The Biodiversity Bargaining Problem

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Abstract

The need for a global cooperative solution to the problem of biodiversity conservation has long been understood. International institutions, in particular those of Trade-Related Intellectual Property Rights (TRIPS) and the Biodiversity Convention (CBD), have since been created with a view to allowing the potential gains from the production and international exchange of biotechnological inputs and outputs to be realized. Contrary to the intended effects, the rate of degradation of biodiverse habitats in the South has – by most estimates – not decreased. Explanations for this observation range from government failure to speculation and corruption. This paper pursues a different angle. Employing the tool of cooperative bargaining theory, it examines whether it is perhaps the very institutions designed to stimulate conservation that actually create incentives for biodiverse lands to be degraded. Building on Nash's idea of 'rational threats', we demonstrate that rather than removing the strategic incentives in the game of surplus division, current arrangements may in fact generate such incentives. This leads to two prescriptive results with a view to reconsidering the current institutional regime.

Keywords: North-South bargaining, biodiversity conservation, biotechnology, Convention on Biodiversity (CBD), contracts, Trade Related Intellectual Property Rights (TRIPS).

JEL Classification: Q15, Q16, Q21, O13, O34.

1 Introduction

The need for global cooperation for the conservation of biological diversity has long been understood (Barrett 1994, Swanson 1996). In stylized terms, developed countries of the North attribute significant values to biodiversity that exists predominantly in tropical and sub-tropical areas of the developing South. The global nature of the benefits from biodiversity makes it clear that the North and the South must engage one another in order to ensure that external costs are considered in arriving at the land-use decisions that ultimately determine the amount of biodiversity conserved. This requires that both regions determine not only the appropriate allocation of their individual physical resources, but also that they come to an agreement on a reasonable division of the global surplus that results from their respective allocation decisions.

The need for cooperation is particularly palpable in the biotechnology sector. Research and development (R&D) in the pharmaceutical and plant breeding industries in the North generate innovations from which both regions stand to gain. However, it is countries in the South that are endowed with the biological diversity required as inputs into biotechnological R&D. Exchange of biodiversity inputs and biotechnological outputs between North and South therefore offers scope

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for considerable welfare improvements and each region must cooperate in combining their jointly valuable endowments in order to realize these gains.

What complicates this mutual interdependence between North and South is that due to the informational nature of the goods exchanged, market prices, and therefore simply trade, cannot be relied upon to sufficiently coordinate the activities of the parties involved. A different set of institutions than market-based exchange is required to allow the potential gains from cooperation to be realized. In response to this challenge and the ongoing loss of biodiversity over the last decades (Leaky and Lewin 1995), countries agreed in early 1990s to create international institutions in order to capture the externalities inherent in biodiversity inputs and R&D outputs and thus to incentivize their production and international exchange. The Convention on Biological Diversity (CBD) in 1992 and the Trade-Related Intellectual Property Rights (TRIPS) agreement in the context of the World Trade Organization in 1994, both of which make explicit reference to biological and genetic diversity, represent the international institutions intended to facilitate cooperation and distribute the global surplus in the biotechnology sector[1]. The expected result of their creation is increased investment into biotechnological R&D in the North as a result of rents earned on intellectual property; and increased transfers going into conservation in the South as a result of payments under the Global Environment Facility (GEF), the financial vehicle created by the CBD. With the successful creation of these two institutions and implementation of their operation, the difficulty of cooperation appears to be solved.

One problem with the institutions thus designed is that by most estimates, the rate of degradation of biodiverse habitats in the South does not seem to have been affected by their introduction. Various explanations are possible. Much of the literature discusses why despite these new institutions, conservation efforts are lacking. The reasons fall under various headings. One is government failure, such as perverse subsidies (Margulis 2004), dysfunctional property rights (Southgate 2000), lack of complementary farmers' rights (Soete and Droege 2001), or insufficient pass-through of transfers from governments to local decision-makers in developing countries (Day-Rubinstein and Frisvold 2001). A second broad heading is land speculation in developing countries (Margulis 2004) and a third simply corruption (Smith et al. 2003). A less sophisticated explanation may be that ten years are not enough time for these institutions to truly impact on a process as complex as local land-use decisions.

The contribution of this paper is to ask a more fundamental question, namely whether it is perhaps the very institutions designed to stimulate conservation that actually create incentives for biodiverse lands to be degraded. The focal point of our analysis is therefore the precise nature of the institutional response to the coordination problem inherent in global biodiversity management. In other words, our aim is to understand more about the specific solution to the biodiversity bargaining problem between North and South that gives this paper its title. To do this, we apply the tool of cooperative bargaining theory to derive propositions regarding two important aspects: The first is the determination of the bargaining frontier, from which a measure of efficiency of the institutions chosen can be derived. The second aspect is the set of feasible and individually rational strategies of the bargaining parties. A particular focus of this inquiry is whether – in a manner similar to the idea of 'rational threats' posited by Nash (1953) – the degradation of biodiversity is a bargaining option for the South.

We have five main results. The first is that the current institutional arrangements are an 'extreme point contract' that leaves the South indifferent between cooperation and non-cooperation. From this follows our second result, namely that the current institutional arrangements are not

[1] In Section 27(b) of the TRIPS agreement explicit reference is made to intellectual property rights being extended to lifeforms and genetic material, while developing countries are encouraged to develop sui generis property rights systems for traditional knowlege and indigenous flora and fauna.

robust against the use of 'rational threats' by the South. In other words, continued degradation of biodiversity may very well be in the interest of the South even in the presence of conservation rewards paid through the GEF. Thirdly, even though the institutional arrangements are globally and individually welfare-improving, they are generally second best. In sum, we demonstrate that rather than removing the strategic incentives in the game of surplus division, current arrangements may induce such incentives. This leads to two prescriptive results with a view to reconsidering the current institutional regime: The first is that any institutional solution intended to avoid degradation of biodiversity requires payment for the stock of existing conservation as well as for any marginal increments. This is in marked contrast with the current policy of the GEF which enshrines an incremental cost approach. The second is that if the policy choice is – for some reason - between choosing to protect R&D outputs or R&D inputs, the South may prefer a regime that protects intellectual property rights (such as TRIPS) to an 'extreme point' contract of conservation rewards such as the GEF.

The paper proceeds as follows: In the following section, we introduce a stylized model of the biotechnology and land use in a North-South world and go on to describe the biodiversity bargaining problem between a 'technology-rich' North and a 'gene-rich' South in section 3. The conditions for the existence of rational threats and thus 'strategic destruction' are established and illustrated with an example. Section 4 investigates the current institutional arrangements in the light of the preceding analysis with respect to their relative efficiency and bargaining strategies. We show that current institutions appear to place bargaining power initially in the North, and yet strategic destruction remains a viable strategy for the South. Section 5 summarizes the analysis and concludes.

2 The Model: Biotechnology and Land Use

Here we develop a model to explore the interdependency between technological change, the distribution of gains between North and South, and land use decision making. This interdependence is placed in the context of agricultural biotechnology in which genetic resources, emanating from *in situ* biological diversity found in a 'Reserve' sector, is the major input into a plant breeding sector. In this sense we model biodiversity as an explicitly productive resource. The plant breeding sector undertakes research and development of new innovations in the form of high yielding varieties of seeds (HYVs). These HYVs are intermediate goods and can be used by domestic intensive agricultural sectors in the North, or purchased by the South, for final good production. In order to focus upon the essential elements of the North-South interaction in this context, and in line with previous models in this area (e.g. Krugman 1979, Helpman 1993, Droege and Soete 2001), we make a stylised distinction between North and South. The model builds upon the stylised fact that biodiversity is predominant in the South; the South is 'gene rich', whilst R&D is predominant in the North; the North is 'technology rich'. For the purposes of the model it is assumed that the R&D sector exists solely in the North whilst the biological diversity exists solely in the South. It is also assumed that these stylised facts are inalterable, i.e. biodiversity loss is irreversible and technological innovation cannot occur in the South. In addition, the intensive and Reserve sectors in the South are assumed to be in competition with a 'traditional' agricultural sector which does not use HYVs from the North and thus is not augmented by technological innovations. The precise nature of these land-uses, North-South interaction, and the benefits of joint production is described in detail below.

2.1 The North

The Northern land endowment (L_N) represents land that has been formerly cleared of biological diversity and is allocated between two potential land uses: a relatively unproductive baseline agricultural sector and an intensive agricultural sector. In addition, the plant breeding sector is located in the North. The baseline and intensive sectors produce final output, whilst the plant breeding sector engages in R&D and produces intermediate seeds.

Baseline production in the North produces final output but is not augmented by the innovations process and thereby the presence of Reserves in the South. It therefore represents a base-line technology. Final output from the baseline sector is represented by the net output function:

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

where l is the land devoted to this sector and b is a net productivity parameter[2]. We take final output as the numeraire.

We represent the intensive and plant breeding sectors parsimoniously by assuming that they are vertically integrated. Thus the intensive sector in the North produces final output, y_N^i, using seeds, n. We assume a fixed 1 to 1 relationship between seed and land, hence land used in intensive production is equal to n. Innovations (HYVs) arrive with a probability which is positively affected by the stock of biodiversity, the Reserve sector, R, in the South. These innovations are embodied in the seeds and effectively cause a land augmenting productivity increase in the intensive sector. This innovation process is represented in a stylized fashion by the function, $\pi(R)$, which pre-multiplies the intensive sector production function.Thus, final intensive output 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]:

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

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

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

R&D and seed production for the intensive sector is undertaken by the plant breeding sector at a cost $c(.)$, where $c(0) = 0, c'(.) \geq 0, c''(.) > 0$. In addition to domestic production of seed, the North can also supply seed to the South (s). From Equations (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. Given the land constraint the utility function for North represents all sectors and payments and is given by:

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

[2]This represents the output net of costs valued in terms of output. This represents a constant returns to scale production technology. The coefficient b can be thought of as a being equal to a 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 baselne sector.

[3]Where $\pi'(.)$ is the first derivative of the function and $\pi''(.)$ is the second derivative with respect to its argument. This notation holds for the remainder of the paper and for other functions.

2.2 The South

The South is endowed with land, L_S. However, this land endowment represents unconverted 'Reserve' land which is rich in genetic diversity. Southern land can be maintained as Reserves with area R, or converted by either a traditional sector, t, or the intensive agricultural sector using seed imported from the North, s. The South benefits from the presence of Reserves, R, in precisely the same way as the North in that the productivity of the intensive agricultural sector is augmented by the arrival of new HYV's from the R&D sector. The joint nature of final output from the intensive sector is represented by an analogous production function:

$$y_S = \pi (R)\, s \tag{5}$$

The cost of seed imports to the South is captured in the transfer T. The traditional sector is unaffected by technological innovation and hence its productivity is not augmented by the presence of Reserves. Traditional production incurs a cost $k(t)$: $k(0) = 0, k'(t) > 0, k''(t) > 0$. Southern utility is given by:

$$U_S = \pi(R)s + t - k(t) + T, \tag{6}$$

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.

3 The Biodiversity Bargaining Problem: North-South Conflict and Cooperation

The North and South are characterised as interdependent: the South provides essential genetic materials as inputs to the North for the R&D process, whilst the North develops HYVs which outperform the domestic baseline sector and the traditional sector in the South. Both parties stand to gain from this interaction provided that they can facilitate the exchange of resources and adequately share the cooperative gains. This simple model represents to a large extent the fundamental facets of the North-South relationship in this industry. In this section we characterise the conflict point of this negotiation and the extent of the cooperative gains.

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

We define the conflict point as the outcome under Autarky. This provides the benchmark against which the solutions are measured. Autarky is characterised by two features: i) the absence of seed sales from North to South: $s = 0$ ii) the absence of transfers (T) that allow the social planner to achieve the optimal. Consequently the South fails to internalise the value of Reserves (R) and an externality exists. Under these circumstances the problems of the North and South are as follows:

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

$$\max_t U_S = t - k(t) \tag{7}$$

$$s.t. : L_S = t + R \text{ and } 0 \le t \le L_S \tag{8}$$

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

$$1 - k'(t^a) = 0 \tag{9}$$

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:

$$\max_n U_N = (\pi(R) - b)\, n - c(n) + bL_N \tag{10}$$

$$s.t. : 0 \leq n \leq L_N \tag{11}$$

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:

$$\pi(R^a) - b - c'(n^a) = 0 \tag{12}$$

This Autarky problem shows how the South causes a production externality on the North when choosing its land allocation in that it ignores the productive value of Reserves in the North. The greater the size of the traditional sector in the South (t^a) the lower is the marginal productivity of the North's intensive sector (n).

As either region always has the opportunity of production in isolation, the Autarky solutions will constitute the Conflict Point in any bargaining game conducted between the two, and the corresponding payoffs will be referred to as the 'Conflict payoffs' from hereon[4]. Furthermore, we will refer to the Autarky solution as being an 'interior solution' whenever $R^a, t^a, l^a, n^a > 0$[5]. In summary the conflict point/Autarky solution is characterised by the land allocations and payoffs (t^a, R^a, l^a, n^a) and (U_S^a, U_N^a) respectively.

3.2 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:

$$\max_{n,s,t,D} U = U_S + U_N = \pi(R)(n+s) - bn + t - c(n+s) - k(t) + bL_N \tag{13}$$

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

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

Whenever $R^* > 0$,the first order necessary conditions yield[6]:

$$s^* \geq 0 : \pi(R) - \pi'(R)(s^* + n) - c'(n + s^*) \leq 0 \tag{14}$$

$$n^* \geq 0 : \pi(R) - b - c'(n^* + s) \leq 0 \tag{15}$$

[4] Welfare in the Sorth under autarky, U_S^a, is defined as $U_S^a = t^a - k(t^a)$, and welfare in the North is defined by $U_N^a = (\pi(R^a) - b)\, n^a - c(n^a) + bL_N$.

[5] Sufficient conditions for the existence of an interior solution to the Autarky problem are that $k'(0) < 1 < k'(L_S)$, $c'(0) = 0$ and $c'(L_N) > \pi(L_S) - b$.

[6] In this case $\frac{\partial R}{\partial s} = \frac{\partial R}{\partial t_S} = -1$.

$$t^* \geq 0 : 1 - \pi'(R)(n+s) - k'(t^*) \leq 0 \tag{16}$$

where $l^* = L_N - n^* \geq 0$.

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

LEMMA 1: If the Autarky solution is interior, and the social planner wishes to keep Reserves ($R^* > 0$) then:

a) intensive agricultural production will always be positive: $(n^* + s^*) > 0$;

b) optimal traditional production in the South will be less than under Autarky: $t^* < t^a$;

c) whenever there is intensive production in the North: $n^* > 0$, then the Reserve sector increases with global intensive agriculture. In short: $R^* > (<) R^a \iff n^* + s^* > (<)\, n^a$;

d) if $b = 0$, i.e. profits are equal to zero in the baseline sector, then $s^* > 0$ only when $n^* = L_N$.

PROOF: a) From Equation (16) if $(n^* + s^*) = 0$ then $t^* = t^a$ and so $R^* = R^a$. Comparing Equations (12) and (15) 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 $1 - k'(t^*) \geq \pi'(R^*)(n^* + s^*) > 0 = 1 - k'(t^a)$, thus $t^* < t^a$ as $k''(.) > 0$.

c) Comparing Equations (12) and (15), if $n^* > 0$, then $n^* + s^* > (<)\, n^a \iff R^* > (<) R^a$.

d) Given $b = 0$, comparing Equations (14) and (15); $n^* < L_N \Longrightarrow s^* = 0$ and therefore

Lemma 1(b) shows that the optimal traditional sector in the South is smaller than under Autarky, however 1(c) shows that since the social value of reserves is derived from their value as an input to R&D for intensive agricultural production, 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. A low value for b increases the likelihood that the socially optimal level of Reserves is higher than under Autarky. Lemma 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 conversion would entail, and where $b = 0$ the social planner would choose specialised regional functions: intensive production in the North and Reserves in the South.

Defining the optimal welfare under the social planner by:

$$U^* = U_N^* + U_S^* \tag{17}$$

allows us to define the extent of the social gains from cooperations, U^C, as the difference between the welfare under the social planner and that under Autarky:

$$U^C = U^* - (U_N^a + U_S^a) \tag{18}$$

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

Figure 1 shows the Autarky and optimal outcomes. U^* is the socially optimal welfare frontier and represents different distributions of the surplus. Although the Social Planner is not concerned with the regional distribution of cooperative gains from biodiversity preservation, a system of lump sum transfers can facilitate any desired distribution. This can also be interpreted as the bargaining frontier of a fully cooperative outcome.

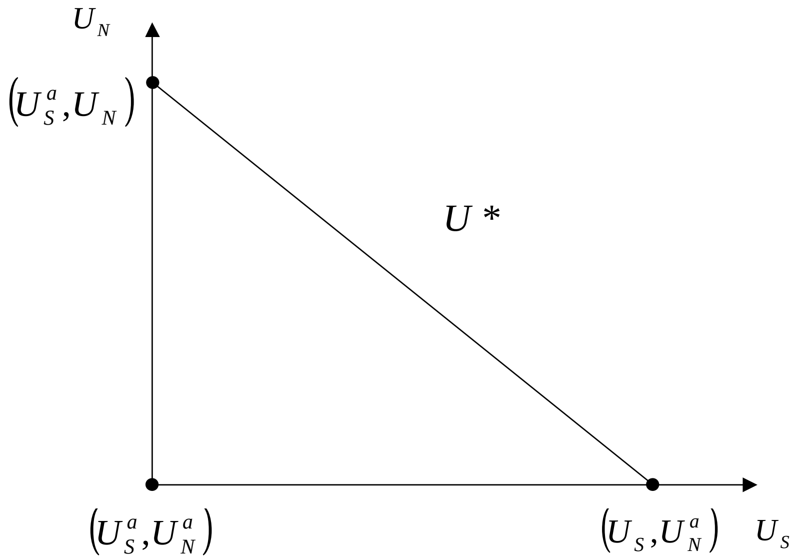

Fig 1. The Bargaining Frontier and Conflict Point

Each one of the points along U^* can be sustained as the Nash Equilibrium of a cooperative bargaining game[7]. However, as is well known, choosing among these Nash equilibria, i.e. the solution to bargaining problem, will depend upon the specifics of the bargaining process: the nature of the interaction between the two agents, the institutions that determine or officiate this interaction, and the assumptions that one is willing to make concerning the behaviour of the agents. For the Biodiversity Bargaining Problem we have defined it is not easy to see how one might specify the structure of the bargaining game and therefore in moving towards a solution it is useful and informative to consider the theoretical bargaining solutions and the institutions that have actually arisen to address these issues. The following section addresses the former.

3.3 Bargaining Solutions

3.3.1 Extreme Point Contracts

The bargaining problem can be resolved by the specification of a contract between the North and the South. Given that in the model specified there is no uncertainty or asymmetry in information between agents, an optimal contract can always be constructed to achieve any allocation of the gains from coordination between North and South. The contract actually implemented will depend upon the relative bargaining power of the two regions, that is, the biodiversity bargaining problem needs to be resolved before any optimal contract can be implemented.

Extreme point contracts specify outcomes at the end points of the bargaining frontier U^*. Such contracts are only acceptable when one or other party has absolutely no bargaining power. These types of contract are of particular interest in the present case since one of them is directly relevant to the financial mechanism of the Convention on Biological Diversity. This relation is described in the following section. This leads to Proposition 1:

[7] See e.g. Example 1 below.

PROPOSITION 1: a) The optimal contract for the South when the North has no bargaining power is for the South to specify n^* and s^* and to offer North the transfer:

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

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

b) Inversely, the optimal contract for North when the South has no bargaining power is for the North to offer South s^* seed and the transfer:

$$T = T_N(t) = \int_t^{t^a} [1 - k'(x)]\, dx - \pi(L_S - s^* - t)s^*$$

PROOF: a) and b): See Appendix 1.

Proposition 1 states that if the North has no bargaining power the optimal contract offered by the South will specify (U_S, U_N^a) in terms of Figure 1, while inversely if the South has no bargaining power optimal contract offered by the North will specify (U_S^a, U_N)[8]. Each contract is optimal in the sense that it allows the agents to attain the bargaining frontier, but each merely compensates the party to whom the contract is offered for the marginal costs of changing their behaviour, leaving their welfare at Autarky levels. It is in this sense that the contracts can be thought of as 'extreme point' contracts, since in each case welfare for the region offered the contract is bounded only by their participation constraint $(U_i^a : i = N, S)$, i.e. the same as at the conflict point, and therefore they are indifferent between accepting or rejecting the offer. These specific contracts define the limits of the bargain.

3.3.2 Strategic Destruction

One feature of many alternative bargaining solutions, including Nash Bargaining, is that the value received by one player (U_i^*) is not only increasing in the value of any outside option available (U_i^a) but also increasing in the maximum value of cooperation for the other player: the 'bargaining pie', $U^* - U_j^a$. Actions by one player which increase the value of cooperation for the other player, without reducing the value of their own outside option, can be used as 'threats' to extract higher payoffs in a bargaining process (Nash 1953). Indeed, even where the threats are costly they may be credible depending upon the relative costs and benefits[9].

One obvious threat available to the South in this model is to destroy Reserves, making the land upon which Reserves exist (L_S) a strategic variable. In reality the destruction of Reserves can be understood either as a literal threat to destroy resources directly, as witnessed in Latin America (World Bank 2003), or as a static representation of an ongoing and irreversible process of conversion that persists in the absence of cooperation. Both interpretations imply a reduction in the land available for production: the land endowment, and the level of Reserves. Destruction of Reserves by the South is strategically viable if the value the North places on protecting the remaining Reserves increases, thus strengthening the South's bargaining position. If the South is able to costlessly destroy land, making it incapable of supporting either Reserves or traditional production, then any Reserves remaining in Autarky can be strategically destroyed without affecting the South's conflict

[8] To see an example of this for the Nash Bargaining outcome see Example 1 and evaluate (19), below, and the welfare outcomes for $\alpha = 1$ and $\alpha = 0$. These represent the cases when all the bargaining power resides in the North and South respectively.

[9] The possibility of incentives for stratregic destruction of environmental resources has also been highlighed by Copeland (1990) in the context of international fisheries management.

payoff. The degree to which the South will want to implement strategic destruction will of course depend on the specific bargaining structure.

For example, any point of the bargaining frontier can be the solution to an asymmetric Nash Bargaining Game (NBG). It is then easy to show that strategic destruction can be a viable option for the South almost regardless of the relative bargaining power of the two parties. The solution of the NBG is a point (U_N, U_S) which maximises:

$$(U_N - U_N^a)^\alpha (U_S - U_S^a)^{(1-\alpha)} \text{ s.t. } U_N + U_S = U^* \tag{19}$$

where $\alpha \in [0,1]$ denotes the relative bargaining strength of the North. 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). Hence, any point on the bargaining frontier U^* can be supported depending upon the relative bargaining power.

The viability of strategic destruction in the biodiversity bargaining model can be shown as follows. Let $\overline{L_S}$ denote the maximum level of Reserves available to the South, and let $L_S = \overline{L_S} - D$ be the amount of land the South wishes to maintain, where D is the amount of land destroyed. The South will maximise returns from any asymmetric NBG by selecting $D^* = \overline{L_S} - \max[L_S^*, t^a]$ where L_S^* maximises the value of $(U^* - U_N^a)$ and has no effect upon the South's conflict point U_S^a. Sufficient conditions for the South to credibly threaten positive levels of destruction are that $\overline{L_S} > t^a$ $(R^a > 0)$ and:

$$\pi'(\overline{L_S} - t^a)(n^a) > \pi'(\overline{L_S} - s^* - t^*)(n^* + s^*) \tag{20}$$

PROOF: See Appendix 2.

In essence, condition (20) ensures that destruction increases the difference between conflict and maximum welfare obtainable for the North: the size of the 'bargaining pie', despite reducing social welfare. Example 1 illustrates this process using a Nash Bargaining solutions to the biodiversity bargaining problem modelled here.

EXAMPLE 1. Strategic Destruction in a Nash Bargaining Game: If we 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 $\gamma > 1$. Assume that $b = 0$. Then for L_N sufficiently large, destruction is worthwhile to the South if and only if:

$$\overline{L_S} > \left(\frac{1}{\gamma}\right)^{\gamma-1} \text{ and } \beta > \frac{1}{1-\delta} \tag{21}$$

PROOF: See Appendix 2.

Equation (20) states that for destruction to increase the value of cooperation for the North, and hence be a credible threat for the South, it is sufficient that the marginal value of Reserves under the Autarky solution is higher than in the Social Planner solution. Equation (21) shows an explicit example of how this outcome can depend upon the relative curvature of the seed cost and R&D functions, $c(.)$ and $\pi(R)$ respectively: seed costs must change more quickly than R&D productivity does in Reserves.

Example 1 and the preceding discussion reveal two important points with regard to North-South biodiversity bargaining which can be illustrated by reference to Figure 2. Firstly, in the process of bargaining over the rents from optimal land-uses, conditions exist in which the South can use the threat of strategic destruction to improve its payoff. It does this by increasing the value of cooperation to the North, in which its payoff is increasing, despite the fact that carrying out this threat would reduce the value of social welfare due to the loss of valuable Reserves. In terms of Figure 2, if the Nash Bargaining solution in the absence of threats is represented by point a on the optimal bargaining frontier, and if the conditions for strategic destruction are satisfied and threats are carried out, the solution would move in a South South Easterly direction to point b : the North's payoff decreases, the South's increases (to U_S^D)[10]. The new solution, point b, is on a bargaining frontier that is everywhere inside of the optimal frontier as a result of the loss of productive Reserves. Note that the use of destruction as a bargaining ploy is virtually independent of distribution of bargaining power. This means that the threat of destruction remains a possibility when the South is offered a contract like the extreme point contract specified in Proposition 1(b)[11].

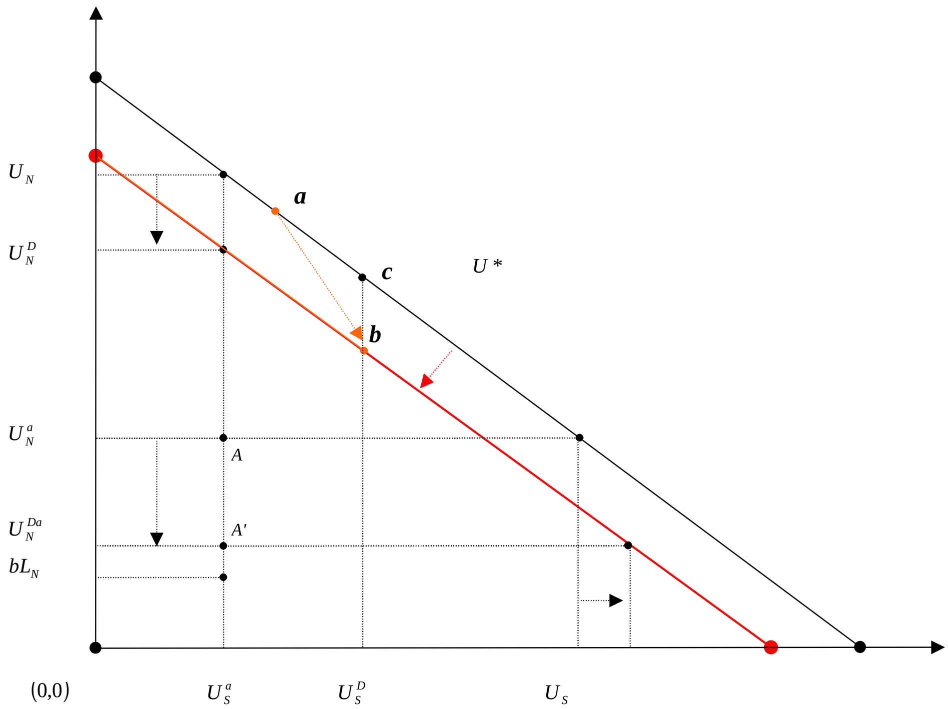

Fig 2. Strategic Destruction as Bargaining Ploy

Secondly, the only way that the North can eradicate the incentive for strategic destruction is to offer the South a payoff that leaves the South at least as well off as if the threats had been carried out, i.e. U_S^D, and therefore specify a solution to the bargaining game such as point c in Figure 2. In effect this means that, where strategic destruction is credible i.e. if $D^* > 0$, any truly optimal contract must make two provisions; i) in order to remove the threat of destruction the South must be at least as well off as at the destruction solution, U_S^D, and hence must be compensated for the Reserves it would have kept under Autarky and; ii) compensation must be conditioned upon the *stock* of Reserves to ensure a solution on the optimal frontier. In this way a solution such as point c, in Figure 2 can be attained.

[10] Note that the value $U_N^D - U_N^{Da}$, the maximal gains from cooperation to the North after destruction has taken place, is greater than the value $U_N - U_N^a$, the gains before destruction. This reflects the sufficient condition in (20). Note that the effective autarky point shifts from A to A' after destruction.

[11] It is important to recognise that there is a discontinuity at the extreme point which can make the strategy of strategic destruction in Example 1, and in other bargaining models, only weakly rather than strictly preferred where destruction is costless.

It should be noted that strategic destruction shifts the conflict point in such a way as to reduce the North's conflict payoff but to leave the South's unaffected. This reflects the costless nature of destruction in the South which in turn reflects the residual nature of Reserves under Autarky. In Figure 2 this is reflected by the conflict point moving due South from A to A'[12,13]. However, the costless nature of destruction in this case does not drive the result since such threats are still credible provided the benefits outweigh the costs.

The precise nature of the bargaining solution will depend upon the particular circumstances underlying the bargaining process. In the absence of any institutional or bargaining structure in the biodiversity bargaining problem it is sufficient to define the extreme point contracts and to identify the possibility of strategic destruction as a bargaining strategy for the South under a wide variety of bargaining models. In particular it is important to recognise that the incentive for strategic destruction of Reserves exists even at the extreme points of the bargaining frontier. However, if we are willing to assume that both parties are sophisticated and fully informed, we could posit that where incentives for destruction exist, the solution to the bargaining problem would be a contract specifying a point such as point c in Figure 2. This point maximises global welfare and provides a more even division of rents than the suggested Nash Bargaining solution, a, and the extreme point contracts.

Having developed the theory in this particular case it is now apposite to investigate the impact of current institutional approaches to the biodiversity bargaining problem and how these solutions relate to theory.

4 Investigating the Impact of Current Institutions: Contracts and Intellectual Property Rights

There are a number of different institutions which have emerged in response to the biodiversity bargaining problem. In this section we discuss two such institutions relevant to the case in hand, one based on contracts and the other on property rights. Firstly we analyse the Convention on Biological Diversity (CBD) and the contracts implied by its financial mechanism the Global Environment Facility (GEF) 'incremental cost' approach. We show how this financial mechanism, which has emerged as the main coercive instrument for biodiversity conservation for signatories of the CBD, can be interpreted in light of the preceding. Secondly we model the impact of Intellectual Property Rights (IPRs), such as Plant Breeders Rights (PBRs) and patents, on this bargaining problem. In both cases we are interested in the extent to which such institutions capture the value of biodiversity and facilitate mutually beneficial joint production. Similarly, in both cases we show that current institutions appear to initially place the bargaining power in the North, and yet strategic destruction is a viable source of bargaining power for the South.

[12] In this way, the analysis here differs from other models of strategic destruction. Similar strategies have been the subject of some interest in the game theoretical literature and are relevant here. For example Ben-Porath and Dekel (1992) talk of 'burning money'. In that case the purpose of such a strategy is to determine ones preferred outcome in a coordination game with multiple equilibria. Ben-Porath and Dekel (1992) show that this can be done by destroying one's own resources or simply threatening (signalling) to do so. The difference in our case is that the South can costlessly destroy Reserves rather than engaging in self sacrifice, and the problem is one of surplus division rather than coordination.

[13] In Figure 2 the point bL_N represents the welfare in the North when the Reserves in the South are competely destroyed. Since we have assumed that $\pi(0) = b$, welfare in the North is equal to bL_N. This represents another limit to the bargain.

4.1 The CBD and Strategic Destruction

The CBD represents the major international institution that has emerged in response to the what we have called the biodiversity bargaining problem. The CBD recognises that there are considerable gains to be made from cooperation in this regard. In short it recognises the bargaining frontier. However, article 20 of the CBD states explicitly that the implementation of commitments under the convention will depend upon the extent of financial transfers from the developed country signatories. This is implemented by means of the 'agreed incremental cost' concept of the Global Environment Facility (GEF) under which the North compensates the South for the costs it incurs in relation to the commitments contained in the CBD, e.g. the opportunity cost of foregone land uses[14].

Applying the incremental cost approach to the case in hand, the indicated contract is one in which the North receives the cooperative gains from innovations/intensive production and compensates the South for the welfare loss associated with the alternative use of land that occurs as the South moves away from the Autarky allocation. Thus the South ends up at its conflict payoff, represented by point (U_N, U_S^a) in Figure 1, which is the extreme point contract specified in Proposition 1b above. More precisely this extreme point contract very much reflects the idea of 'net incremental' cost: the minimum compensation required to ensure participation, which maintains the South at its pre-contract welfare level (Cervigni 1998).

Ultimately, the optimal contract between the North and South is indeterminate in the absence of some previously agreed resolution of the bargaining problem and there is no basis in principle for preferring any one over the others. The incremental cost approach merely defines one of an entire family of contracts that could facilitate the optimal outcome. The choice of an extreme point contract does not represent a complete solution to the bargaining problem for two reasons. Firstly, it implicitly assumes zero bargaining power for the South ($\alpha = 1$ in Example 1), and secondly it ignores the capacity of the South to engage in strategic bargaining, i.e. strategic destruction.

In reality bargaining power is not so unevenly allocated between regions and such bargaining strategies have been observed in practice. For example, incremental cost contracts offered by the GEF and World Bank to farmers in Latin America to encourage both changes in agricultural practices to agro-forestry and conservation of remaining forests were met with the response '*Bueno, corto todo*' (OK, I'll cut the lot!) when compensation for the existing forests was excluded from the offered contract (World Bank 2003). This brings to light the fact that dissatisfaction with the share of the surplus can lead the South not only to reject the initial contract but also to exert bargaining power in the hope of securing higher welfare upon renegotiation. The South can and does bargain with destruction as predicted by the theory outlined above. Indeed the analysis suggests that in order to eradicate the incentives for strategic destruction the optimal North-South contract should not only compensate the South for the incremental cost of biodiversity conservation, but compensation should also be conditioned upon the *stocks* of Reserves. This recommendation is intuitive and similar to previous work on international transfers (van Soest and Lensink 2000).

4.2 Bargaining under Intellectual Property Rights

The discussion above shows that resource ownership is an important determinant of the bargaining outcome. In the case in hand the outcome turns upon the ownership of innovations and Reserves. Therefore, it is critical to investigate the nature of property rights that currently prevail in this sector and the impact they have on the solution to the Biodiversity Bargaining problem. In this

[14] Cervigni (1998) discusses the extent to which the compensation should reflect the gross or net incremental costs, where net incremental cost is net of any additional benefits that the recipient country alone obtains from the presence of an unconverted or preserved environment. In this way net incremental cost is that minimum compensation required to maintain the recipient at pre-agreement welfare levels.

section we model what we call the Prevailing Property Rights structure (PPR) and analyse some implications for North-South bargaining.

Intellectual Property Rights (IPR) protection of innovations has long been an important institution for R&D and the focus of much investigation in the North-South context (e.g. Helpman 1993), where Plant Breeders Rights (PBRs) and patents are pertinent examples in plant breeding and biotechnology. Indeed, the potential for conflict in enforcement of IPRs across countries led to calls for international harmonisation. This culminated in the General Agreement on Trade Related aspects of Intellectual Property Rights (TRIPS) under the auspices of the World Trade Organisation (WTO)[15]. TRIPS specifies that any product or process innovation emanating from a signatory nation can be subject to patent protection, including plant varieties and animals. Yet, while property rights are allowed in genetic resources, most states require that they be 'improved' or 'products of human intervention' rather than simple selections or discoveries of diverse genetic resources. This allows property rights to be taken in genetic resources by those states with the human capital and technological capacity to develop natural genetic resources. It should also be recognised that in the context of the plant breeding sector the discussion about IPRs over high yielding varieties (HYVs) reflects the other side of marginal land use decisions to the CBD. That is, since modern agriculture is one of the major causes of deforestation and loss of traditional landraces (Swanson 1996), the extent to which there is transfer of HYVs to the South represents another important determinant of the extensive margin and hence the level of Reserves.

The model developed here reflects this property rights structure, that is, the PPR scenario is characterised by IPRs for innovations in the North and very little in the way of intellectual property in the South. The model allows an analysis of the impact of this property rights structure on the choice of contract by our stylised North (endowed with technology) and South (endowed with biological resources). To reflect this apparent imbalance in the strength and implementation of IPRs for innovations in biotechnology, and the absence of specific property rights for genetic traits found in South, we assume that IPRs only exist for seed innovations emanating from the North. Distinct property rights (intellectual, cultural, historical etc.) are assumed to be non-existent for the stock of information accumulated in *in situ* genetic resources supplied by the South[16].

Ultimately, in the PPR model it is the North-South market for seeds that facilitates the solution to the biodiversity bargaining problem, with the solution being determined by the underlying property rights structure. The enforcement and location of IPRs gives the North some considerable advantage in determining the outcome. The PPR model places the North in the position of monopolist in the export to the South of seeds embodying technology and gives the North free access to the resources important for generating the innovations (the Reserves)[17]. In short, discoveries of genetic information contained in Reserves are treated as a global public good. Both of these characteristics of the North reflect to a large extent the current property rights with regard to innovations and access to genetic material (Goeschl and Swanson 2002). Given this, the North is able to capture the marginal rental value of both human and fixed capital inputs to R&D (from the North) *and* the rents associated with the genetic diversity (from the South)[18].

[15] The 1993 round of the GATT negotiation proposed the establishment of such an agreement, leading to the 1994 WTO TRIPS agreement.

[16] It can also be thought to tacitly represent the presence of informational spillovers which undermine the extent to which the rental value of an innovation can be uniquely attributed to a particular genetic resource in a particular country when similar traits are likely to be found in many other plant varieties in other southern countries.

[17] The importance of the location of property rights as a means to ensure efficient incentives at each layer of a vertical industry have also been highlighted in the literature (e.g. Grossman and Hart 1986). See Goeschl and Swanson (2000, 2003a, 2003b) for a discussion relating specifically to the biotechnology industry.

[18] Evenson (1995) reminds us that plant genetic diversity had been estimated to represent up to 30% of the marginal value of innovations in the plant breeding sector.

Characterised in this way, it seems that there are two reasons why the prevailing property rights are unlikely to be a sufficient mechanism to guarantee the supply of biodiversity from the South. Firstly, IPRs contain no provision for the South to be directly remunerated for its contribution to the R&D process. Secondly, the emergence of an intensive agricultural sector in the South has the potential to lead to greater conversion of Reserve land through expansion at the extensive margin. However, there remains an important countervailing force in the PPR model: the impact of technology transfer. The North can internalise the value of biodiversity to the South through the export of seeds which embody innovations. Assuming perfect information, the South will understand that the productivity of intensive agriculture is dependent upon the presence of Reserves. Although such technology transfers can be globally suboptimal[19], they cause the South to share the North's interest in biodiversity conservation (supply), and represent an important mechanism when contracting directly on Reserves is not possible[20].

This section examines the implications of the nature and location of IPRs for the resolution of the bargaining problem. The way in which the market for seeds facilitates the solution to the bargaining problem and the countervailing effects that emerge are captured in the model. The bargaining power in the North which is captured by the presence of a *first mover advantage* in a sequential model. This allows the monopolistic North to dictate the price of seeds and the extent of the technology transfer to the South, i.e. the price and quantity of seeds. By extension, the North dictates the nature of the South's land-use[21]. In this guise, the model consists of 2 periods. In the first period the North selects the profit maximising price and quantity of exported seeds, s, and the level of domestic production, n. In the second period the South chooses its land allocations taking the price of seeds as, s, as given. The model is solved by backwards induction.

4.2.1 2 Period Model of Prevailing Property Rights (PPR)

PERIOD 1: THE NORTH. The monopolistic North faces the inverse demand curve for seeds in the South, $p(s)$ for each $s > 0$. Given this, the problem for the North is to select domestic production and export of seeds to the South, n and s, taking into account the South's choice of Reserves, $\widehat{R}$. The North's objective becomes:

$$\begin{aligned} \max_{n,s} U_N &= (\pi(\widehat{R}) - b)n + p(s)s - c(n+s) + bL_N \\ s.t. &: \quad 0 \le n \le L_N \end{aligned}$$

This yields the first order conditions:

$$\widehat{n} \ge 0 : \pi(\widehat{R}) - b - c'(n+s) \le 0 \tag{22}$$

$$\widehat{s} \ge 0 : \pi'(\widehat{R})\frac{d\widehat{R}}{ds}n + p\left(s\right) + sp'\left(s\right) - c'(n+s) \le 0 \tag{23}$$

with at least one inequality in each case.

PERIOD 2: THE SOUTH. The South takes as given the price of seeds, p, and the maximum quantity of seeds supplied by the North, $\widehat{s}$. Given perfect information with regard to the role

[19] For example, Lemma 1 showed that where $b = 0 \Longrightarrow s^* = 0$ for $0 < n^* < L_N$. Also, see Proposition 3.

[20] We assume the absence of the transfers, T.

[21] A first mover advantage for innovators is not uncommon in the literature. For theoretical approaches and empirical evidence see Petrin (2002) and Jones et al (2001).

of Reserves in R&D, and hence the productivity of the Southern intensive sector, the South internalises the value of Reserves in making its land-use decisions. This captures what we have described above as technology transfer. Following on from the previous sections, the South's objective then becomes:

$$\max_{t,s} U_S = [\pi(L_S - t - s) - p]s + t - k(t) \tag{24}$$

$$s.t:.t + s \leq L_S, t \geq 0, 0 \leq s \leq \widehat{s}$$

This yields the following first order conditions[22]:

$$\widehat{t} \geq 0 : 1 - \pi'(L_S - t - s)s - k'(t) \leq 0 \tag{25}$$

$$\overline{s} \geq 0 : \pi(L_S - t - s) - \pi'(L_S - t - s)s - p \leq 0 \tag{26}$$

From (26), we see that the inverse demand curve for seeds in the South is[23]:

$$p\,(s) = \pi(L_S - t - \overline{s}) - \pi'(L_S - t - \overline{s})\overline{s} \tag{27}$$

Given (27), $\widehat{t} > 0$ solves[24]:

$$1 - \pi'(L_S - \widehat{t} - \overline{s})\overline{s} - k'(\widehat{t}) = 0 \tag{28}$$

Some comparative statics of these solutions come from total differentiation of (28), and show that $\frac{d\widehat{t}}{d\overline{s}} < 0$[25]. Hence the optimal choice of traditional production in the South is decreasing in the supply of seeds from the North. Furthermore, setting $\widehat{R} = L_S - \widehat{t} - \overline{s}$ yields:

$$\frac{d\widehat{R}}{d\overline{s}} = -\frac{d\widehat{t}}{d\overline{s}} - 1 \tag{29}$$

The relationship in (29) is of particular interest in our land use model since it characterises the net marginal effect of intensive agriculture in the South upon Reserves. For example, where (29) is less than zero, intensive agriculture will encroach upon Reserves. However, where (29) is greater than zero the North can use the transfer of technology (provision of seeds) to the South as an incentive mechanism for increasing land held as Reserves. The necessary conditions for this incentive to exist are that $\widehat{t} > 0$ and $\frac{d\widehat{t}}{d\overline{s}} < -1$, so in this case intensive production *and* Reserves replace the traditional sector in the South[26]. Hence there are two possible motives for the North to transfer technology to the South. One is to obtain profits from the export of seeds and the other is to incentivise the provision of Reserves. The relative strength of these motives will determine the optimal marginal response by the South to an increase in intensive production and ultimately the net effect on Reserves as compared to the Autarky and social planner outcomes.

[22] It is important that the second order conditions are also satisfied: $\frac{d^2U}{dt^2} = \pi''(L_S - t - s)s - k''(t) < 0$, $\frac{d^2U}{ds^2} = \pi''(L_S - t - s)s - 2\pi'(L_S - t - s) < 0$, $\frac{d^2U}{dsdt} = \pi''(L_S - t - s)s - \pi'(L_S - t - s)$, and $\left(\frac{d^2U}{dt^2}\right)\left(\frac{d^2U}{ds^2}\right) - \left(\frac{d^2U}{dsdt}\right)^2 > 0$. These conditions are worked out explicitly in Appendix 3 for Example 2.

[23] In effect this assumes that $\overline{s} = \widehat{s}$.

[24] $\widehat{t} > 0$ provided that $1 - k'(0) - \pi'(L_S - \overline{s})\overline{s} > 0$.

[25] Note that $\frac{d\widehat{t}}{d\overline{s}} = \frac{-[\pi''(L_s - \widehat{t} - \overline{s})\overline{s} - \pi'(L_s - \widehat{t} - \overline{s})]}{\pi''(L_s - \widehat{t} - \overline{s})\overline{s} - k''(\widehat{t})} < 0$. This comes from the second order conditions.

[26] From the previous footnote: $\pi'(L_S - \widehat{t} - \overline{s}) > k''(\widehat{t})$ ensures that $\frac{dt}{ds} < -1$.

The 2 period PPR model represents another solution to the biodiversity bargaining problem outlined above. A number of important issues arise in the characterisation of this solution, primary among which are the relationship with the social planner solution and the incentives for strategic bargaining. Firstly, we analyse the welfare implications for each region under the PPR, then we analyse the incentives for strategic destruction that emerge in the South. The implications of the model are summarised in a series of propositions.

4.2.2 PPR vs Social Planner

The following proposition provides the first fundamental distinction between PPR and social planner outcomes:

PROPOSITION 2: When the social planner solution is interior, the PPR problem is never a solution to the social planner problem and therefore the solution falls within the bargaining frontier (U^* in Figure 1)[27]. If $b = 0$, there are zero profits in the Northern baseline sector, the social planner chooses specialised functions for each region (intensive production in the North, Reserves in the South) and again the PPR and social planner solutions never coincide and the PPR solution falls within the bargaining frontier.

PROOF: Where the social planner solution is interior: $n^*, l^*, s^*, R^*, t^* > 0$, from (25), if $(n^*, s^*) = (\widehat{n}, \widehat{s})$ then if $R^* = \widehat{R}$ it follows due to the convexity of $k(.)$ that $t^* < \widehat{t}$. If $b = 0$ then by Lemma 1 $s^* = 0$, but if $\widehat{s} = 0$ the PPR solution coincides with the Autarky solution, which is not the social planner solution. QED.

It is clear from comparison of (25) and (16) that the decentralised South always imposes an externality upon the North under the PPR in determining traditional and Reserve land use, albeit smaller than under Autarky. This externality, which arises because the transfer of technology (seeds) only internalises the private value of Reserves to the South, captures the fact that the South is not being explicitly remunerated for the provision of Reserves. This effect will tend to reduce the level of Reserves below R^*. As a result, where the North is unable to contract directly over Reserves, and can only determine the price and quantity of seeds, the PPR outcome will be suboptimal and within the bargaining frontier. This situation is depicted in Figure 3.

This externality is but one source of inefficiency in the PPR model. Indeed a comparison of (23) with (15) shows that there exist two further distortions. Firstly there is the effect of monopolistic pricing reflected by the term $p'(s)$ in (23). This reflects the pure monopoly distortion. Secondly, there is a distortion introduced by the term $\frac{d\widehat{R}}{ds}$, which reflects the optimal response of Reserves to intensive agriculture by the South. As discussed above, the sign of $\frac{d\widehat{R}}{ds}$ is critical to determining the overall effect of technology transfer to the South on land allocations in the PPR model compared to the social planner and Autarky outcomes. Gatti et al (2004) discuss these effects in more detail, labelling the former effect the 'IPR effect' and the latter the 'Spillover effect', referring to extent

[27] Indeed this is generally the case. There are several other cases to consider. a) $n^* = L_N, s^* = L_S$: From the assumption that $\pi'(0) = \infty$, this is not a solution to the social planner problem (SP); b) Where $s^* = \widehat{s} = 0$ then PPR solution collapses to the autarky solution which by Lemma 1 is not a solution to the SP; c) where the autarky solution is interior, $s^* = n^* = 0$ is not a solution to the SP and so the SP, autarky and PPR solutions will not all coincide in this way. The only other case to consider is where $n^* = 0$ and $s^* > 0$, i.e. the SP solution is not interior. If we assume that the PPR and SP land allocations are identical and that $n^* = 0$ and $s^* > 0$, we can set (23) and (14) equal and using the inverse demand curve $p(s)$ we can rearrange to show that the PPR solution and the SP solution coincide only if $p'(s) = 0$, i.e, if the North has no monopoly power and the price of seeds represents their (global) social value.

of knowledge spillovers. They also show that where the marginal value in R&D is relatively high, Reserves in the PPR solution are higher than under Autarky but that, given the other distortions, Reserves in the PPR regime are generally lower than optimal: $R^* > \widehat{R} > R^a$. This reflects the discussion above: on the one hand intensive agriculture may encroach upon the Reserve sector, but on the other this technology transfer may internalise the value of Reserves to the South sufficiently to increase the South's provision of Reserves compared to Autarky.

In sum these two externalities ensure that the solution to the PPR falls within the bargaining frontier. However, our main interest here is the regional welfare arising from the PPR solution. This is captured by the following proposition:

PROPOSITION 3: When the PPR solution has $\widehat{s} > 0$, the South is as least as well off under the PPR solution than under either Autarky or the optimal extreme point contract offered by the North under the GEF, i.e. $\widehat{U}_S \geq U_S^a$. The North is better off under the PPR regime than under Autarky: $\widehat{U}_N > U_N^a$.

PROOF: The Autarky solution is available in the PPR model but is not chosen.

Proposition 3 states that, although global welfare is less than that under the social planner solution or the GEF contract described above, the PPR regime offers a more favourable solution from the perspective of the South as compared to either Autarky or the GEF contract. The North is also better off under this regime than under Autarky[28]. Figure 3 provides a diagrammatic representation of the PPR solution. Despite the inefficiency introduced by the North's monopoly over innovations, and the South's tendency to impose an externality upon the North in its land-use decision, both parties can improve their welfare compared to Autarky levels when IPRs underlie the bargaining process. The North-South market for seeds allows the South to share in the rents generated from Reserves as an input to R&D and aligns regional incentives for the conservation of Reserves such that they increase compared to Autarky. Of course, the extent to which the sharing of rents aligns regional incentives depends upon the information available to the South and even then the threat of strategic destruction may persist.

[28]It is ambiguous whether the North and/or the South are better off in the PPR than under the GEF with the threats of strategic destruction actually carried out.

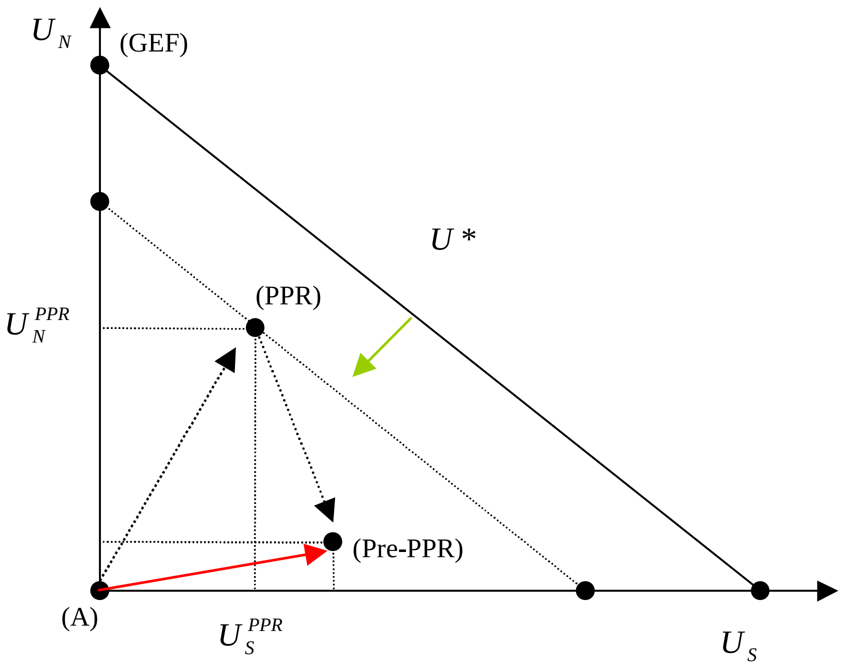

Fig 3. Strategic Destruction in the PPR model.

4.2.3 Strategic Destruction: Pre-PPR

In this section we follow on from Section 2 and investigate the extent to which incentives exist for strategic destruction The PPR scenario differs from the pure contracts case since, given the transfer of technology in the form of seeds, destruction of Reserves is a costly activity for both the North and the South. We model the decision to engage in strategic destruction as the 'Pre-PPR' decision in which in a period 0 prior to the supply decisions of the North, the South makes a supply decision of its own: the supply of Reserves. As before, the ability of the South to make this supply decision prior to the North, reflects the only semblance of bargaining power that the South holds: the control of its land endowment and hence Reserves.

PERIOD 0: THE SOUTH CHOOSES DESTRUCTION For strategic destruction to be a credible action for the South requires welfare to increase as the land endowment decreases: $\frac{dU_S}{dL_S} < 0$. From the 2 period problem described above, and using the inverse demand curve (27) U_S can be written:

$$U_S = \left(\pi\left(\widehat{R}\right) - p\left(\widehat{s}\right)\right)\widehat{s} + \widehat{t} - k\left(\widehat{t}\right) = \pi'\left(\widehat{R}\right)\widehat{s}^2 + \widehat{t} - k\left(\widehat{t}\right) \tag{30}$$

Given $\widehat{R} = L_S - \widehat{s} - \widehat{t}$, and the envelope theorem, we obtain:

$$\frac{dU_S}{dL_S} = 2\pi'\left(\widehat{R}\right)\frac{d\widehat{s}}{dL_S}\widehat{s} + \pi''\left(\widehat{R}\right)\left[1 - \frac{d\widehat{s}}{dL_S}\right]\widehat{s}^2 \tag{31}$$

This leads to the following proposition:

PROPOSITION 4: A sufficient condition for strategic destruction of Reserves by the South being a welfare enhancing policy is that the equilibrium level of the intensive sector in the South is increasing with destruction in the South: $\frac{d\widehat{s}}{dL_S} < 0$. Indeed, $\frac{d\widehat{s}}{dL_S} < 0$ is a necessary condition when

$\pi''(.) = 0$. Where $\frac{d\widehat{R}}{ds} > (<)\ 0$, this is more (less) likely where; i) $\pi''(.)$ is large in absolute value; ii) $c''(.)$ is large;and iii) n is large.

PROOF: It is easy to see from (31) the sufficiency of $\frac{d\widehat{s}}{dL_S} < 0$ for the case where $\pi''(.) < 0$ and the necessity of $\frac{d\widehat{s}}{dL_S} < 0$ when $\pi''(.) = 0$. The conditions i) - iii) under which $\frac{d\widehat{s}}{dL_S} < 0$, can be derived from comparative statics analysis using equations (22) and (23) and Cramer's rule[29].

The general case is complicated so we illustrate the credibility of strategic destruction with the following example in which we assume that $\pi(R)$ is linear ($\pi''(.) = 0$). This is a more restrictive case in the sense that while $\pi''(.) < 0$, the incentive for strategic destruction may exist even when $1 > \frac{d\widehat{s}}{dL} > 0$. In the linear case below, $\frac{d\widehat{s}}{dL_S} < 0$ is a necessary condition for strategic destruction.

EXAMPLE 2. Strategic Destruction in the IPR model: We use the following algebraic form for the functions described above: $\pi(R) = \delta R$, $c(x) = \beta x^2$, $k(t) = t^2$. Some algebra yields the following expressions for the quantities and prices that determine the South's utility in the 2-period model:

$$\widehat{t} = \frac{1-\delta\widehat{s}}{2},\ \widehat{s} = \frac{\delta^2(\frac{\delta}{2}-1)\left(L_S - \frac{1}{2}\right) + b\left(2\beta - \delta(\frac{\delta}{2}-1)\right)}{\left(4\delta\beta - \left(\delta(\frac{\delta}{2}-1)\right)^2\right)},\ \widehat{R} = L_S - \frac{1}{2} + (\frac{\delta}{2}-1)\widehat{s} \tag{32}$$

and from (27):

$$p(s) = \delta\left(L_S - \frac{1}{2}\right) + 2\left(\frac{\delta}{4}-1\right)\delta\widehat{s} \tag{33}$$

There are a number of cases to consider, however we restrict our analysis to the interior. An interior solution for t requires that $\widehat{s} < \frac{1}{\delta}$, while $\frac{d\widehat{p}}{d\widehat{s}} < 0$ if $\delta < 4$. It is only in this case that the North can employ its optimal pricing policy, $p(s)$[30]. From Proposition 4 we have that $\frac{d\widehat{s}}{dL_S} < 0$ is a sufficient condition for $\frac{dU_S}{dL_S} < 0$ in general, but a necessary condition in the linear case. The expression for $\widehat{s}$ in (32) above shows that the necessary condition is satisfied when $\delta < 2$ and the second order conditions. Interior solutions for the remaining variables place restrictions on the other parameters in the system. However, the result is that strategic destruction occurs under the following parameter values for example: $\delta = 1, \beta = \frac{1}{4}, b = \frac{1}{3}$ and $L_S = 1$. See Appendix 3 for a formal proof.

4.2.4 Discussion of the PPR model and Strategic Destruction

In the previous sections we have motivated a model of prevailing property rights in the biotech industry in which the North has monopoly power over the sale of seeds by virtue of the intellectual property rights over embodied innovations. Within this institution the South is modelled as having no bargaining power over the price of seed and hence the North has some discretion over the intensive

[29] The condition being: $\frac{ds}{dL_S} < 0 \Leftrightarrow \frac{dR}{ds}\left[\frac{\pi'(.)}{c''(.)} + n\frac{\pi''(.)}{\pi'(.)}\right] < 1$.

[30] Where $\frac{dp}{ds} > 0$ it is easy to show that $\frac{dU_S}{ds} < 0$. Note that where $\widehat{s} < \frac{1}{\delta}$ the pricing formula becomes:
$p(\widehat{s}) = \delta\left(L_S - \widehat{t} - \widehat{s}\right) - \delta\widehat{s} = \delta\left(L_S - \frac{1}{2}\right) + 2\left(\frac{\delta}{2}-1\right)\widehat{s}$. Hence when $\delta > 4$, $\frac{dp}{ds} > 0$. In this case the South's utility becomes: $U_S = \frac{1}{4} + \delta\widehat{s}^2\left(1 - \frac{\delta}{4}\right)$, and therefore if $\delta > 4$ the South is better off with $\widehat{s} = 0$, i.e. under Autarky. In other words, when $\delta > 4$ the optimal pricing policy of the North does not satisfy the South's participation constraint and hence prices must be tempered to ensure participation.

land allocation in the South by virtue of being a monopolist over seeds[31]. In the two period model the South makes residual decisions over the traditional and Reserve sector. The PPR model offers a solution to the bargaining problem described in Section 2 which is facilitated primarily by the market for seeds and the technology transfer that this entails. However, we have also shown that this institutional solution to the biodiversity bargaining problem may still introduce incentives for strategic destruction by the South and, importantly, the conditions under which these incentives exist are less restrictive than for the pure Nash Bargaining game outlined in Example 1. In the NBG case the productivity of Reserves ($\pi(R)$) must be concave whereas Example 2 shows that such incentives exist in the PPR even in the restrictive case where production is linear in Reserves. In short, the South has bargaining power to the extent that it can exert control over the supply of its own unique endowments in order to increase its welfare.

The PPR model brings to light some interesting points with regard to the behaviour of the North. When the North is a monopolist there are potentially two separate reasons for providing seeds to the South (see Gatti et al 2004, for more detail). On the one hand the North wishes to make profits from this transfer of technology and this is facilitated by pricing seeds according to the profit maximising pricing formula in (27) above. On the other hand, where $\frac{d\widehat{R}}{ds} > 0$, the North can use technology transfer as a means of incentivising the South to conserve Reserve land. In general, in the former case the North will act more or less like a conventional monopolist by restricting seed sales to the South compared to the social planner. It is interesting to note that the extent to which the monopolist can exert this monopoly power is limited by the potential introduction of the traditional sector in the South, the presence of which increases the elasticity of demand for seeds[32]. In the latter case, where technology transfer encourages the conservation of reserves, the incentives for the North to restrict seeds will be diminished since the increase in Reserves will increase R&D and benefit both their domestic intensive productivity and the price they are able to charge the South. As the power of the incentive (value of $\frac{d\widehat{R}}{ds}$) increases, the Northern monopolist could end up supplying more seed than the social planner would choose. Of course, the extent to which this incentive exists is limited by the extent to which there is a traditional sector in the South to replace. Once $\widehat{t} = 0$, then the intensive sector and Reserve margins meet and further intensive production necessarily encroaches on Reserves: $\frac{d\widehat{R}}{ds} = -1$.

Which of these cases prevails depends upon a number of factors but hinges crucially upon the marginal value of Reserves to R&D: the higher the value the more likely it is that $\frac{d\widehat{R}}{ds} > 0$. Example 2, is illustrative of this point. Where the traditional sector exists in the South $\left(\widehat{t} > 0\right)$, the term $\frac{d\widehat{R}}{ds} = \left(\frac{\delta}{2} - 1\right)$, where δ is the marginal value of Reserves, is constant and hence the analysis is much simplified. If Reserves have a low value (< 2) then $\frac{d\widehat{R}}{ds} < 0$ and the North behaves as a conventional monopolist by restricting the sale of seeds to the South. Alternatively if Reserves have a moderate value ($4 > \delta > 2$) then $\frac{d\widehat{R}}{ds} > 0$. In this case the sale of seeds incentivises the South to provide Reserves hence reducing the incentive for the monopolist to restrict seeds since domestic intensive production becomes more productive as seed is exported[33].

[31] This is stark of course with the assumed fixed proportions technology, but this general point still holds without this assumption.

[32] Evaluating (25) at $\widehat{t} = 0$, it is clear that the traditional sector, t, will be introduced when $1 - \pi'(R)\, s > 0$. Note that where $\widehat{t} = 0$, $\widehat{R} = L_S - s$, so as s becomes smaller the term $\pi'(R)\, s$ declines. Thus, restricting the seeds sold to the South will increase the likelihood that the traditional sector will be introduced. This acts as a limit to the monopoly power of the North.

[33] This is in part due to that fact that when $\frac{d\widehat{R}}{ds} > 0$ and $\frac{d\widehat{p}}{ds}$ becomes smaller, and demand becomes more elastic in the South. In the extreme, where $\alpha > 4$, both $\frac{d\widehat{R}}{ds}$and $\frac{d\widehat{p}}{ds} > 0$, i.e, the demand for seeds in the South is upward sloping. In this case the North cannot employ the optimal pricing policy and is bound to set a price which satisfies

Under the conditions outlined in Proposition 4, strategic destruction still remains a viable means by which the South can increase its welfare. These conditions are also crucially related to the sign of $\frac{d\widehat{R}}{ds}$ and hence to the value of Reserves in R&D. When $\frac{d\widehat{R}}{ds} < 0$, strategic destruction is more likely where the North has low monopoly power ($\pi''(.)$ is small in absolute terms), where the marginal costs of seed production/R&D costs do not increase too rapidly ($c''(.)$ is small) and the intensive sector in the North (n) is small. These conditions can be understood easily. When $\frac{d\widehat{R}}{ds} < 0$ and the North has minimal monopoly power it is less inclined to restrict seeds to the South making it easier for the South to coerce more seeds from the North. Furthermore, producing more seeds for the South is more likely where the marginal costs are not rising quickly, whilst the North is more inclined to encourage intensive production in the South where the opportunity cost of land in the North is higher, and hence the North's intensive sector is small. These incentives are reversed when $\frac{d\widehat{R}}{ds} > 0$.

As described above, which of these cases arises depends upon the marginal value of Reserves $(\pi'(.))$. Again, the linear case of Example 2 provides a simple illustration of this point. The observant reader will have noticed that the same critical value for δ that determines the sign of $\frac{d\widehat{R}}{ds}$ determines whether or not strategic destruction can be welfare enhancing for the South, i.e. the sign of $\frac{d\widehat{s}}{dL_S}$. In short, only where Reserves have a low value (< 2), and where the intensive sector in the South encroaches upon the Reserve sector, will strategic destruction be viable in the linear case. The opportunity cost of land in the North is also important here. In Example 2 strategic destruction requires that the alternative use of land in the North yields positive marginal profit ($b > 0$). Where the opportunity cost of intensive production in the North is relatively high the North is encouraged to export seed to the South rather than produce domestically. If Reserves increase, intensive production is augmented and the North becomes increasingly inclined to increase land allocated to domestic intensive production rather than export seeds to the South. With $\frac{d\widehat{R}}{ds} < 0$, the amount of seed that the South receives can fall as Reserves increase. The corollary of this is that, the South can reduce Reserves by employing strategic destruction and therefore induce the North to export more seeds, which at the margin is welfare enhancing.

In the linear case, where $\frac{d\widehat{R}}{ds} > 0$, this incentive does not exist. However, in the general case the South may be able to exert what is a type of monopoly power on the North as measured by the second term in (31) even when $\frac{d\widehat{R}}{ds} > 0$. In this case the North responds to the strategic destruction by supplying more seeds in an attempt to incentivise the conservation of Reserves, or at least halt the destruction.

This discussion gives us some insight into the solution to the biodiversity bargaining problem offered by the PPR model and how this solution might be preferred to Autarky despite reducing global welfare. It also explains the mechanism by which incentives for strategic destruction can be introduced in the South by the prevailing IPR institution, despite the potential for increased southern welfare. Clearly, the value of biodiversity contained in Reserves is of considerable moment in determining the bargaining incentives, regional welfare, and the extent to which this market can approximate the global optimal. The PPR model shows that the prevailing IPRs are likely to provide an inadequate mechanism to harness the global value of biodiversity and that this leads to an inefficient solution to the biodiversity bargaining problem. The inefficiencies arise not only due to the absence of direct remuneration for Reserves and the presence of monopolistic behaviour which can increase the conversion of Reserves, but also due to the scope for strategic destruction that this bargaining solution can introduce.

the South's participation constraint: $U_S \geq U_S^a$.

5 Conclusion

This paper has characterised the issue of North-South interactions concerning biodiversity conservation as one of cooperative bargaining. The interdependence, and therefore the need for cooperation between these regions is described in the context of R&D in the plant breeding sector of the biotechnology industry. Only if the two regions can cooperate in combining their unique resource endowments of human and natural capital and establish a satisfactory division of the surplus, can global welfare be maximised. Using cooperative bargaining theory allows us to analyse two institutions that have arisen in order to solve the biodiversity problem: the Convention on Biological Diversity (CBD) and the TRIPS agreement on intellectual property rights and ultimately posit i) an additional and fundamental reason for the continued losses in primary forest observed even in the presence of these institutions and agreements, and in light of this ii) some presciptive findings for these institutions.

Chief among the ideas presented here is that the institutions which attempt to solve the biodiversity bargaining problem actually introduce incentives for strategic destruction of biological resources by the South. I.e. in a manner similar to the 'rational threats' described by Nash (1953) the South has the potential to destroy its valuable reserves of biological resources as a strategic bargaining strategy. For the Nash bargaining case, where the South can influence this value for the North through the destruction of its residual biological reserves, we provide the conditions under which a destruction strategy is viable. What is more, we show that this strategy is largely invariant to the initial balance of bargaining power and is therefore potentially present at the extreme points of the bargaining frontier. The significance of these theoretical solutions is brought to light in the analysis of the bargaining solutions implied by the CBD and TRIPS and provides and answer to the following questions: Do existing institutions provide an agreed determination of this bargaining problem? Are these institutions efficient?

Firstly, the 'incremental cost' approach of the financial mechanism of the CBD, facilitated by the Global Environment Facility (GEF), can be interpreted as one of the end points of the family of optimal contracts: an extreme point contract. We show that the GEF reflects the North offering the South a contract for biodiversity preservation, which leaves the South no better off than in the absence of the contract. This indicates two things to us. Firstly, Southern indifference between the GEF contract and the conflict point may induce the South to use rational threats and employ destruction as a bargaining ploy. Indeed, such a response to the extreme point contract has been observed in Latin America with regard to the GEF (World Bank 2003). Consequently this approach is unlikely to represent a real solution to the biodiversity bargaining problem. We then show that the optimal contract should both compensate the South over and above incremental cost by making compensation reflect the stock of reserves, while specifying precisely the level of the Reserves in order to remove completely the incentives for strategic destruction. This recommendation is in line with previous work in this area (van Soest and Lensink 2000).

Secondly, another possibility is that the agreement regarding property rights to embodied innovation might provide the vehicle for solving the biodiversity bargaining problem. Intellectual Property Rights (IPRs) represent another important institutional mechanism for capturing the value of biological diversity as an input to R&D. We analyse the prevailing property rights regime (PPR) where IPRs are located in the North, reflecting both the location of R&D and the relative strength of Northern IPRs in light of the TRIPS agreement. The PPR affords the North an advantage in bargaining with the South and facilitates cooperation largely on its own terms by acting as a monopolist over in the market for seeds embodying innovations. This set up introduces a number of countervailing effects but the market for seeds facilitates the solution to the bargaining problem by transferring technology to the South and allowing the South to share in the cooperative gains.

However, despite making the South better off than under the extreme point contract, we show that this outcome is inefficient for two reasons. Firstly, there are a number of countervailing distortions arising from the presence of a monopolistic North, the net impact of which depends extent to which intensive agriculture encroaches upon Reserves in the South. Secondly, the South may respond once more by asserting its sole source of bargaining power: the irreversible destruction of its biological Reserves. In either case the bargaining solution afforded by IPRs leads to an outcome within the bargaining frontier.

In conclusion, this paper shows how both the CBD/GEF and IPRs, and the allocation of bargaining power that these institutions imply, represent an inadequate mechanism for capturing the global value of biodiversity. Indeed, in conclusion, in describing global biodiversity conservation as a cooperative bargaining game, this paper alerts us to the idea that the very institutions that have arisen to generate North-South cooperation have the potential to exacerbate the losses of biodiversity and habitat that were the impetus for their creation.

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Appendix 1: PROOF of PROPOSITION 1 If South selects $(\widetilde{n}, \widetilde{s}, \widetilde{t})$ and a transfer payment:

$$\begin{aligned}
-T &= T_S(n, s : \widetilde{n}, \widetilde{s}, \widetilde{t}) = \int_n^{\widetilde{n}} \left[\pi(\widetilde{R}) - b\right] dx - \int_{n+s}^{\widetilde{n}+\widetilde{s}} c'(x)dx + [U_N^a - (\pi(\widetilde{R}) - b)\widetilde{n} + c(\widetilde{n} + \widetilde{s}) - bL_N] \\
&= \left[\pi(\widetilde{R}) - b\right] (\widetilde{n} - n) - c(\widetilde{n} + \widetilde{s}) + c(n + s) + [U_N^a - (\pi(\widetilde{R}) - b)\widetilde{n} + c(\widetilde{n} + \widetilde{s}) - bL_N] \\
&= \left[\pi(\widetilde{R}) - b\right] (-n) + c(n + s) + [U_N^a - bL_N]
\end{aligned}$$

where $\widetilde{R} = L_S - \widetilde{t} - \widetilde{s}$

North's utility is given by

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

thus the North is indifferent between any level of n and s, including $\widetilde{n}$ and $\widetilde{s}$. Introducing a, possibly tiny, penalty for deviation from the target levels specified would ensure compliance.

Given North selects $\widetilde{n}$ and $\widetilde{s}$, the South's problem is to select (n, s, R, t) to maximise

$$\begin{aligned}
U_S(n, s, R, t) &= \pi(R)s + t - k(t) - T_S(n, s : n, s, R) \\
&= U^* - U_N^a = U^C + U_S^a
\end{aligned}$$

Thus the South's optimisation problem is therefore equivalent to the Social Planners problem and hence the solution is the same, (n^*, s^*, R^*, t^*).

b) The proof is equivalent for the other extreme point contract: If the North selects $\widetilde{s}$ and $\widetilde{t}$:

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

Then the South's utility is given by:

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

Hence the South is indifferent to any level of t including $\widetilde{t}$. Once again, a small penalty for deviation from $\widetilde{t}$ ensures compliance. Given the South selects $\widetilde{t}$ the North's problem is to select (n, s, R, t) to maximise:

$$\begin{aligned}
U_N\left(n, s, R, t\right) &= \left(\pi\left(R\right) - b\right) n - c\left(n + s\right) - T_N\left(t : s, t\right) \\
&= U^* - U_S^a = U^C + U_N^a
\end{aligned}$$

Once again, this is equivalent to the Social Planner problem and the solution is (n^*, s^*, R^*, t^*).

Appendix 2: PROOF OF EXAMPLE 1. Strategic Destruction by the South

GENERAL FORMULATION:

$$\frac{dU_S^*}{dL_S} = \alpha\frac{dU_S^a}{dL_S} + (1-\alpha)\frac{d(U^* - U_N^a)}{dL_S}$$

For $L_S > t^a$, from Equation (19) $\frac{dU_S^a}{dL_S} = 0$, and $\frac{dU_S^*}{dL_S} = (1-\alpha)\frac{d(U^*-U_N^a)}{dL_S}$. Therefore for all $\alpha > 0, \frac{dU_S^*}{dL_S} \gtreqless .0 \; iff \; \frac{d(U^*-U_N^a)}{dL_S} \gtreqless 0$ and U_S^* is maximised when $(U^* - U_N^a)$ is maximised, irrespective of the value of α. From equations (13) and (10) and the Envelope Theorem:

$$\begin{aligned}\frac{d(U^* - U_N^a)}{dL_S} &= \frac{\partial U}{\partial L_S}(n^*, s^*, t^*) - \frac{\partial U_N^a}{\partial L_S}(n^a, t^a) \\ &= \pi'(L_S - s^* - t^*)(n^* + s^*) - \pi'(L_S - t^a)(n^a)\end{aligned}$$

and so

$$\pi'(\overline{L_S} - t^*)(n^a) > \pi'(\overline{L_S} - s^* - t^*)(n^* + s^*) \Rightarrow \frac{d(U^* - U_N^a)}{dL_S} < 0 \text{ at } \overline{L_S}$$

and destruction of arable land will increase Utility for the South. QED

For $L_S < t^a$, $R^a = 0$ and, from Equation (12),$\frac{dU_N^a}{dL_S} = 0$, so from Envelope Theorem:

$$\begin{aligned}\frac{dU_S^*}{dL_S} &= \alpha\frac{dU_S^a}{dL_S} + (1-\alpha)\frac{dU^*}{dL_S} \\ &= \alpha(1 - k'(L_S)) + (1-\alpha)[\pi'(L_S - s^* - t^*)(n^* + s^*)] \\ &> 0\end{aligned}$$

and the optimal solution is therefore to increase L_S up to t^a which is the Autarky solution.

PROOF OF EXAMPLE 1: >From Equation (14) & (15) we have $s^* = 0$ (as $b = 0$) and $n^* = \left(\frac{(L_S - t^*)^\delta}{\beta}\right)^{\frac{1}{\beta-1}} > 0$ when $L_N > n^*$.

Let $\Phi(L_S, t, n) = \pi'(L_S - t)(n) = \delta(L_S - t)^{\delta-1}\left(\frac{(L_S-t)^\delta}{\beta}\right)^{\frac{1}{\beta-1}} = \left(\frac{\delta}{\beta^{\frac{1}{\beta-1}}}\right)(L_S - t)^{\delta-1+\frac{\delta}{\beta-1}}$.

Destruction is beneficial to the South if, $\overline{L_S} > t^a = \left(\frac{1}{\gamma}\right)^{\gamma-1}$ and $\frac{d(U^*-U_N^a)}{dL_S} < 0$ at $\overline{L_S}$.

The last condition requires that $\Phi(\overline{L_S}, t^a, n^a) > \Phi(\overline{L_S}, t^*, n^*)$

$$\Longleftrightarrow \left(\frac{\delta}{\beta^{\frac{1}{\beta-1}}}\right)(\overline{L_S} - t^a)^{\delta-1+\frac{\delta}{\beta-1}} > \left(\frac{\delta}{\beta^{\frac{1}{\beta-1}}}\right)(\overline{L_S} - t^*)^{\delta-1+\frac{\delta}{\beta-1}}$$

given that $t^a > t^*$, this inequality hold iff $\left(\delta - 1 + \frac{\delta}{\beta-1}\right) < 0 \Leftrightarrow \beta > \frac{1}{1-\delta}$

Appendix 3: Proof of Example 2.

Period 2:The South Chooses s, t **and** R. The functional forms are $\pi(R) = \delta R$, $c(x) = \beta x^2$, $k(t) = t^2$. This yields an expression for the South's utility as follows:

$$U_S = \delta R + t - t^2 = \delta(L_S - t - s) + t - t^2 \tag{34}$$

The first order conditions for maximisation yield:

$$\widehat{t} = \frac{1 - \delta\widehat{s}}{2}, \ \widehat{R} = L_S - \frac{1}{2} + (\frac{\delta}{2} - 1)\overline{s} \tag{35}$$

and the inverse demand curve for s faced by the monopolist is,

$$p(s) = \delta(L_S - t - \overline{s}) - \delta\overline{s} = \delta\left(L_S - \frac{1}{2}\right) + 2\left(\frac{\delta}{4} - 1\right)\delta\overline{s} \tag{36}$$

The second order conditions are as follows:
$\frac{d^2U_S}{dt^2} = \pi''(L_S - t - s)s - k''(t) = -2$, $\frac{d^2U}{ds^2} = \pi''(L_S - t - s)s - 2\pi'(L_S - t - s) = -2\delta$, $\frac{d^2U_S}{dsdt} = \pi''(L_S - t - s)s - \pi'(L_S - t - s) = -\delta$, $\left(\frac{d^2U}{dt^2}\right)$ therefore $\left(\frac{d^2U}{ds^2}\right) - \left(\frac{d^2U}{dsdt}\right)^2 = 4\delta - \delta^2 > 0$ as required.

It is interesting to note that $\frac{d\widehat{R}}{d\overline{s}} > 0$ if $\delta > 2$, i.e. the North will provide seed to the South as a means of incentivising the provision of Reserves in the South. Even if this is not satisfied the North may still want to provide seed to provided that p sufficiently high.

Case 1: $\widehat{t} > 0$, i.e. $\overline{s} < \frac{1}{\delta}$:

$$\begin{aligned} U_S &= (\delta R - p)\overline{s} + t - t^2 = \left(\delta\left(L_S - \frac{1}{2} + (\frac{\delta}{2} - 1)\overline{s}\right) - \delta\left(L_S - \frac{1}{2}\right) - \left(\frac{\delta}{2} - 2\right)\delta\overline{s}\right)\overline{s} \\ &\quad + \frac{1 - \delta\overline{s}}{2} - \left(\frac{1 - \delta\overline{s}}{2}\right)^2 \\ &= \frac{1}{4} + \delta\overline{s}^2(1 - \frac{\delta}{4}) \end{aligned}$$

So $U_S \geq \frac{1}{4} = U_S^a$ is the participation constraint for the South and whenever $\overline{s} > 0$ and $\delta < 4$, it follows that $\frac{dU_S}{d\overline{s}} > 0$ and $U_S > U_S^a$ as suggested in Proposition 3.

Case 2: $\widehat{t} = 0$, $\overline{s} \geq \frac{1}{\delta}$.

If $\delta < 4$, then $p(s) = \delta L_S - 2\delta\overline{s}$, $\widehat{R} = L_S - \overline{s}$ and

$$U_S = (\delta\widehat{R} - p)\overline{s} = (\delta(L_S - \overline{s}) - \delta L_S + 2\delta\overline{s})\overline{s} = \delta\overline{s}^2 > \frac{1}{\delta} > \frac{1}{4} = U_S^a$$

If $\delta > 4$, then the North must set the price in order to maximise profits given the binding participation constraint. I.e. the North must set the price to ensure that $U_S = U_S^a = 1/4$. The pricing formula then becomes:

$$\begin{aligned} (\delta\widehat{R} - p)\overline{s} &= (\delta(L_S - \overline{s}) - p)\overline{s} = \frac{1}{4} \\ p(s) &= \delta(L_S - \overline{s}) - \frac{1}{4\overline{s}} \end{aligned}$$

We do not consider this case further here. See Gatti et al (2004) for a deeper discussion.

Strategic Destruction:

Proposition 4 shows that for strategic destruction requires that $\frac{dU_S}{dL_S} < 0$, and that a necessary condition in the linear case where $\delta < 4$ and $\frac{dU_S}{d\overline{s}} > 0$ is that $\frac{d\overline{s}}{dL_S} < 0$[34]. In order to the conditions in which this can occur we need an expression for $\overline{s}$.

Period 1:The North chooses $\widehat{s}$ and $\widehat{n}$ Remembering that $\pi(R) = \delta R$ and $c(n+s) = \beta(n+s)^2$, we have:

$$U_N = (\delta R^* - b)n + p^*(s)s - \beta(n+s)^2 + bL_N$$

Case 1: $\widehat{t} > 0$, i.e. $\overline{s} = \widehat{s} < \frac{1}{\delta}$:
The North's utility is given by:

$$U_N = \left(\delta\left(L_S - \frac{1}{2} + (\frac{\delta}{2} - 1)s\right) - b\right)n + \left(\delta\left(L_S - \frac{1}{2}\right) + 2\left(\frac{\delta}{4} - 1\right)\alpha s\right)s - \beta(n+s)^2 + bL_N$$

The first order conditions give us the following solutions for $\overline{s}$ and $\widehat{n}$:

$$\widehat{n} = \frac{\left(\left(\frac{\delta}{2} - 1\right)\delta - 2\beta\right)\widehat{s} + \delta\left(L_S - \frac{1}{2}\right) - b}{2\beta} \tag{37}$$

and:

$$\widehat{s} = \frac{\delta(\frac{\delta}{2} - 1)\widehat{n} + b}{\delta\left(3 - \frac{\delta}{2}\right)} \tag{38}$$

$\frac{d^2U_N}{dn^2} = -2\beta < 0$, $\frac{d^2U_N}{ds^2} = (\delta - 4)\,\delta - 2\beta < 0$, $\frac{d^2U_N}{dsdn} = \delta(\frac{\delta}{2} - 1) - 2\beta$, and $\left(\frac{d^2U_N}{dn^2}\right)\left(\frac{d^2U_N}{ds^2}\right) - \left(\frac{d^2U_N}{dsdn}\right)^2 = 4\beta^2 + 2\delta\beta(4-\delta) - \left(\delta^2(\frac{\delta}{2} - 1)^2 - 4\delta\beta(\frac{\delta}{2} - 1) + 4\beta^2\right) = 4\delta\beta - \delta^2(\frac{\delta}{2} - 1)^2$. So maximisation requires that $4\delta\beta - \delta^2(\frac{\delta}{2} - 1)^2 > 0$, or $\beta > \left(\frac{\delta}{2}(\frac{\delta}{2} - 1)\right)^2$. Solving out for $\widehat{s}$ and $\widehat{n}$ yields:

$$\widehat{s} = \frac{\delta^2(\frac{\delta}{2} - 1)\left(L_S - \frac{1}{2}\right) + b\left(2\beta - \delta(\frac{\delta}{2} - 1)\right)}{\left(4\delta\beta - \left(\delta(\frac{\delta}{2} - 1)\right)^2\right)} \tag{39}$$

and:

$$\widehat{n} = \frac{\delta\left(3 - \frac{\delta}{2}\right)\widehat{s} - b}{\delta(\frac{\delta}{2} - 1)} \tag{40}$$

PROOF OF EXAMPLE 2. From above strategic destruction requires $\frac{d\widehat{s}}{dL_S} < 0$. In the linear case:

$$\frac{d\widehat{s}}{dL_S} = \frac{\delta^2(\frac{\delta}{2} - 1)}{\left(4\delta\beta - \left(\delta(\frac{\delta}{2} - 1)\right)^2\right)}$$

Given the second order conditions the denominator is positive, so $\frac{d\widehat{s}}{dL_S} < 0$ requires that $\delta < 2$. For an interior solution a number of other restrictions need to be placed upon the parameters. Given (39) for $\widehat{s} < \frac{1}{\delta}$, and hence $\widehat{t} > 0$ we have:

[34] When $\alpha > 4$, $\frac{dU_S^*}{d\overline{s}} = 0$, strategic destruction has no direct impact on South's utility but could perhaps be used to 'bargain' over price p. This goes beyond this particular paper however.

$$b < \frac{\left(4\beta - \delta(\frac{\delta}{2}-1)^2\right) + \delta^2(1-\frac{\delta}{2})\left(L_S - \frac{1}{2}\right)}{\left(2\beta + \delta(1-\frac{\delta}{2})\right)} \tag{41}$$

Given (40) some algebra gives us that $\widehat{n} > 0$ requires:

$$b < \frac{\delta\left(3-\frac{\delta}{2}\right)\delta^2(1-\frac{\delta}{2})\left(L_S-\frac{1}{2}\right)}{(\delta\beta(2-\delta) + \delta^2(1-\frac{\delta}{2})(4-\delta)} \tag{42}$$

Hence, if $\delta = 1$ the second order condition requires $\beta > \frac{1}{16}$. Then $\widehat{s} > 0$, requires $b > \frac{\delta^2(1-\frac{\delta}{2})\left(L_S-\frac{1}{2}\right)}{\left(2\beta+\delta(1-\frac{\delta}{2})\right)} = \frac{\left(\frac{1}{2}\right)\left(L_S-\frac{1}{2}\right)}{\left(2\beta+\left(\frac{1}{2}\right)\right)} = \frac{\left(L_S-\frac{1}{2}\right)}{4\beta+1}$, and $\widehat{n} > 0$, requires $b < \frac{\delta\left(3-\frac{\delta}{2}\right)\delta^2(1-\frac{\delta}{2})\left(L_S-\frac{1}{2}\right)}{(\delta\beta(2-\delta)+\delta^2(1-\frac{\delta}{2})(4-\delta)} = \frac{\frac{5}{4}\left(L_S-\frac{1}{2}\right)}{\beta+\frac{3}{2}} = \frac{5\left(L_S-\frac{1}{2}\right)}{4\beta+6}$

(Note: $\frac{5\left(L_S-\frac{1}{2}\right)}{24\beta+14} > \frac{\left(L_S-\frac{1}{2}\right)}{16\beta+2}$ when $\beta > \frac{1}{16}$ and $L_S > \frac{1}{2}$. Hence if we let $\beta = \frac{1}{4}$ we have $\widehat{s} > 0$ and $\widehat{n} > 0$ when $\frac{\left(L_S-\frac{1}{2}\right)}{2} < b < \frac{5\left(L_S-\frac{1}{2}\right)}{7}$. For $\widehat{s} < \frac{1}{\delta}$ we need:

$$b < \left(\frac{3}{4}\right) + \frac{1}{2}\left(L_S - \frac{1}{2}\right)$$

Thus strategic destruction possible if, for example, $\delta = 1, \beta = \frac{1}{4}, b = \frac{1}{3}$ and $L_S = 1$.