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Abstract

We consider a world economy, in which the global public good 'biodiversity' is positively correlated with that share of land which is protected by land-use restrictions against the deterioration of habitats and ecosystems. The willingness-to-pay for biodiversity conservation is positive in 'rich' developed countries (North), but very low in 'poor' developing countries (South). Taking the no-policy scenario (Regime 1) as our point of departure, we analyze the changes in allocations and welfare when the North financially supports biodiversity conservation in the South – as stipulated in the Convention on Biological Diversity (1992). We model that support as a market for biodiversity conservation and distinguish the cases, in which the North does (Regime 3) or does not (Regime 2) coordinate its biodiversity conservation actions. Our numerical examples exhibit various unexpected and even undesirable results. The move from Regime 1 to Regime 2 hardly improves welfare and biodiversity in our examples irrespective of whether governments act strategically. That may explain the low level of North's financial support of biodiversity in the South we observe in practice. Without strategic action, the move from Regime 1 to 3 enhances aggregate welfare, because Regime 3 is efficient, but the North or the South may be worse off due to unfavorable changes in their terms-of-trade. If governments act strategically, the aggregate welfare may decline when moving from Regime 1 to 3, but the welfare changes with opposite signs for North and South tend to be smaller than without strategic action.

JEL-Codes: Q150, Q570, Q580.

Keywords: biodiversity, conservation, protected areas, developing countries.

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1 The problem

There is mounting evidence on rapid human-induced losses of biodiversity over the last centuries (Butchart et al. 2010) with indications of mass extinction of species being underway (Ceballos et al. 2015). The Convention on Biological Diversity (1992) considers biodiversity conservation, BC for short, "a common concern of humankind". The substantial efforts made under the convention's umbrella to enhance BC have been insufficient to halt the loss of biodiversity. In developing countries, where the leading biodiversity hotspots are located, the ongoing biodiversity loss is particularly serious, but declining biodiversity is a serious threat in developed countries, too.[1] The Convention on Biological Diversity urges both developed countries, called the North for short, and developing countries, called the South, to step up their conservation effort. It also stipulates in Article 20 that the "... developed country Parties shall provide new and additional financial resources to enable developing country Parties to meet the agreed full incremental costs to them of implementing measures ..." to conserve their domestic biodiversity. In practice, the North provides funds for BC in the South through various channels, in particular through the Global Environment Facility. However, that facility's current scale of operations is too small to avoid biodiversity loss in the South (Panayotou 1994, p. 102, Mee et al. 2008).[2]

In view of the bleak prospects for global BC, it is important to scrutinize further the suitability of policies and institutions aimed at promoting BC. Specifically, we will focus on two different policy concepts closely related to the spirit of the Convention on Biological Diversity, which we refer to as *North-South compensation* and *North-North coordination*. North-South compensation is short for compensation payments of the North for additional conservation efforts in the South. North-North coordination stands for the coordinated action of all North countries to raise the North's conservation efforts towards efficient levels. Our goal is to analyze the effectiveness and the distributional consequences of these international BC policies. We are interested in investigating how they affect BC, the world welfare, and the welfare of North and South, in particular.

We will employ the land-use approach to BC, which suggests that the conversion of

[1]In its recent Fifth Report to the Convention on Biological Diversity (European Commission 2014), the European Union states that areas of extensive agriculture, grasslands and wetlands continue to decline across Europe while artificial surfaces continue to expand.

[2]Ferraro and Simpson (2002) have investigated the cost-effectiveness of payments for ecosystem conservation.

natural land deteriorates or even destroys species-rich habitats and therefore is a major cause for the loss of biodiversity (e.g. Panayotou 1994, Montero and Perrings 2011, Perrings and Halkos 2015).[3] In our simple setup, each country divides the land it is endowed with into a protected and a non-protected area.[4] The protected area is land dedicated to habitat provision and wildlife protection. It is favorable for biodiversity because appropriate landuse restrictions are implemented and only those kinds and levels of economic activities are admitted, which leave natural habitats and ecosystems unimpaired. The nonprotected area is subject to low regulation and therefore hosts all economic activities that are incompatible with or detrimental to biodiversity. In both areas, we allow for the production of consumption goods that are traded on world markets, but obviously the production of goods in the protected area must be 'biodiversity-friendly'. To avoid clumsy wording, we denote as green goods and grey goods the goods produced on – and by means of – protected and non-protected land, respectively.

The notion that BC is a common concern of humankind translates into the assumption that the global community attaches a positive non-market value to global biodiversity. It is plausible that the willingness-to-pay for biodiversity is higher in the 'rich' North than in the 'poor' South, which appears to be the rationale of the Convention on Biological Diversity (1992) for calling on the North to compensate the South for extra conservation efforts. However, for reasons of complexity reduction we set the South countries' non-market value of biodiversity equal to zero. That simplification allows decomposing all biodiversity externalities into two types of externalities. The South's protected area generates positive external biodiversity benefits in all North countries (*South-North externalities*) and each North country's protected area generates positive external biodiversity benefits in all fellow North countries (*North-North externalities*). With the restriction of our analysis to these two types of externalities we have the following assignment of policies and externalities: the North-South compensation works towards internalizing the South-North externalities and the North-North coordination works towards internalizing the North-North externalities.

We will model the North-South compensation as an international competitive BC market.[5] The item traded on that market is land-use rights or land-use restrictions on

[3]In Ecology a large literature applies the "species area curve", which describes the relationship between the area of a habitat and the number of species found within that area. The reduction of the size of habitat reduces biodiversity by the species area relationship (e.g. Kinzig and Harte 2000, May et al. 1995) that is also used in economic papers on land use and biodiversity conservation (e.g. Barbier and Schulz 1997, Polasky et al. 2004).

[4]For a more realistic land-use approach based on the new economic geography with centrifugal-centripetal forces in economic and ecological systems, see Rauscher and Barbier (2010).

[5]Panayotou (1994) describes a similar market concept without providing a formal analysis. Since the North is willing to pay for biodiversity in the South, it is in the North's interest to compensate the South

specified areas of land that qualify as non-protected areas before and as protected areas after the transaction. The North-North coordination raises the North's conservation efforts because no North countries ignores anymore the BC benefits its own protected area generates in its fellow North countries. Technically, North-North coordination amounts to treating the North as a single agent whose objective function is the aggregate welfare of all North countries.[6]

The no-policy benchmark Regime 1 is defined as the market economy in the absence of North-North coordination and North-South compensation. Our focus is on the changes of allocations and welfares that occur when moving from Regime 1 to a scenario with North-South compensation, i.e. with a BC market. The BC market may be in operation either without or with North-North coordination, which leads to the distinction of the Regimes 2 and 3 in Table 1. This distinction is relevant, because the trade volume on the BC market will turn out to be much smaller in Regime 2 than in Regime 3 for the following reason. When North countries offer or demand land protection on the BC market in Regime 2, their willingness-to-pay for BC is inefficiently low because they ignore the BC benefits, they generate in their fellow North countries, by their own protected area and by their purchase of land protection in the South. This observation gives rise to the important question whether the real-world institutional arrangements for BC, in particular the Convention on Biological Diversity and the Global Environment Facility, are more closely related to Regime 2 or to Regime 3.[7]

North supports biodiversity conservation in South		
NO	YES, and North acts as a single agent	
	NO	YES
Regime 1	Regime 2	Regime 3

Table 1: Alternative biodiversity conservation regimes

Governments may act strategically or non-strategically in the sense that they may or may not take into consideration the impact of their policy parameter(s) on equilibrium market prices. If they act non-strategically, Regime 3 is efficient, but the Regimes 1 and 2 are inefficient. Regime 2 can be expected to be less inefficient than Regime 1 because in

for expanding its protected area ideally until the positive South-North externalities are internalized.

[6]It may be preferable to model North-North coordination differently, e.g. as a North-North BC market or a self-enforcing North-North agreement (e.g. Barrett 1994). The motivation for our simple modeling is to avoid distraction from and to sharpen the focus on the North-South issue.

[7]The prevailing institutional arrangements hardly fit Regime 2 or Regime 3 precisely. We will argue, however, that they may be closer to Regime 2 than to Regime 3.

Regime 1 all and in Regime 2 only some positive biodiversity externalities are uninternalized. Since it is unclear, which way of modeling is more realistic, we apply both hypotheses and discuss the differences in results.

Summing up, we take the no-policy Regime 1 as the point of departure and determine the impact of the world economy's move from Regime 1 to the Regimes 2 and 3. We proceed alternatively under the assumption of non-strategic and strategic government action and investigate in both cases how the shift from Regime 1 to the Regimes 2 and 3 changes BC efforts, aggregate welfare[8] and the welfare distribution between North and South.

Although our model is very simple, we need to replace the general functional forms we use in the first part of the paper for the discussion of allocation rules by simple parametric functions. In order to obtain informative results we then compute with three numerical examples assuming either strategic or non-strategic action. In our Example 1 all countries in North and South are alike except that North benefits from BC and South does not. If governments act non-strategically, Example 1 yields the results one expects – or hopes to get – when moving from Regime 1 to the social optimum. The protected area expands in all countries and both the North and the South are better off. However, quite unexpectedly, the move from Regime 1 to Regime 2 raises the countries' welfare and the aggregate protected area only slightly – a result that is confirmed in all of our numerical exercises. Other unexpected changes occur in examples we consider more realistic. If the North is either more productive than the South in the production of grey goods (Example 2) or sufficiently less productive in the production of green goods (Example 3), the move from Regime 1 to Regime 3 without strategic action may cause a welfare loss in the South due to the South's deteriorating terms of trade.[9] If governments act strategically, it is clear that the move from Regime 1 to 3 is not a move towards efficiency anymore. In fact, aggregate welfare may be lower in Regime 3 than in Regime 1. While terms-of-trade induced welfare effects with opposite signs in North and South are strong only when countries act non-strategically, strategic action seems to smooth such effects.

Our paper contributes to the literature on trade and biodiversity conservation and to the literature on biodiversity as an international public good.[10] Brander and Taylor (1997, 1998) analyze the welfare effects of trade liberalization in partial and general equilibrium with open access resources. Trade liberalization makes the resource-rich country worse off. Smulders et al. (2004) extend Brander and Taylor (1998) by a habitat-dependent natural

[8]We know that the aggregate welfare rises, if we move from Regime 1 to 3, because Regime 1 is inefficient and Regime 3 is socially optimal. This does not imply, however, that all countries' welfare increases.

[9]Although Bhagwati's (1958) seminal 'immiserizing growth' paradigm is unrelated to our immiserizing result, their common explanation is the South's deteriorating terms-of-trade.

[10]Perrings (2014) reviews recent pertaining literature.

resource. The traded good requires land and a renewable resource as inputs, and land is also needed as habitat for the renewable resource. Smulders et al. (2004) show that the effects of trade liberalization critically depend on the role of habitats. Polasky et al. (2004) investigate a two-country model where each type of land is an input in production and causes biodiversity loss measured by the species-area relationship. If countries are symmetric, trade reduces biodiversity. However, none of these papers considers compensation payments or a market for BC. As for the second strand of literature, Barrett (1994), Sandler (1993) and Montero and Perrings (2011) consider biodiversity without explicit modeling of land use and its opportunity cost.[11] Barrett (1994) analyzes coalition formation to conserve biodiversity and finds that the net benefits of a stable coalition are only slightly larger than in the absence of cooperation. In Sandler (1993), the countries' BC produce private goods, country-specific public goods and global public goods. Markets are inefficient due to the externalities associated with the public good BC. In simple matrix games Montero and Perrings (2011) study whether unilateral action of a small (given) coalition of countries make sufficiently large voluntary contributions to an environmental global public good.

The paper is organized as follows. Section 2 develops the model and derives the allocation rules for the Regimes 1 - 3. In Section 3, we describe and discuss the allocative effects of moving from Regime 1 to the Regimes 2 and 3 in the Examples 1, 2 and 3 assuming alternatively non-strategic and strategic action on the part of governments. Section 4 concludes.

2 The model

2.1 The analytical framework

Let Ω be the set of all countries in the world economy and divide Ω into the subsets $\mathcal{N}$ (for North) and $\mathcal{S}$ (for South). We denote the number of countries in the groups $\mathcal{N}$ and $\mathcal{S}$ by n and s, respectively. Each country $i \in \Omega$ has an endowment of land, ℓ_i, and its government divides ℓ_i into the areas b_i and e_i,

$$b_i + e_i = \ell_i \quad \text{all } i \in \Omega. \tag{1}$$

The area b_i is the *protected area* with effective land-use restrictions and the area e_i is the *non-protected area*, i.e. the land that is intensively used for commercial and industrial purposes without effective land-use restrictions. The non-protected area comprises towns with their

[11] In our setup, the opportunity costs of converting protected into non-protected land consist of the loss of green goods and biodiversity.

artificial surfaces, business districts, industrial zones, residential areas (urban sprawl), traffic infrastructure (e.g. sealed roads), ecologically detrimental agriculture or forestry etc. The protected area comprises nature reserves, national parks and, more generally, areas with stringent land-use restrictions banning all economic production and consumption activities that seriously deteriorate or destroy habitats and ecosystems in that area. We assume that the protected area is the predominant home of fauna and flora and that biodiversity increases with the size of the protected area.[12]

Each country produces and consumes two kinds of internationally tradable goods, called *grey goods* and *green goods*, by means of the increasing and concave production functions

$$x_i = X_i(e_i) \quad \text{and} \quad y_i = Y_i(b_i) \quad \text{all } i \in \Omega. \tag{2}$$

$x_i = X_i(e_i)$ is the quantity of grey goods produced with the input non-protected land, e_i.[13] $y_i = Y_i(b_i)$ is the quantity of green goods produced with the input protected land, b_i. The underlying assumptions are that biodiversity is positively correlated with the size of protected land and that some set of marketable (green) goods can be produced in protected areas without damaging habitats and ecosystems.[14]

The utility of the representative consumer in country i is

$$V_i(x_i^d) + U_i(y_i^d) + \delta(i)B\left(\sum_{\Omega} b_j\right) \quad \text{all } i \in \Omega,$$

$$\text{with} \quad U_i(y_i^d) = y_i^d \quad \text{and} \quad \delta(i) = \begin{cases} 1 & \text{if } i \in \mathcal{N}, \\ 0 & \text{if } i \in \mathcal{S}. \end{cases} \tag{3}$$

The functions V_i and B are increasing and concave and δ switches the term $B(\cdot) > 0$ on (for $i \in \mathcal{N}$) and off (for $i \in \mathcal{S}$). The basic hypothesis is that the global biodiversity is the greater, the larger the aggregate protected area $\sum_\Omega b_j$. Correspondingly, $\delta(i)B'\left(\sum_\Omega b_j\right)$ is country i's benefit from increasing the aggregate protected area by one unit. We refer to $\delta(i)B\left(\sum_\Omega b_j\right)$ as country i's benefit from BC. The dependence of the function B on $\sum_\Omega b_j$ characterizes BC

[12]It is obvious that the real world exhibits all kinds of intermediate forms of land use. Nonetheless, the partition of land in protected and non-protected areas captures the essence of the allocation problem for the purpose of our conceptual analysis and secures tractability at the same time.

[13]To simplify, inputs other than land are assumed sector specific and constant. While all economic activities have some spatial dimension, it is also true that their space requirements differ and in some cases are small.

[14]There exist other 'local' green goods, such as outdoor recreation, that are also positively valued but unpriced. To the extent that their provision increases with the protected area, the individual countries have an incentive to protect land. We disregard these non-market green goods in our formal analysis, because their consideration would complicate the analysis without changing the results qualitatively.

as a global public good to which all countries contribute through their domestic protected area. The term $\delta(i)$ marks an important difference between South and North countries. We interpret the former as developing countries with low per capita income, which (therefore) attach no value to the global good BC. The 'rich' North countries do value BC ($B' > 0$).

Green and grey goods are traded on perfectly competitive international markets at prices p_x and $p_y \equiv 1$, respectively. The income of the representative consumer of country i consists of the domestic producers' revenues $p_x x_i + p_y y_i$, as shown in Appendix A. The consumer takes the prevailing BC and the pertaining benefits as given and maximizes (3) with respect to x_i^d and y_i^d subject to her budget constraint[15] $p_x x_i^d + p_y y_i^d = p_x x_i + p_y y_i$. The straightforward implications are

$$V_i'(x_i^d) = p_x \quad \text{and} \quad p_y = U_i'(y_i^d) = 1 \quad \text{all } i \in \Omega. \tag{4}$$

Since the division of land fully determines the firms' inputs and outputs (in our parsimonious model), the firms' profit-maximizing plan is degenerate. The government of country i divides the land ℓ_i country i is endowed with into a protected area b_i and a non-protected area $e_i = \ell_i - b_i$.[16]

We begin the analysis with the benchmark Regime 1 (see Table 1) in which the North does not support the biodiversity in South. In Regime 1 the competitive equilibrium is characterized by the marginal conditions (4) and by the market clearing conditions

$$\sum_{\Omega} \left[X_j(\ell_j - b_j) - x_j^d\right] = 0 \quad \text{and} \quad \sum_{\Omega} \left[Y_j(b_j) - y_j^d\right] = 0. \tag{5}$$

Accounting for the consumers' demand for grey goods[17] $x_i^d = (V_i')^{-1}(p_x)$ from (4) the equilibrium condition of grey goods in (5) determines the price of grey goods for given b_i (for all $i \in \Omega$), formally

$$p_x = P^x\left(b_1, \ldots, b_{n+s}\right). \tag{6}$$

In Regime 1 we consider a Nash game at which country i determines its protected land b_i for given protected land of the other countries b_j all $j \in \Omega$, $j \neq i$. Country i's land-zoning decision is the solution of maximizing with respect to b_i the welfare

$$V_i(x_i^d) + P^x\left(b_1, \ldots, b_{n+s}\right)\left[X_i(\ell_i - b_i) - x_i^d\right] + p_y Y_i(b_i) + \delta(i) B\left(\sum_{\Omega} b_j\right). \tag{7}$$

[15]We denote by x_i and y_i the supply of grey and green goods and by x_i^d and y_i^d their demand.

[16]We let the governments determine b_i directly in a command-and-control way for analytical convenience. Alternatively, one could explicitly introduce national land markets with government i determining b_i indirectly by subsidizing the protected area or taxing the non-protected area or vice versa. For details see Appendix A.

[17]$(V_i')^{-1}$ is the inverse of the utility function V_i.

The first-order first-order condition yields

$$p_y Y_i' + \frac{\partial P^x}{\partial b_i} \cdot \left(X_i - x_i^d\right) + \delta(i) B' = p_x X_i' \quad \text{all } i \in \mathcal{N}. \tag{8}$$

It is clear from (8) that even if production technologies would be the same across countries, production would be distorted because of both the asymmetry $\delta(i)B'$ between North and South and the strategic effects $\partial P^x/\partial b_i \cdot \left(X_i - x_i^d\right)$.

Standard arguments suggest that in the absence of strategic effects each country's protected area, and hence the aggregate protected area, is sub-optimally small, because no country takes into account the external BC benefits generated by its own protected area.

2.2 North's support of South without and with North-North coordination

In the world economy of the preceding Section 2.1, referred to as Regime 1, all positive biodiversity externalities are uninternalized. The South countries ignore the 'South-North externalities', i.e. the benefits their protected areas generate in the North and the North countries ignore the 'North-North externalities', i.e. the benefits their protected areas generate in their fellow North countries. In addition, there are distortions from the countries' incentives to manipulate the terms of trade. In this section, we investigate two BC concepts, each of which addresses one kind of externalities.

We will consider the North countries' option to (fully) internalize the North-North externalities by merging – i.e. by coordinating their BC efforts such that each North country chooses that protected area which maximizes the aggregate welfare of the North. Technically speaking, North-North coordination means that North acts as a single agent whose objective function is the aggregate welfare of the North. To internalize the North-South externalities, North may offer South financial compensation for expanding its protected areas (North-South compensation) as recommended by the biodiversity convention. This internalization strategy follows the 'beneficiaries-pay principle' and will be introduced here in the form of an international market for biodiversity conservation, called BC market. Obviously, the amount of North-South compensation, i.e. the volume of trade on the BC market, depends on whether North acts as a single agent. As suggested in Table 1, we will therefore distinguish the Regimes 2 and 3 according to whether North-South compensation takes place without or with North-North coordination. In both cases, the benchmark Regime 1 serves the role of assessing the performance of the Regimes 2 and 3 with regard to the allocation rules that characterize their equilibrium.

Regime 2: North-South compensation without North-North coordination. Now we consider Regime 1 as the fallback regime that prevails in the absence of the BC market and we denote by[18] ${}_1b_i, i \in \Omega$, the protected land in Regime 1. The international market for BC implements the beneficiary-pays principle in the Coaseian spirit[19] as follows:

$$b_i = {}_1b_i + z_i \quad \text{and} \quad e_i = \ell_i - {}_1b_i - z_i \quad \text{all } i \in \Omega, \tag{9}$$

$$\sum_\Omega z_j = \sum_\Omega z_j^d. \tag{10}$$

(9) states that given the fallback land zones $({}_1b_i, \ell_i - {}_1b_i)$, $z_i > 0$ is the domestic area country i offers for protection in addition to the protected area it would choose in the absence of the BC market.[20] We will refer to z_i as country i's offer of BC. $z_i^d > 0$ is country i's demand for land to be protected in addition to the protected area country i or any other country would choose in the absence of the BC market. We will refer to z_i^d as i's demand for BC.[21] Equation (10) is the condition for clearing the BC market. The price per unit of BC offered or demanded is $p_z \geq 0$. With the introduction of the BC market, the governments' policy parameters change from protected area, $(b_i)_{i\in\Omega}$, to supplies and demands of BC, $(z_i, z_i^d)_{i\in\Omega}$.

The equilibrium of the economy in Regime 2 is characterized by the market clearing conditions (1), (10) and

$$\sum_\Omega \left[X_j(\ell_j - {}_1b_j - z_j) - x_j^d\right] = 0, \quad \sum_\Omega \left[Y_j({}_1b_j + z_j) - y_j^d\right] = 0. \tag{11}$$

The market clearing condition for good X in (11) determines the price function

$$p_x = P^x\left(z_1, \ldots, z_{n+s}\right) \tag{12}$$

In order to investigate how the BC market operates in the absence of North-North coordination, we assume, that all South and North countries again play Nash. In that case, country $i \in \Omega$ maximizes with respect to z_i and z_i^d its welfare

$$\begin{aligned} W_i &= V_i(x_i^d) + P^x\left(z_1, \ldots, z_{n+s}\right)\left[X_i(\ell_i - {}_1b_i - z_i) - x_i^d\right] + p_y Y_i({}_1b_i + z_i) \\ &\quad + \delta(i) B\left[\sum_\Omega ({}_1b_j + z_j^d)\right] + p_z(z_i - z_i^d) \end{aligned} \tag{13}$$

[18]The prescript k for $k = 1, 2, 3$ refers to Regime k.

[19]See Coase (1960) for the basic idea. Pearce (2004) discusses that concept and its potential for BC without formal modeling.

[20]The information in (9) about the size of protected area in the fallback Regime 1 is important to rule out the offer of protected areas in the BC market that would also be protected area in Regime 1.

[21]Note that z_i and z_i^d are sign-unconstrained and that negative equilibrium values will turn out to emerge under certain conditions.

taking the other countries' policies z_j and z_j^d, all $j \in \Omega$, $j \neq i$, as given. The first-order conditions yield

$$\frac{\partial W_i}{\partial z_i} = p_y Y_i' + \frac{\partial P^x}{\partial z_i} \cdot \left(X_i - x_i^d\right) - p_x X_i' + p_z = 0 \quad \text{all}\, i \in \Omega, \tag{14}$$

$$\frac{\partial W_i}{\partial z_i^d} = \delta(i)B' - p_z \begin{cases} < 0 & \text{if } i \in \mathcal{S}, \\ = 0 & \text{otherwise.} \end{cases} \tag{15}$$

We restrict our attention to economies in which the BC market is active, i.e. in which $p_z > 0$. Then (14) implies $z_i \neq 0$ for all $i \in \Omega$, in general. (15) yields $z_i^d = 0$ for all $i \in \mathcal{S}$ but $z_i^d > 0$ holds for $i \in \mathcal{N}$, in general, because $p_z = B'\left[\sum_{\mathcal{S}}{}_1b_j + \sum_{\mathcal{N}}({}_1b_j + z_j^d)\right]$ for all $i \in \mathcal{N}$.[22] Thus, we infer from (14) and (15) that the allocation rules of Regime 2 are

$$z_i^d = 0 \quad \text{all } i \in \mathcal{S} \quad \text{and} \quad p_y Y_i' + \frac{\partial P^x}{\partial z_i} \cdot \left(X_i - x_i^d\right) + B' = p_x X_i' \quad \text{all } i \in \Omega. \tag{16}$$

Regime 3: North-South compensation with North-North coordination The North countries' supply and demand of BC result from maximizing with respect to $(z_j, z_j^d)_{j\in\mathcal{N}}$ the aggregate welfare of the North,

$$\sum_{\mathcal{N}} \left\{V_j(x_j^d) + P^x\left(z_1, \ldots, z_{n+s}\right)\left[X_j(\ell_j - {}_1b_j - z_j) - x_j^d\right] + p_y Y_j({}_1b_j + z_j)\right.$$
$$\left. + B\left[\sum_{\mathcal{S}}{}_1b_k + \sum_{\mathcal{N}}({}_1b_k + z_k^d)\right] + p_z(z_j - z_j^d)\right\}. \tag{17}$$

The pertaining first-order conditions are $p_y Y_i' + \frac{\partial P^x}{\partial z_i} \cdot \left(X_j - x_j^d\right) + p_z = p_x X_i'$ for all $i \in \mathcal{N}$ and $p_z = nB'$ and hence

$$p_y Y_i' + \frac{\partial P^x}{\partial z_i} \cdot \sum_{\mathcal{N}}\left(X_j - x_j^d\right) + nB' = p_x X_i' \quad \text{all } i \in \mathcal{N}. \tag{18}$$

The South country i maximizes its welfare (13) with respect to[23] z_i. Combined with $p_z = nB'$, the first-order condition yields (18). Hence, the equilibrium of Regime 3 is characterized by the market clearing conditions (1), (10), (11) and the marginal condition (18) that holds for all $i \in \Omega$.

In the absence of strategic effects, the strong marginal benefit nB' in the allocation rule (18) suggests that the BC market is an effective instrument for the promotion of BC. In order to confirm that, we characterize the social optimum by solving the social planner's problem of maximizing the sum of the welfares of North and South subject to the resource

[22]This conclusion relies on our simplifying assumption that $B_i = B$ for all $i \in \mathcal{N}$.

[23]Recall that $z_i^d = 0$ for all $i \in \mathcal{S}$.

constraints (1), (10) and (11). The corresponding Lagrangean is

$$\mathcal{L} = \sum_{\Omega}\left[V_j(x_j^d)+U_j(y_j^d)\right]+nB\left[\sum_{\mathcal{S}}{}_1b_k+\sum_{\mathcal{N}}{}_1b_k+z_{\mathcal{N}}^d\right]+\lambda_z\sum_{\Omega}(z_j-z_{\mathcal{N}}^d)$$
$$+\lambda_x\sum_{\Omega}\left[X_j(\ell_j-{}_1b_j-z_j)-x_j^d\right]+\lambda_y\sum_{\Omega}\left[Y_j({}_1b_j+z_j)-y_j^d\right]. \quad (19)$$

We show in the Appendix B that solving (19) with respect to x_i^d, y_i^d, z_i^d and z_i yields the allocation rules (4) and (18) (if $\frac{\partial P^x}{\partial z_i}\equiv 0$, and after having decentralized the social planner's solution by prices) for all $i\in\Omega$. Hence in the absence of strategic effects the equilibrium allocation in Regime 3 is socially optimal.

	North	**South**
Regime 1	$p_yY_i'+\frac{\partial P^x}{\partial b_i}\cdot\left(X_i-x_i^d\right)+B'=p_xX_i'$	$p_yY_i'+\frac{\partial P^x}{\partial b_i}\cdot\left(X_i-x_i^d\right)=p_xX_i'$
Regime 2	$p_yY_i'+\frac{\partial P^x}{\partial z_i}\cdot\left(X_i-x_i^d\right)+B'=p_xX_i'$	$p_yY_i'+\frac{\partial P^x}{\partial z_i}\cdot\left(X_i-x_i^d\right)+B'=p_xX_i'$
Regime 3	$p_yY_i'+\frac{\partial P^x}{\partial z_i}\cdot\sum_{\mathcal{N}}\left(X_j-x_j^d\right)+nB'=p_xX_i'$	$p_yY_i'+\frac{\partial P^x}{\partial z_i}\cdot\left(X_i-x_i^d\right)+nB'=p_xX_i'$
Efficiency	$p_yY_i'+nB'=p_xX_i'$	$p_yY_i'+nB'=p_xX_i'$

Table 2: Supply-side allocation rules in the Regimes 1 - 3 and in the Social Optimum

Table 2 summarizes the supply-side allocation rules of the Regimes 1 - 3 and allows comparing the regimes in a straightforward way. All regimes share three features. First, all countries put aside some protected area for the production of green goods (term p_yY_i' in Table 2). Second, each country sets its policy to influence the terms of trade (term $\frac{\partial P^x}{\partial b_i}\cdot\left(X_i-x_i^d\right)$ in Regime 1, term $\frac{\partial P^x}{\partial z_i}\cdot\left(X_i-x_i^d\right)$ in Regime 2, and terms $\frac{\partial P^x}{\partial z_i}\cdot\sum_{\mathcal{N}}\left(X_j-x_j^d\right)$ $i\in\mathcal{N}$ and $\frac{\partial P^x}{\partial z_i}\cdot\left(X_i-x_i^d\right)$ $i\in S$ in Regime 3). In Regime 3 the North country has stronger strategic incentives due to merging. Third, each North country i accounts for the positive effect of its own protected area on BC (term $B', i\in\mathcal{N}$, in Table 2) with and without North-North coordination. In the North countries, the difference between merging and independent action is also clear. Without [with] merging, the North countries disregard [regard] the positive externality of their protected area on their fellow North countries. If the BC market is in operation in the Regimes 2 and 3, it induces the South countries to take into account, partially (Regime 2) of fully (Regime 3), the positive externalities of their own protected area on the North countries' welfare. If the North countries fail to coordinate their action, their allocation rule is as in Regime 1, but the South countries make some internalization effort, which they did not make in Regime 1. However, as Regime 3 demonstrates, full internalization of all externalities requires both North-North coordination and North-South compensation. We summarize our findings as follows:

In our model of the world economy, each North country's protected area generates a positive externality in all fellow North countries (North-North externalities) and each South country's protected area generates a positive externality in all North countries (South-North externalities). In addition, countries have strategic incentives to manipulate the terms of trade in their favor.

(i) Suppose all countries act non-strategically and consider the regimes listed in Table 1.

   (a) Regime 1 is inefficient, because neither the North-North externalities nor the South-North externalities are internalized.

   (b) Regime 2 is inefficient, because the North-North externalities are not internalized and the South-North externalities are only partly internalized.

   (c) Regime 3 is efficient (or socially optimal), because it fully internalizes all externalities.

(ii) Suppose all countries act strategically, then the Nash equilibria of Regimes 1-3 are distorted through the non-internalized externalities of (ia)-(ib) and through strategic effects.

Although the preceding analysis allowed for some important insights, it leaves many questions unanswered. Is the intuition correct that the transition from Regime 1 to the Regimes 2 and 3 increases the aggregate protected area as well as the protected areas in North *and* South countries? In the absence of strategic effects we know that the transition to Regime 3 increases aggregate welfare because Regime 1 is inefficient and Regime 3 is socially optimal. It is not clear, however, how the aggregate welfare changes when moving from Regime 1 to Regime 2 with and without strategic effects and how it changes the welfare of North and South when moving from Regime 1 to Regimes 2 and 3. Particularly important for the political acceptance of BC strategies is how the aggregate welfare gain, if any, is distributed between North and South. Are strategic effects small or do they change the allocative and welfare effects in a significant manner.

3 From laissez-faire towards internalization of BC benefits

In the preceding section, we have characterized the allocation rules that govern laissez-faire (Regime 1) and the regimes of North-South BC support without and with North-North coordination, when countries do or do not act strategically. Now we aim to investigate in more detail the impact of North's BC support of South on the allocation of the world economy. Although our model of Section 2 consists of few building blocks only, it is not possible to derive informative results on the move from Regime 1 to North's BC support of South with the general functional forms B, X_i, Y_i and V_i. To make progress, we introduce the following simplifications.

(i) Within their groups $\mathcal{N}$ and $\mathcal{S}$, all countries are alike so that we write $b_i = b_{\mathcal{N}}$ for all $i \in \mathcal{N}$, $b_i = b_{\mathcal{S}}$ for all $i \in \mathcal{S}$ etc.

(ii) We employ the parametric model[24]

$$\begin{array}{ll} n = s = 50, \quad \ell_i = \ell, \quad X_i(e_i) = 2\alpha_{xi}\sqrt{e_i}, \quad Y_i(b_i) = \alpha_{yi} b_i, & \\ B\left(\sum_\Omega b_j\right) = \gamma \sum_\Omega b_j, \quad V_i(x_i^d) = a x_i^d - \frac{\beta}{2}(x_i^d)^2, & \end{array} \quad i = \mathcal{N}, \mathcal{S}. \tag{20}$$

In (20), $a, \alpha_{xi}, \alpha_{yi}, \beta, \gamma$ and ℓ are positive parameters. North and South are identical with respect to the parameters a, β and ℓ, but we allow for asymmetry with respect to the parameters α_{xi}, α_{yi} and γ. Despite the model's simplicity, we are not able to derive closed form solutions of the parametric model (20) for strategic action.[25] Therefore, we resort to numerical analysis, which we organize as follows.

We will analyze three different numerical specifications of the model (20) in the subsequent Sections 3.1 - 3.3. In Example 1, North and South countries differ only with respect to the utility they derive from BC. Example 2 differs from Example 1 only in that grey goods are more productive in North ($\alpha_{x\mathcal{N}} > \alpha_{x\mathcal{S}}$), and in Example 3 North's productivity of green goods is lower than in Example 1 ($\alpha_{y\mathcal{N}} < \alpha_{y\mathcal{S}}$). The investigation of the asymmetry $\alpha_{x\mathcal{N}} > \alpha_{x\mathcal{S}}$ in Example 2 is motivated by interpreting North as being more industrialized and 'developed' than South, and Example 3 is to capture the observation that 'nature' is more productive in South than in North. In each of the Sections 3.1 - 3.3 our focus will be on the allocative changes that occur when moving from Regime 1 to the Regimes 2 and 3. In addition, we will investigate how the impact of these moves differs when the countries do or do not act strategically. To avoid clumsy wording, we will use the term Regime $k = 1, 2, 3$ in cases of strategic *and* non-strategic action, and we explicitly refer to 'Regime k without strategic action' or 'Regime k with strategic action' if that is necessary to avoid confusion. To keep focused, we will restrict our attention to the variables

$$\sum {}_k b := n\, {}_k b_{\mathcal{N}} + s\, {}_k b_{\mathcal{S}}, \quad {}_k b_i, \quad \sum {}_k w := n\, {}_k w_{\mathcal{N}} + s\, {}_k w_{\mathcal{S}}, \quad {}_k w_i \tag{21}$$

[24] U_i is already defined as a parametric function in (3).

[25] The first-order conditions of the Regimes 1-3 for the parametric model are given in Appendix C. Moreover, closed-form solutions for non-strategic action are presented in Appendix D.

with $k = 1, 2, 3, 4$ and $i = \mathcal{N}, \mathcal{S}$. w_i is the welfare of a country in group $i = \mathcal{N}, \mathcal{S}$ and the prescript k refers to Regime k. Specifically, we focus on the changes

$$\begin{aligned} \Delta \sum {}_k b &:= n\Delta {}_k b_{\mathcal{N}} + s\Delta {}_k b_{\mathcal{S}}, \qquad & \Delta {}_k b_i &:= {}_k b_i - {}_1 b_i, \\ \Delta \sum {}_k w &:= n\Delta {}_k w_{\mathcal{N}} + s\Delta {}_k w_{\mathcal{S}}, \qquad & \Delta {}_k w_i &:= {}_k w_i - {}_1 w_i \end{aligned} \tag{22}$$

with $k = 2, 3, 4$ and $i = \mathcal{N}, \mathcal{S}$.

3.1 Internalization of BC benefits in Example 1

We denote as Example 1 the numerical specification

$$a = 100, \quad \alpha_{x\mathcal{N}} = \alpha_{x\mathcal{S}} = 10, \quad \alpha_{y\mathcal{N}} = \alpha_{y\mathcal{S}} = 10, \quad \beta = 0.5, \quad \ell = 100, \quad \text{and} \quad \gamma = 0.1, \tag{23}$$

of the parametric model (20). For each regime, we have computed - and listed in Table 6 of the Appendix C - the equilibrium values (21) needed to determine the allocative displacement effects (22) of moving from Regime 1 to the Regimes 2 and 3. These effects are presented in Table 3. We begin explaining and interpreting them for the case that the countries refrain from acting strategically.

Move from Regime 1 to ↓	Strategic action	$\Delta_k(\sum_j b_j)$	$\Delta_k b_N$	$\Delta_k b_S$	$\Delta_k(\sum_j w_j)$	$\Delta_k w_N$	$\Delta_k w_S$
Regime 2	NO	9	-0.8	1.1	40	1	0
Regime 3		697	6.1	7.6	$1,770$	14	22
Regime 2	YES	8	-0.1	0.3	30	1	0
Regime 3		696	6.8	7.2	$1,760$	17	18

Table 3: Moving from Regime 1 to Regimes 2 and 3 in Example 1

Suppose first all countries act non-strategically and consider the move from the inefficient Regime 1 to Regime 3 in the second row of Table 3. Since we know that Regime 3 is efficient, it is clear that the aggregate welfare increases ($\Delta_3(\sum w_j) = 1,770$). Overall, the changes reported in the second row of Table 3 conform to our expectation of a desirable outcome: All countries in North and South step up their land protection and share the total welfare gain; South receives a larger share of the gain than North but the distributional inequality is modest. The impact of the move from Regime 1 to Regime 2 (first row of Table 3) is significantly different. In Regime 2, the BC market is in operation but not all positive biodiversity externalities are internalized. North countries still ignore the external biodiversity benefits they generate in their fellow North countries and do not coordinate their support of BC in South. Consequently, the volume of trade on the BC market is much lower than in Regime 3 implying that Regime 2 improves upon Regime 1 only slightly. The small aggregate welfare gain is entirely absorbed by North, which is somewhat unexpected, because it is North which pays for additional protected land in South ($\Delta\, {}_2b_{\mathcal{S}} = 1.1$).

We have not expected either that North almost offsets its 'purchase' of protected land in South by reducing its own protected land ($\Delta\, {}_2b_{\mathcal{N}} = -0.8$),[26] which will turn out to be characteristic of Regime 2 in all examples. To explain that puzzle, observe that in Regime 1 the South countries' choice of ${}_1b_{\mathcal{S}}$ balances at the margin the benefits from producing grey and green goods, whereas the North countries balance at the margin the benefits from grey goods on the one hand and from green goods and BC on the other hand. If a North country wishes to boost its BC benefits, it has to increase the production of green goods uno actu. So it needs to compromise by choosing more green-goods production and less BC benefits than it would do if green goods and BC benefits were no complements via protected land. When moving from Regime 1 to Regime 2, North countries take advantage of the BC market to decouple the production of green goods from their BC benefits. They purchase BC in South but simultaneously reduce their domestic protected area and thus achieve both reducing the domestic production of green goods and expanding the aggregate protected area. In sum, when moving from Regime 1 to Regime 2 North's financial support of BC in South has only a very small positive net effect on total protected area and welfare. The aggregate welfare rises slightly because BC increases slightly and the production inefficiency of Regime 1 is eliminated.

From Regime 1 to the Regimes 2 and 3 with strategic action.[27] The third and fourth row of Table 3 show the changes in protected areas and welfares following the move from Regime 1 to Regime 2 and 3, respectively, when countries act strategically. The overall message for Example 1 is that strategic action does not significantly change the results we have obtained in the case of price-taking governments. As above, the improvement of Regime 2 over Regime 1 is very small, while the move from Regime 1 to Regime 3 boosts welfares and BC more pronouncedly. It is worth pointing out, however, that the distribution of the total welfare gain between North and South is less unequal with than without strategic action.

The great similarity of results we derived for shifting regimes without and with strategic action is due to the special feature of Example 1 that all countries are alike except that North does but South does not derive utility from BC. To see that suppose all countries refrain from strategic action. Then the North countries import grey goods in Regime 1 although

[26] Recall that we have rounded off the numbers in Table 3.

[27] In this subsection, Regime k always means Regime k *with* strategic action.

production technologies are identical across countries. In the efficient Regime 3, production must not differ across countries, and since demand for grey goods is the same in all countries, there is no international trade in grey goods. It follows immediately that no country can gain by manipulating the price of grey goods when moving from Regime 1 to the Regimes 2 or 3. This is why Regime 3 happens to be socially optimal in Example 1 even if countries act strategically.[28]

3.2 Internalization of BC benefits in Example 2

In Example 1 all countries use the same production technology. In order to characterize in a stylized way the North countries as being rich and industrialized and the South countries as being poor and developing, we now assume that North has a productivity advantage over South with respect to industrial (here: grey) goods. In the subsequent Example 2 all parameter values (23) of Example 1 remain unchanged except that we replace $\alpha_{x\mathcal{N}} = 10$ by $\alpha_{x\mathcal{N}} = 12.25$. Following the procedure of the last subsection, we have computed for each regime - and listed in Table 7 of the Appendix C - the equilibrium values (21) needed to determine the allocative displacement effects (22) of moving from Regime 1 to the Regimes 2 and 3. The impact of these moves are listed in Table 4, and we begin explaining and interpreting them for the case that the countries refrain from acting strategically.

Move from Regime 1 to ↓	Strategic action	$\Delta_k(\sum_j b_j)$	$\Delta_k b_N$	$\Delta_k b_S$	$\Delta_k(\sum_j w_j)$	$\Delta_k w_N$	$\Delta_k w_S$
Regime 2	NO	4	-0.6	0.7	30	2	-1
Regime 3		475	5.1	4.5	1,200	130	-106
Regime 2	YES	9	0	0.2	60	1	0
Regime 3		719	9.3	5.0	-90	-4	2

Table 4: Moving from Regime 1 to Regimes 2 and 3 in Example 2

As in Section 3.1, we first comment on the move from the inefficient Regime 1 to the Regime 3 in the absence of strategic action (second row of Table 4). Since Regime 3 is efficient, aggregate welfare increases ($\Delta_3(\sum w_j) = 1,200$). However, the distributional effects are stunning. The North countries experience a substantial welfare gain ($\Delta_3 w_{\mathcal{N}} =$

[28]The numbers in the second and fourth row of Table 3 are different, because the baseline allocations in Regime 1 depend on whether countries act or do not act strategically.

130) while the South countries suffer a welfare loss of almost the same order of magnitude ($\Delta\, {}_3w_{\mathcal{S}} = -106$). The gain of all North countries exceeds by far the net welfare gain of the move from Regime 1 to Regime 3 and thus makes South severely worse off than in Regime 1. At first glance, one may consider that result counterintuitive because South receives a compensation via the BC market for the expansion of its protected land that is high enough to make the BC market transaction a voluntary exchange.

The key for understanding this strong distributional effect is the change in the terms of trade. When moving to Regime 3, the internalization of the South-North externalities expands $b_{\mathcal{S}}$ from ${}_1b_{\mathcal{S}} = 44.5$ to ${}_3b_{\mathcal{S}} = 49.0$, via North's purchases on the BC market, and the internalization of the North-North externalities increases from ${}_1b_{\mathcal{N}} = 18.4$ to ${}_3b_{\mathcal{N}} = 23.5$. Hence, the aggregate protected area becomes larger, the total production of grey goods declines and the price of grey goods rises by about 45 % (from $p_x = 7.4$ to 10.7). Since North is more productive in grey goods, it exports grey goods in Regime 1. When moving to Regime 3 it experiences a massive improvement of its terms of trade that translates into a welfare gain, and that gain is particularly large because the export quantity is not much smaller in Regime 3 than in Regime 1 (${}_1x_{\mathcal{N}}{}^s - {}_1x_{\mathcal{N}}{}^d = 36.2$ versus ${}_3x_{\mathcal{N}} - {}_3x_{\mathcal{N}}{}^d = 35.8$). In sum, the pronounced terms-of-trade effect that is favorable for North and adverse for South explains the strong opposite welfare changes in North and South.

The impact of the move from Regime 1 to Regime 2 (first row of Table 4) is similar as in Example 1. Regime 2 hardly improves upon Regime 1 with respect to protected areas and welfares. The allocation of land is almost the same as in Regime 1 so that production, exports and the terms-of-trade remain almost unchanged as well. Hence, North does not benefit from improved terms of trade as in the move from Regime 1 to Regime 3, which saves South, in turn, from suffering a severe welfare loss due to deteriorated terms of trade.

The move from Regime 1 to Regime 3 with strategic action (fourth row in Table 4) yields some unexpected results. The economy is slightly worse off than in Regime 1 ($\Delta_3(\sum w_j) = -90$) which is strange because one would think that the awareness in Regime 3 of all external biodiversity benefits would raise the aggregate welfare - as it does in the absence of strategic action. The reason for that overall loss is a severe distortion of production. The protected area - and input for producing green goods - is excessive in North by $49.3 - 23.5 = 25.8$ units and falls short of its efficient level in South by $49.0 - 24.5 = 24.5$ units. When moving from Regime 1 to 3 North and South step up their protected area such that the total protected land increases and even (slightly) exceeds its socially optimal level. The price of grey goods rises strongly along with the aggregate protected land. However, due to the reshuffling of production North's export of grey goods almost ceases in Regime 3 such that North cannot benefit from the favorable terms-of-trade effect. Combined with the distortion of production this observation explains the marked difference in outcome of the move from Regime 1 to Regime 3 without and with strategic action. The price of grey goods rises significantly in both cases, but while the opposite welfare changes it triggers in North and South are strong in case of non-strategic action, they are very small in case of strategic action with winners and losers being reversed. Although that move from Regime 1 to 3 is a move to the social optimum in the absence of strategic action, it implies heavy gains for North and heavy losses for South and hence is not Pareto improving. Conversely, that move (slightly) increases the inefficiency of Regime 1 in case of strategic action, but induces only rather small welfare changes in North and South.

Consider finally the impact of the move from Regime 1 to Regime 2 with strategic action (third row of Table 4). We observe a very small increase of the aggregate welfare but the general message is - as before - that Regime 2 hardly improves upon Regime 1 with respect to protected areas and welfares. The allocation of land is almost the same as in Regime 1 so that production, exports and the terms-of-trade also remain almost unchanged. North does not benefit from improved terms of trade as in the move from Regime 1 to Regime 3, which saves South, in turn, from suffering a severe welfare loss due to deteriorated terms of trade.

3.3 Internalization of BC benefits in Example 3

Move from Regime 1 to ↓	Strategic action	$\Delta_k(\sum_j b_j)$	$\Delta_k b_N$	$\Delta_k b_S$	$\Delta_k(\sum_j w_j)$	$\Delta_k w_N$	$\Delta_k w_S$
Regime 2	NO	3	-0.8	0.9	10	1	-1
Regime 3		715	9.7	4.6	$1,800$	54	-18
Regime 2	YES	7	-0.1	0.2	40	1	0
Regime 3		798	8.9	6.5	1,720	20	15

Table 5: Moving from Regime 1 to Regimes 2 and 3 in Example 3

Example 3 departs from Example 1 (only) by assuming the North has a productivity disadvantage over South with respect to green goods. All parameter values (23) of Example 1 remain unchanged except that we replace $\alpha_{y\mathcal{N}} = 10$ by $\alpha_{y\mathcal{N}} = 9$. Consider first the move from Regime 1 to Regime 3 without strategic action (second row of Table 5). Qualitatively, that move is similar to the same move in Example 2 except that North's gain and South's loss are much less pronounced in Example 3. That similarity is unexpected, because in Example 2 North has a productivity advantage (in grey goods) over South whereas in Example 3 South has a productivity advantage (in green goods) over North. The common feature that South loses is disturbing because the assumptions of asymmetric productivities in the Examples 2 and 3 have greater 'empirical appeal' than the symmetry assumption in Example 1 (in which South gains when moving from Regime 1 to 3 without strategic action). The move from Regime 1 to 2 (first row of Table 5) exhibits the same patterns than in the Examples 1 and 2, in particular a negligibly small improvement upon Regime 1.

Turning to the case of strategic action, we also find similar patterns as in the other examples. The improvement of Regime 2 upon Regime 1 is insignificant again, while the move from Regime 1 to 3 exhibits larger increases in total protected area and aggregate welfare, and North and South obtain an almost equal share of the welfare gain. As in Example 2, the difference in the distribution of welfare between North and South is particularly interesting when we compare the move from Regime 1 to 3 without and with strategic action. The driving force is the same in the Examples 2 and 3. If the countries act non-strategically, North benefits and South loses because to term-of-trade effect is favorable for North and adverse for South. With strategic action, the pertaining welfare effects are small because the increase in either the price of grey goods or the volume of North's exports of grey goods is very small.

3.4 Some tentative conclusions

We have to emphasize from the outset that intractability has prevented us from fully characterizing the moves from Regime 1 to Regime 2 and 3 in our parametric model. Therefore, the robustness of our numerical results is difficult to assess. Nevertheless, the examples we have computed for the cases of strategic and non-strategic action exhibit some features that may be relevant beyond the examples we have chosen.[29]

(i) When moving from Regime 1 to Regime 3, we found cases where North gains and South loses. The reason for such opposite welfare effects are changes in the terms of trade that are favorable for North and adverse for South. However, we also found that North could not benefit from improving terms of trade because its export quantity became very small. In our examples, terms-of-trade induced welfare effects have been strong only when countries act non-strategically. Strategic action seems to smooth the differential welfare effects, but it is unclear whether that feature holds beyond our

[29] We have conducted many more examples all of which displayed the same features. The Figures 1-6 of the Appendix E show continuous variations of $\alpha_{x\mathcal{N}}$ and $\alpha_{y\mathcal{N}}$ in Example 1 for non-strategic action.

examples.

(ii) In all of our examples without and with strategic action, the volume of trade on the BC market is very low in Regime 2. North pays for some expansion of protected area in South, but reduces, at the same time, its own protected area, which means in technical terms that North's supply of additional protected land is negative. The net effect of substituting own protected land with new protected land in South is an very small net increase in total protected area. Thus, apparently, North countries are not only reluctant in Regime 2 to support BC in South substantially, but they also take advantage of the BC market to decouple their production of green goods from their BC benefits.

(iii) Another important feature of the move from Regime 1 to Regime 2 we found in all examples is the ineffectiveness of the BC market without North-North coordination. Recall from the introduction that in the real world North does provide some resources for BC in South through various channels and that the overall volume of that support is too small to halt the biodiversity loss. In the light of our theoretical approach, we interpret North's observable financial support of BC in South as trade on the BC market. That gives rise to the interesting question whether the real-world international institutional arrangements for BC, encompassing in particular the Convention on Biological Diversity and the Global Environmental Facility, are more closely related to Regime 2 or to Regime 3. Suppose the empirical institutional setting resembles Regime 2 more than Regime 3. It would then be incorrect to argue that there is no inefficiency involved in the ongoing decline of biodiversity. Our analysis showed that in Regime 2 the volume of trade on the BC market is very low whether or not action is strategic. That is, in Regime 2 North's *revealed* willingness-to-pay for BC is very low because the external biodiversity benefits are incompletely internalized in Regime 2. In fact, the revealed net willingness-to-pay is even lower due to the observation made in the preceding point (ii) that North reduces its own protected land when moving from Regime 1 to 2. In the absence of strategic action, North reveals its *true* willingness-to-pay in Regime 3, which manifests itself in a much larger trade volume on the BC market.[30]

Whether the prevailing institutional arrangements are more closely related to Regime 2 or to Regime 3 is an important empirical issue, the thorough investigation of which is beyond the scope of the present paper, however. Here we content ourselves with pointing to the relevance of the distinction between the Regimes 2 and 3 for assessing the adequateness of the existing institutions to cope with biodiversity loss effectively.

[30] In case of strategic action, the trade volume on the BC market is also larger in Regime 3 than in Regime 2 although the willingness-to-pay in both regimes is 'strategically distorted'.

4 Concluding remarks

The paper analyzes concepts to conserve the global public good 'biodiversity' based on the assumption that biodiversity is positively correlated with that share of land which is effectively protected by land-use restrictions against the deterioration of habitats and ecosystems (land-use approach). The size of the aggregate protected land is taken as an indicator of biodiversity conservation (BC). The willingness-to-pay for BC is assumed to be positive in developed North, but much lower (here: zero) in developing South. We denote as Regime 1 the world economy in which no external biodiversity benefits are internalized and focus on North's compensation for BC in South modeled as a BC market, which may operate either without North-North coordination (Regime 2) or with North-North coordination (Regime 3). We investigate the impact on BC and welfare of the move from Regime 1 to the Regimes 2 and 3 assuming alternatively that the governments act or do not act strategically. We derive a number of unexpected and some disturbing results. For example, the move from Regime 1 to Regime 2 hardly improves BC and welfare in our numerical exercises. The distributional effects of the move from Regime 1 to Regime 3 may be undesirable, because it can make South severely worse off in the absence of strategic action or because the aggregate welfare declines in case of strategic action. The welfare effect with opposite signs in North and South appear to be stronger without than with strategic action.

The paper's message is that unexpected and undesirable results are possible. It is true that the robustness and empirical relevance of the results are not clear due to the simplicity of the model and the small number of examples. However, our model does point to important channels of market and non-market interdependencies between all countries not yet explored to the best of our knowledge, that improve our understanding of the economic drivers of BC. Regime changes affect the aggregate welfare and the welfares of North and South directly via BC benefits or losses and indirectly via markets, via opportunity costs of land-use changes and most importantly via changing terms of trade.

Promoting BC via a market for BC in the Regimes 2 and 3 is appealing, in our view, but it is difficult to determine empirically to what extent North-North coordination is taking place in reality. In our formal model, North-North coordination is a strong ad hoc concept of internalizing, by presupposition, all external biodiversity benefits the North countries generate in their fellow North countries. In the absence of that kind of coordination, the North countries have free-rider incentives since they benefit from the protected area a fellow North country provides either via its domestic protected area or via its 'purchase' of additional protected land in the South. Replacing North-North coordination by a BC market for North countries is subject to similar limitations as the BC market in our analytical framework. Replacing it by an agreement among all North countries would raise intricate issues of free-riding and self-enforcement well-known from the literature on international environmental agreements.

It is necessary and desirable to deepen and extend our analysis in various directions. We need to know how robust the results are when countries are less alike and when functional forms are less restrictive. The premise that the non-market benefits from BC are linear in aggregate protected area and the same for all North countries provides analytical relief, but prevents generality. To study these desiderata adequately, large-scale CGE models are indispensable with realistic calibration to identify empirically relevant results in the set of possible outcomes. Not least, our static model cannot offer insights in the dynamics of irreversible biodiversity loss that is currently occurring or pending in the real world. There is some literature on the dynamics of biodiversity conservation, e.g. on landscape heterogeneity that affects species' growth and biodiversity (Brock et al. 2010) or on biodiversity conservation in a Hotelling model with a non-renewable resource (Perrings and Halkos 2012). However, tractability usually requires a difficult choice between dynamics with strong reductions of complexity on the one hand and statics with more complexity and sharp results on the other hand.

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Appendix

Appendix A: Subsidizing protected area

In the main text of the paper, we treat the protected area b_i as the governments' policy parameter implicitly assuming that the land zones are imposed in a command and control fashion. An alternative and equivalent way to implement land zones is to subsidize the input of protected areas in the firms producing green goods. To model that kind of price regulation, we need to consider country i's (domestic) land market in the formal model. Denote by p_i the land price in country i and by σ_i the subsidy per unit of protected area used as input in the production of green goods. Maximization of profits $p_x X_i(e_i) - p_i e_i$ and $Y_i(b_i) - (p_i - \sigma_i)b_i$ of the price-taking firms yields

$$p_x X_i'(e_i) - p_i = 0 \quad \text{with} \quad X_i' \mathrm{d}p_x + p_x X_i'' \mathrm{d}e_i - \mathrm{d}p_i = 0, \tag{A1}$$

$$Y_i'(b_i) - p_i + \sigma_i = 0 \quad \text{with} \quad Y_i'' \mathrm{d}b_i - \mathrm{d}p_i + \mathrm{d}\sigma_i = 0. \tag{A2}$$

Combining (A1) and (A2) with the land market equilibrium condition

$$b_i + e_i = \ell_i \quad \text{with} \quad \mathrm{d}b_i + \mathrm{d}e_i = \mathrm{d}\ell_i = 0 \tag{A3}$$

leads to $\mathrm{d}\sigma_i = X_i' \mathrm{d}p_x - (p_x X_i'' + Y_i'') \mathrm{d}b_i$ and $\mathrm{d}p_i = X_i' \mathrm{d}p_x - p_x X_i'' \mathrm{d}b_i$ after some rearrangement of terms. These equations give us the functional relationships

$$\sigma_i = \sigma_i(\underset{(+)}{b_i}, \underset{(+)}{p_x}) \quad \text{and} \quad p_i = p_i(\underset{(+)}{b_i}, \underset{(+)}{p_x}). \tag{A4}$$

(A4) shows that the government's increase of protected area triggers an increase of both the subsidy on the protected area and the price of land, ceteris paribus. The subsidy on the protected area increases the firms' profits that are transferred to the representative consumer. However, the government imposes a (lump-sum) tax, say $\pi_i = \sigma_i b_i$, on the consumer to finance the subsidy such that the consumer's income is $p_x X_i(e_i) - p_i e_i + Y_i(b_i) - (p_i - \sigma_i) b_i + p_i \ell_i - \pi_i = p_x X_i(e_i) + Y_i(b_i)$. In other words, the land market and the subsidy on the protected area do not play a role in the formal model so long as we take the land-zoning decisions $(b_i, e_i = \ell_i - b_i)$ to be the governments' policy parameters.

Appendix B: Social Optimum

Maximizing the Lagrangean (19) yields the first-order conditions

$$\frac{\partial \mathcal{L}}{\partial x_i^d} = V_i' - \lambda_x = 0 \quad i \in \Omega, \tag{B1}$$

$$\frac{\partial \mathcal{L}}{\partial y_i^d} = U_i' - \lambda_y = 0 \quad i \in \Omega, \tag{B2}$$

$$\frac{\partial \mathcal{L}}{\partial z_i} = \lambda_x X_i' + \lambda_y Y_i' + \lambda_z = 0 \quad i \in \Omega, \tag{B3}$$

$$\frac{\partial \mathcal{L}}{\partial z_{\mathcal{N}}^d} = nB' - \lambda_z = 0. \tag{B4}$$

The standard procedure of equating shadow prices with prices on perfectly competitive markets yields $\lambda_y = p_x$, $\lambda_y = p_y$ and $\lambda_z = p_z$ and proves that the allocation in Regime 3 without strategic action is efficient.

Appendix C: Parametric functions and numerical examples

Regime 1. The consumer's demand for grey goods is given by

$$V'(x_i^d) = p_x \quad \Longleftrightarrow \quad x_i^d = \frac{a - p_x}{\beta} \equiv x^d \quad \text{for } i = \mathcal{N}, \mathcal{S}. \tag{C1}$$

Inserting the demand (C1) and the supply $x_i = 2\alpha_{xi}\sqrt{\ell - b_i}$ into the equilibrium condition $(n+s)x^d = n x_{\mathcal{N}} + s x_{\mathcal{S}}$ we obtain

$$p_x = P^x(b_{\mathcal{S}}, b_{\mathcal{N}}) = a - \frac{2\beta}{n+s}\left[s\alpha_{x\mathcal{S}}\sqrt{\ell - b_{\mathcal{S}}} + n\alpha_{x\mathcal{N}}\sqrt{\ell - b_{\mathcal{N}}}\right]. \tag{C2}$$

Inserting the parametric functions into (8) we get

$$\alpha_{yi} - \frac{p_x \alpha_{xi}}{\sqrt{\ell - b_i}} + \delta(i)\gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C3}$$

for non-strategic action and

$$\alpha_{yi} - \frac{p_x \alpha_{xi}}{\sqrt{\ell - b_i}} + \frac{\partial P^x}{\partial b_i} \cdot \left(2\alpha_{xi}\sqrt{\ell - b_i} - \frac{a - p_x}{\beta}\right) + \delta(i)\gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C4}$$

for strategic action.

Regime 2. In the Regime 2 the consumer's demand is given by $x^d = \frac{a-p_x}{\beta}$ and the price function by

$$p_x = P^x(z_{\mathcal{S}}, z_{\mathcal{N}}) = a - \frac{2\beta}{n+s}\left(s\alpha_{x\mathcal{S}}\sqrt{\ell - {}_1b_{\mathcal{S}} - z_{\mathcal{S}}} + n\alpha_{x\mathcal{N}}\sqrt{\ell - {}_1b_{\mathcal{N}} - z_{\mathcal{N}}}\right). \tag{C5}$$

For the parametric functions the first-order conditions (16) turn into

$$\alpha_{yi} - \frac{p_x\alpha_{xi}}{\sqrt{\ell - {}_1b_i - z_s}} + \gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C6}$$

for non-strategic action and

$$\alpha_{yi} - \frac{p_x\alpha_{xi}}{\sqrt{\ell - {}_1b_i - z_s}} + \frac{\partial P^x}{\partial z_i}\cdot\left(2\alpha_{xi}\sqrt{\ell - {}_1b_i - z_s} - \frac{a-p_x}{\beta}\right) + \gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C7}$$

for strategic action.

Regime 3. For Regime 3 the first-order conditions (18) turn into

$$\alpha_{yi} - \frac{p_x\alpha_{xi}}{\sqrt{\ell - {}_1b_i - z_s}} + n\gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C8}$$

for non-strategic action and

$$\alpha_{yi} - \frac{p_x\alpha_{xi}}{\sqrt{\ell - {}_1b_i - z_s}} + \frac{\partial P^x}{\partial z_i}\cdot\left(2\alpha_{xi}\sqrt{\ell - {}_1b_i - z_s} - \frac{a-p_x}{\beta}\right) + n\gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C9}$$

for strategic action.

	$\sum_j {}_kb_j$	${}_kb_{\mathcal{N}}$	${}_kb_{\mathcal{S}}$	$\sum_j {}_kw_j$	${}_kw_{\mathcal{N}}$	${}_kw_{\mathcal{S}}$	${}_kp_x$	${}_kX_{\mathcal{N}} - {}_kx^d$
	non-strategic action							
Regime 1	1742	18.3	16.6	1017800	10265	10091	9.1	-0.9
Regime 2	1751	17.5	17.5	1017840	10266	10091	9.2	0
Regime 3	2439	24.4	24.4	1019570	10279	10113	13.0	0
	strategic action							
Regime 1	1743	17.6	17.2	1017810	10265	10091	9.1	-0.2
Regime 2	1751	17.5	17.5	1017840	10266	10091	9.2	0
Regime 3	2439	24.4	24.4	1019570	10282	10109	13.0	0

Table 6: Equilibrium values in Example 1

	non-strategic action							
	$\sum_j {}_kb_j$	${}_kb_{\mathcal{N}}$	${}_kb_{\mathcal{S}}$	$\sum_j {}_kw_j$	${}_kw_{\mathcal{N}}$	${}_kw_{\mathcal{S}}$	${}_kp_x$	${}_kX_{\mathcal{N}} - {}_kx^d$
Regime 1	3149	18.4	44.5	1041680	10713	10121	7.4	36.2
Regime 2	3153	17.8	45.2	1041710	10715	10120	7.5	37.0
Regime 3	3624	23.5	49.0	1042880	10843	10015	10.7	35.8
	strategic action							
Regime 1	2972	40.0	19.5	1038690	10678	10096	7.7	5.2
Regime 2	2981	40.0	19.7	1038750	10679	10096	7.7	5.3
Regime 3	3691	49.3	24.5	1038600	10674	10098	12.9	0.3

Table 7: Equilibrium values in Example 2 ($\alpha_{x\mathcal{S}} = 12.25$)

	$\sum_j {}_kb_j$	${}_kb_{\mathcal{N}}$	${}_kb_{\mathcal{S}}$	$\sum_j {}_kw_j$	${}_kw_{\mathcal{N}}$	${}_kw_{\mathcal{S}}$	${}_kp_x$	${}_kX_{\mathcal{N}} - {}_kx^d$
	non-strategic action							
Regime 1	1646	8.6	24.3	1016690	10241	10093	8.7	8.6
Regime 2	1649	7.8	25.2	1016700	10242	10092	8.7	9.5
Regime 3	2361	18.3	28.9	1018490	10295	10075	12.7	6.0
	strategic action							
Regime 1a	1667	15.4	17.9	1016630	10241	10091	8.7	1.4
Regime 2a	1674	15.3	18.1	1016670	10242	10091	8.8	1.5
Regime 3a	2435	24.3	24.4	1018350	10261	10106	13.0	0.1

Table 8: Equilibrium values in Example 3 ($\alpha_{yN} = 9$)

Appendix D: Closed-form solution for non-strategic action (only for the referees)

For non-strategic action we get the following closed-form solutions.

Regime 1. Solving (C3) we get

$$\ell - {}_1b_{\mathcal{N}} = {}_1e_{\mathcal{N}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}^2}{{}_1\phi^2}, \tag{D1}$$

$$\ell - {}_1b_{\mathcal{S}} = {}_1e_{\mathcal{S}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2(\alpha_{y\mathcal{N}}+\gamma)^2}{{}_1\phi^2}, \tag{D2}$$

$${}_1b_{\mathcal{N}} = \ell - {}_1e_{\mathcal{N}}, \quad {}_1b_{\mathcal{S}} = \ell - {}_1e_{\mathcal{S}} \tag{D3}$$

$${}_1p_x = \frac{a(n+s)(\alpha_{y\mathcal{N}}+\gamma)\alpha_{y\mathcal{S}}}{{}_1\phi}, \tag{D4}$$

where ${}_1\phi := n\alpha_{y\mathcal{S}}\left(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma\right) + s\left(\alpha_{y\mathcal{N}}+\gamma\right)\left(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta\right)$. The welfare levels of North and South countries are given by

$$\begin{aligned} {}_1w_{\mathcal{N}} &= a\,{}_1x^d - \frac{\beta}{2}({}_1x^d)^2 + {}_1p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_1e_{\mathcal{N}}} - {}_1x^d\right) + \alpha_{y\mathcal{N}}(\ell - {}_1e_{\mathcal{N}}) \\ &\quad + \gamma[(n+s)\ell - n\,{}_1e_{\mathcal{N}} - s\,{}_1e_{\mathcal{S}}], \end{aligned} \tag{D5}$$

$${}_1w_{\mathcal{S}} = a\,{}_1x^d - \frac{\beta}{2}({}_1x^d)^2 + {}_1p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_1e_{\mathcal{S}}} - {}_1x^d\right) + \alpha_{y\mathcal{S}}(\ell - {}_1e_{\mathcal{S}}). \tag{D6}$$

Regime 2. Solving (C6) one gets

$$\sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}} = \frac{a(n+s)\alpha_{x\mathcal{N}}(\alpha_{y\mathcal{S}}+\gamma)}{{}_2\phi}, \tag{D7}$$

$$\sqrt{{}_1e_{\mathcal{S}} - z_{\mathcal{S}}} = \frac{a(n+s)\alpha_{x\mathcal{S}}(\alpha_{y\mathcal{N}}+\gamma)}{{}_2\phi}, \tag{D8}$$

$${}_2p_x = \frac{a(n+s)(\alpha_{y\mathcal{N}}+\gamma)(\alpha_{y\mathcal{S}}+\gamma)}{{}_2\phi}, \tag{D9}$$

where ${}_2\phi := n(\alpha_{y\mathcal{S}}+\gamma)(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma) + s(\alpha_{y\mathcal{N}}+\gamma)(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta + \gamma)$. Inserting (D1) and (D2) into (D7) and (D8) and solving for $z_{\mathcal{N}}$ and $z_{\mathcal{S}}$ yields

$$\begin{aligned} {}_2z_{\mathcal{N}} &= a^2(n+s)\alpha_{x\mathcal{N}}^2\left[\frac{\alpha_{y\mathcal{S}}^2}{[s(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)(\alpha_{y\mathcal{N}}+\gamma) + n\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta+\gamma)]^2}\right. \\ &\quad \left. - \frac{(\alpha_{y\mathcal{S}}+\gamma)^2}{{}_2\phi^2}\right], \end{aligned} \tag{D10}$$

$$\begin{aligned} {}_2z_{\mathcal{S}} &= a^2(n+s)\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}}+\gamma)^2 \\ &\quad \left[\frac{1}{s(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)(\alpha_{y\mathcal{N}}+\gamma) + n\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta+\gamma)]^2} - \frac{1}{{}_2\phi^2}\right], \end{aligned} \tag{D11}$$

$${}_2e_{\mathcal{N}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2(\alpha_{y\mathcal{S}}+\gamma)^2}{{}_2\phi^2} + {}_2z_{\mathcal{N}}, \tag{D12}$$

$${}_2e_{\mathcal{S}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}}+\gamma)^2}{{}_2\phi^2} + {}_2z_{\mathcal{S}}. \tag{D13}$$

The welfare levels are

$$
\begin{aligned}
{}_2w_{\mathcal{N}} &= a_2x^d - \frac{\beta}{2}\left({}_2x^d\right)^2 - {}_2p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_2e_{\mathcal{N}}} - {}_2x^d\right) + \alpha_{y\mathcal{N}}\left(\ell - {}_2e_{\mathcal{N}}\right) \\
&\quad + \gamma\left[(n+s)\ell - n_2e_{\mathcal{N}} + s_2e_{\mathcal{S}}\right] + {}_2p_z\left({}_2z_{\mathcal{N}} - {}_2z_{\mathcal{N}}{}^d\right), \qquad \text{(D14)} \\
{}_2w_{\mathcal{S}} &= a_2x^d - \frac{\beta}{2}\left({}_2x^d\right)^2 - {}_2p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_2e_{\mathcal{S}}} - {}_2x^d\right) + \alpha_{y\mathcal{N}}\left(\ell - {}_2e_{\mathcal{S}}\right) + {}_2p_{z2}z^d, \qquad \text{(D15)}
\end{aligned}
$$

where ${}_2p_z = \gamma$ and ${}_2z_{\mathcal{N}}{}^d = \frac{1}{n}(n_2z_{\mathcal{N}} + s_2z_{\mathcal{S}})$.

Regime 3. Solving (C8) and (C9), we obtain

$$
\begin{aligned}
\sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}} &= \frac{a(n+s)\alpha_{x\mathcal{N}}(\alpha_{y\mathcal{S}} + n\gamma)}{{}_3\phi}, \qquad \text{(D16)} \\
\sqrt{{}_1e_{\mathcal{S}} - z_{\mathcal{S}}} &= \frac{a(n+s)\alpha_{x\mathcal{S}}(\alpha_{y\mathcal{N}} + n\gamma)}{{}_3\phi}, \qquad \text{(D17)} \\
{}_3p_x &= \frac{a(n+s)(\alpha_{y\mathcal{N}} + n\gamma)\alpha_{y\mathcal{S}}}{{}_3\phi}, \qquad \text{(D18)}
\end{aligned}
$$

where

$$
\begin{aligned}
{}_3\phi &= s\alpha_{y\mathcal{N}}\left(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta\right) + n^3\gamma^2 + n^2\gamma\left(\alpha_{y\mathcal{N}} + \alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{N}}^2\beta + s\gamma\right) \qquad \text{(D19)} \\
&\quad + n\left[2\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}\beta + s\gamma\left(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta\right) + \alpha_{y\mathcal{N}}\left(\alpha_{y\mathcal{S}} + s\gamma\right)\right]. \qquad \text{(D20)}
\end{aligned}
$$

Inserting (D1) and (D2) into (D16) and (D17) and solving for $z_{\mathcal{N}}$ and $z_{\mathcal{S}}$ yields

$$
\begin{aligned}
{}_3z_{\mathcal{N}} &= a^2(n+s)^2\alpha_{x\mathcal{N}}^2\left[\frac{\alpha_{y\mathcal{S}}^2}{\left[s(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)(\alpha_{y\mathcal{N}} + \gamma) + n\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma)\right]^2}\right. \\
&\quad \left. - \frac{(\alpha_{y\mathcal{S}} + n\gamma)^2}{{}_3\phi^2}\right], \qquad \text{(D21)} \\
{}_3z_{\mathcal{S}} &= a^2(n+s)^2\alpha_{x\mathcal{S}}^2\left[\frac{(\alpha_{y\mathcal{N}} + \gamma)^2}{\left[n(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma)\alpha_{y\mathcal{S}} + s(\alpha_{y\mathcal{N}} + \gamma)(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)\right]^2}\right. \\
&\quad \left. - \frac{(\alpha_{y\mathcal{N}} + n\gamma)^2}{{}_3\phi^2}\right]. \qquad \text{(D22)}
\end{aligned}
$$

$$
\begin{aligned}
{}_3e_{\mathcal{N}} &= \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2(\alpha_{y\mathcal{S}} + n\gamma)^2}{{}_3\phi^2} + {}_3z_{\mathcal{N}}, \qquad \text{(D23)} \\
{}_3e_{\mathcal{S}} &= \frac{a^2(n+s)^2\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}} + n\gamma)^2}{{}_3\phi^2}{}_3z_{\mathcal{S}}, \qquad \text{(D24)}
\end{aligned}
$$

$$
{}_3b_{\mathcal{N}} = \ell - {}_3e_{\mathcal{N}}, \quad {}_3b_{\mathcal{S}} = \ell - {}_3e_{\mathcal{S}}. \qquad \text{(D25)}
$$

The welfare levels are given by

$$
\begin{aligned}
{}_3w_{\mathcal{N}} &= a_3x^d - \frac{\beta}{2}({}_3x^d)^2 + {}_3p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_3e_{\mathcal{N}}} - {}_3x^d\right) + \alpha_{y\mathcal{N}}(\ell - {}_3e_{\mathcal{N}}) \\
&\quad + \gamma\left[(n+s)\ell - n_3e_{\mathcal{N}} - s_3e_{\mathcal{S}}\right] + {}_3p_z({}_3z_{\mathcal{N}} - {}_3z_{\mathcal{N}}{}^d), \qquad \text{(D26)} \\
{}_3w_{\mathcal{S}} &= a_3x^d - \frac{\beta}{2}({}_3x^d)^2 + {}_3p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_3e_{\mathcal{S}}} - {}_3x^d\right) + \alpha_{y\mathcal{S}}(\ell - {}_3e_{\mathcal{S}}) + {}_3p_{z3}z_{\mathcal{S}}, \qquad \text{(D27)}
\end{aligned}
$$

where ${}_3p_z = n\gamma$ and ${}_3z_{\mathcal{N}}{}^d = \frac{1}{n}\left(n_3z_{\mathcal{N}} + s_3z_{\mathcal{S}}\right)$.

Appendix E: Continuous variations of $\alpha_{x\mathcal{N}}$ and $\alpha_{y\mathcal{N}}$ for non-strategic action (only for the referees)

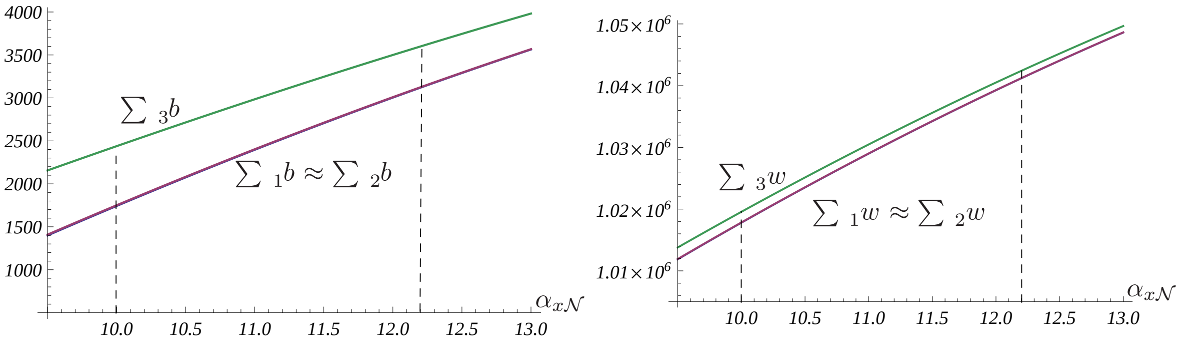

Figure 1a

Figure 1b

Figure 1: Comparison of aggregate protected areas and aggregate welfare (for variations of $\alpha_{x\mathcal{N}}$)

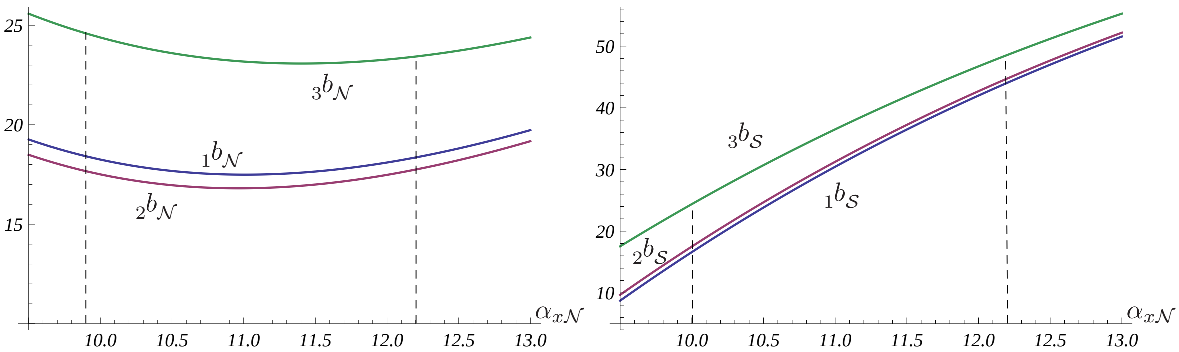

Figure 2a

Figure 2b

Figure 2: Comparison of protected areas (for variations of $\alpha_{x\mathcal{N}}$)

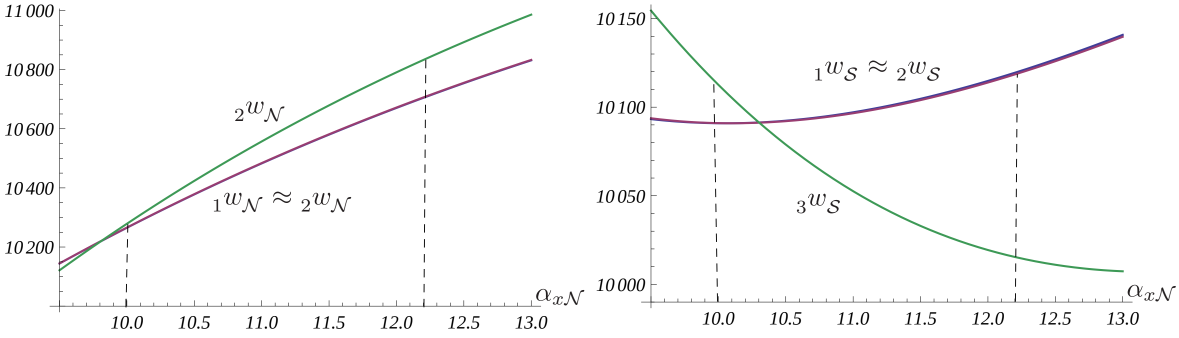

Figure 3a   Figure 3b

Figure 3: Welfare comparison (for variations of $\alpha_{x\mathcal{N}}$)

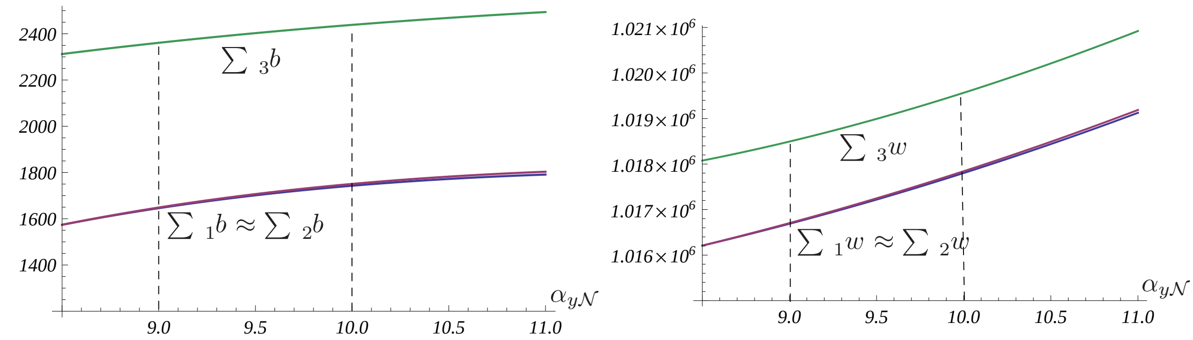

Figure 4a   Figure 4b

Figure 4: Comparison of aggregate protected areas and welfares (for variations of $\alpha_{y\mathcal{N}}$)

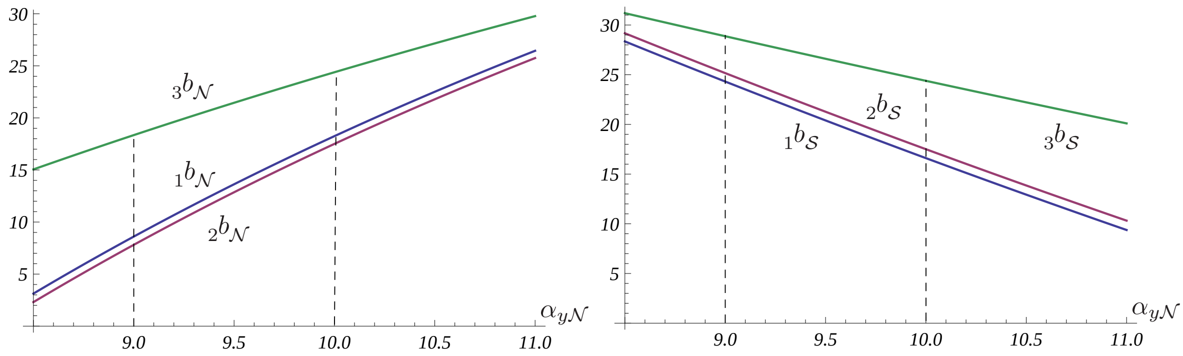

Figure 5a   Figure 5b

Figure 5: Comparison of protected areas (for variations of $\alpha_{y\mathcal{N}}$)

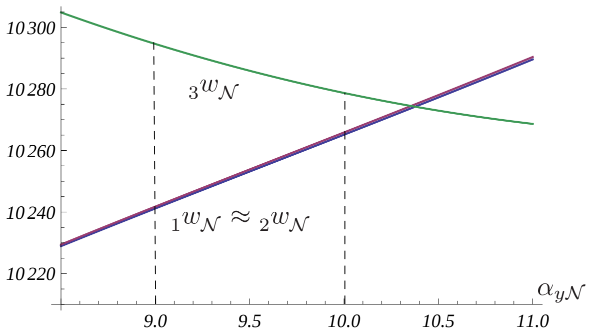

Figure 6a

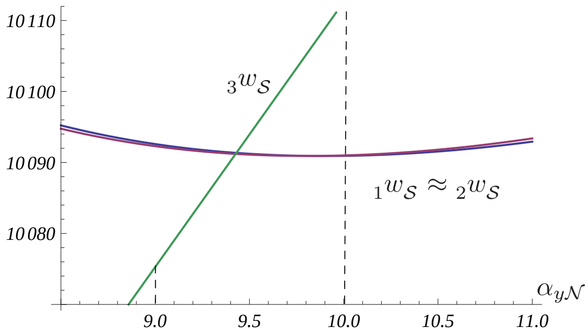

Figure 6b

Figure 6: Welfare comparison (for variations of $\alpha_{y\mathcal{N}}$)