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The Biodiversity Bargaining Problem

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Abstract We employ cooperative bargaining theory and Nash's 'rational threats' idea to cast light on the *biodiversity bargaining problem*. The problem of global environmental negotiations is argued to be of the nature of a bargaining problem, in which bargainers must agree on the distribution of cooperative surplus in order to move to the bargaining frontier. We discuss the importance of both efficiency (bargaining frontier) and fairness (recognition of characteristics of bargainers) in the choice of the appropriate contract. We show that the incremental cost contract, used to resolve the biodiversity bargaining problem, is of the form of an extreme point contract that fails to recognise the contributions of the South to the production of cooperative surplus. A rational response to such a contract is the use of threats of biodiversity destruction. Contracts must evince both efficiency and fairness in order to represent lasting solutions.

Keywords Biodiversity · Incremental costs · International environmental agreements · Nash cooperative bargaining · North–south bargaining · Rational threats

JEL Classification Q15 · Q16 · Q21 · O13 · O34

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1 Introduction

International agreements would be relatively straightforward to devise and to implement if states were homogeneous. Obligations could then be made uniform and implementation could be achieved through reciprocity. Real difficulties arise in international agreements when the states are very different from one another (Barrett 1994). One context in which this problem is obvious is the management of global biodiversity. There is increasing recognition of the important role to be played by genetic resources in addressing problems in the life sciences (health, agriculture) even as the decline of biodiversity continues apace (Leakey and Lewin 1995).[1] The Convention on Biological Diversity (CBD) was created in part to ensure that sustainable utilisation and management of genetic resources is implemented. The problem for the CBD lies in implementing these obligations when states are so different from one another in this respect. Some parts of the world are highly endowed with biodiversity (here, the "South") while others have very little (the "North"). The North is the primary location of the research and development (R&D) industries relying upon these resources, while the South does not (Swanson 1996). Finally the domestic institutions relating to these capital endowments are very different, with clear property rights institutions in most forms of capital but few in regard to biodiversity.[2]

These asymmetries across endowments, industries and institutions result in an unbalanced bargaining process in which each party is negotiating from a position of relative strength in some respects, and abject weakness in others. So, this is the core of the biodiversity bargaining problem (BBP). While both North and South must combine inputs to generate the cooperative surplus, some means of compensating the respective contributions must be agreed in order to sustain the cooperative solution. The solution to the BBP requires the agreement upon an international institution that generates the *efficient* solution while implementing an *agreed* distribution. Efficiency concerns the achievement of the bargaining frontier, while agreement hinges upon recognising the parties' respective contributions to the same. In terms of Nash bargaining, fundamentally this means recognising the relative movement away from the conflict point deriving from each party's participation. If this contribution is unrecognised, it is in Nash terms "unfair" (Nash 1953). Without solving *both* aspects of the BBP, efficiency and fairness, a lasting solution cannot be achieved.

After our initial formulation of the BBP, we then turn to the discussion of the implementation of solutions to the BBP. Then we turn to the CBD's resolution of the BBP—the *incremental cost contract*. We demonstrate that this is a solution of the form of an extreme point contract, representing a corner solution on the bargaining frontier. In short, our analysis indicates that in terms of Nash bargaining the solution concept employed by the CBD to address the BBP is efficient but unfair.

[1] It is recognised that genetic resources will likely play a crucial role in supplying the solution concepts within the life sciences industries. Biodiversity does this by supplying genetic resources to R&D sectors supplying the life sciences industries (Kassar and Lasserre 2004; Goeschl and Swanson 2002).

[2] What complicates this mutual interdependence between North and South is the specialised and sequential nature of the R&D process within this industry. It is only the South that contains the genetic inputs required for the R&D process. It is only the North that contains the expertise to convert these into the protected intermediate goods (patented products) that contain these valuable genes. Although both North and South may then use the intermediate goods to advance production and welfare, it is the North that appropriates the value of the R&D process through its exclusive rights in the intermediate goods. This vertical structure to the R&D industry can render the industry susceptible to the "hold up problem" and makes it difficult to coordinate the activities of the parties concerned (Sarr and Swanson 2009). There is little doubt that cooperation is important, but there is little within the nature of the problem that suggests the specific nature of an agreeable solution.

This leads us to examine the sorts of responses available to the South, when an unfair division of surplus is imposed by contract. That is, how can the South exercise its bargaining power when the proposed outcome does not recognise it's contribution? We examine this in the context of Nash's model of rational threats, demonstrating how residual bargaining power is able to alter the terms of agreement (Nash 1953). Our analysis leads us to predict that the rational response of the South to the incremental cost contract is to threaten the further destruction of biodiversity resources. We find that an efficient contract that fails to recognise the inherent contributions of individual agents is unstable, and predict that a lasting solution will be based upon the essential contributions of the parties.

In sum, the specific contributions of this paper are threefold. One is to apply cooperative bargaining theory within the biodiversity context, demonstrating the bargaining frontier and the wide range of efficient contracts available for attaining it. The second is to use the insights of bargaining theory to characterize the observed incremental cost contract as an extreme point contract, and to demonstrate the division of surplus that this represents. Thirdly, by extending the bargaining situation to include the use of 'rational threats' (Nash 1953; Busch et al. 1998), the paper shows that the existing contractual terms can be explained as an outcome of the BBP, but an unlikely long-term solution.

The paper proceeds as follows. In Sect. 2 we present a basic model of biotechnology, R&D and land use in a North–South world and describe the bargaining problem between a 'technology-rich' North and a 'gene-rich' South. The BBP as a Nash Cooperative Bargaining Game between North and South is also presented, indicating the factors determinative of the cooperative solution within this framework. Section 3 examines the contractual approaches which would uphold the bargaining solution and compares these with those actually in use to implement efficient solutions of the problem. In Sect. 4 we turn to the possible conflict between the solution concepts outlined in the previous two sections and discuss the role of strategic threats of destruction in the BBP. The conditions for the existence of rational threats are established and illustrated. Section 4 discusses the importance of efficiency and fairness in implementing long-term solutions to global problems and provides examples of how strategic threats have been deployed in practice. Section 5 concludes.

2 The Biodiversity Bargaining Problem (BBP)

We commence our discussion by setting out a Nash cooperative bargaining model that incorporates the manner in which North and South must cooperate in order to generate joint surplus. We set this out as a world in which both agents have inputs that are essential to the production of the surplus, but where each is capable of a much-reduced level of production when operating on its own. For purposes of concreteness, we will present these assumptions within a stylised representation of the global agricultural biotechnology industry, in which genetic resources emanating from a 'reserve' sector situated only in the South are the major inputs into a plant breeding sector situated exclusively in the North. This plant breeding sector relies upon the skilled human capital endowment in the North to undertake research and development activities based upon the genetic resources from the South. This R&D sector produces innovations in the form of new seeds, within which the information from the genetic resources is embedded. These intermediate goods can then be used in intensive agricultural sectors in either the North or South. Of course, the expansion of intensive agriculture in the South is a means by which cooperative surplus might be shared, but it is also in conflict with the objective of retaining the maximum amount of genetic resources (i.e. reserves) for purposes of R&D. The problem we examine is how the North and South might simultaneously determine land uses and distribute joint surplus within such an asymmetric bargaining environment.

To set up the BBP, we must also understand the way in which the two parts of the world would work in the absence of cooperation. The world of autarky (or conflict) in this model is one in which the South uses its genetic resources to produce agricultural output, but without the technical know-how to translate them into high production agriculture. For the North, conflict represents the situation in which high-technology is available but the genetic resources for supplying it are not. When the North and South elect to cooperate, a high-production agricultural sector is possible in both parts of the world by reason of the combination of the specialised inputs from each. The sole hurdle to cooperation is the agreement on the division of surplus: How much should the South be compensated for the provision of biodiversity reserves? How much should the North be compensated for the provision of the technology that makes use of these?

2.1 The Model: Biotechnology, R&D and Land Use

In this section we develop a model to explore the nature of Nash bargaining between these two very distinctive parts of the world, termed North and South. This is in line with previous models in this context (e.g. Droege and Soete 2001; Krugman 1979; Polasky et al. 2004). We stylise these agents as being distinctive in several important respects: capital endowments, industrial structures and land use choices. We also assume that these stylised facts are inalterable, i.e. the South is the only possible source of biodiversity and the North is the only possible source of R&D. This implies that biodiversity losses are irreversible and that existing human capital endowments cannot be significantly altered within the timescale of this analysis. The differences between the different parts of the world are fundamental to the BBP.

2.1.1 The North

The North is endowed with basic natural capital (land) but a rich human capital base. The Northern land endowment (L_N) represents land that has been cleared of biological diversity and is allocated between two alternative land uses: a technologically inactive and relatively unskilled baseline sector and an intensive and technologically-active agricultural sector. We assume that all land is homogeneous for a given use, so marginal products will be constant.

Baseline production in the North produces final output by the application of an unvarying technology to some part of the land endowment. It therefore represents a base-line production sector in the sense that its productivity is not associated with the outcome of the bargaining process, or any choices made by the South. Production in this baseline sector is represented by the net output function:

$$y_N^b = bl \tag{1}$$

where l is the land devoted to this sector and b is a net productivity parameter. This is the output net of costs valued in terms of output, and represents a constant returns to scale production technology. The coefficient b can be thought of as being equal to some value $(e - d)$, where e represents the productivity of land devoted to this sector and d represents the costs. Thus, setting $b = 0$ is the same as assuming a zero profit condition for the baseline sector. It may be instructive to think of this sector as being a capital intensive but low-technology sector, such as “organic food production”; however, the only function the baseline sector serves is to supply a base level of Northern production in the event of conflict with the South. We take final output as the numeraire.

The other productive sector in the North is technologically more active, and reliant upon decisions taken in the South. This "intensive" sector produces final output, y_N^i, using seeds, n, developed within the R&D sector. For tractability, we (reasonably) assume a fixed relationship between seed and land, hence the amount of land used in intensive production is equal to n. The R&D sector operates by combining the North's human capital with the genetic resources from the South to generate productivity-enhancing innovations. The dependence on the South is captured in the assumption that innovations in the form of High Yielding Varieties (HYV) which increase productivity are positively related to the South's choice of the size of the Reserve sector, R, in the South.

An innovation has the impact of effectively causing a land-augmenting productivity increase in the intensive sector, captured by the function, $\pi(R)$, which pre-multiplies the intensive sector production function. Thus, final output in the intensive sector captures the interdependent/joint nature of production as it is a function of HYVs from the North and Reserves in the South. Intensive production is represented by the net output function[3]:

$$y_N^i = \pi(R)n, \quad \left(\pi\ (0) = b, \pi'(R) > 0, \pi'\ (0) = \infty, \pi''(R) \leq 0\right) \tag{2}$$

The land constraint is $L_N = n + l$ and total output is therefore represented by:

$$y_N = \pi(R)n + b\,(L_N - n) \tag{3}$$

The costs of R&D are assumed to rise with the quantity of the intermediate output, i.e. $c\,(x)$, where $c\,(0) = 0, c'\,(\cdot) \geq 0, c''\,(\cdot) > 0$. These increasing costs are attributable to the need to draw larger amounts of skilled labour into the sector at larger scales of production.[4] There is no significant amount of land used in the sector. The R&D sector can supply seed to the South (s) as well as the North so the total quantity of seed produced is equal to: $x = n + s$. We assume that the point of the R&D sector is to increase productivity over the baseline. From Eqs. 1 and 2 it is clear that when $R = 0$ both the baseline and the intensive sectors are equally productive. However, when $R > 0$ the functional forms ensure that the intensive sector is preferred to the baseline sector over some range, and l is the residual use of land. Lastly, the North can make a transfer payment, T, to the South which may be dependent upon the levels n and s and other variables; so, for example, this transfer might be negative in quantity, and representative of the value transferred by the South for the intermediate good of the North, or positive and representative of the value transferred by the North for reserves in the South.

The utility function for the North is thus given by:

$$U_N(n, s, t) = (\pi(R) - b)\,n - c(n + s) - T + bL_N \tag{4}$$

2.1.2 The South

In contrast, the South is endowed with a rich natural capital base and a basic labour endowment. The South is endowed with land, L_S. In contrast to the North, this land endowment includes substantial amounts of unconverted 'reserve' land that is rich in genetic diversity.

[3] Where $\pi'\,(\cdot)$ and $\pi''\,(\cdot)$ are the first and second derivative. This notation holds throughout.

[4] The relationship between the scale of production and the scale of the required inputs into R&D is well-known in the biotechnology context. This is attributable to the observation that larger scales of use induce a more rapid evolutionary response, and thus hasten technological obsolescence (Goeschl and Swanson 2002, 2003).

Southern land can be maintained as Reserves with area R, or converted to either a traditional sector, t, or to an intensive agricultural sector using seed imported from the North, s, which, as in the North is applied in fixed proportions with land. As above, land is homogenous regarding a particular use, and so marginal productivity is constant.

Production in the traditional sector occurs via a fixed proportions production function based on labour and land and is unaffected by technological innovation. Gross output in the traditional sector is t and traditional production incurs a labour-related cost $k(t)$, (where $k(0) = 0, k'(\cdot) > 0, k''(\cdot) > 0$ as labour is drawn from other parts of the economy such that the net output function is

$$y_S^t = t - k(t) \tag{5}$$

In the intensive sector, the South benefits from the presence of Reserves, R, in precisely the same way as the North in that productivity is augmented by the arrival of intermediate goods from the R&D sector. The joint nature of final output from the intensive sector is represented by an analogous production function:

$$y_S^i = \pi(R)s \tag{6}$$

Southern utility is then given by:

$$U_S(n, s, t) = \pi(R)s + t - k(t) + T, \tag{7}$$

which is maximised with respect to t, s and the Southern land constraint: $L_S = R + t + s$, where R is the residual land allocation and the transfer T has the same interpretation as in the North.

This simple model provides each part of the world with a land use allocation problem that exists in isolation (i.e. in the absence of any recognised inter-linkages) and also a much more interesting problem which exists in the presence of this interdependence. This set-up is intended solely for the purpose of establishing a baseline land use allocation that would exist in each part of the world when acting independently, and another when acting cooperatively.[5] In the following section we characterise the conflict point of this game and the extent of the potential gains from cooperation.

2.2 North–South Conflict and Cooperation

2.2.1 The Conflict Point: $(s = 0, T = 0)$

The conflict point provides the benchmark against which all bargaining solutions are measured. Here the conflict point represents an 'Autarky' outcome that is characterised by: (i) the absence of seed sales from North to South: $s = 0$; and (ii) the absence of North–South transfers (T). Consequently the South fails to internalise the value of reserves (R) and there is an under-supply of this global good. Under these circumstances the problems of the North and South in Autarky are as follows:

[5] Specifically, it is assumed without any real loss of generality that the only sectors with rising marginal costs are the intermediate goods sector in the North and the traditional agriculture sector in the South. These assumptions serve no purpose other than to provide a determinant solution to the baseline problem in each region, i.e. the optimal choice of each region if acting in isolation. In order to provide such a solution, rising marginal costs are assumed to inhere in the labour markets of that sector where production is most labour-intensive (R&D in the North, traditional agriculture in the South). This supplies the conflict point from which the analysis is initiated, but there are no other implications that flow from this assumption.

THE SOUTH: The South maximises utility with respect to t.

$$\max_t U_S(s=0, T=0) = t - k(t) \tag{8}$$

$$s.t.: L_S = t + R \quad \text{and} \quad 0 \leq t \leq L_S \tag{9}$$

If $k'(0) \leq 1 < k'(L_S)$, the South's optimal use of land under Autarky, t^a, will be an interior solution and satisfy the first order condition:

$$1 - k'(t^a) = 0 \tag{10}$$

Let $R^a = L_S - t^a$ be the South's Reserves under Autarky.

THE NORTH: The North takes the behaviour of the South as given and maximises utility over its choice of n and l. The North's problem is as follows:

$$\max_n U_N(s=0, T=0) = (\pi(R) - b)\, n - c(n) + bL_N \tag{11}$$

$$s.t.: 0 \leq n \leq L_N \tag{12}$$

If $c'(0) = 0$ and $c'(L_N) > \pi(L_S)$, the North's optimal land use, n^a, will be an interior solution satisfying the first order condition:

$$\pi\left(R^a\right) - b - c'\left(n^a\right) = 0 \tag{13}$$

This Autarky problem shows the interdependence of North and South. The North is dependent upon the South's selection of reserves to generate productivity in its intensive sector, while the South has no reason to supply reserves in the absence of a flow of intermediate goods from the North. For this reason, the South in Autarky maximises production in its traditional sector, which serves to lower the marginal productivity of the North's intensive sector (n). In the Autarky case the value of Reserves affects the North's welfare despite the absence of transfers and intensive production. This non-excludability reflects the historically weak property rights for biodiversity and the genetic inputs it provides to the North, and the commensurately low remuneration for these inputs that the South receives even now.[6]

As either region always has the opportunity of production in isolation, the Autarky solutions will constitute the Conflict Point in any bargaining game over land use and distribution. Welfare in the South under autarky, U_S^a, is defined as $U_S^a = t^a - k(t^a)$, and welfare in the North is defined by $U_N^a = (\pi(R^a) - b)\, n^a - c(n^a) + bL_N$. Furthermore, we characterise the Autarky solution by the land allocations and payoffs (t^a, R^a, l^a, n^a) and $\left(U_S^a, U_N^a\right)$ and describe it as an 'interior solution' whenever $R^a, t^a, l^a, n^a > 0$.

2.2.2 First Best (Social Planner) Allocation

The social planner problem involves the maximisation of global surplus with respect to the land allocations n, s and t. The problem can be stated as follows:

$$\max_{n,s,t} U(n,s,t) = U_S + U_N = \pi(R)(n+s) - bn + t - c(n+s) - k(t) + bL_N \tag{14}$$

$$s.t.\ R = L_S - s - t \quad \text{and} \quad l = L_N - n$$

$$\text{and} \quad s, n, t, l, R \geq 0$$

[6] Two alternative cases can also be considered here. Firstly, where the value of biodiversity held in the North includes existence values for biodiversity. Secondly, where Northern values include carbon sequestration. Both require reserves in situ, rather than trade and hence neither are excludable.

A complete characterisation of the optimal solution is unnecessary for our purposes, however Proposition 1 provides an analysis of the comparative statics of the optimal and Autarky solutions.

Proposition 1 *If the Autarky solution is interior, and the social planner wishes to hold positive levels of Reserves* $(i.e. R^* > 0)$ *then:*

(a) *intensive agricultural production will always be positive, i.e.* $(n^* + s^*) > 0$*;*
(b) *optimal traditional production in the South will be less than under Autarky,* $(i.e.\ t^* < t^a)$*;*
(c) *whenever there is intensive production in the North, the optimal Reserve sector increases with global intensive agriculture* $(i.e.\quad R^* > (<) R^a \iff n^* + s^* > (<)\, n^a)$*; and*
(d) *if profits are equal to zero in the baseline sector* $(b = 0)$*, then* $s^* > 0$ *only when* $n^* = L_N$.

Proof See "Appendix 1". □

Proposition 1(b) shows that the optimal size of the traditional sector in the South is smaller than under Autarky, however 1(c) shows that the overall level of Reserves will rise and fall with the size of the global intensive sector. How the socially optimal allocation compares with the Autarky state will depend upon the parameters of the model, particularly the relative productivity of the baseline sector in the North and the traditional sector in the South. For low values of b the socially optimal level of Reserves is higher than under Autarky.

Proposition 1(d) shows that in the extreme case where the profits from the baseline sector are equal to zero ($b = 0$) the ambiguity is resolved and $R^* > R^a$ whenever the North's baseline sector remains active. In sum, the social planner is reluctant to have intensive agriculture in the South due to the loss of socially valuable Reserves this land use would entail, and where $b = 0$ the social planner would choose for each region to specialise in its own function for agriculture: intensive production in the North and Reserves in the South. Specialisation here is the result of the fact that only the South can provide Reserves while the value from intensive production may be pursued in either region. Although both are necessary for the production of joint surplus, under these conditions the emphasis is on the South providing that which only it can provide (i.e. Reserves).

This is indicative of the role of cooperation in the context of heterogeneous agents: when acting separately each pursues a similar mix of relatively unproductive activities, when acting cooperatively the two agents generate a vertically integrated industry in which each specialises at its own level of production (as determined by respective capital endowments). The incentive to cooperation is found in the value of such specialisation. We turn now to defining the level of that cooperative surplus.

2.2.3 The Cooperative Surplus and the Bargaining Frontier

Defining optimal welfare under the social planner solution by $U^* = U_N^* + U_S^*$ allows us to define the extent of the social gains from cooperation, U^C, as the difference between the welfare under the social planner and that under Autarky:

$$U^C = U^* - \left(U_N^a + U_S^a\right) \tag{15}$$

Clearly, as the social planner is always able to select the Autarky outcome, $U^C \geq 0$. From Proposition 1, when the Autarky solution is interior then $t^* < t^a$ and it follows that the inequality is strict—so there exist strictly positive gains from cooperation.

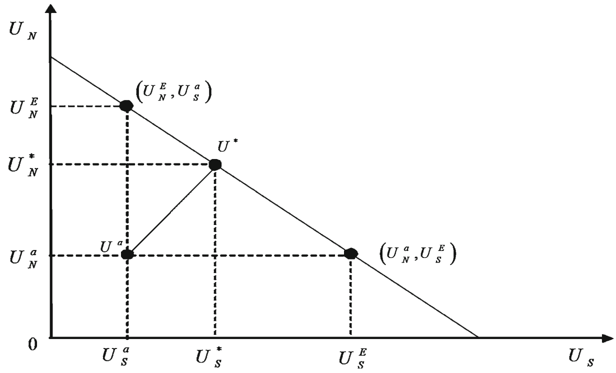

Fig. 1 The fixed threat Nash BBP

Figure 1 shows the Autarky and optimal outcomes. U^* is any point on the welfare frontier. U^a is the conflict point. The set of efficient distributions is termed the bargaining frontier, since the parties are able to achieve any point along this frontier so long as they can agree on which point they wish to attain. Although the Social Planner is not concerned with the distribution of cooperative gains from biodiversity preservation, a system of lump sum transfers ordered by the Social Planner can facilitate any desired distribution along U^*.

2.3 The Nash Cooperative Bargaining Solution

The solution concept developed by Nash, based on an axiomatic approach to bargaining, consists of the application of several axioms of rationality in order to separate out the set of bargaining outcomes that are consistent with those axioms (Nash 1953). The Nash approach to cooperative bargaining indicates that the parties within such a framework, acting in accordance with basic axioms of rationality, would jointly focus their attention on the set of options to the NE of the conflict point (U_S^a, U_N^a) but within the bargaining frontier set forth in Fig. 1.

In addition, Nash proposed a solution concept that would enable the selection of a single outcome on the bargaining frontier. In order to do so, he hypothesised that specific characteristics of the bargaining agents would determine each agent's capacity to capture a share of the cooperative surplus, and he labelled this determinate outcome the respective "bargaining powers" of the parties. If the parties are informed of the nature of the BBP as well as the bargaining powers of the respective parties, then the general form of the Nash solution to a BBP is a point (U_N, U_S) which maximises:

$$(U_N - U_N^a)^\alpha (U_S - U_S^a)^{(1-\alpha)} \text{ s.t. } U_N + U_S = U^* \tag{16}$$

where $\alpha \in [0, 1]$ denotes the bargaining power of the North and $(1 - \alpha)$ denotes the bargaining power of the South. The solution gives $U_N^* = (1 - \alpha)U_N^a + \alpha(U^* - U_S^a)$ and $U_S^* = \alpha U_S^a + (1-\alpha)(U^* - U_N^a)$ (Nash 1953). The important point is that any solution to the bargaining problem will lie to the NE of the conflict point and somewhere on the bargaining frontier, but that the specific point that is chosen will be the outcome of some sort of process rendered determinate by the relative "bargaining powers" of the parties.

2.4 The Biodiversity Bargaining Problem: Discussion

This section has set out a basic framework for thinking about North–South cooperation in the context of global biodiversity management. The BBP (set forth in Fig. 1) illustrates how the respective choices of North and South will determine the joint outcome, as well as the individual outcomes, they achieve. We have emphasised here the importance of the differences between the two agents. With heterogeneous agents, the core of the BBP is that cooperation requires the two agents to make very different choices. One must invest in one form of capital investment and production (natural reserves and genetic resources) and the other must invest in another very different form of capital and production (human capital and R&D). If they are able to cooperate, then a vertical industry based on high technology and specialised production will result. If they are unable to cooperate, then each engages in a more similar set of activities but at a lower level of production and a lower level of technology. This setup implies that an optimal solution to the biodiversity bargaining problem requires very different choices by very different agents.

3 Contractual Approaches to the BBP: Efficient and Incremental Cost Contracts

In this section we turn to a positive approach to the BBP. The outcome to the BBP will require the conclusion of some sort of a contract between N and S, and the agreement of its terms (van Soest and Lensink 2000). This contract will then specify the precise point within the BBP that is agreed to be the implemented outcome. In this section we set out the class of contracts capable of determining a solution to the BBP. We then look at what has in fact occurred within the context of biodiversity negotiations: We demonstrate that the outcome of the BBP lies on the bargaining frontier, as predicted, but is representative of an unlikely bargaining power distribution.

3.1 Contractual Solutions to the BBP

Proposition 2 describes a contractual mechanism that would support the entire range of potential solutions to the BBP. Within this one-offer bargaining framework, the party designated as having the ability to make the offer of the contract holds the residual rights to the cooperative surplus, and specifies lump-sum transfers to satisfy the other agent's participation constraints and to uphold the contracted division of surplus:

Proposition 2 General case (optimal contracts for BBP): *General (N to S): If framed as an offer by N to the S, the optimal contract to uphold an asymmetric Nash bargaining solution would have North specify the contractual terms s^* and n^* and the transfer:*

$$T_N(t) = \int_t^{t^a} \left[1 - k'(z)\right] dz - \pi(L_S - s^* - t)s^* + (1 - \alpha)\, U^C$$

Proof See "Appendix 1". □

This general form of contract has three components.[7] The first component compensates the South at the margin for choosing values of t other than t^a, the second represents a transfer

[7] The equivalent contractual form when contracts are offered by the South to the North, and the former has residual rights to intensive production is:

$$T_S(n, s) = \left[\pi(R^*) - b\right](-n) + c(n + s) + [U_N^a - bL_N] + \alpha U^C.$$

of surplus to the North (reflecting the idea that the residual rights lie with the party offering the contract, here the North). Together these terms ensure that the South is indifferent to any choice of t, including t^*, and pushes the South back to its autarky level of welfare. The last term represents the sharing of cooperative surplus induced by the relative power distribution. Depending upon that power distribution, any point along the bargaining frontier is feasible. We turn now to define the special cases in which either one party or the other is able to capture the entirety of the cooperative surplus—this is the definition of the *extreme point contract*.

Proposition 2 Special case (extreme point contracts):

(a) *Extreme Point* (*S to N*)*: The optimal contract when the North has no bargaining power is for the South to specify the contractual terms* n^*, s^* *and* t^* *and the transfer:*

$$-T = T_S(n, s) = \left[\pi(R^*) - b\right](-n) + c(n + s) + [U_N^a - bL_N]$$

where $R^* = L_S - s^* - t^*$.

(b) *Extreme Point* (*N to S*)*: The optimal contract when the South has no bargaining power is for the North to specify the contractual terms* n^* *and* s^* *and the transfer:*

$$T = T_N(t) = \int_t^{t^a} \left[1 - k'(z)\right] dz - \pi(L_S - s^* - t)s^*$$

Proof See "Appendix 1". □

The outcomes identified here may be related once again to the basic BBP structure set forth in Fig. 1. Proposition 2(a) states that the extreme point contract offered by the South will specify $\left(U_S^E, U_N^a\right)$ in terms of Fig. 1. Proposition 2(b) states that the extreme point contract offered by the North will specify $\left(U_S^a, U_N^E\right)$. Each extreme point contract is efficient in the sense that it allows the agents to attain the bargaining frontier, but each extreme point contract merely compensates the party receiving the offer for the costs of its participation. As set out in Proposition 2, these sorts of extreme point outcomes may result from the bargaining process only if all of the bargaining power resides only with one of the parties.[8]

3.2 Application: Incremental Cost Contracts as Extreme Point Contracts

The concept of incremental cost contracting under the CBD is an example of an extreme point contract in practice.[9] In terms of the BBP, the IC contract requires the North to compensate the South for the additional costs it incurs by electing the cooperative option (choosing t^*)

[8] To see an example of this for the Nash Bargaining outcome see Example 15 and evaluate (16) and the welfare outcomes for $\alpha = 1$ and $\alpha = 0$.

[9] Under the terms of the CBD is the South must commit to provide the biodiversity resource, and the focus of the agreement is the means by which the South is compensated for doing so - the answer to which is found in the concept of *incremental costs [IC] contracting:*

'[the North] *shall provide new and additional financial resources to enable* [the South]*to meet the agreed full incremental costs to them of implementing measures which fulfil the obligations of this Convention*'. [Art. 20, CBD].

The meaning of the term "incremental costs" is further defined within the founding instrument of the GEF as:

'[the costs of] *additional national action beyond what is required for national development [the baseline] that imposes additional [or incremental] costs on countries beyond the costs that are strictly necessary for achieving their own development goals, but nevertheless generates additional benefits that the world as a whole can share ...'* [GEF/C.7/Inf.5: para.2 & GEF/C.2/6 para.2, see King (1994)].

rather than its unconstrained development strategy (choosing t^a). There is no provision for the South to be paid any share of the cooperative surplus, but only provision for the compensation of its additional costs that are incurred to generate that "surplus": i.e., the "additional benefits that the world as a whole can share."[10] The IC contract is a straightforward offer of the extreme point contract, in which the North offers the South compensation for the costs it incurs for participating in the cooperative strategy. This extreme point contract could only be the Nash solution to the BBP if both North and South believed the South's relative bargaining power to be zero.

4 Nash Bargaining with Rational Threats: Strategic Destruction

We have seen that any point on the bargaining frontier represents a potential solution to the BBP. An extreme point contract is a particularly extreme example of one such solution—one where the assumed bargaining power of one of the parties is effectively zero. In this section we consider what is likely to occur when the contract offer assumes this, but reality differs.

4.1 Rational Threats in the BBP

We use the concept of rational threats, first analysed by Nash (1953) to model how bargaining power might be asserted within a Nash framework. One feature of many solution concepts to bargaining games is that the value received by one player (e.g. U_i^*) is not only increasing in the value of any outside option available to that player (U_i^a) but also increasing in the maximum value of cooperation to the *other* player $\left(U_j^* - U_j^a\right)$. More generally, rational threats imply that prior to negotiation of the bargaining solution, parties can *commit* to actions to be played in the event that bargaining fails (i.e. in conflict) and by manipulating the conflict point in this way affect the terms of the agreement in their favour. In short, commitments are not made because the agents are interested in the conflict payoffs themselves, but rather in the effect of these strategies on the final bargaining outcome.

4.2 BBP with Strategic Threats of Destruction

We model the BBP as a bargaining game with threats by the South. At first glance it would appear that the asymmetric endowments would result in equivalent and reciprocal threat capacities: the North could threaten to reduce R&D while the South could threaten to limit the supply of Reserves,[11] resulting in no real bargaining advantage. Here there is a clear asymmetry in bargaining capacities: the South can credibly threaten the irreversible destruction of its genetic resources, but the North cannot credibly threaten to destroy human capital. Furthermore, irreversibility means this threat contains a 'natural' commitment mechanism. In short, the asymmetry in capital endowments means that only the South can satisfy the necessary conditions for a credible threat in the BBP.

[10] Elsewhere in the CBD there are provisions for benefit-sharing that provide for sovereignty over national genetic resources and prior informed consent for making access to and use of these resources. We deal in companion papers with the issues surrounding the use of property rights mechanisms to distribute the cooperative surplus (Sarr and Swanson 2009).

[11] Parallels can be easily drawn between this type of threat for the North and the trade restrictions and limitations on technology transfer that have been the focus of the strategic trade literature (e.g. Krugman 1979; Lai and Qiu 2003).

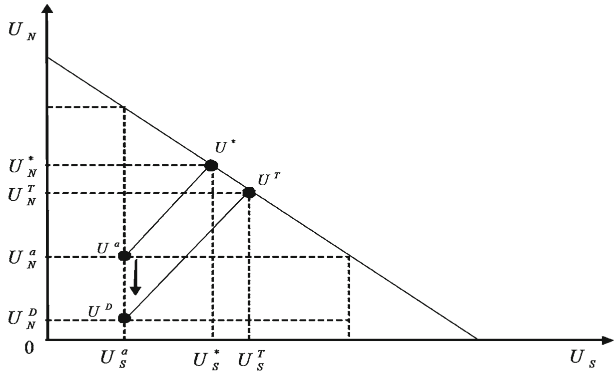

Fig. 2 The variable threat Nash BBP

The rational threats take the form of threats of strategic destruction and are modelled as the permanent loss of some part of the land containing Reserves.[12] This implies a reduction in the land available for production: the land endowment (L_S), and the level of Reserves (R). This makes L_S a strategic variable. Through this lens the BBP unfolds as follows: (i) the initial non-cooperative outcome or conflict point is determined as Autarky (U^a); (ii) the South issues its threat in the form of a land allocation in the event that cooperation fails $\left(L_S^D = L_S - D\right)$, where D represents land strategically destroyed, and defines a new conflict point $\left(U^D\right)$; (iii) the bargaining game is solved by reference to this new conflict point yielding payoffs U_i^T, where the superscript refers to threats, as illustrated in Fig. 2.

The credibility of strategic threats requires a commitment mechanism (irreversibility in Assumption 1). We also require that the South must be at least as well off in any bargaining game situation subsequent to destruction, regardless of whether this ends in cooperation or conflict. This requires *viability* and *autarky independence*:

Definition 1 (*Viability*) A strategic threat is viable if it could be carried out and yet leave the South with a payoff in any subsequent Nash solution no less than it could expect in the fixed threat Nash solution.[13]

Definition 2 (*Autarky Independence*) A strategic threat satisfies Autarky Independence if it could be carried out and leave the Autarky payoff no less than in the fixed threat bargaining game.

First, with regard to autarky independence, it is not very restrictive to assume that this condition is easily met under the conditions of the BBP. Since Reserves are residual to the South in Autarky, reflecting the informational nature of the goods they supply and the associated market failure, autarky independence is guaranteed in the BBP so long as no disproportionate amount of ancillary resources is expended in choosing to destroying Reserves. In the BBP the primary factor of concern in the South is the land endowment, and in regard to this, the destruction of reserves is costless. In regard to ancillary resources (such as labour), the

[12] To simplify the presentation, we assume that destruction renders land incapable of supporting either Reserves or traditional production.

[13] This condition resembles Sub Game Perfection in a repeated game. The solution to a dynamic bargaining game with strategic destruction has been examined elsewhere (Busch et al. 1998). Our viability conditions resemble the credibility conditions required there.

activity of destruction is not obviously more labour intensive than other uses of the land (such as conservation), and so the cost-neutrality of destruction is a reasonable assumption.

Secondly, with regard to viability, there is a plausible condition under which the payoff in Autarky is not reduced. Note that actual destruction would cause the bargaining frontier to move inwards. Given the interdependence of the North and South in the biotech industry it seems likely that viability will be an extremely stringent condition. The following Proposition shows the conditions under which viability is feasible:

Proposition 3 (Viable Strategic Destruction) *If cooperative and autarky solutions are interior and autarky independence holds, strategic threats are viable in terms of Definition 1 if:*

$$\pi'(L_S - t^a)(n^a) > \pi'(L_S - s^* - t^*)(n^* + s^*). \tag{17}$$

Proof See "Appendix 2". □

Proposition 3 describes the circumstances under which the South's share of surplus would increase with destruction more than the associated loss of global surplus. It states that strategic destruction is a viable strategy if the social marginal value of reserves increases rapidly as reserves become scarce.[14] Specifically, the marginal value must be higher in autarky than on the bargaining frontier. This condition is not unreasonable and can be supported by plausible functional form restrictions.[15]

The condition of viability requires that *actual* destruction would increase the benefits of cooperation for the North, therefore increasing the Nash payoff for the South in any subsequent Nash bargaining game. The viability condition can be understood by inspection of Fig. 3. Here, destruction would shift the conflict point downwards as reserves are destroyed. Condition (17) ensures that the Nash bargaining solution subsequent to destruction $\left(U_S^{*D}\right)$ lies below and to the right of the Nash solution with fixed threats $\left(U^*\right)$ such that: $U_S^{*D} > U_S^*$. Strategic threats would then yield the payoff $U_S^T > U_S^*$.

We have analysed the Nash solution which has some convenient properties when it comes to considering fairness in bargaining. However, destruction can be effective when considering other solutions also. For instance, it is likely that the North would accept any contract along the original frontier between $U^\#$ and U^E conditional on no destruction. As shown in Fig. 3, this would yield a payoff at least as good as an incremental cost contract after destruction, U_N^{ED}, and could involve sharing with the South.[16]

In either case, an attempt to impose an efficient but unfair solution to the BBP by one side of the world may be met with a rational threat from the other. In the Nash case, if the conditions in Proposition 2 apply the credibility and viability of such a threat asserts the

---

[14] Strategic destruction is an equilibrium strategy in a repeated bargaining game with trigger strategies where one party has the power to destroy (Busch et al. 1998). Credibility in that case does not depend on discount factors equal to one, as are implied here.

[15] *Example 1* (Strategic Destruction in the BBP) Assume the following functional forms: $\pi(R) = R^\delta$, where $\delta < 1, c(x) = x^\beta$, where $\beta > 1$ and $k(t) = t^\gamma$, where $\gamma > 1$, and assume that $b = 0$. Then for L_N sufficiently large, destruction is worthwhile to the South if and only if:

$$L_S > \left(\frac{1}{\gamma}\right)^{\gamma-1} \quad \text{and} \quad \beta > \frac{1}{1-\delta}$$

The proof is available on request. This shows how viability can depend upon the relative curvature of the seed cost and R&D functions, $c(\cdot)$ and $\pi(R)$ respectively.

[16] We thank an anonymous referee for alerting us to this possibility.

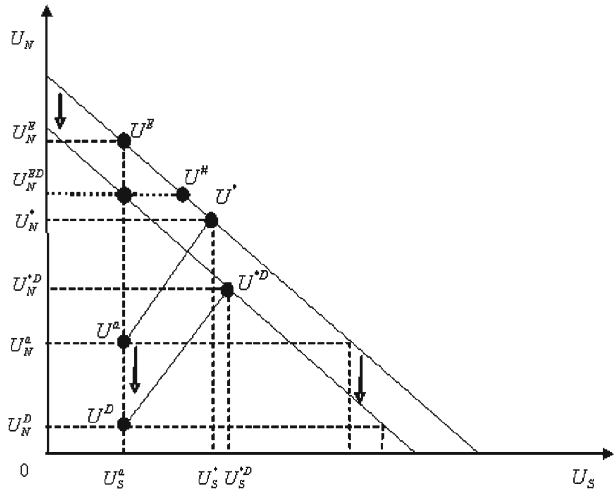

Fig. 3 Credible strategic destruction

bargaining power of that threatening agent, if it has been ignored. For this reason the attempt to impose an extreme point contract in the face of real bargaining power—supported by a rational threat—must ultimately fail.[17]

4.3 Application: Rational Threats in the BBP

What can strategic destruction mean in the context of biodiversity?[18] For concreteness, strategic destruction can be understood as a literal threat to destroy resources, as witnessed in Latin America (World Bank 2003) and discussed in relation to fisheries.[19] For instance, Canada's "aggressive fishing policy", in the ongoing negotiations of the Pacific Salmon Treaty in the late 90's, has been described as strategic destruction (Miller et al. 2000; Copeland 1990).

[17] The optimal North to South contract that could preclude destruction would take the same general form as in Proposition 2 (General Case), but premised on the new conflict point $\left(U_N^D, U_S^a\right)$ in Fig. 2:

$$T_N\left(L_S, t\right) = \int_t^{t^a} \left[1 - k'\left(z\right)\right] dz - \pi(L_S - s^* - t)s^* + (1-\alpha)\left(U^{CD}\right)$$

where $U^{CD} = U^* - \left(U_N^D + U_S^a\right)$. The difference between this contract and that in Proposition 2 indicates that the optimal contract compensates for the value of Reserves that can be credibly destroyed $\left(L_S - L_S^D\right)$:

$$(1-\alpha)\left(U_N^a - U_N^D\right) = (1-\alpha)\int_{L_S^D}^{L_S} \left[\pi'\left(x - t_a\right) n^a\right] dx$$

That is, the contract is conditioned on those stocks of Reserves which can be credibly detroyed. As argued in the text, the strategic threat effectively asserts any ignored bargaining power $(1-\alpha)$ in the South.

[18] In other contexts Karp (1996) shows that strategic destruction of its resources maintains monopoly power for a monopolist producing a durable good. Furthermore, such threats of destruction were also noted in the negotiations surrounding the North Pacific Fur-Seal Convention (Barrett 2002, Ch.2).

[19] One farmer was recorded as saying "bueno, corto todo" in response to failure to compensate farmers for existing forests via the Global Environmental Facility (World Bank 2003).

Strategic destruction could also be understood as the static representation of a threat to allow ongoing and irreversible land conversion in the absence of cooperation.

The best documented examples of such rational threats in regard to reserves are demonstrated in statements by the Governments of Cameroon and Ecuador. In Cameroon in 2008 the Minister of Forestry, Joseph Thatta, made a clear statement of what the government perceived to be fair share of the cooperative surplus, while effectively redefining the conflict point in the negotiations with international conservation organisations over the Ngoyla-Mintom forest. An annual fee of US$1.6m for 830,000 ha of biodiverse tropical forest was requested to prevent the concessions being sold to logging companies.[20] Rough calculations suggest that the global value in terms of carbon sequestration alone is double the value of the logging concessions, so conservation is on the bargaining frontier.[21] In the absence of any offers, in March 2009 the Government made good on its threat and the process of determining forest concessions began. In terms of the bargaining framework, the process appears to be stuck at the conflict point with the bargaining frontier contracting.[22]

Similar threats were issued by President Rafael Correa of Ecuador in relation to the Yasuni–Ishpingo Tambococha Tiputini (Yasuni–ITT) region of Ecuador, which lies in the Amazon rainforest, at a meeting of the United Nations (UN) in September of 2007.[23] Again, the conflict point and the share of the surplus was clearly defined, albeit under different circumstances to Cameroon. The conflict point was defined as the development of the oil fields beneath the Yasuni–ITT region. The share of the cooperative surplus, arising from leaving oil in the ground, would include compensation for lost oil revenues from the international community, which resembles the incremental cost component, and carbon credits amounting to the foregone carbon emissions, reflecting a payment for the stock of carbon.[24] This contractual solution, which would conserve 38% of Ecuador's land from damage by extractive industries, bears more than a passing resemblance to the optimal contract under strategic threats (see footnote 16). With funds to be administered by the UN and held in the Yasuni–ITT trust, and conditional on continued conservation, this initiative has been more successful than in the case of Cameroon. In the first instance numerous pledges of finance. were received, and in April 2010 a deal worth $3bn was signed between the Ecuadorian government and overseas governments to support the initiative.[25] This is one case in which strategic bargaining appears to have worked.

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[20] See "The price of conservation: the unkindest cut", in The Economist print edition, 14 February 2008.

[21] The 830,000 ha of forest in the Ngoyla–Mintom store over 200 million tonnes of carbon dioxide (assuming a conservative 250 tonnes of carbon dioxide/ha). Assuming conservation reverses the 1% trend in deforestations, and assuming emissions of 160 tonnes of carbon dioxide/ha from logging, at US$3/tonne of CO2, payments for carbon through the REDD scheme would generate credits with an NPV of US$64 million (over 30 years at 5% discount). This exceeds the US$26 million in logging concession fees (The Economist print edition, 14th February 2008).

[22] Coordination problems between environmental NGOs most likely contributed to the deadlock here also. Eduard Niesten, Conservation International, personal comment.

[23] See e.g."Oil and Climate Change: some voices from the South", by Joan Martinez–Alier and Leah Temperer: http://antalya.uab.es/icta/activitats/doc_seminaris_07_08/. See also Martinez-Alier (2007).

[24] It is estimated that leaving the ITT oil undeveloped would result in permanently sequestering nearly 436 million tons of carbon dioxide in the ground (Martinez-Alier 2007).

[25] In 2009, Belgium, Germany, Spain and Sweden promised half the required funds ($1.7bn). A further $250m is anticipated from NGOs.http://www.coha.org/ecuador-yasuni-initiative-standstill/ (last accessed 17/5/2010).

The recent completion of the Yasuni–ITT deal was reported by: http://www.ens-newswire.com/ens/apr2010/2010-04-26-02.html (last accessed 17/5/2010).

In the months prior to this, in November 2009, a significant bilateral forest conservation agreement was signed between the governments of Norway and Guyana to conserve 50 million hectares for an investment of £ 150 m. Previous offers had been made by Guyana's president Bharrat Jagdeo to the UK government in 2007 to conserve rainforests in return for development aid and technical assistance, but to no avail. The agreement with Norway arose only after the timber value of the forest and a potential development plan was revealed to the international community. The action has been described as a threat or even "blackmail" in some quarters.[26] What the this paper reveals is that such actions reflect a credible bargaining position based on asymmetric endowments.

These examples represent attempts to dislodge the status quo and certainly represent active use of threats, or, at the very least, a laying bare of the structure of the bargaining game. Threats are not the only responses to the status quo that have been witnessed in the realm of biodiversity. The formation of the Group of Like Minded Mega-Diverse Countries (LMMC) represents an alternative means through which the South has attempted to garner bargaining power and dislodge current solutions. In sum, these examples demonstrate the main argument here, that extreme point solutions to the BBP are unlikely to be stable in the presence of rational threats.

5 Conclusion

This paper has set out to make three basic points regarding institution-building for global environmental management. First, it is important to begin thinking about global environmental problems as questions of cooperation over the production of joint surplus. The basic problems of biodiversity and climate change have little to do with preventing externalities or with conserving amenities. These are problems dealing with the fundamental notion of the division of the surplus available from certain forms of production. Biodiversity concerns the product available from the life sciences industries. A basic problem of global cooperation concerns how the states will agree to divide up the product from these basic industries. These are the basics of bargaining problems, which also apply to other global problems such as climate change, the bargain over which concerns the division of the product available from fossil fuel based production. In each case, Nash cooperative bargaining is an appropriate way to think about these problems.

Second, these problems are made fundamentally difficult by reason of the asymmetries between the states concerned. In the context of biodiversity, the North and South differ in terms of endowments of human and natural resources, industrial structure and property rights. These fundamental differences mean that "regime building" is about dealing with these differences in an efficient fashion. It is about finding ways to move toward the bargaining frontier in the presence of these fundamental asymmetries.

Third, the essence of the Nash cooperative bargaining approach is that important differences between the parties must be part of the ultimate solution concept for the bargaining problem. That is, the notion of a fair distribution will emanate from these essential differences. There are many efficient contractual solutions, but divisions of surplus that are not based upon the essential characteristics between the parties will provoke a rational response for that characteristic to be recognised. Any lasting contractual solution to the BBP will

[26] New York Times Special Report: "Guyana Offers a Model to Save Rain Forest" By Erica Gies. December 8, 2009 http://www.nytimes.com/2009/12/08/business/global/08iht-rbogeco.html.

consider the potential for such rational threats, offer divisions of surplus that incorporate this possibility, and will be based upon the characteristics identified within that framework.

In conclusion, the most interesting result obtained here is the observation that bargaining power derives from real differences—those important to the production of cooperative surplus. Contracts chosen on the basis of perceived political power that fail to recognise inherent economic power must fail. What will turn out to be "efficient" (in the form of a long run cooperative equilibrium) will also turn out to be "fair" (in the sense of Nash theory). Recent experiences in Ecuador, Guyana and Cameroon can be understood in this way.

Appendix 1

Proof of Proposition 1 (Optimal and Autarky Solutions) Whenever $L_S > R^* > 0$, $\frac{\delta R}{\delta S} = \frac{\delta R}{\delta T} = -1$ and the first order Kuhn–Tucker conditions yield:

$$s^* \geq 0 : \pi(R) - \pi'(R)\left(s^* + n\right) - c'(n + s^*) \leq 0 \tag{18}$$

$$n^* \geq 0 : \pi(R) - b - c'(n^* + s) \leq 0 \tag{19}$$

$$t^* \geq 0 : 1 - \pi'(R)\,(n + s) - k'\left(t^*\right) \leq 0 \tag{20}$$

with the inequalities in Eqs. 15 and 17 strict equalities whenever $l^* = L_N - n^* \geq 0$.

Hence the proof follows in parts: (a) From Eq. 20 if $(n^* + s^*) = 0$ then $t^* = t^a$ and so $R^* = R^a$. Comparing Eqs. 13 and 19 when $R^* = R^a$, we have that $(n^* + s^*) = n^a > 0$, which is a contradiction; (b) If $t^* = 0$ then $t^* < t^a$ by assumption. If $t^* > 0$ then $1 - k'(t^*) = \pi'(R^*)(n^* + s^*) > 0 = 1 - k'(t^a)$, thus $t^* < t^a$ as $k''(\cdot) > 0$; (c) Comparing Eqs. 13 and 19, if $n^* > 0$, then $n^* + s^* > (<)\, n^a \iff R^* > (<) R^a$; (d) Given $b = 0$, comparing Eqs. 18 and 19; $n^* < L_N \implies s^* = 0$ and therefore $R^* > R^a$. □

Proof of Proposition 2 (General and "Extreme Point" Contracts Extreme point contracts (North to South)) If the South selects output level $t = \widetilde{t}$, the desired output levels $(n, s) = (\widetilde{n}, \widetilde{s})$ and the transfer

$$T_S(n, s : \widetilde{t}) = \left[\pi(L_S - s - \widetilde{t}) - b\right](-n) + c(n + s) + \left[U_N^a - bL_N\right]$$

then the North's utility is given by

$$\begin{aligned} U_N(n, s, t) &= (\pi(R) - b)\,n - c(n + s) + T_S(t : n, s) + bL_N \\ &= U_n^a \end{aligned}$$

which is independent of (n, s). Thus the North is willing to produce at any output levels, including $(n, s) = (\widetilde{n}, \widetilde{s})$. Of course a small deviation penalty could be included to ensure compliance. □

Given that the North will select $(n, s) = (\widetilde{n}, \widetilde{s})$, the South's problem is to select the values of $(\widetilde{n}, \widetilde{s}, \widetilde{t})$ to maximise

$$\begin{aligned} U_S(n, s, t) &= \pi(L_S - s - t)s + t - k(t) - [\pi(L_S - s - t) - b]\,(-n) - c(n + s) \\ &\quad - \left[U_N^a - bL_N\right] = \pi(L_S - s - t)(n + s) - bn - c(n + s) + t - k(t) - \left[U_N^a - bL_N\right] \\ &\quad = U(n, s, t) - U_N^a \end{aligned}$$

which, as U_N^a is a constant, is equivalent to the social planner's problem and has solution (n^*, s^*, t^*) as required.

Extreme Point Contracts (South to North)

If the North selects output levels $(n, s) = (\widetilde{n}, \widetilde{s})$, a desired output level $\widetilde{t}$ and the transfer

$$
\begin{aligned}
T_N(t : \widetilde{n}, \widetilde{s}) &= \int_t^{t^a} \left[1 - k'(z)\right] dz - \pi(L_S - \widetilde{s} - t)\widetilde{s} \\
&= \left[t^a - t\right] - \left[k\left(t^a\right) - k(t)\right] - \pi(L_S - \widetilde{s} - t)\widetilde{s}
\end{aligned}
$$

then the South's utility is given by

$$
\begin{aligned}
U_S(t : \widetilde{n}, \widetilde{s}) &= \pi(L_S - \widetilde{s} - t)\widetilde{s} + t - k(t) + T_N(t) \\
&= t^a - k\left(t^a\right) = U_S^a
\end{aligned}
$$

which is independent of t. Thus the South is willing to produce at any level of t, including $t = \widetilde{t}$.

Given that the South selects $t = \widetilde{t}$, the North's problem is to select the values of $(\widetilde{n}, \widetilde{s}, \widetilde{t})$ to maximise

$$
\begin{aligned}
U_N(n, s, t) &= (\pi(R) - b)\, n - c(n + s) - T_N(t : n, s) + bL_N \\
&= \pi(R)(n + s) - bn - c(n + s) + t - k(t) - \left[t^a - k(t^a)\right] + bL_N \\
&= U(n, s, t) - \left[t^a - k(t^a)\right]
\end{aligned}
$$

which, as $\left[t^a - k(t^a)\right]$ is a constant, is equivalent to the social planner's problem and has solution (n^*, s^*, t^*) as required.

General Contracts

The only difference between general and extreme point contracts is the inclusion of a constant term $(1 - \alpha)U^C$ in the transfer payment. A constant transfer payment has no impact on the optimising decisions of the agents, thus the solutions remain unchanged. □

Appendix 2

Proof of Proposition 3 (Strategic Destruction by the South)

Let $U^*(L_S)$ and $(U_N^a(L_S), U_S^a(L_S))$ represent the optimal social planner and autarky payoffs for particular values of L_S, with the payoffs to the Nash bargaining solution given by

$$
\begin{aligned}
U_N^*(L_S) &= (1 - \alpha)\, U_N^a(L_S) + \alpha\left(U^*(L_S) - U_S^a(L_S)\right) \\
U_S^*(L_S) &= \alpha U_S^a(L_S) + (1 - \alpha)\left(U^*(L_S) - U_N^a(L_S)\right)
\end{aligned}
$$

We are interested in finding conditions for $\frac{dU_S^*(L_S)}{dL_S} < 0$ at $L_S = L_S^*$, so that a reduction in L_S improves the South's payoff after the bargaining game.

From the above equations, we have

$$
\frac{dU_S^*(L_S)}{dL_S} = \alpha \frac{dU_S^a(L_S)}{dL_S} + (1 - \alpha)\left(\frac{dU^*(L_S)}{dL_S} - \frac{dU_N^*(L_S)}{dL_S}\right)
$$

As $\frac{dU_S^a(L_S)}{dL_S} = 0$ whenever $L_S > t_a$, we have that

$$\frac{dU_S^*(L_S)}{dL_S} < 0 \Longleftrightarrow \frac{dU^*(L_S)}{dL_S} - \frac{dU_N^*(L_S)}{dL_S} < 0$$

From Eqs. 11 and 14, and the Envelope Theorem, for any interior solution we have that

$$\frac{dU^*(L_S^*)}{dL_S} - \frac{dU_N^*(L_S^*)}{dL_S} = \pi'(L_S^* - s^* - t^*)(n^* + s^*) - \pi'(L_S^* - t^a)(n^a)$$

thus

$$\frac{dU_S^*(L_S^*)}{dL_S} < 0 \Longleftrightarrow \pi'(L_S^* - s^* - t^*)(n^* + s^*) < \pi'(L_S^* - t^a)(n^a). \qquad \square$$

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