# Coaseian biodiversity conservation. Who benefits?[1]

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**Abstract**

We assume that the global public good 'biodiversity' is positively correlated with that share of land which is effectively protected by land-use restrictions against the deterioration of habitats and ecosystems. The willingness-to-pay for biodiversity conservation is positive in developed countries (North), but very low (here: zero) in developing countries (South). Taking the no-policy scenario (Regime 1) as our point of departure, we analyze two concepts of biodiversity conservation: the northern countries' coordinated action for efficient land protection in the North (Regime 2) and financial support of biodiversity conservation from North to South (Regime 3). The focus is on changes in biodiversity and welfare of the world economy's move from Regime 1 to the Regimes 2 and 3 and to the Regime 4, consisting of the combination of the Regimes 2 and 3. In a parametric version of the model, we derive a number of unexpected and undesirable results. It is possible that the move from Regime 1 to Regime 2 reduces biodiversity and welfare in North and South. Regime 3 fares better, but it hardly improves welfare and biodiversity in our simulations. Although Regime 4 is socially optimal, the North or the South is worse off in Regime 4 than in Regime 1 for some subsets of parameters.

JEL classification: Q15, Q57, Q58
Key words: 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) that entered into force some 20 years ago considers biodiversity conservation, BC for short, "a common concern of humankind". The substantial efforts made under the convention's umbrella to enhance BC were 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 policy concepts closely related to the spirit of the Convention on Biological Diversity: (i) the coordinated action of all northern countries to raise the North's conservation efforts to efficient levels and (ii) compensation payments from the North for additional conservation efforts of the South that (also) benefit the North. Our goal is to analyze the effectiveness and the distributional consequences of these concepts by investigating, how they affect BC, the world welfare, and the welfare of North and South.

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

[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.

[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

protected and a non-protected area.[4] In particular, the protected area is land dedicated to habitat provision and wildlife protection. It is favorable for biodiversity because appropriate land-use restrictions are implemented and only those kinds and levels of economic activities are admitted, which leave natural habitats and ecosystems (almost) unimpaired. The non-protected area is subject to low regulation and therefore hosts all economic activities that are detrimental to biodiversity. In both areas, we allow for the production of consumption goods that are traded on world markets, but obviously the production processes of goods produced 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.

In sum, we assume that biodiversity is positively correlated with the protected area, that the global community attaches a positive non-market value to global biodiversity and that the willingness to pay for biodiversity is higher in the North than in the South. The low valuation of biodiversity in the South appears to be also the rationale of the Convention on Biological Diversity (1992) for calling on the North to compensate the South for extra conservation efforts. We simplify further by setting the South countries' non-market value of biodiversity equal to zero, because that allows decomposing all reciprocal biodiversity externalities into two types of externalities. The South's protected area generates external biodiversity benefits in all North countries (South-North externalities) and each North country's protected area generates external biodiversity benefits in all fellow North countries (North-North externalities).

We will analyze two BC concepts, each of which is designed to internalize one of these externalities. The compensation payments from the North for additional conservation efforts of the South, called *'North-South compensation'*, are modeled as an international competitive *BC market*[5] that will be shown to internalize the South-North externalities.[6] The item traded on that market is land-use rights or land-use restrictions on areas of land that qualify as protected area after the transaction. As an externality-internalizing institution, the BC market satisfies the beneficiaries-pay principle. The coordinated action of all northern countries, called *'North-North coordination'*, raises the North's conservation efforts to efficient levels, i.e. it internalizes the North-North externalities. In the Coaseian spirit, we refrain

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.

[6]Since the North is willing to pay more for biodiversity than the South, it is in the North's interest to compensate the South for expanding its protected area until the positive South-North externalities are internalized.

from providing an institutional structure for the North-North coordination such as a North-North BC market or a self-enforcing North-North agreement (as e.g. Barrett 1994) to focus on the North-South issue without unnecessary analytical complexity.

The BC concepts 'North-North coordination' and 'North-South compensation' can be absent, they can stand alone or they can be applied in combination. Correspondingly, we obtain the four regimes listed in Table 1.

| | | North-South compensation | |
|---|---|---|---|
| | | NO | YES |
| North-North coordination | NO | Regime 1 | Regime 3 |
| | YES | Regime 2 | Regime 4 |

Table 1: Alternative biodiversity conservation (BC) regimes

Obviously, Regime 1 is inefficient, because it leaves both kinds of biodiversity externalities un-internalized. The Regimes 2 and 3 are also inefficient, because each regime internalizes only one of the externalities leaving the other un-internalized. Regime 4 internalizes both kinds of externalities and therefore is efficient or socially optimal.[7] We take Regime 1 as the benchmark and determine the impact of the world economy's transition from that regime to the Regime 2, 3 or 4. In particular, we wish to know how the shift from Regime 1 to Regime $k$, $k = 2, 3$ or 4, changes BC efforts, aggregate welfare[8] and its distribution in North and South.

Although our model is very simple, we need to replace the general functional forms by simpler parametric functions, in order to obtain informative results. In the parametric model we show that the opportunity costs of the BC strategies under review take the form of an increase in the price of grey goods (in terms of green goods) which reduces the worldwide production of these goods. A particular specification of parameters, referred to as the *'base economy'*, 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 transition from Regime 1 to Regime 3 hardly raises the countries' welfare and the aggregate protected area. The move from Regime 1 to Regime 2 even reduces aggregate welfare and aggregate protected area, which

[7]The Convention on Biological Diversity combined with the Global Environment Facility hardly fits any of the four regimes, but may perhaps come close to Regime 3.

[8]We know that the aggregate welfare rises, if we move from Regime 1 to 4, because Regime 1 is inefficient and Regime 4 is socially optimal. This does not imply, however, that all countries' welfare increases.

is a counterintuitive outcome, because coordination or cooperation is usually associated with welfare when the allocation of externalities and public goods is at issue.

We then modify the 'base economy' and find that the implementation of the Regimes 2, 3 and 4 may produce changes that differ from those in the base economy even in sign. The most unexpected change occurs in empirically relevant scenarios, in which the North is either sufficiently more productive than the South in the production of grey goods or sufficiently less productive in the production of green goods. If the economy then moves from Regime 1 to the socially optimal Regime 4, it is possible that the South immiserizes despite North-South compensation due to deteriorating terms of trade in the South.[9]

Our paper contributes to two strands of literature, 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 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 a 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 making explicit 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 1-4. In the first part of Section 3 we describe and discuss

[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.

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

the allocative effects of moving from Regime 1 to the Regimes 2, 3 and 4 in a numerically specified 'base economy'. In the second part of Section 3, we change parameters of the base economy and analyze the effects of those parameter variations on results. Section 4 concludes.

# 2 The basic model and two complementary BC concepts

## 2.1 The basic no-policy model

Let $\Omega$ be the set of all countries in the world economy and divide $\Omega$ into the subsets $\mathcal{N}$ (for North) and $\mathcal{S}$ (for South). Each country $i$ has an endowment of land, $\ell_i$, and its government splits up $\ell_i$ 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 $e_i$ – or *non-protected area* – is land intensively used for commercial and industrial purposes without effective land-use restrictions. The non-protected area comprises towns with their 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 the biodiversity increases with the size of the protected area. 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.

Each country produces and consumes two kinds of internationally tradable goods, called *grey goods* (quantity $x$) and *green goods* (quantity $y$), 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, $e_i$. We interpret grey goods to be the bulk of standard consumption goods whose provision requires space (land).[12] Green goods represent commodities and services that use protected land as a major input. 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.[13]

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 $\delta$ 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, $\delta(i)B'(\sum_\Omega b_j)$ is country $i$'s benefit from increasing the aggregate protected area by one unit. We refer to $\delta(i)B(\sum_\Omega b_j)$ as country $i$'s benefit from BC. The dependence of the function $B$ on $\sum_\Omega b_j$ characterizes BC 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[14] $p_x x_i^d + p_y y_i^d = p_x x_i + p_y y_i$. 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 $\ell_i$ country $i$ is endowed with into a protected area $b_i$ and a non-protected area

[12] 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.

[13] 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.

[14] 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.

$e_i = \ell_i - b_i$ according to national interest taking the land-zoning decisions of all other countries taken as given.[15] In terms of the formal model, country $i$'s land-zoning decision is the solution of maximizing with respect to $b_i$ the welfare

$$V_i(x_i^d) + p_x\left[X_i(\ell_i - b_i) - x_i^d\right] + p_y Y_i(b_i) + \delta(i) B\left(\sum_{\Omega} b_j\right). \tag{5}$$

The first-order condition yields

$$p_y Y_i' = p_x X_i' \quad \text{all } i \in \mathcal{S} \quad \text{and} \quad p_y Y_i' + B' = p_x X_i' \quad \text{all } i \in \mathcal{N}. \tag{6}$$

According to (6), country $i$ chooses the protected area such that the sum of the marginal benefits, $p_y Y_i'$ and $\delta(i)B'$, equals marginal costs $p_x X_i'$. The competitive equilibrium is fully characterized by the marginal conditions (4) and (6) and by the market clearing conditions[16]

$$\sum_{\Omega}\left[X_j(\ell_j - b_j) - x_j^d\right] = 0 \quad \text{and} \quad \sum_{\Omega}\left[Y_j(b_j) - y_j^d\right] = 0. \tag{7}$$

To interpret the equilibrium allocation rules, we combine (4) and (6) and obtain

$$\frac{\delta(i)B'}{p_x Y_i'} = \frac{X_i'}{Y_i'} - \frac{p_y}{p_x} = \frac{X_i'}{Y_i'} - \frac{U_i'}{V_i'} \quad \text{all } i \in \Omega. \tag{8}$$

If $i \in \mathcal{S}$ in (8), the marginal rate of transformation $(X_i'/Y_i')$ equals the marginal rate of substitution in consumption $(U_i'/V_i') = (p_y/p_x)$. That is, the South countries' zoning does not distort production. An illustration is the point $A$ in Figure 1, which satisfies $(X_i'/Y_i') = (U_i'/V_i') = \tan\alpha$. If $i = \mathcal{N}$ and hence $\delta(i)B' = B' > 0$, the corresponding equilibrium also satisfies (8). However, in this case, $\delta(i)B' > 0$ drives a wedge between the marginal rate of transformation (now $\tan\beta$ in Figure 1) and the marginal rate of substitution (still $\tan\alpha$). Figure 1 illustrates that if $\delta(i)B' = 0$ – and a fortiori if $\delta(i)B' > 0$ – country $i \in \Omega$ has an incentive to set aside some protected area. Although a full characterization of the land allocation is not possible with general functional forms, the protected area tends to increase with increasing benefits from BC. To show that, suppose the transformation functions of all countries are identical and let $p_x = (p_x/p_y) = (1/\tan\alpha)$ be given. If $i \in S$, the allocation in country $i$ is represented by the point $A$ in Figure 1. However, if $i \in \mathcal{N}$, country $i$ produces in point $B$. This illustration suggests that each country's protected area $b_i$, and hence the aggregate protected area $\sum_{\Omega} b_j$, is typically sub-optimally small, because no country takes into account the *external* BC benefits generated by its own protected area.

[15]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.

[16]The resource constraint (1) is already accounted for in (7) and (8).

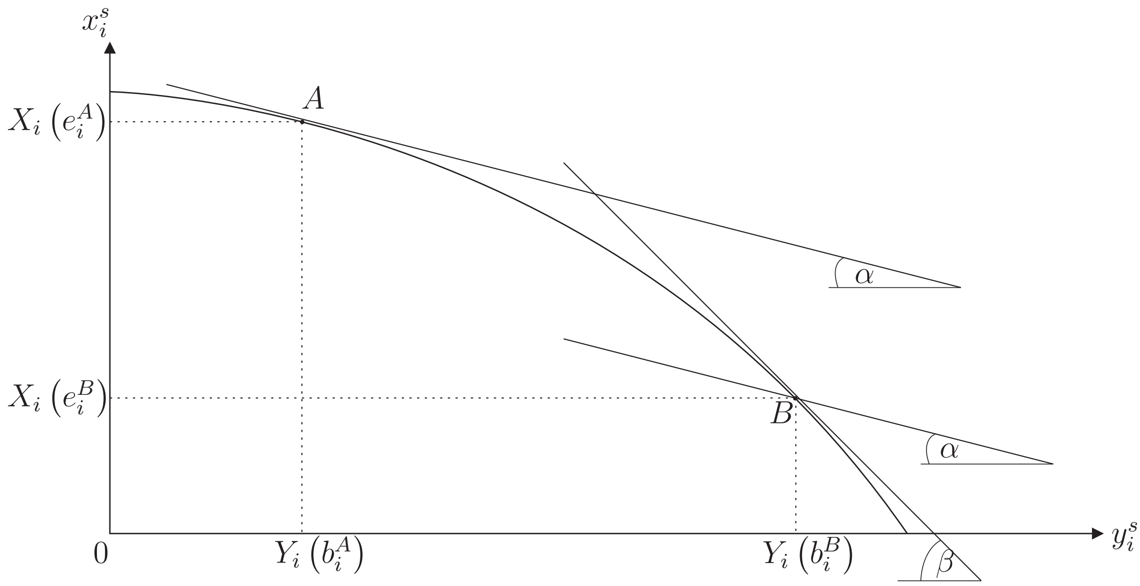


Figure 1: Production and land allocation in Regime 1 of the world economy

## 2.2 Two complementary concepts of BC

In the perfectly competitive world economy of the preceding Section 2.1, which we refer to as *Regime 1*, all positive biodiversity externalities are un-internalized. The South countries ignore the 'South-North externalities', i.e. the benefits the protected areas of the South generate in the North and the North countries ignore the 'North-North externalities', i.e. the benefits the North countries' protected areas generate in their fellow North countries. In this section, we investigate two different BC concepts, each of which internalizes one kind of externalities.

(i) *North-South compensation.* The North internalizes the South-North externalities by inducing the South to expand its protected areas via the 'beneficiaries-pay principle'; in terms of the formal model this is done by creating an international market for biodiversity conservation, called BC market.

(ii) *North-North coordination.* The North countries internalize the North-North externalities by coordinating their BC efforts such that each North country chooses that protected area which maximizes the aggregate welfare of the North.

We have listed in Table 1 (Section 1 above) the four regimes that result when the BC concepts (i) ad (ii) stand alone, are applied jointly or not at all. The benchmark Regime 1 serves the role of assessing the performance of the Regimes 2, 3 and 4 with regard to the allocation rules that characterize their equilibrium.

**Regime 2: North-North coordination without North-South compensation.** North-North coordination means that the North countries act as a single agent who maximizes the aggregate welfare of all North countries. Specifically, the North countries' supplies and demands of protected areas result from maximizing with respect to $(b_j)_{j \in N}$ the welfare

$$\sum_{\mathcal{N}} \left\{ V_j(x_j^d) + p_x \left[ X_j(\ell_j - b_j) - x_j^d \right] + p_y Y_j(b_j) + B_j \left( \sum_{\mathcal{N}} b_k \right) \right\}. \tag{9}$$

The pertaining first-order conditions are

$$p_y Y_i' + \sum_{\mathcal{N}} B_j' = p_x X_i' \quad \text{all } i \in \mathcal{N}. \tag{10}$$

The South countries' allocation rule is the same as in Regime 1, because in Regime 2 country $i \in \mathcal{S}$ maximizes (5) with respect to $b_i$ and obtains $p_y Y_i' = p_x X_i'$ as in (6). Thus in Regime 2, the equilibrium of the economy is characterized by the market clearing conditions (1) and (7), and by the marginal conditions (6) for $i \in \mathcal{S}$ and (10).

**Regime 3: 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[17] ${}_1b_i, i \in \Omega$, the protected land in Regime 1. The international market for BC implements the beneficiary-pays principle in the Coaseian spirit[18] as follows:

$$b_i = {}_1b_i + z_i \quad \text{and} \quad e_i = \ell_i - {}_1b_i - z_i \quad \text{all } i \in \Omega, \tag{11}$$

$$\sum_{\Omega} z_j = \sum_{\Omega} z_j^d. \tag{12}$$

(11) 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.[19] 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.[20] Equation (12) is the condition for clearing the BC market. The price per unit of BC offered or demanded is $p_z \geq 0$, and all countries are assumed price takers. 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, $(z_i, z_i^d)_{i \in \Omega}$.

[17]The prescript $k$ for $k = 1, 2, 3, 4$ refers to Regime $k$.

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

[19]The information in (11) 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.

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

In order to investigate how the BC market operates in the absence of North-North coordination, we assume, as in Regime 1, that all South and North countries disregard the impact of their protected area on the welfare of other countries. In that case, country $i \in \Omega$ maximizes with respect to $z_i$ and $z_i^d$ its welfare

$$\begin{aligned} W_i &= V_i(x_i^d) + p_x\left[X_i(\ell_i - {}_1b_i - z_i) - x_i^d\right] + p_y Y_i({}_1b_i + z_i) + \delta(i) B\left[\sum_{\Omega}({}_1b_j + z_j^d)\right] \\ &\quad + p_z(z_i - z_i^d). \end{aligned} \tag{13}$$

The first-order conditions yield

$$\frac{\partial W_i}{\partial z_i} = -p_x X_i' + p_y Y_i' + p_z = 0 \quad \text{all}\, i \in \Omega, \tag{14}$$

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

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 $i \in \mathcal{N}$.[21] Thus, we infer from (14) and (15) that the allocation rules of Regime 3 are

$$z_i^d = 0 \quad \text{all } i \in \mathcal{S} \quad \text{and} \quad p_y Y_i' + B' = p_x X_i' \quad \text{all } i \in \Omega. \tag{16}$$

The equilibrium of the economy in Regime 3 is characterized by the market clearing conditions (1), (12) and

$$\sum_{\Omega}\left[X_j(\ell_j - {}_1b_j - z_j) - x_j^d\right] = 0, \quad \sum_{\Omega}\left[Y_j({}_1b_j + z_j) - y_j^d\right] = 0 \tag{17}$$

and by the allocation rules (16).

**Regime 4: North-North coordination** *and* **North-South compensation.** The North countries' supply and demand of BC results from maximizing with respect to $(z_j, z_j^d)_{j\in\mathcal{N}}$ the aggregate welfare of the North,

$$\begin{aligned} &\sum_{\mathcal{N}}\Big\{V_j(x_j^d) + p_x\left[X_j(\ell_j - {}_1b_j - z_j) - x_j^d\right] + p_y Y_j({}_1b_j + z_j) \\ &\qquad + B\left[\sum_{\mathcal{S}} {}_1b_k + \sum_{\mathcal{N}}({}_1b_k + z_k^d)\right] + p_z(z_j - z_j^d)\Big\}. \end{aligned} \tag{18}$$

The pertaining first-order conditions are $p_y Y_i' + p_z = p_x X_i'$ and $p_z = \sum_{\mathcal{N}} B' = nB'$ and hence

$$p_y Y_i' + nB' = p_x X_i' \tag{19}$$

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

for all $i \in \mathcal{N}$, where $n$ is the number of North countries. The South country $i$ maximizes its welfare (13) with respect to[22] $z_i$. Combined with $p_z = nB'$, the first-order condition yields (19). Hence, the equilibrium of Regime 4 is characterized by the market clearing conditions (1), (12), (17) and the marginal condition (19) that holds for all $i \in \Omega$.

The strong marginal beneficial effect $nB'$ in the allocation rule (19) 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 constraints (1), (12) and (17). The corresponding Lagrangean is

$$\begin{aligned}\mathcal{L} &= \sum_{\Omega}\left[V_j(x_j^d) + U_j(y_j^d)\right] + nB\left[\sum_{\mathcal{S}} {}_1b_k + \sum_{\mathcal{N}} {}_1b_k + z_{\mathcal{N}}^d\right] + \lambda_z \sum_{\Omega}(z_j - z_{\mathcal{N}}^d) \\ &\quad + \lambda_x \sum_{\Omega}\left[X_j(\ell_j - {}_1b_j - z_j) - x_j^d\right] + \lambda_y \sum_{\Omega}\left[Y_j({}_1b_j + z_j) - y_j^d\right]. \qquad (20)\end{aligned}$$

We show in the Appendix B that solving (20) with respect to $x_i^d, y_i^d, z_i^d$ and $z_i$ yields the allocation rules (4) and (19) (after having decentralized the social planner's solution by prices) for all $i \in \Omega$, which proves that the equilibrium market allocation in Regime 4 is socially optimal.

| | North | South |
|---|---|---|
| Regime 1 | $p_y Y_i' + B' = p_x X_i'$ | $p_y Y_i' = p_x X_i'$ |
| Regime 2 | $p_y Y_i' + nB' = p_x X_i'$ | $p_y Y_i' = p_x X_i'$ |
| Regime 3 | $p_y Y_i' + B' = p_x X_i'$ | $p_y Y_i' + B' = p_x X_i'$ |
| Regime 4 | $p_y Y_i' + nB' = p_x X_i'$ | $p_y Y_i' + nB' = p_x X_i'$ |

Table 2: Supply-side allocation rules in the Regimes 1 - 4

Table 2 summarizes the supply-side allocation rules of the Regimes 1 - 4 and allows comparing the regimes in a straightforward way. All regimes share two features. First, all countries put aside some protected area for the production of green goods (term $p_y Y_i'$ in Table 2). Second, 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. The common feature of the Regimes 1 and 2 is that the South countries disregard the positive external effect of their protected area on the North countries. In the North countries, the difference between coordination and non-coordination is also clear. Without [with] coordination, the North countries disregard [regard] the positive externality of their protected area on their

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

fellow North countries. If the BC market is in operation in the Regimes 3 or 4, it induces the South countries to take into account, partially (Regime 3) of fully (Regime 4), 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 4 demonstrates, full internalization of all externalities requires both North-North coordination and North-South compensation. We summarize our findings in

**Result 1.** *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).*

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

*(ii) In Regime 2 the North-North externalities are internalized, but that regime is inefficient nonetheless, because the South-North externalities remain non-internalized.*

*(iii) Regime 3 is inefficient, because the North-North externalities are not internalized and the South-North externalities are only partly internalized.*

*(iv) Regime 4 is efficient (or socially optimal), because it fully internalizes all externalities.*

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, 3 or 4 increases the aggregate protected area as well as the protected areas in North *and* South countries? We know that the transition to Regime 4 increases aggregate welfare because Regime 1 is inefficient and Regime 4 is socially optimal. It is not clear, however, how the aggregate welfare changes when moving from Regime 1 to the Regimes 2 and 3 and how it changes the welfare of North and South when moving from BAU to Regime 2, 3 or 4. Particularly important for the political acceptance of BC strategies is how the aggregate welfare surplus is shared between North and South.

# 3 Moving from Regime 1 to the Regimes 2, 3 and 4

In the preceding section, we have characterized the allocation rules in the Regimes 1 - 4. Now we aim to investigate in more detail the impact of the Regimes 2, 3 and 4 on the allocation of the world economy. Although our model of Section 2 consists of few simple building blocks only, it is not possible to derive informative results regarding the transition from Regime 1 to the Regimes 2 - 4 with the general functional forms functions $B$, $X_i$, $Y_i$ 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., and we denote the number of countries in the groups $\mathcal{N}$ and $\mathcal{S}$ by $n$ and $s$, respectively.

(ii) We employ the parametric model[23]

$$\begin{array}{ll} n = s = 50, \quad \ell_i = \ell, \quad X_i(e_i) = 2\alpha_{xi}\sqrt{e_i}, \quad Y_i(b_i) = \alpha_{yi} b_i, & \\ B\left(\sum_\Omega b_j\right) = \gamma \sum_\Omega b_j, \quad V_i(x_i^d) = a x_i^d - \frac{\beta}{2}(x_i^d)^2, & \end{array} \quad i = \mathcal{N}, \mathcal{S}. \tag{21}$$

In (21), $a, \alpha_{xi}, \alpha_{yi}, \beta, \gamma$ and $\ell$ are positive parameters. North and South are identical with respect to the parameters $a, \beta$ and $\ell$, but we allow for asymmetry with respect to the parameters $\alpha_{xi}, \alpha_{yi}$ and $\gamma$. We establish[24]

**Result 2.** *In the transition of the economy (21) from Regime 1 to Regime 2, 3 and 4 the price of grey goods in terms of green goods (terms of trade) increases, and the aggregate consumption and production of grey goods declines.*

According to Result 2, the BC strategies under review have opportunity costs in the form of reduced consumption of grey goods, and the terms of trade improve in countries that export grey goods. Result 2 is remarkable because, in qualitative terms, the opportunity costs and the terms-of-trade effect are independent of how effective the Regimes 2, 3 and 4 are in enhancing BC and how the countries' welfare changes compared to the welfare in Regime 1.

With the help of the parametric model (21) we are able to derive closed form solutions[25] but despite its simplicity, the computations in Appendix C show that the equilibrium values consist of terms so complex that it is impossible to derive further informative results. To make progress, we turn to numerical analysis, which we organize as follows. First, we focus on a specific 'numerical' economy, called the *base economy*, defined by the parameter values[26]

$$\hat{a} = 180, \quad \hat{\alpha}_{x\mathcal{N}} = \hat{\alpha}_{x\mathcal{S}} = 1, \quad \hat{\alpha}_{y\mathcal{N}} = \hat{\alpha}_{y\mathcal{S}} = 11, \quad \hat{\beta} = 10, \quad \ell = 75, \quad \text{and} \quad \hat{\gamma} = 1. \tag{22}$$

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

[24] The proof of Result 2 can be found in Appendix C.

[25] The functional forms (21) are the only parametrization of the model we were able to find that allows us to calculate explicitly all relevant equilibrium allocations and prices, which is indispensable for welfare comparisons.

[26] Note that in the base economy North and South differ only with respect to the parameter $\gamma$, i.e. with respect to their valuation of BC.

We describe and discuss the allocative changes in the equilibrium allocation of the base economy when moving from Regime 1 to the Regimes 2, 3 or 4. After that, we modify the base economy by varying the parameters $\alpha_{x\mathcal{N}}, \alpha_{y\mathcal{N}}$ and $\gamma$, one at a time, and investigate again the allocative changes of the transition from Regime 1 to the other regimes. Due to space limitations, we restrict our attention to the variables

$$\sum {}_k b := n\,{}_k b_{\mathcal{N}} + s\,{}_k b_{\mathcal{S}}, \quad {}_k b_i, \quad \sum {}_k w := n\,{}_k w_{\mathcal{N}} + s\,{}_k w_{\mathcal{S}}, \quad {}_k w_i \tag{23}$$

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

$$\begin{aligned} \Delta \sum {}_k b &:= n\Delta\,{}_k b_{\mathcal{N}} + s\Delta\,{}_k b_{\mathcal{S}}, \qquad & \Delta\,{}_k b_i &:= {}_k b_i - {}_1 b_i, \\ \Delta \sum {}_k w &:= n\Delta\,{}_k w_{\mathcal{N}} + s\Delta\,{}_k w_{\mathcal{S}}, \qquad & \Delta\,{}_k w_i &:= {}_k w_i - {}_1 w_i \end{aligned} \tag{24}$$

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

## 3.1 From Regime 1 to Regimes 2 - 4 in the base economy (21, 22)

We determine the signs of the terms (24) that describe the transition of the base economy from Regime 1 to Regime $k = 2, 3, 4$ with the help of the Figures[27] 2, 3 and 4 as follows. We select the curves depicting the equilibrium value of a variable, say $q$, in the Regimes $k$ and 1 and denote the equilibrium values as ${}_k q$ and ${}_1 q$, respectively. Then we identify those points on these curves that correspond to the parameter value $\hat{\alpha}_{x\mathcal{N}} = \hat{\alpha}_{x\mathcal{S}} = 1$ and look for the sign of the difference $\Delta\,{}_k q := {}_k q - {}_1 q$.

**From Regime 1 to Regime 2.** The allocative displacement effects of that transition (first row in Table 3) are surprising. The North countries' welfare declines ($\Delta\,{}_2 w_{\mathcal{N}} < 0$, Figure 4a), the South countries' welfare rises ($\Delta\,{}_2 w_{\mathcal{S}} > 0$, Figure 4b) and the aggregate welfare declines ($\Delta \sum {}_2 w < 0$, Figure 2b). The North countries expand their protected area ($\Delta\,{}_2 b_{\mathcal{N}} > 0$, Figure 3a) massively but the South countries reduce theirs almost by the same extent ($\Delta\,{}_2 b_{\mathcal{S}} < 0$, Figure 3b). It remains a small increase in aggregate protected land ($\Delta \sum {}_2 b > 0$, Figure 2a). To explain the welfare loss of the North and the welfare gain of the South, observe first that the joint action in the North results in an increase of each North country's protected area, as expected, because it now internalizes the positive externalities its protected area generates in its fellow North countries.[28] The shift from non-protected to protected areas amounts to subsidizing protecting areas or taxing non-protecting areas. That

[27]For the time being, we disregard the variations of the parameter $\alpha_{x\mathcal{N}}$ in the Figures 2 - 4. We will turn to them after the discussion of Table 3.

[28]Figure 3a shows that ${}_2 b_{\mathcal{N}}$ is even larger than the socially optimal ${}_4 b_N$!

raises the costs and reduces the production of grey goods in the North; it gives the South a comparative advantage in grey goods and the North a comparative advantage in green goods. The South countries strengthen that comparative advantage by taxing and hence reducing their protected area or by subsidizing their non-protected area. The distortions in production created by North and South point in opposite directions, and they are so strong that aggregate welfare declines.

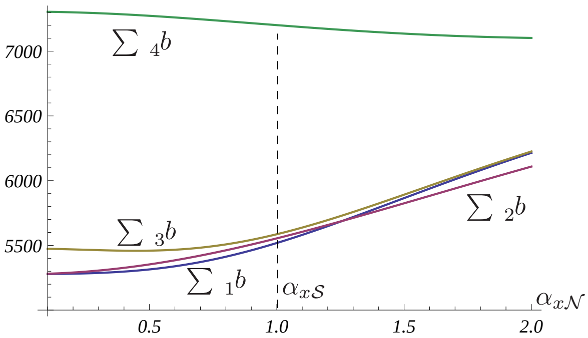


Figure 2a

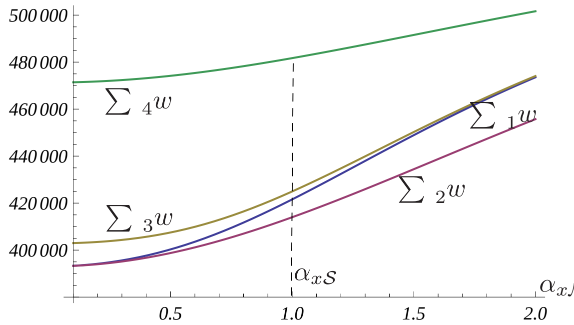


Figure 2b

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

**From Regime 1 to Regime 3.** If the BC market is in operation without coordination in the North (second row in Table 3), the aggregate protected area and the aggregate welfare are larger in Regime 3 than in Regime 1 ($\Delta \sum {}_3b > 0, \Delta \sum {}_3w > 0$, Figure 2). Although the increases are relatively small, these results mildly qualify the creation of a BC market without North-North coordination as a strategy to promote BC. However, it is unexpected that the entire (small) welfare gain accrues to the North ($\Delta\, {}_3w_{\mathcal{N}} > 0, \Delta\, {}_3w_{\mathcal{S}} > 0$ but small, Figure 4) and that the small increase $\Delta \sum {}_3b > 0$ is accompanied by a massive shift of protected area from North to South, $\Delta\, {}_3b_{\mathcal{N}} = {}_3z_{\mathcal{N}} < 0$ and $\Delta\, {}_3b_{\mathcal{S}} = {}_3z_{\mathcal{S}} > 0$ (Figure 3). To explain that shift, observe that the South countries' choice of ${}_1b_i$ in Regime 1 balances at the margin the benefits from grey and green goods. However, the North countries' BC benefits and green goods are complements with respect to $b_i$ such that in Regime 1 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 $i$ wishes to boost $B(\cdot)$, it must increase $Y_i(b_i)$ as well; so it chooses more of green goods and less BC benefits than it would choose if green goods and BC benefits were no complements. Put differently, the BC market enables North countries to decouple the production $Y_i(b_i)$ of green goods and the BC benefits $B(\cdot)$.

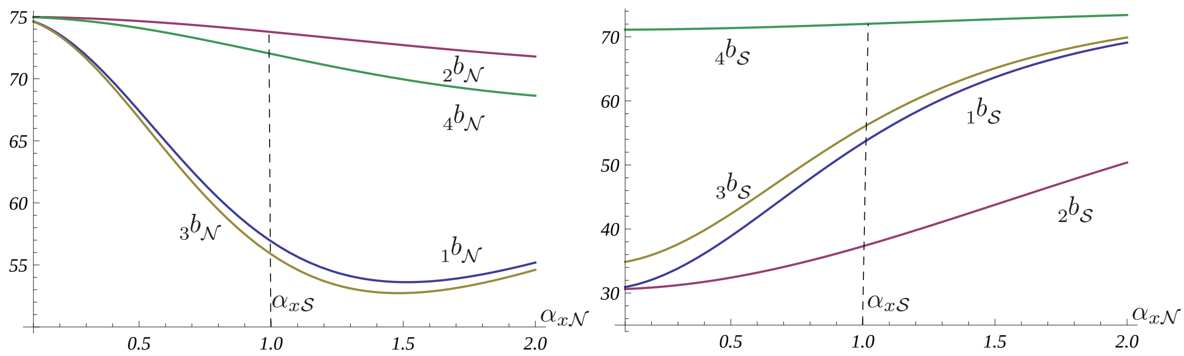


Figure 3a

Figure 3b

Figure 3: Comparison of protected areas (for variations of $\alpha_{x\mathcal{N}}$)

**From Regime 1 to Regime 4.** The third row in Table 3 describes the changes of moving from Regime 1 to Regime 4. $\Delta \sum {}_4w > 0$ (Figure 2b) is obvious since we know that Regime 4 is socially optimal and Regime 1 is inefficient. From a distributional viewpoint, the transition is also desirable, because North and South share the increase in aggregate welfare ($\Delta\, {}_4w_\mathcal{N} > 0, \Delta\, {}_4w_\mathcal{S} > 0$, Figure 4). The transition is also favorable with respect to BC, because the protected area expands in both North and South ($\Delta\, {}_4b_\mathcal{N} > 0, \Delta\, {}_4b_\mathcal{S} > 0$, Figure 3), and hence the aggregate protected area is massively boosted ($\Delta \sum {}_4b > 0$, Figure 2a). The combination of North-North coordination and North-South compensation in Regime 4 appear to eliminate the unfavorable features of stand-alone implementations of the Regimes 2 and 3. The downside of Regime 2 are massive production distortions and that of Regime 3 are disincentives to protect land in the North.[29] The tendency of the BC market without North-North coordination to discourage land protection in the North and to stimulate land protection in the South ($\Delta\, {}_3b_\mathcal{N} < 0$ and $\Delta\, {}_3b_\mathcal{S} > 0$) meets the tendency of North-North coordination without BC market to stimulate land protection in the North and to discourage land protection in the South ($\Delta\, {}_2b_\mathcal{N} > 0$ and $\Delta\, {}_2b_\mathcal{S} < 0$). Thus, combining North-North coordination with North-South compensation almost neutralizes the opposite shifts in production in the Regimes 2 and 3 and thus avoids the massive efficiency losses in these regimes. In sum, the base economy fully meets our expectation of a desirable transition

[29] A common feature of Regimes 3 and 4 is that in the base economy countries have no comparative advantage of producing goods, since the production parameters $\alpha_x$ and $\alpha_y$ are assumed to be the same.

from the inefficient Regime 1 to the social optimum.

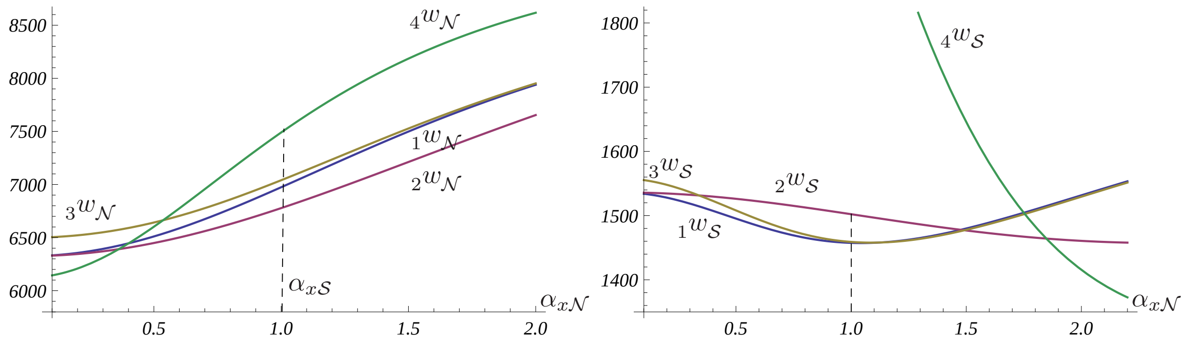


Figure 4a　　Figure 4b

Figure 4: Welfare comparison (for variations of $\alpha_{x\mathcal{N}}$)

**Result 3.** *The transition of the base economy (21, 22) from Regime 1 to the Regimes 2, 3 and 4 changes the allocation is shown in Table 3.*

| Transition from Regime 1 to ↓ | | $\Delta \sum {}_k b$ | $\Delta\, {}_k b_{\mathcal{N}}$ | $\Delta\, {}_k b_{\mathcal{S}}$ | $\Delta \sum {}_k w$ | $\Delta\, {}_k w_{\mathcal{N}}$ | $\Delta\, {}_k w_{\mathcal{S}}$ |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Regime 2** | 1 | $+$ | $++$ | $--$ | $-$ | $-$ | $+$ |
| **Regime 3** | 2 | $+$ | $-$ | $+$ | $+$ | $+$ | $+$ |
| **Regime 4** | 3 | $++$ | $+$ | $+$ | $++$ | $++$ | $++$ |

Table 3: Transition of the base economy (21, 22) from Regime 1 to Regime $k = 2, 3, 4$

## 3.2 Parameter variations

### 3.2.1 The base economy (21, 22) modified by variations of the parameter $\alpha_{x\mathcal{N}}$

In the preceding Section 3.1 we discussed the transition from Regime 1 to the other regimes in the base economy (21, 22) taking advantage of the Figures 2, 3 and 4. That is, we used the information from these figures only for the parameter value $\alpha_{x\mathcal{N}} = \hat{\alpha}_{x\mathcal{N}} = 1$. The Figures 2 - 4 depict the graphs of the equilibrium values of the variables (23) for all economies that differ from the base economy by the parameter $\alpha_{x\mathcal{N}}$. Now we seek to determine the changes in

Table 3 that result from modifying the base economy by reducing or increasing the value of $\alpha_{x\mathcal{N}}$ in the interval $[0, 2]$ which includes the value $\hat{\alpha}_{x\mathcal{N}} = \hat{\alpha}_{x\mathcal{S}} = 1$ of the base economy. $\alpha_{x\mathcal{N}}$ determines the productivity of producing grey goods. If we interpret the North countries as industrialized countries and the South countries as developing countries, the relevant case probably is $\alpha_{x\mathcal{N}} > \hat{\alpha}_{x\mathcal{S}} = 1$.

According to the Figures 2 and 3, the sign of the variables $\Delta \sum {}_k b$ for $k = 3, 4$, $\Delta\, {}_k b_{\mathcal{N}}$, $\Delta\, {}_k b_{\mathcal{S}}$ and $\Delta \sum {}_k w$ for $k = 2, 3, 4$ remain the same as in the base economy (Table 3) although significant changes in the size of these differences occur. Leaving the discussion of the changes in *size* to the reader, we will restrict our attention to the *sign* of the differences $\Delta\, {}_k w_{\mathcal{N}}$ and $\Delta\, {}_k w_{\mathcal{S}}$ in Figure 4.

**From Regime 1 to Regime 2.** We find $\Delta\, {}_2 w_{\mathcal{N}} < 0$ for all $\alpha_{x\mathcal{N}} \in [0, 2]$ and $\Delta\, {}_2 w_{\mathcal{S}} > 0$ for all $\alpha_{x\mathcal{N}} \in [0, \approx 1.5]$ as in the base economy. However, ${}_2 w_{\mathcal{S}}$ is decreasing in $\alpha_{x\mathcal{N}}$, while ${}_1 w_{\mathcal{S}}$ is increasing for $\alpha_{x\mathcal{N}} > \hat{\alpha}_{x\mathcal{S}}$ such that $\Delta\, {}_2 w_{\mathcal{S}}$ turns negative for $\alpha_{x\mathcal{N}} > 1.5$. The explanation is that if the North countries become significantly more productive in producing grey goods than the South, the South's comparative advantage of producing grey goods declines, which reduces its welfare until eventually all countries are worse off than in Regime 1. That devastating result appears to be relevant, because in the real world North countries produce grey goods with significantly more effective technology than South countries. Increasing $\alpha_{x\mathcal{N}}$ increases the welfare weight on the North's production of grey goods relative to the welfare weight on the North's production of green goods. As a consequence there is a shift from protected to non-protected area such the sign of the difference $\Delta \sum {}_2 b$ switches from positive to negative for large values of $\alpha_{x\mathcal{N}}$. The reduced aggregate protected land in turn diminishes BC and causes the losses of the North's welfare and the aggregate welfare.

**From Regime 1 to Regime 3.** The difference $\Delta\, {}_3 w_{\mathcal{N}}$ is positive for all $\alpha_{x\mathcal{N}} \in [0, 2]$. The difference $\Delta\, {}_3 w_{\mathcal{S}}$ turns negative for $\alpha_{x\mathcal{N}} \gg \hat{\alpha}_{x\mathcal{N}}$. Both get smaller with increasing $\alpha_{x\mathcal{N}}$. The explanation is the same, in qualitative terms, as in the base economy for all $\alpha_{x\mathcal{N}} \in [0, 2]$ with the exception that the South does not achieve a small welfare gain but suffers a small welfare loss for $\alpha_{x\mathcal{N}} \gg \hat{\alpha}_{x\mathcal{N}}$.

**From Regime 1 to Regime 4.** In Figure 4 we find two threshold values of the parameter $\alpha_{x\mathcal{N}}$, say $\alpha'_{x\mathcal{N}} \in ]0, 1[$ and $\alpha''_{x\mathcal{N}} \in ]1, 2[$, such that $\Delta\, {}_4 w_{\mathcal{N}}, \Delta\, {}_4 w_{\mathcal{S}} > 0$ for all $\alpha_{x\mathcal{N}} \in ]\alpha'_{x\mathcal{N}}, \alpha''_{x\mathcal{N}}[$ as in the base economy. For all $\alpha_{x\mathcal{N}} < \alpha'_{x\mathcal{N}}$ the North countries lose $(\Delta\, {}_4 w_{\mathcal{N}} < 0, \Delta\, {}_4 w_{\mathcal{S}} > 0)$ and for all $\alpha_{x\mathcal{N}} > \alpha''_{x\mathcal{N}}$ the South countries lose $(\Delta\, {}_4 w_{\mathcal{N}} > 0, \Delta\, {}_4 w_{\mathcal{S}} < 0)$. These unexpected differential welfare effects call for an explanation. Suppose first that $\alpha_{x\mathcal{N}} < \alpha'_{x\mathcal{N}}$. Then the average and marginal productivity of the non-protected area is higher in the South than in the North such that the South exports grey goods to and imports green goods from the North. The North countries' welfare drops below its level in Regime 1, because of their payments $p_z z^d_{\mathcal{N}} > 0$ to the South and because their terms of trade deteriorate ($\Delta p_x > 0$, Result 2). Scenarios with $\alpha_{x\mathcal{N}} < \alpha'_{x\mathcal{N}}$ appear to be implausible, however, because in the real world the productivity of producing grey goods is higher in developed countries by a wide margin and because we take it as a stylized fact that developing countries import grey goods from and export green goods to the North. In the more relevant case $\alpha_{x\mathcal{N}} > \alpha''_{x\mathcal{N}}$ the terms of trade favor the North and are so unfavorable for the South that the South countries are worse off in Regime 4 than in Regime 1 ($\Delta_4 w_{\mathcal{S}} < 0$).

We summarize the findings we consider relevant in

**Result 4.** *Let the world economy differ from the base economy (21, 22) in that the productivity in the production of grey goods is significantly higher in the North than in the South ($\alpha_{x\mathcal{N}} \gg \hat{\alpha}_{x\mathcal{N}} = \hat{\alpha}_{x\mathcal{S}} = 1$).*

- *(i) When moving from Regime 1 to Regime 2, the North countries' welfare and the aggregate welfare decline as in the base economy (22), but now the South countries are worse off as well, in contrast to the base economy.*
- *(ii) When moving from Regime 1 to Regime 3, the North countries' welfare and the aggregate welfare rises as in the base economy (22), but now the South countries are worse off, in contrast to the base economy.*
- *(iii) If the economy moves from Regime 1 to Regime 4, the North gains and the South loses although the South receives compensation from the North for the moderate expansion of its protected area.*

In our view, the most counterintuitive and disturbing outcome is the Result 4(iii). It states that the South loses when the economy moves from the inefficient Regime 1 to the socially optimal Regime 4 although it receives compensation from the North for stepping up its BC efforts. This case of the South's 'immiserizing compensation for BC' is reminiscent of Bhagwati's (1958) 'immiserizing' growth. The common feature of both anomalies is that they are caused by falling terms of trades in the South.

#### 3.2.2 The base economy (21, 22) modified by variations of the parameter $\alpha_{y\mathcal{N}}$.

Now we replace the parameter value $\hat{\alpha}_{y\mathcal{N}} = 11$ used in the base economy by $\alpha_{y\mathcal{N}} \in [2.5, 16]$, and we infer the signs of the corresponding differences (24) from the Figures 5, 6 and 7.

Inspection of the graphs in Figure 6 shows that sign $\Delta\,_k b_{\mathcal{N}} > 0$ for $k = 2, 4$, sign $\Delta\,_3 b_{\mathcal{N}} < 0$, sign $\Delta\,_k b_{\mathcal{S}} > 0$ for $k = 3, 4$ and sign $\Delta\,_2 b_{\mathcal{S}} < 0$ as in the base economy. For all $\alpha_{y\mathcal{N}} > \hat{\alpha}_{y\mathcal{N}}$ the welfare results are also as in the base economy. It remains to discuss the case $\alpha_{y\mathcal{N}} < \hat{\alpha}_{y\mathcal{N}} = \hat{\alpha}_{y\mathcal{S}}$ that arguably is empirically relevant, because biodiversity plays a greater economic role in the South than in the North.

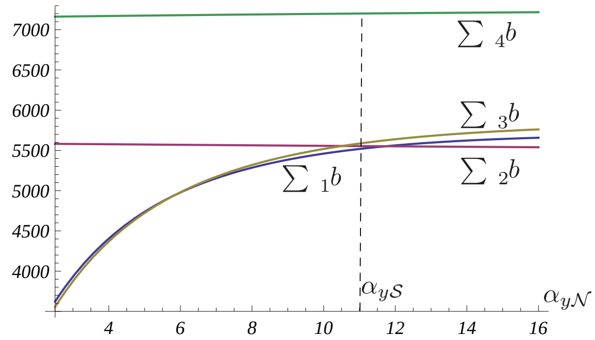


Figure 5a

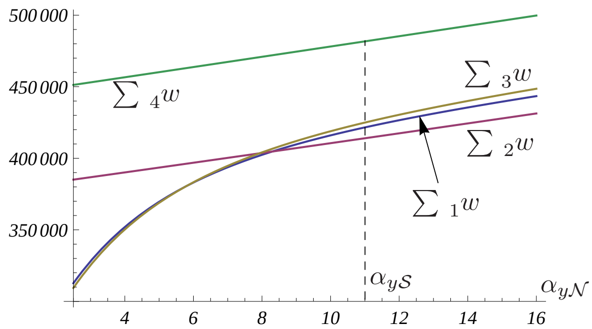


Figure 5b

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

**From Regime 1 to Regime 2 for $\alpha_{y\mathcal{N}} < \hat{\alpha}_{y\mathcal{S}}$.** Figure 5 reveals that there exists a positive value of $\alpha_{y\mathcal{N}}$ such that the difference $\Delta \sum\,_2 w$ turns positive for all $\alpha_{y\mathcal{N}}$ smaller than this threshold value. $\Delta\,_2 b_{\mathcal{N}}$ remains positive and $\Delta\,_2 b_{\mathcal{S}}$ remains negative, as in the base economy, but the difference $\Delta \sum\,_2 b > 0$ increases for low values of $\alpha_{y\mathcal{N}}$. The switch in sign of $\Delta \sum\,_2 w$ occurs because $\Delta\,_2 w_{\mathcal{N}}$ turns positive. Decreasing $\alpha_{y\mathcal{N}}$ reduces the comparative advantage of producing green goods in the North, which leads to an alignment of input use in North and South. That alignment reduces production distortions and enhances BC. In Figure 7a, the increase of BC induces, in turn, the switch of $\Delta\,_2 w_{\mathcal{N}}$ from negative to positive for sufficiently small $\alpha_{y\mathcal{N}}$.

**From Regime 1 to Regime 3 for $\alpha_{y\mathcal{N}} < \hat{\alpha}_{y\mathcal{S}}$.** We infer from Figure 5 that for sufficiently small values of $\alpha_{y\mathcal{N}}$ the differences $\Delta \sum\,_3 b$ as well as $\Delta \sum\,_3 w$ turn from positive to negative. That switch in sign also happens to $\Delta\,_3 w_{\mathcal{N}}$ for sufficiently small values of $\alpha_{y\mathcal{N}}$ (Figure 7a), while $\Delta\,_3 w_{\mathcal{S}}$ is close to zero for all $\alpha_{y\mathcal{N}} \in [2.5, 16]$. If $\alpha_{y\mathcal{N}}$ is small, the South has a comparative advantage in producing green goods. The idea of the BC market is to shift some

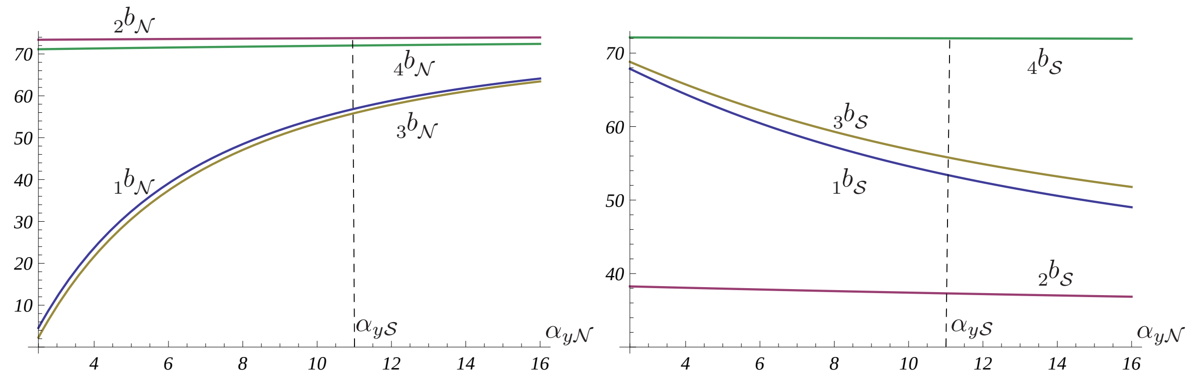


Figure 6a Figure 6b

Figure 6: Comparison of protected areas (for variations of $\alpha_{y\mathcal{N}}$)

production of green goods that is less productive than the production of grey goods from North to South. That does not work if $\alpha_{y\mathcal{N}} < \hat{\alpha}_{y\mathcal{S}}$ and $|\alpha_{y\mathcal{N}} - \hat{\alpha}_{y\mathcal{S}}|$ large. Although the South expands its protected area, the reduction in the North overcompensates that expansion such that the aggregate protected area decreases. Consequently, not only the North's welfare but also total welfare declines compared to Regime 1 for small values of $\alpha_{y\mathcal{N}}$.

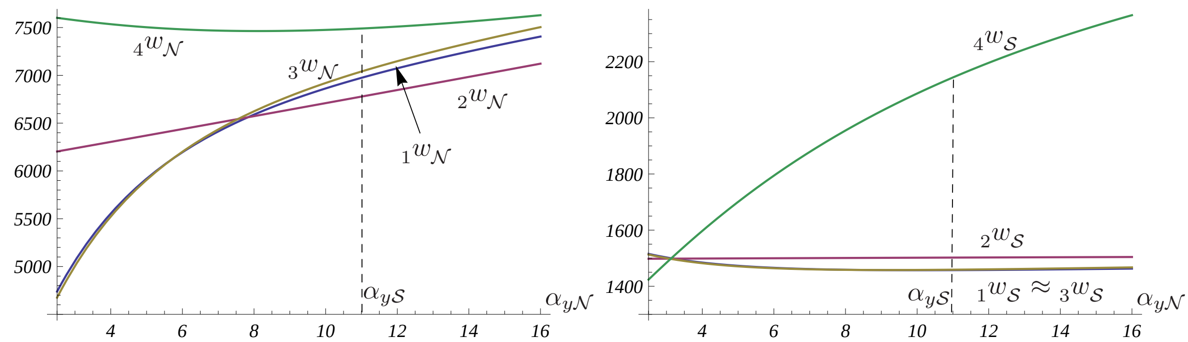


Figure 7a Figure 7b

Figure 7: Welfare comparison (for variations of $\alpha_{y\mathcal{N}}$)

**From Regime 1 to Regime 4 for $\alpha_{y\mathcal{N}} < \hat{\alpha}_{y\mathcal{S}}$.** When the economy moves from Regime 1 to Regime 4, we find that the sign of all changes are as in the third line of Table 3 with the exception of $_4w_{\mathcal{S}}$. In the plausible case that $\alpha_{y\mathcal{N}}$ is much smaller than $\hat{\alpha}_{y\mathcal{S}}$, the average and marginal productivity of the protected area is higher in South than in North such that South exports green goods to and imports grey goods from North. The South countries' welfare falls below the level in Regime 1, because their terms of trade deteriorate ($\Delta p_x > 0$, Result 2), whereas the North countries' welfare rises.

We summarize the findings we consider relevant in

**Result 5.** *Let the world economy differ from the base economy (21, 22) in that the productivity in the production of green goods is significantly higher in the South than in the North ($\alpha_{y\mathcal{N}} \ll \hat{\alpha}_{y\mathcal{S}} = \hat{\alpha}_{y\mathcal{N}} = 1$).*

*(i) When moving from Regime 1 to Regime 2, the aggregate welfare rises in contrast to its decline in the base economy. The beneficiary of this change is the North because ${}_2w_{\mathcal{N}}$ changes from negative to positive.*

*(ii) When moving from Regime 1 to Regime 3, the aggregate protected area and the aggregate welfare decline in contrast to their rise in the base economy. That deterioration hits the North, because ${}_3w_{\mathcal{N}}$ changes from positive to negative.*

*(iii) In qualitative terms, Regime 4 compares with Regime 1 as in the base economy (third line in Table 2) with the important difference that the South countries' welfare is now lower instead of higher than in Regime 1.*[30]

The impact of the parameter variations $\gamma \in [0, 3]$ on the transition of the economy from Regime 1 to the Regimes 2, 3 or 4 does not provide new insights. For the sake of completeness, the associated figures are presented in Appendix D.

# 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 the indicator of biodiversity conservation (BC). The willingness-to-pay for BC is assumed to be positive in developed countries (North), but much lower (here: zero) in developing countries (South). We denote as Regime 1 the world economy in which no external biodiversity benefits are internalized and focus on two concepts to promote BC: (i) the coordinated BC in the North (Regime 2) and (ii) the North's compensation for BC in the South modeled as a BC market (Regime 3). We investigate the impact on BC and welfare of the transition from Regime 1 to the Regimes 2, 3 and 4 (with Regime 4 being the combination of the Regimes 2 and 3). In a parametric

[30]This is another case of 'immiserizing BC support of the South'. See Result 4(iii).

version of the model, we derive a number of unexpected results. The move from Regime 1 to Regime 2 may reduce BC and welfare in North and South. The move from Regime 1 to Regime 3 hardly improves BC and welfare in our simulations. The distributional effects of the move from Regime 1 to the socially optimal Regime 4 may be undesirable, because it can make the North or the South worse off.

The paper's message is that unexpected and undesirable results are possible. Although the robustness and empirical relevance of the results is not clear due to the simplicity of the model and the small number of simulations, our model does capture important channels of market and non-market interdependencies between all countries 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 via changing terms of trade.

The concepts of promoting BC we formalized in the Regimes 2 and 3 are difficult to implement in the real world. The BC market (Regime 3) has great appeal, but the assumption that all agents are price takers on that market is unrealistic unless the North acts as one agent. If not, the North countries on the demand side have free-rider incentives because they benefit from all purchases of their fellow North countries. A similar caveat relates to the North's co-ordinated action that internalizes, by presupposition, all external biodiversity benefits the North countries generate in their fellow North countries. Modeling that perfect North-North coordination as a BC market is subject to the same limitations as the BC market in Regime 3. Modeling it as 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 rewarding to deepen and extend our analysis in various directions. We need to know how robust the results are when countries are allowed to be 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 is not harmless. To study these desiderata adequately, large-scale CGE models are required with realistic calibration to identify the 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 informative results on the other hand.

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# Appendix

## Appendix A

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 $\sigma_i$ 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

Maximizing the Lagrangean (20) 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 4 is efficient.

## Appendix C

**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 $x_i = 2\alpha_x \sqrt{e_i}$ into the equilibrium condition $(n+s)x^d = nx_{\mathcal{N}} + sx_{\mathcal{S}}$ we obtain

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

Inserting the parametric function into

$$Y_i'(b_i) - p_x X_i'(\ell - b_i) + \delta(i)\gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S} \tag{C3}$$

yields

$$\sqrt{e_{\mathcal{N}}} = \frac{p_x \alpha_{x\mathcal{N}}}{\alpha_{y\mathcal{N}} + \gamma}, \qquad \sqrt{e_{\mathcal{S}}} = \frac{p_x \alpha_{x\mathcal{S}}}{\alpha_{y\mathcal{S}}}. \tag{C4}$$

Inserting (C4) into the price function (C2) and solving for $p_x$ we get

$${}_1p_x = \frac{a(n+s)(\alpha_{y\mathcal{N}} + \gamma)\alpha_{y\mathcal{S}}}{{}_1\phi}, \tag{C5}$$

where ${}_1\phi := n\alpha_{y\mathcal{S}}\left(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma\right) + s\left(\alpha_{y\mathcal{N}} + \gamma\right)\left(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta\right)$. Finally, making use of (C5) we get

$${}_1e_{\mathcal{N}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}^2}{{}_1\phi^2}, \tag{C6}$$

$${}_1e_{\mathcal{S}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2(\alpha_{y\mathcal{N}} + \gamma)^2}{{}_1\phi^2} \tag{C7}$$

and

$$ {}_1b_{\mathcal{N}} = \ell - {}_1e_{\mathcal{N}}, \quad {}_1b_{\mathcal{S}} = \ell - {}_1e_{\mathcal{S}}. \tag{C8} $$

The welfare levels of North and South countries are given by

$$ \begin{aligned} {}_1w_{\mathcal{N}} &= a\,{}_1x^d - \frac{\beta}{2}({}_1x^d)^2 + {}_1p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_1e_{\mathcal{N}}} - {}_1x^d\right) + \alpha_{y\mathcal{N}}(\ell - {}_1e_{\mathcal{N}}) \\ &\quad + \gamma[(n+s)\ell - n\,{}_1e_{\mathcal{N}} - s\,{}_1e_{\mathcal{S}}], & \text{(C9)} \\ {}_1w_{\mathcal{S}} &= a\,{}_1x^d - \frac{\beta}{2}({}_1x^d)^2 + {}_1p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_1e_{\mathcal{S}}} - {}_1x^d\right) + \alpha_{y\mathcal{S}}(\ell - {}_1e_{\mathcal{S}}). & \text{(C10)} \end{aligned} $$

**Regime 2.** While the consumer's demand (C1) and the price function (C2) remain unchanged, inserting the parametric functions into the first-order conditions

$$ Y_i'(b_i) - p_x X_i'(\ell - b_i) + \delta(i)n\gamma = 0 \quad \text{for } i = \mathcal{N}, \mathcal{S}. \tag{C11} $$

we obtain

$$ \sqrt{e_{\mathcal{N}}} = \frac{p_x\alpha_{x\mathcal{N}}}{\alpha_{y\mathcal{N}} + n\gamma}, \quad \sqrt{e_{\mathcal{S}}} = \frac{p_x\alpha_{x\mathcal{S}}}{\alpha_{y\mathcal{S}}}. \tag{C12} $$

Calculations analogous to those in Regime 1 yield

$$ \begin{aligned} {}_2p_x &= \frac{a(n+s)\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + n\gamma)}{{}_2\phi}, & \text{(C13)} \\ {}_2e_{\mathcal{N}} &= \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}^2}{{}_2\phi^2}, & \text{(C14)} \\ {}_2e_{\mathcal{S}} &= \frac{a^2(n+s)^2\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}} + n\gamma)^2}{{}_2\phi^2}, & \text{(C15)} \end{aligned} $$

where ${}_2\phi := s\alpha_{y\mathcal{N}}(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta) + n^2\alpha_{y\mathcal{S}}\gamma + n[\alpha_{y\mathcal{N}}\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}\beta + s\gamma(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)]$ and

$$ {}_2b_{\mathcal{N}} = \ell - {}_2e_{\mathcal{N}}, \quad {}_2b_{\mathcal{S}} = \ell - {}_2e_{\mathcal{S}}, \tag{C16} $$

$$ \begin{aligned} {}_2w_{\mathcal{N}} &= a\,{}_2x^d - \frac{\beta}{2}\left({}_2x^d\right)^2 + {}_2p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_2e_{\mathcal{N}}} - {}_2x^d\right) + \alpha_{y\mathcal{N}}\left(\ell - {}_2e_{\mathcal{N}}\right) \\ &\quad + \gamma\left[(n+s)\ell - n\,{}_2e_{\mathcal{N}} - s\,{}_2e_{\mathcal{S}}\right], & \text{(C17)} \\ {}_2w_{\mathcal{S}} &= a\,{}_2x^d - \frac{\beta}{2}\left({}_2x^d\right)^2 + {}_2p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_2e_{\mathcal{S}}} - {}_2x^d\right) + \alpha_{y\mathcal{S}}\left(\ell - {}_2e_{\mathcal{S}}\right). & \text{(C18)} \end{aligned} $$

**Regime 3.** In the Regime 3 the consumer's demand is given by $x^d = \frac{a-p_x}{\beta}$ and the price function by

$$ p_x = P^x(z_{\mathcal{S}}, z_{\mathcal{N}}) = a - \frac{2\beta}{n+s}\left(s\alpha_{x\mathcal{S}}\sqrt{{}_1e_{\mathcal{S}} - z_{\mathcal{S}}} + n\alpha_{x\mathcal{N}}\sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}}\right). \tag{C19} $$

Solving the first-order condition

$$\begin{aligned} Y'_{\mathcal{S}}({}_1b_{\mathcal{S}} + z_{\mathcal{S}}) - p_x X'_{\mathcal{S}}(\ell - {}_1b_{\mathcal{S}} - z_{\mathcal{S}}) + p_z &= 0, & \text{(C20)} \\ Y'_{\mathcal{N}}({}_1b_{\mathcal{N}} + z_{\mathcal{N}}) - p_x X'_{\mathcal{N}}(\ell - {}_1b_{\mathcal{N}} - z_{\mathcal{N}}) + \gamma &= 0 & \text{(C21)} \end{aligned}$$

and $p_z = \gamma$, one gets

$$\sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}} = \frac{p_x \alpha_{x\mathcal{N}}}{\alpha_{y\mathcal{N}} + \gamma}, \quad \sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{S}}} = \frac{p_x \alpha_{x\mathcal{S}}}{\alpha_{y\mathcal{N}} + \gamma}. \tag{C22}$$

Next, we insert (C22) into the price function to obtain the equilibrium price

$${}_3p_x = \frac{a(n+s)(\alpha_{y\mathcal{N}} + \gamma)(\alpha_{y\mathcal{S}} + \gamma)}{{}_3\phi}, \tag{C23}$$

where ${}_3\phi := n(\alpha_{y\mathcal{S}} + \gamma)(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma) + s(\alpha_{y\mathcal{N}} + \gamma)(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta + \gamma)$, and hence

$$\begin{aligned} \sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}} &= \frac{a(n+s)\alpha_{x\mathcal{N}}(\alpha_{y\mathcal{S}} + \gamma)}{{}_3\phi}, & \text{(C24)} \\ \sqrt{{}_1e_{\mathcal{S}} - z_{\mathcal{S}}} &= \frac{a(n+s)\alpha_{x\mathcal{S}}(\alpha_{y\mathcal{N}} + \gamma)}{{}_3\phi}. & \text{(C25)} \end{aligned}$$

Inserting (C5) and (C6) into (C24) and (C25) and solving for $z_{\mathcal{N}}$ and $z_{\mathcal{S}}$ yields

$$\begin{aligned} {}_3z_{\mathcal{N}} &= a^2(n+s)\alpha_{x\mathcal{N}}^2 \left[ \frac{\alpha_{y\mathcal{S}}^2}{[s(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)(\alpha_{y\mathcal{N}} + \gamma) + n\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma)]^2} \right. \\ &\quad \left. - \frac{(\alpha_{y\mathcal{S}} + \gamma)^2}{{}_3\phi^2} \right], & \text{(C26)} \\ {}_3z_{\mathcal{S}} &= a^2(n+s)\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}} + \gamma)^2 \\ &\quad \left[ \frac{1}{s(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)(\alpha_{y\mathcal{N}} + \gamma) + n\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma)]^2} - \frac{1}{{}_3\phi^2} \right], & \text{(C27)} \\ {}_3e_{\mathcal{N}} &= \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2(\alpha_{y\mathcal{S}} + \gamma)^2}{{}_3\phi^2} + {}_3z_{\mathcal{N}}, & \text{(C28)} \\ {}_3e_{\mathcal{S}} &= \frac{a^2(n+s)^2\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}} + \gamma)^2}{{}_3\phi^2} + {}_3z_{\mathcal{S}}. & \text{(C29)} \end{aligned}$$

The welfare levels are

$$\begin{aligned} {}_3w_{\mathcal{N}} &= a\,{}_3x^d - \frac{\beta}{2}\left({}_3x^d\right)^2 - {}_3p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_3e_{\mathcal{N}}} - {}_3x^d\right) + \alpha_{y\mathcal{N}}\left(\ell - {}_3e_{\mathcal{N}}\right) \\ &\quad + \gamma\left[(n+s)\ell - n\,{}_3e_{\mathcal{N}} + s\,{}_3e_{\mathcal{S}}\right] + {}_3p_z\left({}_3z_{\mathcal{N}} - {}_3z_{\mathcal{N}}{}^d\right), & \text{(C30)} \\ {}_3w_{\mathcal{S}} &= a\,{}_3x^d - \frac{\beta}{2}\left({}_3x^d\right)^2 - {}_3p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_3e_{\mathcal{S}}} - {}_3x^d\right) + \alpha_{y\mathcal{N}}\left(\ell - {}_3e_{\mathcal{S}}\right) + {}_3p_z\,{}_3z^d, & \text{(C31)} \end{aligned}$$

where ${}_3p_z = \gamma$ and ${}_3z_{\mathcal{N}}{}^d = \frac{1}{n}(n\,{}_3z_{\mathcal{N}} + s\,{}_3z_{\mathcal{S}})$.

**Regime 4.** Inserting (C1) into the first order conditions

$$Y'_{\mathcal{S}}({}_1b_{\mathcal{S}} + z_{\mathcal{S}}) - p_x X'_{\mathcal{S}}(\ell - {}_1b_{\mathcal{S}} - z_{\mathcal{S}}) + p_z = 0, \tag{C32}$$

$$Y'_{\mathcal{N}}({}_1b_{\mathcal{N}} + z_{\mathcal{N}}) - p_x X'_{\mathcal{N}}(\ell - {}_1b_{\mathcal{N}} - z_{\mathcal{N}}) + n\gamma = 0, \tag{C33}$$

$p_z = n\gamma$ and solving (C32) and (C33), we obtain

$$\sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}} = \frac{p_x \alpha_{x\mathcal{N}}}{\alpha_{y\mathcal{N}} + n\gamma}, \quad \sqrt{{}_1e_{\mathcal{S}} - z_{\mathcal{S}}} = \frac{p_x \alpha_{x\mathcal{S}}}{\alpha_{y\mathcal{S}} + n\gamma}. \tag{C34}$$

Using the same steps of rearrangements as in Regime 3 we get

$${}_4p_x = \frac{a(n+s)(\alpha_{y\mathcal{N}} + n\gamma)\alpha_{y\mathcal{S}}}{{}_4\phi}, \tag{C35}$$

where

$${}_4\phi = s\alpha_{y\mathcal{N}}\left(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta\right) + n^3\gamma^2 + n^2\gamma\left(\alpha_{y\mathcal{N}} + \alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{N}}^2\beta + s\gamma\right) \tag{C36}$$

$$+n\left[2\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}\beta + s\gamma\left(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta\right) + \alpha_{y\mathcal{N}}\left(\alpha_{y\mathcal{S}} + s\gamma\right)\right] \tag{C37}$$

and

$$\sqrt{{}_1e_{\mathcal{N}} - z_{\mathcal{N}}} = \frac{a(n+s)\alpha_{x\mathcal{N}}(\alpha_{y\mathcal{S}} + n\gamma)}{{}_4\phi}, \tag{C38}$$

$$\sqrt{{}_1e_{\mathcal{S}} - z_{\mathcal{S}}} = \frac{a(n+s)\alpha_{x\mathcal{S}}(\alpha_{y\mathcal{N}} + n\gamma)}{{}_4\phi}. \tag{C39}$$

Inserting (C6) and (C7) into (C38) and (C39) and solving for $z_{\mathcal{N}}$ and $z_{\mathcal{S}}$ yields

$${}_4z_{\mathcal{N}} = a^2(n+s)^2\alpha_{x\mathcal{N}}^2\left[\frac{\alpha_{y\mathcal{S}}^2}{\left[s(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)(\alpha_{y\mathcal{N}} + \gamma) + n\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma)\right]^2} - \frac{(\alpha_{y\mathcal{S}} + n\gamma)^2}{{}_4\phi^2}\right], \tag{C40}$$

$${}_4z_{\mathcal{S}} = a^2(n+s)^2\alpha_{x\mathcal{S}}^2\left[\frac{(\alpha_{y\mathcal{N}} + \gamma)^2}{\left[n(\alpha_{y\mathcal{N}} + 2\alpha_{x\mathcal{N}}^2\beta + \gamma)\alpha_{y\mathcal{S}} + s(\alpha_{y\mathcal{N}} + \gamma)(\alpha_{y\mathcal{S}} + 2\alpha_{x\mathcal{S}}^2\beta)\right]^2} - \frac{(\alpha_{y\mathcal{N}} + n\gamma)^2}{{}_4\phi^2}\right]. \tag{C41}$$

$${}_4e_{\mathcal{N}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{N}}^2(\alpha_{y\mathcal{S}} + n\gamma)^2}{{}_4\phi^2} + {}_4z_{\mathcal{N}}, \tag{C42}$$

$${}_4e_{\mathcal{S}} = \frac{a^2(n+s)^2\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}} + n\gamma)^2}{{}_4\phi^2}{}_4z_{\mathcal{S}}, \tag{C43}$$

$${}_4b_{\mathcal{N}} = \ell - {}_4e_{\mathcal{N}}, \quad {}_4b_{\mathcal{S}} = \ell - {}_4e_{\mathcal{S}}. \tag{C44}$$

The welfare levels are given by

$${}_4w_{\mathcal{N}} = a_4x^d - \frac{\beta}{2}({}_4x^d)^2 + {}_4p_x\left(2\alpha_{x\mathcal{N}}\sqrt{{}_4e_{\mathcal{N}}} - {}_4x^d\right) + \alpha_{y\mathcal{N}}(\ell - {}_4e_{\mathcal{N}})$$

$$+\gamma\left[(n+s)\ell - n_4e_{\mathcal{N}} - s_4e_{\mathcal{S}}\right] + {}_4p_z({}_4z_{\mathcal{N}} - {}_4z_{\mathcal{N}}{}^d), \tag{C45}$$

$${}_4w_{\mathcal{S}} = a_4x^d - \frac{\beta}{2}({}_4x^d)^2 + {}_4p_x\left(2\alpha_{x\mathcal{S}}\sqrt{{}_4e_{\mathcal{S}}} - {}_4x^d\right) + \alpha_{y\mathcal{S}}(\ell - {}_4e_{\mathcal{S}}) + {}_4p_{z4}z_{\mathcal{S}}, \tag{C46}$$

where ${}_4p_z = n\gamma$ and ${}_4z_{\mathcal{N}}{}^d = \frac{1}{n}\left(n_4z_{\mathcal{N}} + s_4z_{\mathcal{S}}\right)$.

**Proof of Result 2:** To prove $\Delta\,{}_k p_x$ for $k = 2, 3, 4$ we calculate

$$
\begin{aligned}
{}_2p_x - {}_1p_x &= \frac{2a(n-1)n(n+s)\alpha_{x\mathcal{N}}^2\alpha_{x\mathcal{S}}^2\beta\gamma}{{}_1\phi\,{}_2\phi} > 0,\\
{}_3p_x - {}_1p_x &= \frac{2as(n+s)\alpha_{x\mathcal{S}}^2\beta\gamma(\alpha_{y\mathcal{N}}+\gamma)^2}{{}_1\phi\,{}_3\phi} > 0,\\
{}_4p_x - {}_1p_x &= \frac{2an(n+s)\beta\gamma\left[s\alpha_{x\mathcal{S}}^2(\alpha_{y\mathcal{N}}+\gamma)(\alpha_{y\mathcal{N}}+n\gamma)+(n-1)\alpha_{x\mathcal{N}}^2\alpha_{y\mathcal{S}}(\alpha_{y\mathcal{S}}+n\gamma)\right]}{{}_1\phi\,{}_4\phi} > 0.
\end{aligned}
$$

From $x^d = \frac{a-p_x}{\beta}$, we immediately get $\Delta\,{}_k x^d < 0$ for $k = 2, 3, 4$.

## Appendix D

**The base economy (21, 22) modified by variations of the parameter $\gamma \in [0, 3]$.** The impact of the parameter variations $\gamma \in [0, 3]$ on the transition of the economy from Regime 1 to Regimes 2, 3 or 4 is presented in the Figures 8, 9 and 10. We find that except for the positive sign of $\Delta \sum {}_2b$ for small values of $\gamma$, which is also present in Figure 5 for low values of $\alpha_{y\mathcal{N}}$, all signs of the differences (24) are as in the base economy (Table 3).

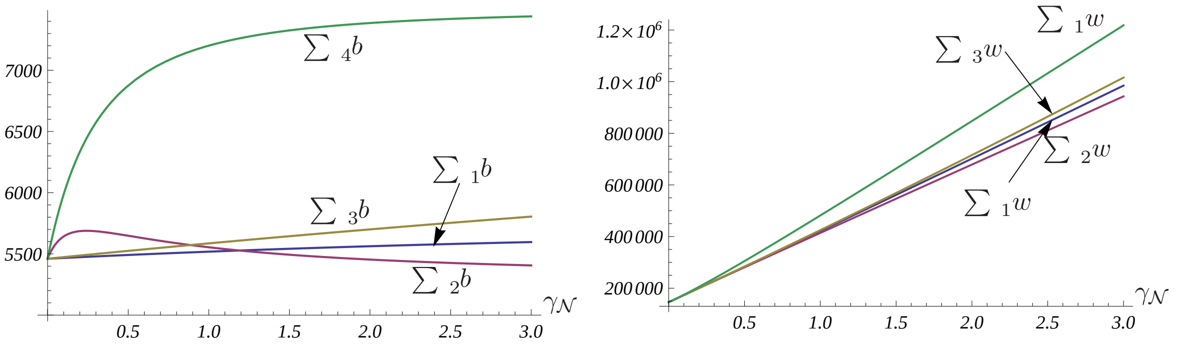


Figure 8a

Figure 8b

Figure 8: Comparison of aggregate protected areas and welfares (for variations of $\gamma_{\mathcal{N}}$)

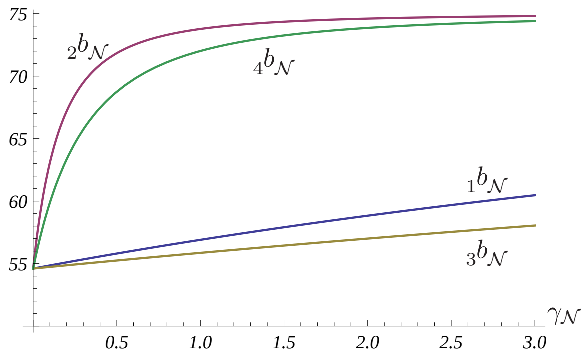


Figure 9a

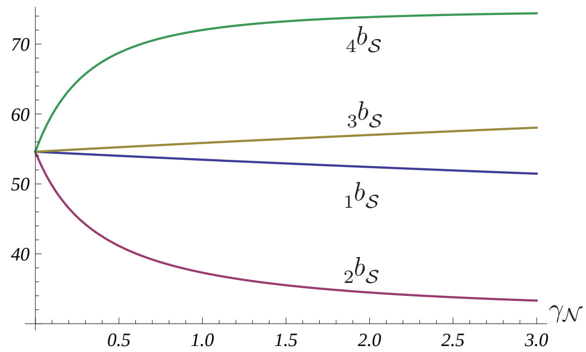


Figure 9b

Figure 9: Comparison of protected areas (for variations of $\gamma_{\mathcal{N}}$)

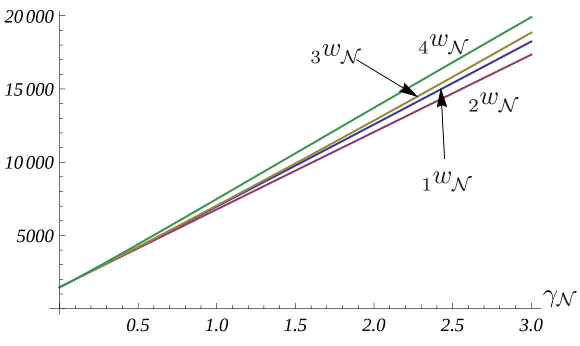


Figure 10a

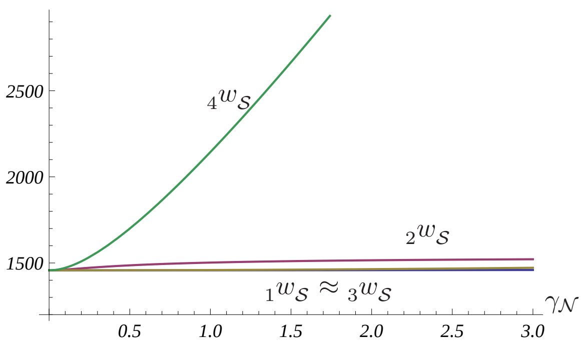


Figure 10b

Figure 10: Welfare comparison (for variations of $\gamma_{\mathcal{N}}$)