of lobby i and η that of the government. As we repeatedly use this concept for different B sets and for different disagreement utilities, it is helpful to summarize its result in a Lemma:

Lemma 1 (Agreement Actions). *The agreement policy maximizes a weighted sum of welfare and profits of the bargaining lobbies:*

$$q^a \in \operatorname{argmax}_{q \in Q} w(q) + \sum_{i \in B} \mu_i \pi_i(q). \quad (2.3a)$$

Lobby i 's policy weight $\mu_i \equiv \frac{\gamma_i}{\lambda_i}$ equals the ratio of the marginal utility of the government of receiving the lobby's money to the lobby's marginal payment cost, and is thus constant. The agreement payments are

$$m_i^a = 0 \quad \text{for } i \notin B, \quad (2.3b)$$

$$m_i^a = \frac{1}{\lambda_i} \frac{\eta + \sum_{h \in B \setminus i} \eta_h}{\eta + \sum_{h \in B} \eta_h} \left(\pi_i^a - l_i^d \right) + \frac{1}{\gamma_i} \frac{\eta_i}{\eta + \sum_{h \in B} \eta_h} \left[g^d - w^a + \sum_{h \in B \setminus i} \mu_h \left(l_h^d - \pi_h^a \right) \right] \quad \text{for } i \in B. \quad (2.3c)$$

Proof. See Appendix A. □

Lobby i at most transfers its entire utility gain, if $\eta_i = 0$, and at least compensates the government and the other lobbies for their total utility loss, if $\eta + \sum_{h \in B \setminus i} \eta_h = 0$.

We now explain the sequence of bargaining in our model, how disagreeing in one bargaining constellation leads to another constellation, and how this determines the disagreement utilities. The government and the two lobbies meet in a *trilateral bargaining* so that $B = \{e, f\}$. If they can agree on some (q, m_e, m_f) vector, then this vector is implemented. The agreement vector is referred to by (q^a, m_e^a, m_f^a) .⁵ Each of the bargaining parties can let this negotiation break down, however. In that case, the government can choose a lobby $j \in \{e, f\}$ (so that $B = \{j\}$) with which to start the *first bilateral bargaining*. The other lobby is referred to by $k \in \{e, f\}$ where $k \neq j$. If this is successful, the result is the profile of agreement actions $(q^{a,j}, m_e^{a,j,1}, m_f^{a,j,1})$. The first superscript after the a refers to the lobby with which the agreement takes place, the last superscript refers to the first round of bilateral negotiation.⁶ Lobby k will pay nothing, see (2.3b). Should the first bilateral bargaining fail, the government can start the *second bilateral bargaining* with lobby k so that $B = \{k\}$. In case of success, we have $(q^{a,k}, m_e^{a,k,2}, m_f^{a,k,2})$. Now lobby j will pay nothing. Finally, should this negotiation fail, the government can unilaterally choose policy and the lobbies pay nothing. Then we have $(q^w, 0, 0)$.

⁵To save on notation, we thus use the notation for a general agreement (Lemma 1) to denote an agreement between all bargaining parties as well. The reader will understand the meaning from the context.

⁶Because the agreement policy is independent of the agreement payments and thus of the disagreement utilities, it is also independent of the bargaining round and we can skip the last superscript for the agreement policy.

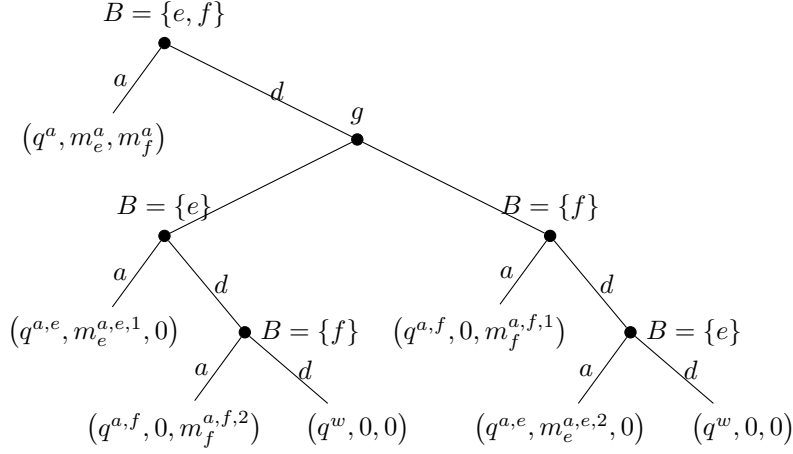


Figure 1: The Bargaining Game

By the proposed structure, the welfare-maximizing policy determines the disagreement utilities in the second bilateral negotiation, the result of the second bilateral negotiation determines the disagreement utilities in the first bilateral negotiation and the first bilateral negotiation determines the disagreement utilities in the trilateral negotiation.

The order of moves is depicted in Figure 1, where d = disagreement, a = agreement, and the profiles denoted at the final nodes contain the variables chosen if that node is reached. Note that at each bargaining node, agreement must yield higher payoff for every bargaining party, otherwise the bargaining breaks down. We call the trilateral bargaining Stage 0, the first bilateral bargaining Stage 1, the second bilateral bargaining Stage 2, and the choice with whom to bargain on Stage 1 is called Stage 0'. The government will choose the order of bargaining so as to maximize its total payoff; put another way, we are searching for the subgame-perfect bargaining order. Thus, we solve by backward induction.

One last thing we do for this is to define a tie-breaking rule:

Assumption 1 (Tie-breaking rule). *If the government is indifferent with whom to bargain, it bargains with lobby e .*

Stage 2.

In the bilateral negotiation between the government and lobby k , a disagreement would lead to welfare-maximization and no payments, so that we can write $g^{d,k,2} = w^w \equiv w(q^w)$ and $l_k^{d,k,2} = \pi_k^w \equiv \pi_k(q^w)$. Then, the Nash product is

$$N^2(q, m_k) \equiv [w(q) + \gamma_k m_k - w^w]^\eta \cdot [\pi_k(q) - \lambda_k m_k - \pi_k^w]^{\eta_k}, \quad (2.4)$$

where η and η_k are the bargaining weights of the government and lobby k . Using Lemma 1, we define the agreement policy

$$q^{a,k} \in \operatorname{argmax}_{q \in Q} w(q) + \mu_k \pi_k(q), \quad (2.5a)$$

where $\mu_k \equiv \frac{\gamma_k}{\lambda_k}$ is lobby k 's policy weight, and the agreement payments are

$$\gamma_j m_j^{a,k,2} = 0, \quad (2.5b)$$

$$\gamma_k m_k^{a,k,2} = \frac{\eta}{\eta + \eta_k} \mu_k (\pi_k^{a,k} - \pi_k^w) + \frac{\eta_k}{\eta + \eta_k} (w^w - w^{a,k}), \quad (2.5c)$$

where $w^{a,k} \equiv w(q^{a,k})$ is the agreement welfare and $\pi_k^{a,k} \equiv \pi_k(q^{a,k})$ is the agreement profit of lobby k on Stage 2. (2.5c) is positive because both terms in round brackets are positive; profit increases and welfare declines due to cooperation. Substituting (2.5) in (2.1) yields the agreement utilities:

$$g^{a,k,2} = w^{a,k} + \gamma_k m_k^{a,k,2} = w^w + \frac{\eta}{\eta + \eta_k} \left[w^{a,k} - w^w + \mu_k \left(\pi_k^{a,k} - \pi_k^w \right) \right], \quad (2.6a)$$

$$l_j^{a,k,2} = \pi_j^{a,k}, \quad (2.6b)$$

$$l_k^{a,k,2} = \pi_k^{a,k} - \lambda_k m_k^{a,k,2} = \pi_k^w + \frac{1}{\mu_k} \frac{\eta_k}{\eta + \eta_k} \left[w^{a,k} - w^w + \mu_k \left(\pi_k^{a,k} - \pi_k^w \right) \right], \quad (2.6c)$$

where $\pi_j^{a,k} \equiv \pi_j(q^{a,k})$ is the agreement profit of lobby j on Stage 2. The government and lobby k are better off than they would be without negotiations. The bargaining maximizes the weighted sum $w + \mu_k \pi_k$, so that the terms in square brackets in (2.6) are positive. Thus, the agreement profile is an equilibrium profile on Stage 2.

Stage 1.

In the bilateral negotiations between the government and lobby j , the disagreement utilities are defined by (2.6), i.e. $g^{d,j,1} = g^{a,k,2}$ and $l_j^{d,j,1} = \pi_j^{a,k}$. Then, the Nash product is

$$N^1(q, m_j) \equiv \left[w(q) + \gamma_j m_j - g^{a,k,2} \right]^\eta \cdot \left[\pi_j(q) - \lambda_j m_j - \pi_j^{a,k} \right]^{\eta_j}, \quad (2.7)$$

where η_j is lobby j 's bargaining weight. Using Lemma 1, we define the agreement policy

$$q^{a,j} \in \operatorname{argmax}_{q \in Q} w(q) + \mu_j \pi_j(q), \quad (2.8a)$$

where $\mu_j \equiv \frac{\gamma_j}{\lambda_j}$ is lobby j 's policy weight, and the agreement payments are

$$\gamma_j m_j^{a,j,1} = \frac{\eta}{\eta + \eta_j} \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) + \frac{\eta_j}{\eta + \eta_j} \left(g^{a,k,2} - w^{a,j} \right) \quad (2.8b)$$

$$\gamma_k m_k^{a,k,1} = 0, \quad (2.8c)$$

where $w^{a,j} \equiv w(q^{a,j})$ is the agreement welfare and $\pi_j^{a,j} \equiv \pi_j(q^{a,j})$ is the agreement profit of lobby j on Stage 1. (2.8b) is positive because both terms in round brackets are positive; profit increases due to cooperation and $g^{a,k,2} > w^w > w^{a,j}$. Substituting (2.8) in (2.1) yields the agreement utilities:

$$g^{a,j,1} = w^{a,j} + \gamma_j m_j^{a,j,1} = g^{a,k,2} + \frac{\eta}{\eta + \eta_j} \left[w^{a,j} - w^{a,k} + \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) - \gamma_k m_k^{a,k,2} \right], \quad (2.9a)$$

$$l_j^{a,j,1} = \pi_j^{a,j} - \lambda_j m_j^{a,j,1} = \pi_j^{a,k} + \frac{1}{\mu_j} \frac{\eta_j}{\eta + \eta_j} \left[w^{a,j} - w^{a,k} + \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) - \gamma_k m_k^{a,k,2} \right], \quad (2.9b)$$

$$l_k^{a,j,1} = \pi_k^{a,j}, \quad (2.9c)$$

where $\pi_k^{a,j} \equiv \pi_k(q^{a,j})$ is the agreement profit of lobby k on Stage 1. The agreement utilities in (2.9) tell us the outcome of the Nash bargaining if it indeed yields higher utility than non-cooperation. However, it is possible that the agreement utilities of the bargaining parties would be below their disagreement utilities. This is the case if the gains from cooperation for the government and lobby j are lower than the potential value of payments from lobby k to the government. If lobby j and the government agree to a bargain, lobby k will not pay a contribution, so that lobby j will at least have to compensate the government for this loss. For later reference, we summarize the respective condition in a Lemma, taking the tie-breaking rule into account:

Lemma 2 (Agreement on Stage 1). *For an agreement between the government and lobby j on Stage 1, it must hold that*

$$\begin{aligned} w^{a,j} - w^{a,k} + \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) &\geq \gamma_k m_k^{a,k,2} & \text{if } (j, k) = (e, f), \\ w^{a,j} - w^{a,k} + \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) &> \gamma_k m_k^{a,k,2} & \text{if } (j, k) = (f, e). \end{aligned} \quad (2.10)$$

Else, there is no agreement and the first bilateral bargaining is skipped. Then the equilibrium profile of Stage 2 is also the equilibrium profile of Stage 1.

To distinguish the equilibrium utilities from the agreement utilities in (2.9), we use a superscript \star instead of a superscript a :

$$g^{\star,j,1} = g^{a,k,2} + \frac{\eta}{\eta + \eta_j} \max \left[w^{a,j} - w^{a,k} + \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) - \gamma_k m_k^{a,k,2}, 0 \right], \quad (2.11a)$$

$$l_j^{\star,j,1} = \pi_j^{a,k} + \frac{1}{\mu_j} \frac{\eta_j}{\eta + \eta_j} \max \left[w^{a,j} - w^{a,k} + \mu_j \left(\pi_j^{a,j} - \pi_j^{a,k} \right) - \gamma_k m_k^{a,k,2}, 0 \right], \quad (2.11b)$$

$$l_k^{\star,j,1} = \begin{cases} \pi_k^{a,j} & \text{if (2.10) holds,} \\ l_k^{a,k,2} & \text{else.} \end{cases} \quad (2.11c)$$

Stage 0'.

Suppose that the bargain on Stage 0 has broken down. The government now chooses whether to bargain with e (that is, $(j, k) = (e, f)$) or with f (that is, $(j, k) = (f, e)$). In the first case, the result for the government would be

$$g^{\star,e,1} = g^{a,f,2} + \frac{\eta}{\eta + \eta_e} \max \left[w^{a,e} - w^{a,f} + \mu_e \left(\pi_e^{a,e} - \pi_e^{a,f} \right) - \gamma_f m_f^{a,f,2}, 0 \right] \quad (2.12a)$$

and in the second case, it would be

$$g^{\star,f,1} = g^{a,e,2} + \frac{\eta}{\eta + \eta_f} \max \left[w^{a,f} - w^{a,e} + \mu_f \left(\pi_f^{a,f} - \pi_f^{a,e} \right) - \gamma_e m_e^{a,e,2}, 0 \right]. \quad (2.12b)$$

The government would choose j so that it obtains the highest utility on Stage 1. We denote the resulting utility by g^d , as it will be the disagreement utility on Stage 0:

$$g^d = \max \left[g^{\star,e,1}, g^{\star,f,1} \right] \quad (2.13a)$$

The government's disagreement utility also determines the respective lobbies' disagreement utilities. Using (2.11) and (2.13a), we can define:

$$l_e^d = \begin{cases} l_e^{\star,e,1} & \text{if } g^d = g^{\star,e,1}, \\ l_e^{\star,f,1} & \text{if } g^d = g^{\star,f,1}, \end{cases} \quad (2.13b)$$

$$l_f^d = \begin{cases} l_f^{\star,e,1} & \text{if } g^d = g^{\star,e,1}, \\ l_f^{\star,f,1} & \text{if } g^d = g^{\star,f,1}. \end{cases} \quad (2.13c)$$

Now we can distinguish between four cases concerning condition (2.10):

Proposition 1 (Bargaining Order). *The government chooses the bargaining order $(j, k) = (e, f)$ if*

A (2.10) holds for $j = e \wedge$ (2.10) does not hold for $j = f$

$$\wedge \mu_e \left(\pi_e^w - \pi_e^{a,f} \right) + \frac{\eta_e}{\eta + \eta_f} \left[w^{a,f} - w^w + \mu_f \left(\pi_f^{a,f} - \pi_f^w \right) \right] \geq 0.$$

B (2.10) does not hold for $j = e \wedge$ (2.10) holds for $j = f$

$$\wedge \mu_f \left(\pi_f^w - \pi_f^{a,e} \right) + \frac{\eta_f}{\eta + \eta_e} \left[w^{a,e} - w^w + \mu_e \left(\pi_e^{a,e} - \pi_e^w \right) \right] \leq 0.$$

C (2.10) does not hold for $j = e \wedge$ (2.10) does not hold for $j = f$

$$\wedge \frac{\eta}{\eta + \eta_e} \left[w^{a,e} - w^w + \mu_e \left(\pi_e^{a,e} - \pi_e^w \right) \right] - \frac{\eta}{\eta + \eta_f} \left[w^{a,f} - w^w + \mu_f \left(\pi_f^{a,f} - \pi_f^w \right) \right] \leq 0.$$

D (2.10) holds for $j = e \wedge$ (2.10) holds for $j = f$

$$\begin{aligned} & \wedge \eta_f \mu_e \left(\pi_e^w - \pi_e^{a,f} \right) - \eta_e \mu_f \left(\pi_f^w - \pi_f^{a,e} \right) \\ & + \eta \left[w^{a,e} - w^{a,f} + \mu_e \left(\pi_e^{a,e} - \pi_e^{a,f} \right) + \mu_f \left(\pi_f^{a,e} - \pi_f^{a,f} \right) \right] \geq 0. \end{aligned}$$

In the complementary cases, the government chooses $(j, k) = (f, e)$.

Proof. Using Lemma 2 and Assumption 1, the result follows from comparing (2.12a) and (2.12b) and simplifying the ensuing inequalities. \square

Point A in Proposition 1 (for brevity: Proposition 1A) reveals the bargaining order if (2.10) just holds for lobby e . Then lobby e has a strong preference to avoid a policy that is bargained between the government and lobby f , and this preference is strong enough to compensate the government for the money it would get from lobby f . At the same time, the preference of lobby f to keep the government from a bilateral bargain with lobby e is not strong enough. In this case, the first possibility for the government is to bargain with lobby e on Stage 1; the disagreement point in this negotiation would be to bargain with lobby f on Stage 2. The second possibility is to bargain with lobby f on Stage 1, but this would immediately break down, and then the government would bargain with lobby e on Stage 2. In both cases, the government would find an agreement with lobby e , so that welfare and profits would be the same. The disagreement utilities in the negotiations between the government and lobby e , however, are different. The government's disagreement utility is higher if it negotiates with lobby e on Stage 1; if this breaks down, it can still bargain with lobby f , after all. The respective surplus is equal to the term in square brackets in the inequality condition of Proposition 1A (for short: in 1A).

Whether the government bargains with lobby e on Stage 1 or Stage 2 also changes lobby e 's disagreement utility. Disagreeing on Stage 1 would imply that the government chooses its policy together with lobby f ; disagreeing on Stage 2 would imply that the government chooses the welfare-maximizing policy. If lobby e prefers the latter to the former, then its disagreement utility on Stage 2 is higher than its disagreement utility on Stage 1, and the first term in round brackets in 1A is positive. The government then prefers to approach lobby e on Stage 1; because lobby e has a worse disagreement utility, contributions to the government will be higher.

Else, if the first term in brackets in 1A is negative, the effects on the disagreement utilities work in different directions, and we have to take the bargaining weights into account. If, for instance, $\eta_e \rightarrow \infty$, lobby e would only compensate the government for its disagreement utility; then the government will choose the order of bargaining so as to make its disagreement utility high. Thus, it first bargains with lobby e because it then still can threaten to bargain with lobby f .

Along the same lines, Proposition 1B reveals the bargaining order if (2.10) just holds for lobby f . Proposition 1C reveals the bargaining order if (2.10) holds for neither of the lobbies. Then the government can negotiate either with lobby e on Stage 2 or with lobby f on Stage 2. In both cases, the government's disagreement utility is maximized welfare. The first square-brackets term, weighted by the relative bargaining weight, is the government's utility surplus if it chooses lobby e ; the second square-brackets term is the respective surplus if it chooses lobby f . The government chooses the lobby with which the respective surplus is higher. This depends on the relative bargaining weights and on the gains from cooperation in the respective cases.

Proposition 1D reveals the bargaining order if (2.10) holds for both lobbies. Then the government can negotiate with either of the lobbies on Stage 1, threatening to bargain with the respective other lobby if the bargaining breaks down. The government's calculations now have to combine all the things already discussed. The bargaining order will change the respective disagreement utilities of the lobbies, its own disagreement utility, and welfare and the respective lobby's profit in case of agreement. The government has to evaluate the relative effects on the different lobbies and the respective bargaining weights.

At the bottom line, it is not possible to make simple general predictions about the chosen bargaining order, but instead a lot depends on the concrete form of the welfare and profit functions. We will look at two general cases further below and at a specific example in Section 3 to make some more predictions about the chosen bargaining order.

Stage 0.

In the trilateral negotiation, the disagreement utilities are defined by (2.13). Then, the Nash product is

$$N(q, m_e, m_f) \equiv \left[w(q) + \gamma_e m_e + \gamma_f m_f - g^d \right]^\eta \cdot \prod_{i \in e, f} \left[\pi_i(q) - \lambda_i m_i - l_i^d \right]^{\eta_i}. \quad (2.14)$$

Using Lemma 1, we define the agreement policy

$$q^a \in \operatorname{argmax}_{q \in Q} w(q) + \mu_e \pi_e(q) + \mu_f \pi_f(q) \quad (2.15a)$$

and the agreement payments are

$$\gamma_e m_e^a = \frac{\eta + \eta_f}{\eta + \eta_e + \eta_f} \mu_e (\pi_e^a - l_e^d) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \left[g^d - w^a + \mu_f (l_f^d - \pi_f^a) \right], \quad (2.15b)$$

$$\gamma_f m_f^a = \frac{\eta + \eta_e}{\eta + \eta_e + \eta_f} \mu_f (\pi_f^a - l_f^d) + \frac{\eta_f}{\eta + \eta_e + \eta_f} \left[g^d - w^a + \mu_e (l_e^d - \pi_e^a) \right], \quad (2.15c)$$

where $w^a \equiv w(q^a)$ is the agreement welfare and $\pi_e^a \equiv \pi_e(q^a)$ and $\pi_f^a \equiv \pi_f(q^a)$ are the agreement profits of lobby e and lobby f on Stage 0, respectively.

Proposition 2 (Agreement Payments on Stage 0). *Suppose the government chooses the bargaining order $(j, k) = (e, f)$. If (2.10) holds for $j = e$, the agreement payments on Stage 0 are*

$$\begin{aligned} \gamma_e m_e^a &= \frac{\eta + \eta_f}{\eta + \eta_e + \eta_f} \mu_e (\pi_e^a - \pi_e^{a,e}) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \left[w^{a,e} - w^a + \mu_f (\pi_f^{a,e} - \pi_f^a) \right] + \gamma_e m_e^{a,e,1} \\ &= \frac{\eta + \eta_f}{\eta + \eta_e + \eta_f} \mu_e (\pi_e^a - \pi_e^{a,e}) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \left[w^{a,e} - w^a + \mu_f (\pi_f^{a,e} - \pi_f^a) \right] \\ &\quad + \frac{\eta}{\eta + \eta_e} \mu_e (\pi_e^{a,e} - \pi_e^{a,f}) + \frac{\eta_e}{\eta + \eta_e} (g^{a,f,2} - w^{a,e}), \end{aligned} \quad (2.16a)$$

$$\gamma_f m_f^a = \frac{\eta + \eta_e}{\eta + \eta_e + \eta_f} \mu_f (\pi_f^a - \pi_f^{a,e}) + \frac{\eta_f}{\eta + \eta_e + \eta_f} [w^{a,e} - w^a + \mu_e (\pi_e^{a,e} - \pi_e^a)] > 0. \quad (2.16b)$$

If (2.10) does not hold for $j = e$, the agreement payments on Stage 0 are

$$\gamma_e m_e^a = \frac{\eta + \eta_f}{\eta + \eta_e + \eta_f} \mu_e (\pi_e^a - \pi_e^{a,f}) + \frac{\eta_e}{\eta + \eta_e + \eta_f} [w^{a,f} - w^a + \mu_f (\pi_f^{a,f} - \pi_f^a)] > 0, \quad (2.17a)$$

$$\begin{aligned} \gamma_f m_f^a &= \frac{\eta + \eta_e}{\eta + \eta_e + \eta_f} \mu_f (\pi_f^a - \pi_f^{a,f}) + \frac{\eta_f}{\eta + \eta_e + \eta_f} [w^{a,f} - w^a + \mu_e (\pi_e^{a,f} - \pi_e^a)] + \gamma_f m_f^{a,f,2} \\ &= \frac{\eta + \eta_e}{\eta + \eta_e + \eta_f} [w^a - w^{a,f} + \mu_e (\pi_e^a - \pi_e^{a,f}) + \mu_f (\pi_f^a - \pi_f^{a,f})] + w^{a,e} - w^a + \mu_e (\pi_e^{a,e} - \pi_e^a) \\ &\quad - [w^{a,e} - w^{a,f} + \mu_e (\pi_e^{a,e} - \pi_e^{a,f}) - \gamma_f m_f^{a,f,2}] > 0. \end{aligned} \quad (2.17b)$$

For the agreement payments of the complementary bargaining order $(j, k) = (f, e)$, replace each e by f and vice versa.

Proof. Using Lemma 2 and Assumption 1, the result follows from substituting (2.11) and (2.6) in (2.15b) and (2.15c), and simplifying the ensuing equations. \square

The sign of (2.16a) is ambiguous. It is possible that lobby e will receive a compensation for not letting the negotiation break down; we illustrate exemplary cases below. It is, however, positive if $\eta_e = 0$; then, (2.16a) simplifies to $\mu_e (\pi_e^a - \pi_e^{a,f}) > 0$.

The first term in brackets in (2.16b) is positive; profit of lobby f increases due to cooperation. Furthermore, in the bilateral negotiation between the government and lobby e , the weighted sum $w + \mu_e \pi_e$ is maximized, so that the term in square brackets in (2.16b) is positive. Thus, (2.16b) is positive. Along the same lines, (2.17a) is positive.

In the trilateral negotiation, the weighted sum $w + \mu_e \pi_e + \mu_f \pi_f$ is maximized, so that the term in square brackets in the first line of (2.17b) is positive. Furthermore, in the bilateral negotiation between the government and lobby e , the weighted sum $w + \mu_e \pi_e$ is maximized, so that the first line of (2.17b) is positive. Finally, (2.10) not holding for $j = e$ implies that the term in square brackets in the second line of (2.17b) is negative. Thus, (2.17b) is positive.

Substituting (2.15) in (2.1) yields the agreement utilities:

$$g^a = w^a + \gamma_e m_e^a + \gamma_f m_f^a = g^d + \frac{\eta}{\eta + \eta_e + \eta_f} [w^a - w^d + \mu_e (\pi_e^a - \pi_e^d) + \mu_f (\pi_f^a - \pi_f^d)], \quad (2.18a)$$

$$l_e^a = \pi_e^a - \lambda_e m_e^a = l_e^d + \frac{1}{\mu_e} \frac{\eta_e}{\eta + \eta_e + \eta_f} [w^a - w^d + \mu_e (\pi_e^a - \pi_e^d) + \mu_f (\pi_f^a - \pi_f^d)], \quad (2.18b)$$

$$l_f^a = \pi_f^a - \lambda_f m_f^a = l_f^d + \frac{1}{\mu_f} \frac{\eta_f}{\eta + \eta_e + \eta_f} [w^a - w^d + \mu_e (\pi_e^a - \pi_e^d) + \mu_f (\pi_f^a - \pi_f^d)]. \quad (2.18c)$$

The government and both lobbies are better off than they would be in the bilateral negotiations. The bargaining maximizes the weighted sum $w + \mu_e \pi_e + \mu_f \pi_f$, so that the terms in square brackets in (2.18) are positive. Thus, the agreement profile is an equilibrium profile on Stage 0. Note that the weighted sum of payments, $\gamma_e m_e^a + \gamma_f m_f^a$ defined by (2.15), is positive because $g^a > g^d > w^w$.

Two Cases

To illustrate, we can consider the following polar cases. Suppose that lobby e and lobby f are identical, i.e. $\mu_e = \mu_f$ and $\pi_e = \pi_f$, so that $w^{a,e} = w^{a,f}$, $\pi_e^{a,e} = \pi_e^{a,f}$, $\pi_f^{a,e} = \pi_f^{a,f}$ and $\pi_e^w = \pi_f^w$. Then the left-hand side of (2.10) in Lemma 2 is zero for $j = e, f$ and the inequality does not hold. This is a public-goods problem between the lobbies; whichever lobby is asked first to bargain will decline, so that the other

lobby will pay the bribe to implement the policy that both lobbies prefer. Because (2.10) does not hold for $j = e, f$, we are in Proposition 1C and the inequality can be rearranged to

$$\left(\frac{\eta}{\eta + \eta_e} - \frac{\eta}{\eta + \eta_f} \right) \left[w^{a,f} - w^w + \mu_f (\pi_f^{a,f} - \pi_f^w) \right] \leq 0, \quad (2.19)$$

so that the government will bargain with lobby e on Stage 1 if $\eta_f \leq \eta_e$. This bargaining will immediately break down, so that this just means that the government will bargain on the decisive Stage 2 with the lobby with the lower bargaining power. Since in this case that lobby will have to pay the government for choosing the compromise policy that both lobbies prefer in the same way, having a low bargaining power is a strong disadvantage in case of disagreement.

Now suppose that there is no conflict of interest between the government and lobby e , so that $w^{a,e} = w^w$, $\pi_e^{a,e} = \pi_e^w$ and $\pi_f^{a,e} = \pi_f^w$. Then lobby e would not pay contributions on Stage 2, (2.5c) is zero for $k = e$, so that the right-hand side of (2.10) in Lemma 2 is zero for $j = f$ and the inequality holds. Because (2.10) holds for $j = f$, we are either in Proposition 1B or in Proposition 1D. In Proposition 1B, the inequality would hold with equality, so that the government would bargain with lobby e on Stage 1: It does not make a difference whether the government bargains with lobby f on Stage 1 with the compromise policy between the government and lobby e determining the disagreement utilities, or whether the government bargains with lobby e on Stage 1, letting this negotiation immediately break down and then bargaining with lobby f on Stage 2 with the welfare-maximizing policy determining the disagreement utilities, because the compromise policy between the government and lobby e coincides with the welfare-maximizing policy. The inequality of Proposition 1D can be rearranged to

$$\mu_e (\pi_e^w - \pi_e^{a,f}) - \frac{\eta}{\eta + \eta_f} \left[w^{a,f} - w^w + \mu_f (\pi_f^{a,f} - \pi_f^w) \right] \geq 0, \quad (2.20)$$

which is equivalent to rearranging (2.10) for $j = e$. Because (2.10) holds for $j = e$ in Proposition 1D, the inequality in Proposition 1D also holds, so that the government will bargain with lobby e on Stage 1: In the negotiation between the government and lobby f , the disagreement utilities are the same on Stage 1 and on Stage 2, but in the negotiation between the government and lobby e , the outside option of the government is better on Stage 1, agreement with lobby f , than on Stage 2, unilateral policy decision. In this case, lobby e could receive a compensation for not letting the trilateral negotiation break down. (2.16a) becomes

$$\begin{aligned} \gamma_e m_e^a = & \frac{\eta + \eta_f}{\eta + \eta_e + \eta_f} \mu_e (\pi_e^a - \pi_e^w) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \left[w^w - w^a + \mu_f (\pi_f^w - \pi_f^a) \right] \\ & + \frac{\eta}{\eta + \eta_e} \mu_e (\pi_e^w - \pi_e^{a,f}) + \frac{\eta_e}{\eta + \eta_e} \frac{\eta}{\eta + \eta_f} \left[w^{a,f} - w^w + \mu_f (\pi_f^{a,f} - \pi_f^w) \right], \end{aligned} \quad (2.21a)$$

which for $\eta = 0$ collapses to

$$\gamma_e m_e^a = \mu_e (\pi_e^a - \pi_e^w) + \frac{\eta_e}{\eta_e + \eta_f} \left[w^w - w^a + \mu_e (\pi_e^w - \pi_e^a) + \mu_f (\pi_f^w - \pi_f^a) \right] < 0, \quad (2.21b)$$

which is negative.

2.3 Dynamic Version

We now turn to the dynamic version of our model. The variables used in the previous section represent actions, utility values etc. for an instant of time (or period) t . Thus, $q(t) \in Q$ is the policy variable in

t , and this control variable of the government changes the state variable by the following equation of motion:

$$\dot{z}(t) \equiv \frac{dz(t)}{dt} = \Phi(q(t)). \quad (2.22)$$

In the following, we will drop the time variable t when there is no necessity to explicitly point it out. The instantaneous utility functions are constructed by extending (2.1) for an effect of z :

$$g(q, m_e, m_f, z) = w(q, z) + \gamma_e m_e + \gamma_f m_f, \quad (2.23a)$$

$$l_i(q, m_i, z) = \pi_i(q, z) - \lambda_i m_i \quad \text{for } i = e, f. \quad (2.23b)$$

Intertemporal utility in t is made up of all utility values from t through infinity, discounted with a rate r :

$$G(t) = W(t) + \gamma_e M_e(t) + \gamma_f M_f(t), \quad (2.24a)$$

$$L_i(t) = \Pi_i(t) - \lambda_i M_i(t) \quad \text{for } i = e, f, \quad (2.24b)$$

where

$$W(t) = \int_t^\infty e^{-r(s-t)} w(q(s), z(s)) \, ds, \quad (2.25a)$$

$$\Pi_i(t) = \int_t^\infty e^{-r(s-t)} \pi_i(q(s), z(s)) \, ds \quad \text{for } i = e, f, \quad (2.25b)$$

$$M_i(t) = \int_t^\infty e^{-r(s-t)} m_i(s) \, ds \quad \text{for } i = e, f. \quad (2.25c)$$

We assume the bargaining procedure to take the same form as in the static setting, but it has to determine q and m_i for every period. The contract has to make sure that these values are time-consistent: In every time period, it must be optimal for the bargaining parties to continue following the contract. This can be ensured if we choose the control variables as if the bargaining would be taking place in every time instant.

To do so, we need two assumptions. The first one concerns the policy choice expected for the future. If control variables today are to be chosen optimally in some sense, then it is necessary to know the future trajectory of the variables. Here it is a natural assumption that the same cooperative policy determination is expected for all the future; given that this policy determination fulfills time-consistency, all bargaining parties know that it will be rational to continue cooperation. The second assumption concerns the consequences of a breakdown of bargaining, so as to determine the (intertemporal) disagreement utility. We assume that if bargaining should fail in any instant in a given constellation of bargaining parties, then it can never again be taken up in that constellation. The agreement payments from the bargaining lobbies and the agreement policy are determined by maximizing the Nash product, which is constructed by extending (2.2a) for an effect of z and t :

$$N(q, \mathbf{m}, z) \equiv \left[W(q, z) + \sum_{i \in B} \gamma_i M_i - G^d \right]^\eta \cdot \prod_{i \in B} [\Pi_i(q, z) - \lambda_i M_i - L_i^d]^{\eta_i}, \quad (2.26a)$$

$$(q^a(t), \mathbf{m}^a(t)) \in \operatorname{argmax}_{q \in Q, \mathbf{m}} N(q, \mathbf{m}, z). \quad (2.26b)$$

For later reference, we summarize the agreement actions in a Lemma:

Lemma 3 (Agreement Actions: Dynamic Version). *The agreement policy maximizes a weighted sum of*

intertemporal welfare and profits of the bargaining lobbies:

$$q^a(t) \in \operatorname{argmax}_{q \in Q} W(q, z) + \sum_{i \in B} \mu_i \Pi_i(q, z). \quad (2.27a)$$

The intertemporal agreement payments are

$$M_i^a(t) = 0 \quad \text{for } i \notin B, \quad (2.27b)$$

$$M_i^a(t) = \frac{1}{\lambda_i} \frac{\eta + \sum_{h \in B \setminus i} \eta_h}{\eta + \sum_{h \in B} \eta_h} (\Pi_i^a - L_i^d) + \frac{1}{\gamma_i} \frac{\eta_i}{\eta + \sum_{h \in B} \eta_h} \left[G^d - W^a + \sum_{h \in B \setminus i} \mu_h (L_h^d - \Pi_h^a) \right] \quad \text{for } i \in B. \quad (2.27c)$$

Taking the time derivatives of (2.27b) and (2.27c) yields the instantaneous agreement payments:

$$m_i^a(t) = 0 \quad \text{for } i \notin B, \quad (2.27d)$$

$$m_i^a(t) = r M_i(t) - \frac{dM_i(t)}{dt} \quad \text{for } i \in B. \quad (2.27e)$$

Proof. The proof follows along the lines of the proof of Lemma 1. \square

Because z does not depend on m_i , the choice of m_i still is a static problem. Thus, maximizing the Nash product is still equivalent to maximizing the respective weighted sum of welfare and profits (in its intertemporal form). Consequently, the results of Section 2.2 remain valid in the dynamic setting. We just have to replace the intratemporal versions of w, π and m by their intertemporal counterparts W, Π and M .

Note that in the dynamic setting, (2.10) in Lemma 2 possibly always, sometimes or never holds for each of the lobbies. Furthermore, the signs in Proposition 1A-D can change several times. Thus, the bargaining order need not be the same in every period. We will show this in Section 3 with linear-quadratic functions.

3 Explicit Example

3.1 Agents

In this Section, we take up the idea from the introduction that an environmental organization e and an extraction firm f are interested in natural resources controlled by a government g . We apply the dynamic version of our model from Section 2.3 and choose an exhaustible resource setting, so that the policy variable $q(t) \geq 0$ is extraction in t and the state variable $z(t) \geq 0$ is cumulative extraction. Then, the equation of motion is

$$\dot{z}(t) \equiv \frac{dz(t)}{dt} = q(t). \quad (3.1)$$

We assume that extraction causes environmental externalities x in terms of flow pollution, depending on $q(t)$, and stock pollution, depending on $z(t)$. The resource can be sold at the world-market price p . Furthermore, there are extraction cost $c(q, z)$ that depend on extraction in t and on cumulative extraction. To keep things simple, we use linear-quadratic functions: $c(q, z) \equiv (c_1 + \frac{c_2}{2} q + c_z z) q$.

We choose a setting in which the government sells extraction rights for each period to the extraction firm, which sells the resource and bears the extraction cost. The environmental organization is concerned about stock pollution $x_z z$, like for example carbon dioxide from resource consumption, and is willing to

pay for less extraction. Finally, the government dislikes flow pollution $(x_1 - \frac{x_2}{2}q)q$, like for example soot or dust from resource extraction. Thus, instantaneous welfare and profits are⁷

$$w(q, z) = - \left(x_1 + \frac{x_2}{2}q \right) q, \quad (3.2a)$$

$$\pi_e(q, z) = -x_z z, \quad (3.2b)$$

$$\pi_f(q, z) = \left(p - c_1 - \frac{c_2}{2}q - c_z z \right) q. \quad (3.2c)$$

Substituting (3.2) in (2.24) and (2.25) then yields utilities, welfare, profits and payments in their intertemporal forms. Obviously, $q^w = q_e^e = 0$, so that there is no conflict of interest between the government and e . From the second case at the end of Section 2.2, we know that the bargaining order then is $j, k = e, f$, so that the government bargains with f on Stage 2.

3.2 Bargaining

Stage 2.

In the bilateral negotiation between the government and f , the disagreement utilities are $G^{d,f,2} = W^w = 0$ and $L_f^{d,f,2} = \Pi_f^w = 0$. We define

$$\alpha \equiv x_2 + \mu_f c_2, \quad \beta \equiv -x_1 + \mu_f (p - c_1) \quad (3.3)$$

and

$$\psi \equiv \frac{2}{\alpha + \sqrt{\alpha^2 + \frac{4}{r}\alpha\mu_f c_z}} < \frac{1}{\alpha}. \quad (3.4)$$

As shown in Appendix B, the agreement policy is

$$q^{a,f}(z) = \begin{cases} \psi (\beta - \mu_f c_z z) & \text{if } z \leq \hat{z}_f \\ 0 & \text{if } z > \hat{z}_f \end{cases}, \quad (3.5)$$

where $\hat{z}_f \equiv \beta/(\mu_f c_z)$ is the *bilateral convergence level* of cumulative extraction. This convergence level is reached asymptotically. If it were reached, further extraction would not be worthwhile anymore because the profit that the extraction firm would make even with the first marginal unit (weighted by its policy-weight parameter) could not exceed the flow pollution it causes: $-x_1 + \mu_f (p - c_1 - c_z z) = 0$. Additionally to β and c_z , extraction is influenced by the *speed-of-convergence* parameter ψ . ψ declines with the quadratic flow-pollution parameter and cost parameter as well as with the stock-cost parameter. It increases with r because a high discount rate means that stock-cost effects become less important.

We also show in Appendix B that intertemporal agreement welfare and profits are

$$W^{a,f}(z) = -\frac{x_1}{r + \psi\mu_f c_z} q^{a,f}(z) - \frac{\frac{x_2}{2}}{r + 2\psi\mu_f c_z} q^{a,f}(z)^2, \quad (3.6a)$$

$$\Pi_e^{a,f}(z) = -\frac{x_z}{r} z - \frac{\frac{x_z}{r}}{r + \psi\mu_f c_z} q^{a,f}(z), \quad (3.6b)$$

⁷ "Welfare" is flow-pollution damage, and we assume other components of welfare to be independent of resource extraction. "Profit" of the environmental organization is stock-pollution damage. Thus, both are negative. We assume e and f to be from foreign countries, so that their profits are not part of welfare; if they pay the government, part of the payments may enter welfare as argued on page 4.

$$\Pi_f^{a,f}(z) = \frac{1}{\mu_f} \left[\frac{x_1}{r + \psi \mu_f c_z} q^{a,f}(z) + \frac{\frac{1}{\psi} - \frac{\mu_f c_2}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2 \right]. \quad (3.6c)$$

Substituting (2.5b) and (2.5c) in (2.25c) and using (3.6a) and (3.6c) as well as $W^w = \Pi_f^w = 0$ yields the intertemporal agreement payments:

$$\gamma_e M_e^{a,f,2}(z) = 0, \quad (3.7a)$$

$$\gamma_f M_f^{a,f,2}(z) = \frac{x_1}{r + \psi \mu_f c_z} q^{a,f}(z) + \frac{\frac{x_2}{2} + \frac{\eta}{\eta + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2} \right)}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2 > 0. \quad (3.7b)$$

Substituting (3.6) and (3.7) in (2.24) yields the intertemporal agreement utilities:

$$G^{a,f,2}(z) = W^{a,f}(z) + \gamma_f M_f^{a,f,2}(z) = \frac{\eta}{\eta + \eta_f} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2, \quad (3.8a)$$

$$L_e^{a,f,2}(z) = \Pi_e^{a,f}(z) = -\frac{x_z}{r} z - \frac{\frac{x_z}{r}}{r + \psi \mu_f c_z} q^{a,f}(z), \quad (3.8b)$$

$$L_f^{a,f,2}(z) = \Pi_f^{a,f}(z) - \lambda_f M_f^{a,f,2}(z) = \frac{1}{\mu_f} \frac{\eta_f}{\eta + \eta_f} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2. \quad (3.8c)$$

Stage 1.

In the bilateral negotiations between the government and e , the disagreement utilities are defined by (3.8), i.e. $G^{d,e,1} = G^{a,f,2}$ and $L^{d,e,1} = \Pi_e^{a,f}$. The agreement policy is

$$q^{a,e}(z) = q^w(z) = 0 \quad (3.9)$$

and intertemporal agreement welfare and profits are

$$W^{a,e}(z) = W^w(z) = 0, \quad (3.10a)$$

$$\Pi_e^{a,e}(z) = \Pi_e^w(z) = -\frac{x_z}{r} z, \quad (3.10b)$$

$$\Pi_f^{a,e}(z) = \Pi_f^w(z) = 0. \quad (3.10c)$$

Substituting (2.8b) and (2.8c) in (2.25c) and using (3.10a) and (3.10b) as well as (3.8a) and (3.8b) yields the intertemporal agreement payments:

$$\gamma_e M_e^{a,e,1}(z) = \frac{\eta}{\eta + \eta_e} \cdot \frac{\mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^{a,f}(z) + \frac{\eta \eta_e}{(\eta + \eta_e)(\eta + \eta_f)} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2 > 0, \quad (3.11a)$$

$$\gamma_f M_f^{a,f,1}(z) = 0. \quad (3.11b)$$

Substituting (3.10) and (3.11) in (2.24) yields the intertemporal agreement utilities:

$$\begin{aligned} G^{a,e,1}(z) &= W^{a,e}(z) + \gamma_e M_e^{a,e,1}(z) \\ &= \frac{\eta}{\eta + \eta_e} \cdot \frac{\mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^{a,f}(z) + \frac{\eta \eta_e}{(\eta + \eta_e)(\eta + \eta_f)} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2, \end{aligned} \quad (3.12a)$$

$$\begin{aligned} L_e^{a,e,1}(z) &= \Pi_e^{a,e}(z) - \lambda_e M_e^{a,e,1}(z) \\ &= -\frac{1}{\mu_e} \left[\mu_e \frac{x_z}{r} z + \frac{\eta}{\eta + \eta_e} \cdot \frac{\mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^{a,f}(z) + \frac{\eta \eta_e}{(\eta + \eta_e)(\eta + \eta_f)} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2 \right], \end{aligned} \quad (3.12b)$$

$$L_f^{a,e,1}(z) = \Pi_f^{a,e}(z) = 0. \quad (3.12c)$$

As in the static setting, it is possible that the agreement utilities are not the equilibrium utilities. This is the case if the agreement utilities of the government and e , (3.12a) and (3.12b), are below their disagreement utilities, (3.8a) and (3.8b). For later reference, we summarize the respective condition in a Lemma:

Lemma 4 (Agreement on Stage 1: Explicit Example). *For an agreement between the government and e on Stage 1, it must hold that*

$$z \geq \tilde{z} \equiv \hat{z} - \frac{\eta + 2\eta_f}{\eta} (\hat{z}_f - \hat{z}), \quad (3.13)$$

where $\hat{z} \equiv (\beta - \mu_e \frac{x_z}{r})/(\mu_f c_z)$. Else, the first bilateral bargaining is skipped and there is an agreement between the government and f on Stage 2. Because $\hat{z}_f > \hat{z}$, (3.13) holds for some $z < \hat{z}$. (3.13) holds for all $z \geq 0$ if $\hat{z}_f \geq \frac{\eta + \eta_f}{\eta/2 + \eta_f} \hat{z}$.

Proof. Taking the difference between (3.12a) and (3.8a), substituting (3.4) and (3.5), taking the tie-breaking rule into account and rearranging yields (3.13). The remainder of the Lemma follows from setting the right-hand side of (3.13) zero and rearranging. \square

Then the intertemporal equilibrium utilities are

$$G^{*,e,1}(z) = G^{a,f,2}(z) + \frac{\eta}{\eta + \eta_e} \max \left[\frac{\mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^{a,f}(z) - \frac{\eta}{\eta + \eta_f} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2, 0 \right], \quad (3.14a)$$

$$L_e^{*,e,1}(z) = \Pi_e^{a,f}(z) + \frac{1}{\mu_e} \frac{\eta_e}{\eta + \eta_e} \max \left[\frac{\mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^{a,f}(z) - \frac{\eta}{\eta + \eta_f} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^{a,f}(z)^2, 0 \right], \quad (3.14b)$$

$$L_f^{*,e,1}(z) = \begin{cases} 0 & \text{if (3.13) holds,} \\ L_f^{a,f,2}(z) & \text{else.} \end{cases} \quad (3.14c)$$

Stage 0.

In the trilateral negotiation, the disagreement utilities are defined by (3.14). As shown in Appendix B, the agreement policy is

$$q^a(z) = \begin{cases} \psi (\beta - \mu_e \frac{x_z}{r} - \mu_f c_z z) & \text{if } z \leq \hat{z} \\ 0 & \text{if } z > \hat{z} \end{cases}, \quad (3.15)$$

where, as defined in Lemma 4, $\hat{z} \equiv (\beta - \mu_e \frac{x_z}{r})/(\mu_f c_z)$. We can now see that it can be understood as the *trilateral convergence level* of cumulative extraction. Like the bilateral convergence level, this convergence level is only reached asymptotically. $\hat{z} < \hat{z}_f$ because now also stock-pollution effects play a role. However, the speed of convergence ψ is the same as in the bilateral agreement between the government and f .

We also show in Appendix B that intertemporal agreement welfare and profits are

$$W^a(z) = -\frac{x_1}{r + \psi \mu_f c_z} q^a(z) - \frac{\frac{x_2}{2}}{r + 2\psi \mu_f c_z} q^a(z)^2, \quad (3.16a)$$

$$\Pi_e^a(z) = -\frac{x_z}{r} z - \frac{\frac{x_z}{r}}{r + \psi \mu_f c_z} q^a(z), \quad (3.16b)$$

$$\Pi_f^a(z) = \frac{1}{\mu_f} \left[\frac{x_1 + \mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^a(z) + \frac{\frac{1}{\psi} - \frac{\mu_f c_2}{2}}{r + 2\psi \mu_f c_z} q^a(z)^2 \right]. \quad (3.16c)$$

Substituting (2.15b) and (2.15c) in (2.25c) and using (3.16) and (3.14) yields the intertemporal agreement payments:

$$\gamma_e M_e^a(z) = \begin{cases} \frac{\eta + \frac{\eta_e}{2} + \eta_f}{\eta + \eta_e + \eta_f} \cdot \frac{\psi\left(\mu_e \frac{x_z}{r}\right)^2}{r + \psi \mu_f c_z} & \text{if } z < \tilde{z}, \\ -\frac{\eta_e \eta_f}{(\eta + \eta_e)(\eta + \eta_f)} \left[\frac{\mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^a(z) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \cdot \frac{\frac{1}{\psi} - \frac{\alpha}{2}}{r + 2\psi \mu_f c_z} q^a(z)^2 \right] \\ + \frac{\eta(\eta + \frac{\eta_e}{2} + \eta_f)}{(\eta + \eta_e)(\eta + \eta_f)} \cdot \frac{\psi\left(\mu_e \frac{x_z}{r}\right)^2}{r + \psi \mu_f c_z} & \text{if } z \geq \tilde{z}, \end{cases} \quad (3.17a)$$

$$\gamma_f M_f^a(z) = \begin{cases} \frac{x_1 + \frac{\eta}{\eta + \eta_f} \mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^a(z) + \frac{\frac{x_2}{2} + \frac{\eta}{\eta + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2}\right)}{r + 2\psi \mu_f c_z} q^a(z)^2 \\ - \frac{\eta_f(\eta + \frac{\eta_e}{2} + \eta_f)}{(\eta + \eta_f)(\eta + \eta_e + \eta_f)} \cdot \frac{\psi\left(\mu_e \frac{x_z}{r}\right)^2}{r + \psi \mu_f c_z} & \text{if } z < \tilde{z}, \\ \frac{x_1 + \mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} q^a(z) + \frac{\frac{x_2}{2} + \frac{\eta + \eta_e}{\eta + \eta_e + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2}\right)}{r + 2\psi \mu_f c_z} q^a(z)^2 & \text{if } z \geq \tilde{z}. \end{cases} \quad (3.17b)$$

(3.17b) is positive and (3.17a) is positive for $z < \tilde{z}$; see also Proposition 2. For $z \geq \tilde{z}$, (3.17a) declines with $q^a(z)$ and thus increases with z . Substituting $z = \tilde{z}$ as a threshold in (3.17a) for $z \geq \tilde{z}$ and rearranging, we can determine the lower bound of $\gamma_e M_e^a(z)$:

$$\gamma_e M_e^a(z) \geq \gamma_e \tilde{M}_e^a(z) \equiv \frac{\eta^2 \left(\eta + \frac{\eta_e}{2} + \eta_f\right) - 2\eta_e \eta_f (\eta + \eta_f)}{\eta^2 (\eta + \eta_e + \eta_f)} \cdot \frac{\psi\left(\mu_e \frac{x_z}{r}\right)^2}{r + \psi \mu_f c_z} \quad \text{if } z \geq \tilde{z}, \quad (3.18)$$

which increases with η and declines with η_e and η_f , is negative for $\lim_{\eta \rightarrow 0}$ and is positive for $\lim_{\eta_e \rightarrow 0}$ or for $\lim_{\eta_f \rightarrow 0}$, and is negative if $\eta = \eta_e = \eta_f$.⁸

Intratemporal Payments.

In Section 3.3, we will illustrate how z , q , m_e and m_f develop over time. From (B.8) in Appendix B, we have

$$z^a(s) = \begin{cases} \hat{z} - [\hat{z} - z(t)] e^{-\psi \mu_f c_z (s-t)} & \text{if } z(t) \leq \hat{z}, \\ z(t) & \text{if } z(t) > \hat{z}, \end{cases} \quad (3.19a)$$

$$q^a(s) = \begin{cases} \psi \left[\beta - \mu_e \frac{x_z}{r} - \mu_f c_z z(t) \right] e^{-\psi \mu_f c_z (s-t)} & \text{if } z(t) \leq \hat{z}, \\ 0 & \text{if } z(t) > \hat{z}. \end{cases} \quad (3.19b)$$

Furthermore, from (2.27e) we have

$$m_i^a(s) = r M_i^a(s) - \dot{M}_i^a(s) \quad \text{for } i = e, f. \quad (3.20)$$

Then, substituting (3.19b) in (3.17) and using (3.20), we have

$$\gamma_e m_e^a(s) = \begin{cases} r \frac{\eta + \frac{\eta_e}{2} + \eta_f}{\eta + \eta_e + \eta_f} \cdot \frac{\psi\left(\mu_e \frac{x_z}{r}\right)^2}{r + \psi \mu_f c_z} & \text{if } z(t) < \tilde{z}, \\ -\frac{\eta_e \eta_f}{(\eta + \eta_e)(\eta + \eta_f)} \left[\mu_e \frac{x_z}{r} q^a(s) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2}\right) q^a(s)^2 \right] \\ + r \frac{\eta(\eta + \frac{\eta_e}{2} + \eta_f)}{(\eta + \eta_e)(\eta + \eta_f)} \cdot \frac{\psi\left(\mu_e \frac{x_z}{r}\right)^2}{r + \psi \mu_f c_z} & \text{if } z(t) \geq \tilde{z}, \end{cases} \quad (3.21a)$$

⁸ Furthermore, $\gamma_e \tilde{M}_e^a(z) \geq 0 \Leftrightarrow \eta \geq \frac{1+\sqrt{17}}{4} \eta_e$ if $\eta_e = \eta_f$.

$$\gamma_f m_f^a(s) = \begin{cases} \left(x_1 + \frac{\eta}{\eta + \eta_f} \mu_e \frac{x_z}{r} \right) q^a(s) + \left[\frac{x_2}{2} + \frac{\eta}{\eta + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2} \right) \right] q^a(s)^2 \\ - r \frac{\eta_f (\eta + \frac{\eta_e}{2} + \eta_f)}{(\eta + \eta_f)(\eta + \eta_e + \eta_f)} \cdot \frac{\psi (\mu_e \frac{x_z}{r})^2}{r + \psi \mu_f c_z} & \text{if } z(t) < \tilde{z}, \\ \left(x_1 + \mu_e \frac{x_z}{r} \right) q^a(s) + \left[\frac{x_2}{2} + \frac{\eta + \eta_e}{\eta + \eta_e + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2} \right) \right] q^a(s)^2 & \text{if } z(t) \geq \tilde{z}. \end{cases} \quad (3.21b)$$

To start with, the intratemporal payments from e are positive and constant for $z(s) < \tilde{z}$. For $z(s) \geq \tilde{z}$, they are lower than before and decline with $q^a(s)$ and thus increase with $z(s)$. Substituting $z(s) = \tilde{z}$ as a threshold in (3.21a) for $z(s) \geq \tilde{z}$ and rearranging, we can determine the lower bound of $\gamma_e m_e^a(s)$:

$$\gamma_e m_e^a(s) \geq \gamma_e \tilde{m}_e^a(s) \equiv \left[r \frac{\eta^2 (\eta + \frac{\eta_e}{2} + \eta_f) - 2\eta_e \eta_f (\eta + \eta_f)}{\eta^2 (\eta + \eta_e + \eta_f)} - \psi \mu_f c_z \frac{\eta_e \eta_f (\eta + 2\eta_e) (\eta + 2\eta_f)}{\eta^2 (\eta + \eta_e) (\eta + \eta_e + \eta_f)} \right] \frac{\psi (\mu_e \frac{x_z}{r})^2}{r + \psi \mu_f c_z} \quad \text{if } z(t) \geq \tilde{z}, \quad (3.22)$$

which can be negative. For large $z(s)$, the intratemporal payments from e are positive but still lower than for $z(s) < \tilde{z}$.

The intratemporal payments from f increase with $q^a(s)$ and thus decline with $z(s)$ for $z(s) < \tilde{z}$. Substituting $z(s) = \tilde{z}$ as a threshold in (3.21b) for $z(s) < \tilde{z}$ and rearranging, we can determine the lower bound of $\gamma_e m_f^a(s)$:

$$\gamma_f m_f^a(s) > \gamma_f \tilde{m}_f^a(s) \equiv x_1 \frac{\eta + 2\eta_f}{\eta} \psi \mu_e \frac{x_z}{r} + \frac{x_2}{2} \left(\frac{\eta + 2\eta_f}{\eta} \psi \mu_e \frac{x_z}{r} \right)^2 + \left[r \frac{3(\eta + \eta_f)(\eta + \eta_e + \eta_f) + \eta_f(\eta_e + \eta_f)}{2\eta(\eta + \eta_e + \eta_f)} + \psi \mu_f c_z \frac{2(\eta + 2\eta_f)}{\eta} \right] \frac{\psi (\mu_e \frac{x_z}{r})^2}{r + \psi \mu_f c_z} \quad \text{if } z(t) < \tilde{z}, \quad (3.23)$$

which is positive. For $z(s) \geq \tilde{z}$, they are higher than before, positive and increase with $q^a(s)$ and thus decline with $z(s)$.

We can also find expressions for $q(s)$, $m_e(s)$ and $m_f(s)$ in case of disagreement. From (3.5), (3.9) and (3.19a), we have

$$q^d(s) = \begin{cases} q^{a,f}(z^a(s)) = \psi [\beta - \mu_e \frac{x_z}{r} - \mu_f c_z z(t)] e^{-\psi \mu_f c_z (s-t)} + \psi \mu_e \frac{x_z}{r} & \text{if } z(t) \leq \tilde{z}, \\ q^{a,e}(z^a(s)) = 0 & \text{if } z(t) > \tilde{z}. \end{cases} \quad (3.24)$$

Substituting (3.24) in (3.7) yields the intertemporal disagreement payments for $z(t) < \tilde{z}$; substituting (3.24) in (3.11) yields the intertemporal disagreement payments for $z(t) \geq \tilde{z}$. Then, using (2.27e), we have

$$\gamma_e m_e^d(s) = \begin{cases} 0 & \text{if } z(t) < \tilde{z}, \\ \frac{\eta(\eta + \eta_e + \eta_f)}{(\eta + \eta_e)(\eta + \eta_f)} \left[\mu_e \frac{x_z}{r} q^a(s) + \frac{\eta_e}{\eta + \eta_e + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2} \right) q^a(s)^2 \right] \\ + r \frac{\eta(\eta + \frac{\eta_e}{2} + \eta_f)}{(\eta + \eta_e)(\eta + \eta_f)} \cdot \frac{\psi (\mu_e \frac{x_z}{r})^2}{r + \psi \mu_f c_z} & \text{if } z(t) \geq \tilde{z}, \end{cases} \quad (3.25a)$$

$$\gamma_f m_f^d(s) = \begin{cases} \left[x_1 + \left(\frac{\eta}{\eta + \eta_f} + \frac{\frac{x_2}{2}}{\frac{1}{\psi} - \frac{\alpha}{2}} \right) \mu_e \frac{x_z}{r} \right] q^a(s) + \left[\frac{x_2}{2} + \frac{\eta}{\eta + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2} \right) \right] q^a(s)^2 \\ + r \left[x_1 \frac{\psi \mu_e \frac{x_z}{r}}{r + \psi \mu_f c_z} + \left[\frac{x_2}{2} + \frac{\eta}{\eta + \eta_f} \left(\frac{1}{\psi} - \frac{\alpha}{2} \right) \right] \frac{(\psi \mu_e \frac{x_z}{r})^2}{r + 2\psi \mu_f c_z} \right] & \text{if } z(t) < \tilde{z}, \\ 0 & \text{if } z(t) \geq \tilde{z}. \end{cases} \quad (3.25b)$$

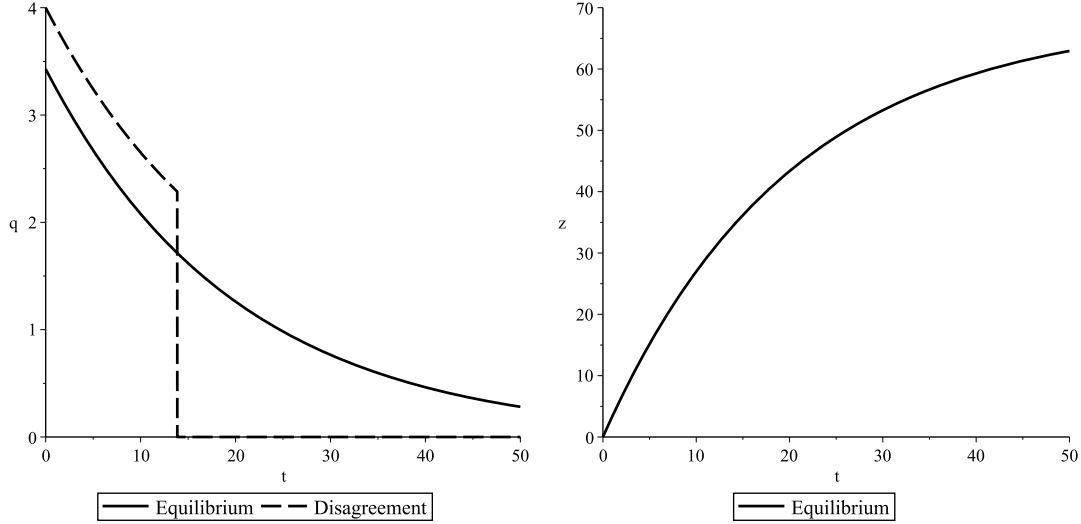


Figure 2: Extraction paths and cumulative extraction path.

For $z(t) \geq \tilde{z}$, the intratemporal disagreement payments from e are higher than the respective agreement payments and converge to them for $\lim_{q \rightarrow 0}$. They are positive and decline with $q^a(s)$ and thus increase with z . Substituting $z(s) = \tilde{z}$ as a threshold in (3.25a) for $z(s) \geq \tilde{z}$ and rearranging, we can determine the upper bound of $\gamma_e m_f^d(s)$:

$$\gamma_e m_e^d(s) \leq \gamma_e \tilde{m}_e^d(s) \equiv \left[r \frac{2(\eta + \eta_f)}{\eta} + \psi \mu_f c_z \frac{(\eta + \eta_e)(\eta + \eta_f)}{\eta(\eta + \eta_e)} \right] \frac{\psi (\mu_e \frac{x_z}{r})^2}{r + \psi \mu_f c_z} \quad \text{if } z(t) \geq \tilde{z}, \quad (3.26)$$

which is greater than $\gamma_e m_e^a(s)$ from (3.21a) for $z(t) < \tilde{z}$.

For $z(t) < \tilde{z}$, the intratemporal disagreement payments from f are higher than the respective equilibrium payments. They are positive and increase with $q^a(s)$ and thus decline with z .

3.3 Illustration

In this section, we will illustrate how z , q , m_e and m_f develop over time. To do this, we use diagrams for specific parameter values. We choose symmetric bargaining and policy weights, that is $\eta = \eta_e = \eta_f = \frac{1}{3}$ and $\gamma_e = \gamma_f = \lambda_e = \lambda_f = 1$ so that $\mu_e = \mu_f = 1$. Furthermore, $r = \frac{1}{10}$, $p = 10$, $c_1 = 1$, $c_2 = \frac{2}{3}$, $c_z = \frac{1}{10}$, $x_1 = 1$, $x_2 = \frac{2}{3}$, $x_z = \frac{4}{35}$. Then $\alpha = \frac{4}{3}$, $\beta = 8$, $\mu_f c_z = \frac{1}{10}$ and $\psi = \frac{1}{2}$. The numbers are chosen to generate nice figures. Finally, we assume cumulative extraction to be zero at the beginning of time, $z(0) = 0$.

Figure 2 shows the extraction paths (left-hand side figure) and the cumulative extraction path (right-hand side figure). Equilibrium extraction declines over time as stock-dependent extraction cost increase and converge to zero as the cumulative extraction approaches the convergence level, $\hat{z} = 70$. In case of disagreement, the government would bargain with f for $z < \tilde{z} = 35$. Then extraction would be higher than in equilibrium because both the government and f are not concerned about stock pollution. Because the speed of extraction ψ does not change, the disagreement extraction is constantly higher than the equilibrium extraction. For $z \geq \tilde{z} = 35$, the government would bargain with e and extraction would be zero.

Figure 3 shows the payments from e (left-hand side figure) and from f (right-hand side figure). As long as the disagreement extraction would be bargained between the government and f , the equilibrium payments from e are positive and constant. In this case, e pays for a constantly lower extraction than in case of disagreement. This is because e is only interested in stock pollution and the marginal pollution

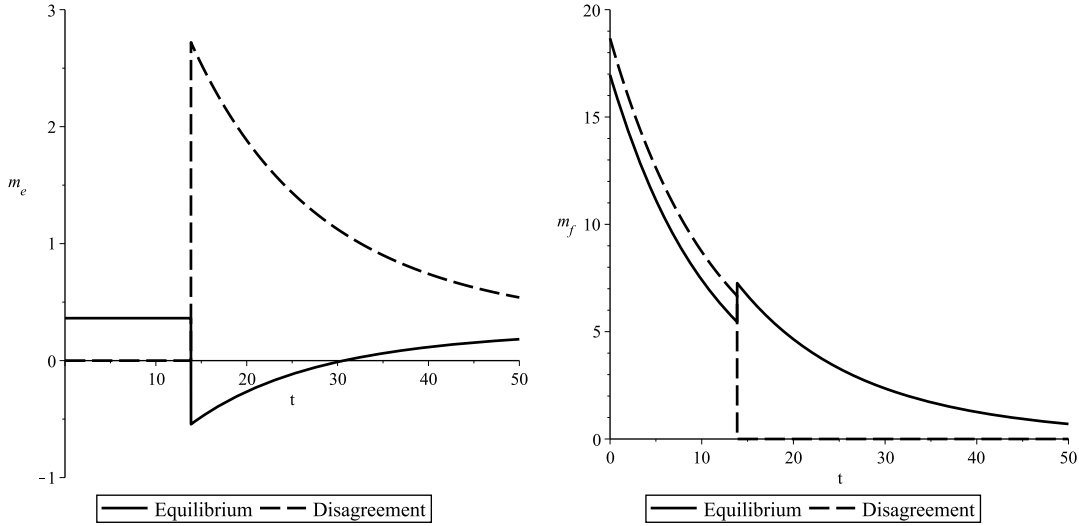


Figure 3: Payment paths.

damage is constant. At $z = \tilde{z} = 35$, the government would start to bargain with e should the trilateral negotiation fail. Then e must be compensated for not letting the negotiation break down, so that its equilibrium payments turn negative. As equilibrium extraction ceases, these payments turn positive again. This is because the additional stock pollution to come declines over time and because e must pay in case of disagreement to prevent an agreement between the government and f , so that the equilibrium profit becomes higher than the disagreement utility in some time period. The respective disagreement payments decline over time and converge to the equilibrium payments from e because in the long run, as equilibrium extraction ceases, e pays for zero extraction, both in case of agreement and in case of disagreement.

As long as there is extraction, the payments from f are positive and decline over time. They are positive because only f wants extraction and thus must pay for it. They decline over time because with z increasing over time, the extraction preferred by f declines as well. For $z < \tilde{z} = 35$, the disagreement payments from f are constantly higher than the respective equilibrium payments because the disagreement extraction is constantly higher than the equilibrium extraction. At $z = \tilde{z} = 35$, the equilibrium payments from f jump up. This is because its disagreement utility deteriorates as disagreement extraction becomes zero. In the long run, as equilibrium extraction ceases, the equilibrium payments from f vanish.

4 Conclusions

In this article, we propose a sequential Nash bargaining solution and apply it to a dynamic bargaining game on exhaustible-resource extraction.

The government and two lobbies bargain via the asymmetric Nash bargaining solution. Should the trilateral negotiation fail, the government chooses one lobby for a bilateral negotiation. In this negotiation, the disagreement point is to bargain with the other lobby. Finally, should this second bilateral negotiation break down, the government chooses the welfare maximizing policy.

The bargaining order depends on the bargaining weights and on the respective equilibrium and disagreement welfare and profits. For the first bilateral negotiation, the government would choose to bargain with that lobby with which the gains of cooperation are high and which has a bad bargaining position vis-a-vis the government. While the weighted sum of payments is positive in the trilateral

equilibrium, the payments from the lobby which the government would choose for the first bilateral negotiation can be negative. Then, the respective lobby receives a compensation from the other lobby for not letting this negotiation break down. Furthermore, we apply the model to a general dynamic setting. We assume that if bargaining should fail in any instant in a given constellation of bargaining parties, then it can never again be taken up in that constellation.

In our explicit example, we have a government that dislikes flow pollution, an environmental organization concerned about stock pollution and an extraction firm that would like to maximize profits. As long as cumulative extraction is still low, stock-dependent extraction cost are low and profits of the firm are high. Then, the disagreement point in the trilateral negotiation is an agreement between the government and the firm. This changes when cumulative extraction exceeds some threshold; then, there is an agreement between the government and the environmental organization should the trilateral negotiation fail.

Extraction declines over time and ceases as stock-dependent extraction cost become prohibitively high. As extraction declines, the conflict of interest between the government and the firm shrinks, so that the payments from the firm in general decline over time. The payments from the environmental organization are constant as long as the disagreement point is an agreement between the government and the firm. Then, the environmental organization pays for a constantly lower extraction than in case of disagreement. Its payments jump down and possibly turn negative when the disagreement point changes. Then, the environmental organization must possibly be compensated for accepting extraction at all.

A Derivation of the Nash Bargaining Solution

The first-order conditions for maximizing (2.2a) are

$$\left[\frac{\eta w'(q^a)}{w(q^a) + \sum_{h \in B} \gamma_h m_h^a - g^d} + \sum_{h \in B} \frac{\eta_h \pi'_h(q^a)}{\pi_h(q^a) - \lambda_h m_h^a - l_h^d} \right] N(q^a, \mathbf{m}^a) = 0, \quad (\text{A.1a})$$

$$\left[\frac{\eta \gamma_i}{w(q^a) + \sum_{h \in B} \gamma_h m_h^a - g^d} - \frac{\eta_h \lambda_i}{\pi_i(q^a) - \lambda_i m_i^a - l_i^d} \right] N(q^a, \mathbf{m}^a) = 0 \quad \text{for } i \in B. \quad (\text{A.1b})$$

Rearranging (A.1b) yields

$$\frac{\eta_i}{\pi_i(q^a) - \lambda_i m_i^a - l_i^d} = \frac{\eta}{w(q^a) + \sum_{h \in B} \gamma_h m_h^a - g^d} \frac{\gamma_i}{\lambda_i}. \quad (\text{A.2})$$

Substituting this into (A.1a) and rearranging yields

$$w'(q^a) + \sum_{h \in B} \frac{\gamma_h}{\lambda_h} \pi'_h(q^a) = 0, \quad (\text{A.3})$$

so that the agreement policy can be written as in (2.3a). Solving (A.2) as a system of equations defining m_i^a for $i \in B$ yields (2.3c).

B Derivation of the Explicit Example

We first derive the agreement policy in the trilateral negotiation, then the agreement policy in the bilateral negotiation between the government and lobby e and finally the respective agreement utilities.

Using Lemma 3, the agreement policy in the trilateral negotiation is defined by

$$q^a(z) \in \operatorname{argmax}_{q \geq 0} W(q, z) + \mu_e \Pi_e(q, z) + \mu_f \Pi_f(q, z). \quad (\text{B.1})$$

Using (2.25), (3.2) and (3.3),

$$\begin{aligned} & W(q, z) + \mu_e \Pi_e(q, z) + \mu_f \Pi_f(q, z) \\ &= \int_t^\infty e^{-r(s-t)} \left[\beta q(s) - \frac{\alpha}{2} q(s)^2 - \mu_f c_z z(s) q(s) - \mu_e x_z z(s) \right] ds. \end{aligned} \quad (\text{B.2})$$

Using (3.1), the current-value Hamiltonian is

$$H = e^{-r(s-t)} \left[\beta q(s) - \frac{\alpha}{2} q(s)^2 - \mu_f c_z z(s) q(s) - \mu_e x_z z(s) \right] + h q(s), \quad (\text{B.3})$$

where h is the shadow value of cumulative extraction, defined in terms of its marginal contribution to the weighted sum of welfare and profits, and the corresponding first-order conditions are

$$\frac{\partial H}{\partial q} = e^{-r(s-t)} [\beta - \alpha q(s) - \mu_f c_z z(s)] + h = 0, \quad (\text{B.4a})$$

$$\frac{\partial H}{\partial z} = -e^{-r(s-t)} [\mu_f c_z q(s) + \mu_e x_z] = -\dot{h}, \quad (\text{B.4b})$$

$$\frac{\partial H}{\partial h} = q(s) = \dot{z}(s). \quad (\text{B.4c})$$

Substituting (B.4c) in (B.4a) and (B.4b) yields

$$\frac{\partial H}{\partial q} = e^{-r(s-t)} [\beta - \alpha \dot{z}(s) - \mu_f c_z z(s)] + h = 0, \quad (\text{B.5a})$$

$$\frac{\partial H}{\partial z} = -e^{-r(s-t)} [\mu_f c_z \dot{z}(s) + \mu_e x_z] = -\dot{h}. \quad (\text{B.5b})$$

Taking the time derivative of (B.5a), substituting it into (B.5b) and rearranging yields a second-order differential equation in $z(s)$:

$$\ddot{z}(s) - r \dot{z}(s) - \frac{r \mu_f c_z}{\alpha} z(s) = -\frac{r (\beta - \mu_e \frac{x_z}{r})}{\alpha}. \quad (\text{B.6})$$

Solving (B.6) yields

$$z(s) = \frac{\beta - \mu_e \frac{x_z}{r}}{\mu_f c_z} + c_1 e^{(s-t) \left(\frac{r}{2} + \sqrt{\frac{r^2}{4} + \frac{r \mu_f c_z}{\alpha}} \right)} + c_2 e^{(s-t) \left(\frac{r}{2} - \sqrt{\frac{r^2}{4} + \frac{r \mu_f c_z}{\alpha}} \right)}. \quad (\text{B.7})$$

We assume $c_1 = 0$ for stability. Substituting $s = t$ in (B.7) then yields $c_2 = z(t) - \frac{\beta}{\mu_f c_z}$, so that

$$z^a(s) = \frac{\beta - \mu_e \frac{x_z}{r}}{\mu_f c_z} - \left[\frac{\beta - \mu_e \frac{x_z}{r}}{\mu_f c_z} - z(t) \right] e^{-\psi \mu_f c_z (s-t)}, \quad (\text{B.8a})$$

where ψ is defined by (3.4). Taking the time derivative of (B.8a) and substituting it into (B.4c) yields

$$q^a(s) = \psi \left[\beta - \mu_e \frac{x_z}{r} - \mu_f c_z z(t) \right] e^{-\psi \mu_f c_z (s-t)}. \quad (\text{B.8b})$$

Substituting $s = t$ in (B.8b) yields (3.15) for $z(t) \leq \hat{z} \equiv (\beta - \mu_e \frac{x_z}{r}) / (\mu_f c_z)$. To determine the agreement policy in the bilateral negotiation on Stage 2, we substitute $\mu_e = 0$ in (B.8a) and (B.8b), which yields

$$z^{a,f}(s) = \frac{\beta}{\mu_f c_z} - \left[\frac{\beta}{\mu_f c_z} - z(t) \right] e^{-\psi \mu_f c_z (s-t)}, \quad (\text{B.9a})$$

$$q^{a,f}(s) = \psi [\beta - \mu_f c_z z(t)] e^{-\psi \mu_f c_z (s-t)}. \quad (\text{B.9b})$$

Substituting $s = t$ in (B.9b) yields (3.9) for $z(t) \leq \hat{z}_f \equiv \beta / (\mu_f c_z)$. Using (2.25) and (3.2), intertemporal welfare and profits are

$$W(s) = - \int_t^\infty e^{-r(s-t)} \left[x_1 + \frac{x_2}{2} q(s) \right] q(s) \, ds, \quad (\text{B.10a})$$

$$\Pi_e(s) = - \int_t^\infty e^{-r(s-t)} x_z z(s) \, ds, \quad (\text{B.10b})$$

$$\Pi_f(s) = \int_t^\infty e^{-r(s-t)} \left[p - c_1 - \frac{c_2}{2} q(s) - c_z z(s) \right] q(s) \, ds. \quad (\text{B.10c})$$

Substituting (B.8a) and (B.8b) in (B.10) and evaluating the infinite sums yields (3.16). Substituting (B.9a) and (B.9b) in (B.10) and evaluating the infinite sums yields (3.6).

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