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Designing Research Coalition in Promoting GEOSS. A brief overview of the literature

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Diskussionspapier
DP-40-2008
Institut für nachhaltige Wirtschaftsentwicklung

September 2008

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universität des lebens

Contents

Abstract The Global Earth Observation System of Systems (GEOSS) links a variety of existing and future observation systems and forecasting models into one comprehensive system of systems to provide accurate environmental data and to enable an encompassing vision and understanding of the Earth system. GEOSS is based on voluntary efforts, and shall be made accessible freely or at a very low cost, such that it bears properties of non-rivalry and non-excludability and can be compared with a public good. Agreements on the provision of a public good often suffer low participation. We apply a game theoretical approach to analyze GEOSS as a research coalition with varying spillover rates, in order to figure out whether a coalition with full participation can exist in equilibrium. We also focus on the question how varying spillover rates influence the size of the equilibrium coalition and suggest two measures, which can increase participation in equilibrium. The revision of the literature shows that the full participation is socially optimal and spillovers which take the form of strategic complements can lead to a high level of cooperation. Also measures like the linkage of negotiations and the formation of multiple coalitions can achieve a high level of participation.

Designing of research coalitions in promoting GEOSS. A brief overview of the literature[1]

Christine Heumesser[2]

1 Introduction

The Global Earth Observation System of Systems (GEOSS) is a very needed and timely effort to adress a range of global environmental challenges. Climate change, biodiversity loss, pollution, resource depletion, - to name a few, have become key factors, which influence many aspects and concerns of the public and human wellbeing. Under the auspice of the Secretariat of the Group on Earth Observations (GEO), GEOSS bundles sophisticated new technologies to collect a vast quantity of purposeful, high resolution Earth observation data, - an immense amount of data about air, water, and land measurements on various time and spatial scales from numerous land-based stations, floating buoys, and orbiting satellites, which ultimately shall be made available publicly or at low cost. GEOSS links a variety of existing and future observation systems and forecasting models, which are developed or provided by 42 task groups, into one comprehensive system of systems to provide accurate environmental data, to enhances the relevance of Earth observation for environmental problems, and to enable an encompassing vision and understanding of the Earth system, and supports policymakers, scientists and many other experts and decision-makers [cp.www.earthobservations.org].

The coordination and implementation of GEOSS lies in the responsibility of GEO, which was called into being after the 2002 World Summit on Sustainable Development and by the Group of Eight (G8). GEO has established a 10-year implementation plan for the Period 2005-2015, which outlines the vision, purpose and expected benefits of GEOSS. The benefits are categorized in nine societal benefits areas (SBA): disaster, health, energy,

[1]This discussion paper resulted from my engagement in the project 'Global earth observation - benefit estimation: now, next and emerging' (GEO-BENE) funded by the European Commission. http://www.geo-bene.eu

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climate, water, weather, ecosystems, agriculture and biodiversity, for which certain targets, like the improved understanding of climate variability, the water cycle, biodiversity loss etc. have been established. As of July 2009, GEO's Members include 79 Governments and the European Commission and 56 intergovernmental, international, and regional participating organizations [cp.www.earthobservations.org].In the course of the discussion paper they will be referred to as agents or countries.

Despite of the common aim to implement GEOSS and provide better information for better decision making, the public good character of these endeavours remains, such that the problems and challenges of GEOSS can be depicted as the cooperative efforts of a research and development (R&D) coalition. In games of R&D cooperation, firms undertake R&D investment to reduce their production cost and develope a strategic advantage over their competitors in the market. Thereby they produce information spillovers, which take the form of leaks, personnel movements, faulty patents [Yi and Shin (2000)], such that competitors benefit from research without paying. Depending on the extent of spillovers, the incentives to procure future investments are reduced; or put differently, give rise to the idea to form a R&D coalition as to internalize the positive spillovers. Members of a R&D coalition decide jointly on their investments taking each others' spillovers into account. This increases the country's profitability and the needless duplications of efforts can be avoided such that research investments and profits are expected to increase adverse to the non-cooperative situationHowever, spillovers to non-participants remain and strongly govern the size of the resulting research coalition, and ultimatly jeopardize the emergence of an industry wide, socially optimal coalition [Poyago-Theotoky (1995)].

GEOSS puts a similar problem on trial. The information and data compiled by individual efforts and investments enable the respective agent or country to implement policies and guidelines which are environmentally efficient, to generate forecasts, or to publish research results to heighten international prestige in a specific area. These information and data are excludable and therefore similar to club goods, but most of the implemented policies concern the utilization and conservation of the environment and natural resources, which are public goods.Benefits derived by the implementation of these policies can be described as private benefits, because the respective agent or country achieves cost advantages by implementing environmentally

friendly policy in a specific national context, by being able to mitigate environmental degradation or by preventing major damage by disaster due to improved forecast mechanisms. It could be argued that by realizing these measures a country could achieve a strategic advantage in the international community.[3] However, by conducting and publishing research, implementing a policy, or realizing a project in the course of bilateral cooperation, spillovers to other parties exist. This is even more apparent when the results are broadly applicable and not specific to the agent's interest. The information spill over to third parties enables them to increase their private benefits and decrease the gap to the competitors in the international community. As a consequence the incentive to invest in these services decreases.
GEOSS, as a research coalition, could function as a remedy to the problem and allows countries to share national data, information systems, or even new technologies on a common platform and to internalize the reciprocal spillovers. The results of this discussion paper confirm this intuition. For a certain spillover rate, profits of coalition members will exceed profits of non-members or profits in a non-cooperative situation. Also a large coalition will yield higher social welfare than smaller coalitions and full cooperation in research maximizes social welfare. The size of the equilibrium coalition depends on the spillover rate.

1.1 Research Objectives & Outline

This discussion paper reviews literature of the branch of Coalition Theory with regards to the formation of research coalitions. The aim is not only to portray the process and challenge of research coalition formation, but also to introduce a set of incentives which could help to overcome the obstacles of spillovers and favour the formation of larger and socially optimal coalitions. The following questions, which are tangent to the challenges and problems of international cooperation in the presence of positive spillovers are central to the analysis:

- In an environment with positive externalities, can a stable grand R&D

[3] I adopt the realist perspective among the theories of international relations and assume that the international system works without an regulatory instance such that states, as central actors of the system, constantly struggle for their survival and hence welfare and profit maximization in an hostil environment. Under these circumstances cooperation is hard to achieve, unless the individual terms are very favourable and profit because states do not trust each other [http://www.weltpolitik.net/; November 2007]

coalition exist which is a social optimum? Which incentives for the formation of a socially optimally sized coalition are given?

- How do spillovers influence the size of the equilibrium coalition?
- Given that coalitions in an environment with positive spillovers tend to be smaller than the socially optimal size, which measures could be integrated in the design of a research coalition to favour broader participation?

The discussion paper is structured as follows: In Section 2 *Formation of Research Coalitions with Positive Spillovers* I present the results of Yi and Shin (2000) who deal with a model of endogenous coalition formation.[4] The model is of rather general nature and provides a framework to understand coalition formation under positive spillovers, assuming an identical intra-coalition or, depending on the amount of coalitions in the equilibrium, inter-coalition spillover rate. They investigate properties of the profit function in a game of R&D cooperation which support the formation of stable coalition structures. Section 3 *Peculiarities of Research Coalitions with Positive Spillovers*, specifies the properties of a R&D coalition. Poyago-Theotoky (1995) introduces a linear-quadratic Cournot oligopoly game to compare the level of cost reduction achieved in a situation of non-cooperation, cooperation, and when an efficient social planner is at work. The results imply that cooperative efforts always exceed non-cooperation. Furthermore, the notion of strategic complements and substitutes with regards to information

[4]Endogenous coalition formation implies that each country has an option to join a coalition or not; hence, the coalition structure is not given exogenously, instead it depicts the outcome of a game. The players accession decision depends on the benefits derived from joining the coalition and the stability of the coalition structure [Yi, 2003, p.81]. According to Hart and Kurz (1983), who provide a comprehensive analysis of endogenous coalition formation, a stable coalition structure can be found by evaluating and comparing each players expected payoff in each possible coalition structure. They consider the entire coalition structure rather than just the individual coalitions because each players payoff depends on the way the other participants are organized. In some situations players might find it convenient to join a coalition, in others they prefer to act separately; all this depends on the configuration of the coalition structure. This implies equally that the overall outcome, the actions of all players in the coalition structure, must be efficient [Hart and Kurz (1983)]. However, the rules of coalition formation, whether only a single or multiple coalitions can form, and whether membership is open or exclusive, are given exogenously [Finus (2003)].

spillovers are explained, and how they affect the size and stability of the equilibrium coalition. The intra-coalition spillover rate is assumed higher than the inter-country/coalititon spillover rate. The results show that spillovers have to be strategic complements to achieve the desired results of high participation. However, the equilibrium size coalition hardly ever coincides with the social optimal size of the coalition. In Section 4 *Expanding a Research Coalition with Positive Spillovers* two suggestions to overcome the problem of free-riding on cooperation, or rather the refusal to enlarge the coalition sufficiently and enhance cooperation are introduced. Based on the framework introduced in Section 3, I introduce the concept of linkage of negotiations to increase participation. The idea is based on the results of Poyago-Theotoky (1995) that members of an equilibrium coalition loose from further expansion of the coalition. Hence, they need to be compensated for instance by externally provided subsidies or, as introduced here, by endogenously linking the public good coalition to a club good agreement. On the basis of the papers by Carraro and Siniscalco (1995, 1997) I present the linkage of the R&D coalition to a trade coalition as to achieve full or nearly full participation. The second proposition stems from Yi and Shin (2000) who suggest multiple coalition formation under two differing membership rules to achieve broader participation. They speak of endogenous coalition formation and investigate the equilibrium coalition structure which emerges under different membership rules. The idea is that by allowing the formation of several coalitions, according to the specific interest of countries instead of focusing only on the formation of one partial or grand coalition, more countries can be motivated to engage in cooperation and to share their data and information. Finally, in Section 5 *Summary and Conclusion* the major results are highlighted and concluding remarks are given.

2 Formation of Research Coalitions with Positive Spillovers

What are the conditions for a stable coalition to exist in an environment with positive externalities? This question will be investigated in the course of a two-stage non-cooperative game amongst n agents. Following rational applies: Countries undertake research to generate a set of improved data and information on the state of the earth, particularly in their national territory

or field of interest, to implement better policies to take 'better' decisions. Consequently, the amount of disseminated and employed data is assumed to be equal to the conducted research.
There are n ex-ante symmetric countries, which at most can form one non-degenerate coalition. In the *first stage* of the game countries choose their level of research, respectively the level of released national data; in the *second stage* they engage in Cournot competition where coalition members maximize their aggregate coalition payoff and non-members their individual payoff. The latter payoff is the second stage Cournot outcome minus the R&D expenditures incurred in the first stage. For simplicity, policies are assumed to be homogenous among all countries; but the implementation costs vary with the amount of data and information available. The more data available, the better the final policy decision and the lower the implementation costs. Cost reduction has diminishing returns [Poyago-Theotoky (1995)].
The agents have at least two possibilities: They can act non-cooperatively and choose their R&D efforts and their policies independently as to maximize their individual payoffs. When deciding on their R&D investment they take other countries' R&D expenditures as given. Secondly, countries can act cooperatively and form a R&D coalition with $k \leq n$ members. Coalition members choose their R&D expenditures and paths cooperatively as to maximize their joint profit. They decide independently on the amount of policies and decisions implemented [Poyago-Theotoky (1995)].
The parameter β denotes the degree of information spillover between countries. Usually the intra-coalition spillover β^c is assumed to be one, whereas the inter-country spillover from the coalition to the non-members and vice versa, takes a value $0 \leq \beta^o \equiv\leq 1$; $\beta^o \equiv \beta$ [Poyago-Theotoky (1995)]. This property is applied in Section 3. The general framework introduced in this section and the analysis of Yi and Shin (2000) in Section 4 assume an identical intra-coalition and inter-country/inter-coalition spillover rate, $\beta^o = \beta^c$.
x_i depicts country i's R&D investment; where $\mathbf{x} \equiv (x_1, ...x_n)$ is the investment vector, and $X \equiv \sum_{i=1}^{n} x_i$ be total R&D investment. The profits depend only on the individual investments and on the aggregate investment and is thus $V^i(\mathbf{x}) \equiv V(x_i, X)$. The countries' profits are concave in x_i. Coalition members choose their R&D investment as to maximize their joint profits $\sum_{i=1}^{k} V(x_i, X)$ [Yi (2003)].

The next subsections introduce assumptions on the profit function and the equilibrium coalition structure.

2.1 Coalition Structure and the Amount of R&D Investment

Assumption 1. $V_X(x_i, X) > 0$

This assumption by Yi and Shin (2000) captures the public good nature of research investment. An increase in a country's R&D investment generates positive spillovers and raises other countries' profits. In the absence of R&D cooperation, when there is no way to internalize these spillovers countries will underinvest.

Assumption 2. *There are three points to consider:*
(a) $V_{xx}(x_i, X) + kV_{xX}(x_i, X) < 0$
(b) $V_{xx}(x_i, X) + (k + N)V_{xX}(x_i, X) + kNV_{XX}(x_i, X) < 0$
(c) $V_X(x_i, X)+kV_{xX}(x_i, X) > 0$ *and* $V_{xx}(x_i, X)-k[V_{xxx}(x_i, X)+kV_{xxX}(x_i, X)] \leq 0$ *with* $k = 1, ..., N$

Point (a) is crucial and implies that a size-k coalition's profit function is concave in member's investment, holding the other investment $(X - x_i)$ constant. Initially profits increase with investment and then decrease. (b) Whenever members of a coalition increase their investments exogenously, the industry's investments increase in the equilibrium as well. According to Yi and Shin (2000), this works as stability condition. (c) states that a large coalition's total investment is more sensitive to changes in membership than a small coalition's total investment [Yi and Shin (2000)].[5]

Assumption 3. $CS(\boldsymbol{x}) = CS(X)$ *and* $CS_X(X) > 0$

Consumer surplus (CS) depends only on the total worldwide R&D investments; an increase in total R&D investments raises consumer surplus. Hence, the more countries cooperate, the more R&D will be generated to raise consumer surplus.

The size of the coalition and the composition of the coalition structure are decisive for the realised R&D. Yi and Shin (2000) introduce the term 'concentration of a coalition structure' to the analysis to facilitate the comparison of equilibrium coalition structures under different rules of coalition formation [Finus and Rundshagen (2003)]. They assume that coalition formation is an endogenous process and that several research coalition can co-exist and

[5]For a detailed proof see Yi and Shin (2000) Appendix A

compete in a coalition structure at a time. Where n_i denotes the size of the coalition D_i with $i = 1, ..., m$; each country can belong to only one research coalition at a time. The resulting coalition structure is $C \equiv \{D_1, D_2, ..., D_m\}$. All affected countries are identical such that only the size of the coalition matters and the structure can be described as $C \equiv \{n_1, n_2, ...n_m\}$. In cases where only one partial research coalition exists, is a special case and can be analyzed within this broader framework denoting $C = \{n_i, 1, ...1\}$.[6]
The concentration of a coalition structure plays a critical role in the analysis of a stable coalition structure and the depiction of positive externalities. The following, somehow intuitive, definition has been proposed by Finus and Rundshagen (2003, p.204)

Definition 1. *Concentration of a Coalition Structure:*
A coalition structure $C = \{n_1, n_2, ...n_m\}$ is a concentration of $C' = \{n'_1, n'_3, ...n'_{m'}\}$, where $m' \geq m$, if one can obtain C from C' by a finite sequence of moving one member at a time from a coalition in C' to another coalition of equal or larger size.

Finus and Rundshagen (2003) provide an example: A coalition structure $(6, 5)$ is more concentrated than a coalition structure $(5, 5, 1)$. Concentration allows only for a partial ranking of coalition structures. For instance $(4, 3)$ and $(5, 11)$ cannot be ranked under concentration.

According to Yi and Shin (2000) there exists a unique interior equilibrium. The per-member equilibrium R&D investment of a member in coalition n_i is $x(n_i, C)$; $X(n_i, C) \equiv n_i x(n_i, C)$ is the total R&D investment of coalition n_i and $X(C) \equiv \sum_{i=1}^{m} n_i x(n_i, C)$ is the industry investment under given coalition structure $C = \{n_1, n_2, ..., n_m\}$.
The per-member equilibrium R&D investment satisfies a set of conditions, which in turn highlight the public good character of the research coalition:

Assumption 4. *$x(n_i, C) > x(n_j, C)$ for $n_i > n_j$ in any $C = \{n_1, n_2, ..., n_m\}$.*

In any coalition structure a member of a large research coalition invests more in R&D than a member of a small coalition or a singleton coalition. A coalition member internalizes the positive externalities that its investments generates on a member countries. Hence, a member or a large coalition

[6] According to Yi (2003) this game can be denoted as Single Coalition Formation Game and is based on a paper of D'Aspremont et al. (1983), who investigate the stability of a price-leadership cartel

invests more in research than a member of a small coalition [Yi and Shin (2000)].

Assumption 5. *$X(C) < X(C')$, where C' is a concentration of C. In particular, $X(C) < X(\{N\})$ for any $C = \{n_1, n_2, ..., n_m\}$, $n_1 < N$.*

If the research coalition becomes more concentrated the industry investment increases. In particular, industry investment are highest under the grand coalition than under any other coalition structure. Larger coalitions increase their research since they internalize the positive externalities on the new members.

2.2 Coalition Structure and Countries' Payoff

The $\pi(n_1; C)$ denotes the per-member equilibrium profit of a size n_1 coalition in the coalition structure $C = \{n_1, ..., n_m\}$. The aggregate payoff of the size n_1 coalition is $n_i \pi(n_i; C)$ [Yi (2003)]. According to Yi and Shin (2000), the profit function has to fulfil three conditions which help to derive an equilibrium coalition structure. The intra and inter-coalition spillover rate is assumed to be equal.

- (P.1) $\pi(n_k; C) < \pi(n_k; C')$, where C' is more concentrated than C and $n_k \in C$ and C'.

If the coalition structure becomes more concentrated, countries which are not involved in the change of the coalition structure and remain free-riders earn higher payoffs.

- (P.2) $\pi(n_j; C) > \pi(n_i; C)$, where $n_i > n_j$ in any $C = \{n_1, n_2, ...n_m\}$.

Singleton players or small coalitions always earn a higher payoff than the coalition members, since they can free-ride on the efforts of the larger coalition in the structure. This depends also on the degree of spillovers.

- (P.3) $\pi(n_j; C) < \pi(n_j - 1; C')$, where $C = \{n_1, n_2, ..., n_m\}$, $C' = C \backslash \{n_i, n_j\} \cup \{n_i + 1, n_j - 1\} = \{n_1, ..., n_{i+1}, ..., n_{j-1}, ...n_m\}$, and $n_i \geq n_j \geq 2$.

If a member of a research coalition joins a larger or equal-sized coalition, the remaining members of the deviator's research coalition earn a higher payoff. Considering the results of Assumptions 4 and 5 that a member of a large research coalition invests more than a member of a small coalition, the above conditions on the payoff function are easily traceable. To demonstrate how these conditions work, Yi (2003) has introduced Lemma 1.

Lemma 1. *Research coalitions for internalization of R&D externalities satisfy (P.1)-(P.3) under Assumption 1 and 2.*

Again, a member of a research coalition can internalize the positive externalities its investments generate on member countries. Hence, a member of a large coalition invests more in R&D than the member of a small coalition. The members of the small coalition or the singleton players free-ride on the higher R&D investment of the large coalition, and earning higher profits due to (P.2). The same reasoning applies for coalitions which are merging or players who join a larger or equal size coalition. They increase their investment as the positive externalities of the new members are internalized. Members who are not involved in the change of coalition structure benefit by free-riding on the increased industry investment due to (P.1) and (P.3) [Yi (2003)].

2.3 Stable Coalition Structures

Yi and Shin (2000) characterize stable coalition structures under Assumption 1 and 2 as long as (P.1)-(P.3) holds:

Definition 1. *Stand-alone stability:*
The size-n_i coalition in $C = \{n_1, ..., n_i, ..., n_m\}$ is stand-alone stable iff $\pi(n_i; C) \geq \pi(1, C_i)$ where $C_i = C \backslash \{n_i\} \cup \{n_i - 1, 1\} = \{n_1, ..., n_i - 1, ...n_m, 1\}$. A research coalition is stand-alone stable if a member earns a lower profit by leaving it to form a one country coalition, and by holding the rest of the coalition structure fixed. The research coalition structure $C = \{n_1, ..., n_m\}$ is stand-alone stable iff all m coalitions in it are stand-alone stable.

3 Peculiarities of Research Coalitions with Positive Spillovers

In the previous section conditions which support coalition formation are identified. To describe the advantages of coalition formation versus the non-cooperative situation and to illustrate the forces at work to decide the equilibrium size of a research coalition, I introduce a linear-quadratic Cournot

model based on the paper of Poyago-Theotoky (1995).
The two-stage game introduced in Section 2 remains; the spillover rate takes the value $0 \leq \beta^o \equiv\leq 1$; $\beta^o \equiv \beta$. There are n identical countries which implement environmentally friendly policies. The policies are costly. Improved data and information, which stem from either individual or collective research efforts, support better policy decision making. Each level of policy Q yields a value of foregone damage P.

$$P = D - b\sum_{i}^{n} q_i$$

where $i = 1, ...n$, $b = 1$, and $D > 0$ is a constant parameter. It is assumed that there are constant returns to scale in policy implementation and the costs of policy implementation are affected by the amount of R&D that each country undertakes to generate improved data. The unit costs of policy implementation for country i are given as

$$c_i = A - z_i - \beta \sum_{i \neq j} z_j$$

where $0 < A < D$ and $z_i + \beta \sum z_j \leq A$. z_i is the cost reduction achieved by country i's research effort x_i and z_j is the cost reduction achieved by the remaining countries due to spillovers $0 \leq \beta \leq 1$. The cost of doing R&D is given by $c(z_i) = \gamma z_i^2/2$ with $\gamma > 0$. Hence, there are diminishing returns to cost reduction [Poyago-Theotoky (1995)].

3.1 Non-cooperative Case

The following results, on the basis of Poyago-Theotky (1995), resemble the n-player Cournot game. The players maximize their profits $\pi_i(q_i, q_{-i}) = p(q_{-i}, q_i)q_i - c_i q_i$ simultaneously, anticipating the produced quantity of their fellow players, q_{-i}. The second-stage Cournot profit of country i, $i = 1, ...n$, can be written as

$$\pi_i = [\frac{D - nc_i + (n-1)c_j}{(n+1)}]$$

where $i \neq j$. The unit costs of country i is given by $c_i = A - z_i - (n-1)z_j$ and for the $(n-1)$ remaining countries they are given by $c_j = A - z_j - \beta z_i - \beta(n-2)z_j$. These expressions are substituted in π_i, the expenditures of R&D

investment are deducted and the equation is maximized with respect to the country's R&D output, z_i:

$$\pi_i = [\frac{(D - A) + (n - \beta n + \beta)z_i + (2\beta - 1)(n - 1)z_j}{(n + 1)}]^2 - \frac{\gamma z_i^2}{2}$$

After this expression has been maximized with respect to z_i, $\delta\pi_i/\delta z_i$, the equilibrium value $\bar{z}$ has to be found, assuming that all countries are identical and achieve a symmetric cost reduction due to R&D:

$$\bar{z} = \frac{2(D - A)(n - \beta n + \beta)}{[\gamma(n + 1)^2 - 2(n - n\beta + \beta)(1 + \beta n - \beta)]}$$

According to Poyago-Theotoky (1995) and for $\beta = 0$, the equilibrium value of cost reduction $\bar{z}$ takes the form $\bar{z} = 2n(D-A)/\gamma(n+1)^2 - 2n$; while for full spillovers, $\beta = 1$, $\bar{z} = 2(D-A)/\gamma(n+1)^2 - 2n$, such that $\bar{z}[\beta = 0] > \bar{z}[\beta = 1]$. R&D effort is greater in the absence of spillovers. Without spillovers countries can lower their costs for implementing policies and increase their significance in the international community. They create a gap between themselves and the other countries. In the case of full spillovers R&D still reduces implementation costs and is desirable, but there exists no strategic advantage in 'being ahead' of other countries, and the R&D efforts are evidently reduced.

3.2 Cooperative Case

A k coalition is formed with $2 \leq k \leq n$. There is full information sharing among the coalition members; from the coalition to the remaining $(n - k)$ members and vice versa $0 \leq \beta \leq 1$ applies.
For simplicity, assume from now on: $z_i = z_{-i} = z$ with $i = 1, ...k$ since the member countries are identical; and $z_j = z_{-i} = \bar{z}$ with $j = 1 + k, ...n$.
For country i the unit costs of production, g, depend on the amount of R&D, z_i, it does, the amount of the other member countries z_{-i}, and the amount the remaining $(n - k)$ countries, z_j: $g = A - kz - \beta(n - k)\bar{z}$.
The unit costs h for country j, depend equally on the amount of R&D, the amount of R&D, z_{-j}, the remaining $(n - 1 - k)$ countries and the R&D of coalition members: $h = A - \bar{z} - \beta(n - k - 1)\bar{z} - \beta kz$.
The second stage Cournot profit is derived analogous to the non-cooperative

case and can be written as:

$$\pi_{i,c} = [\frac{D + (n-k)h + (k-1)g - ng}{(n+1)}]^2 \quad (3.1)$$

Hence, the R&D output z is chosen as to maximize the joint payoffs net of R&D expenditures:

$$max_z \frac{k}{(n+1)^2}[D + (n-k)h + (k-1)g - ng]^2 - (\frac{k\gamma z^2}{2})$$

The unit costs h and g are substituted and the term is rearranged to[7]

$$(D - A) = -\bar{z}(n-k)(2\beta - 1) + z[\frac{\gamma(n+1)^2 - 2k^2[(n-k)(1-\beta)+1]^2}{[2k(n-k)(1-\beta)+1]}] \quad (3.2)$$

A similar expression is derived for the remaining $(n-k)$ agents who do not participate in the coalition. The unit cost of production s for country j are dependent on the amount of R&D of coalition member i, z_i, on its own amount z_j and the amount of the remaining $(n-k-1)$ countries z_{-j}. In this case $z_i = z$, $z_{-j} = \bar{z}$, $z_j = \tilde{z}$ and the unit cost are rewritten as $s = A - \tilde{z} - \beta kz - \beta(n-k-1)\bar{z}$. Any of the remaining $(n-k-1)$ countries face unit costs t: $t = A - \bar{z} - \beta kz - \beta\tilde{z} - \beta(n-k-2)\bar{z}$. Finally, coalition members bear unit costs of v written as: $v = A - kz - \beta\tilde{z} - \beta(n-k-1)\bar{z}$. Given these assumptions of the unit costs the resulting second stage Cournot profits for non-members are:

$$\pi_{j,c} = [\frac{D + (n-k-1)t + kv - ns}{(n+1)}]^2 \quad (3.3)$$

In the first stage the non-member country chooses R&D output as to maximizes their second stage profits net of R&D expenditure:

$$max_{z_j=\bar{z}}(n+1)^{-2}[D + (n-k-1)t + kv - ns]^2 - (\gamma z_j^2/2).$$

t,v and s have to be substituted in the above expression. After the expression has been maximized after $z_j = \bar{z}$ symmetry among $\tilde{z} = \bar{z}$ has to be imposed,

[7]According to Poyago-Theotoky (1995), the second order condition requires that $\gamma > 2k^2[(n-k)(1-\beta)+1]^2/(n+1)^2$.

yielding[8]:

$$(D-A) = -k[\beta(k+1)-k]z+[\frac{\gamma(n+1)^2 - 2[n(1-\beta)+\beta][\beta(n-k)+(1+k)(1-\beta)]}{2[n(1-\beta)+\beta]}]\bar{z} \tag{3.4}$$

To get the equilibrium values of cost reduction z of coalition members and $\bar{z}$ of non-members, equation (3.2) and (3.4), have to be solved simultaneously. Poyago-Theotoky (1995) shows in the Appendix of her paper analytically for $z > \bar{z}$ that a research coalition always generates more R&D output and spends more on R&D than the non-participating countries. Countries in the coalition entirely internalise the spillover externality. The equilibrium amount of cost reduction varies with the size of the spillover rate, which is depicted in Figure 1. It is easy to see that the coalition achieves a higher total cost reduction for all β, even though cost reduction for the coalition members decreases with an increasing β. Wheras non-members enjoy an increase in cost reduction due to spillovers. Poyago-Theotoky (1995) uses numerical simluations with values: $D = 300$, $A = 50$, $\gamma = 50$, $n = 10$.[9] Each country in the coalition spends more resources, achieves a higher level of research output and gains a larger cost reduction than each of the non-cooperative countries. Each country in the coalition can perform research at a lower cost than the independent countries. Since all coalition members enjoy the same level of cost reduction they do not have a strategic advantage over each other, which increases the incentive to invest in research and achieve an even higher cost reduction. In the non-cooperative case, cost reduction increases up to $\beta = 0.5$ and decreases thereafter. The same reasoning for total cost reduction applies for the profits of the coalition members and non-members depicted in Figure 2. Members clearly enjoy higher profits than non-members, but their profits are assimilating for an increasing β.

[8] According to Poayago-Theotoky (1995) the second order condition requires that $\gamma > 2[n(1-\beta)+\beta][\beta(n-2k-1)+(k+1)]/(n+1)^2$.

[9] Poyago-Theotoky (1995) concludes that in order to obtain positive values of R$D output $\gamma > 8(n+1)^2/27$; in the case of $n = 10$ $\gamma = 35.85$; in this example round up to $\gamma = 50$.

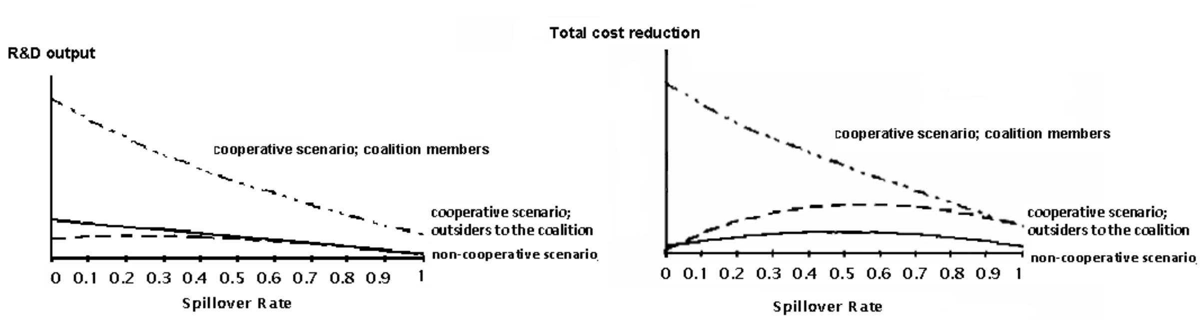


Figure 1: R&D output and total cost reduction by spillover rate β [Poyago-Theotoky (1995)].

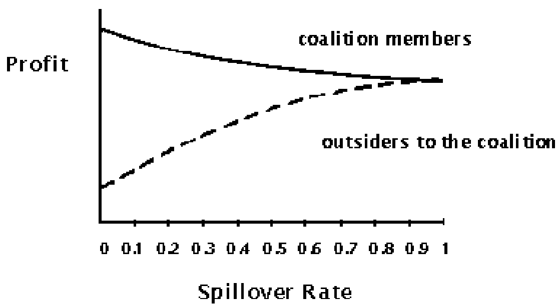


Figure 2: Profit dependend on spillover rate β in a situation of cooperation. [Poyago-Theotoky (1995)].

3.3 Socially Optimal and Equilibrium Size

In order to derive the socially optimal size k for the research coalition, a social planner maximizes the industry profits:

$$max_k[\sum_{i=1}^{k} \pi_{i,k}(\mathbf{q},\mathbf{z}) + \sum_{j=k+1}^{n} \pi_{j,c}(\mathbf{q},\mathbf{z})]$$

where $\mathbf{q} = (q_i, q_j)$ and $\mathbf{z} = (z_i, z_j)$, $i = 1, ..., k$ and $j = k+1, ..., n$. According to Poyago-Theotoky (1995) total industry payoff is convex and increasing in k for all values of β.

The equilibrium size of the coalition is chosen as to maximize the members' payoff. After all accession to the coalition is only granted as long as it is profitable.
The equilibrium size coalition k^e is that size k where no member has an incentive to deviate: $\pi_{i,k}(k^e) > \pi_{i,k}(k^e - 1)$; and no free-rider can profit by acceding to the coalition: $\pi_{i,k}(k^e + 1) < \pi_{i,k}(k^e)$. Poyago-Theotoky (1995) refers to this as a 'entry-blocking' coalition. Table 1 shows this results for the same simulation vales as before. This implies that for certain levels of

β	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
k^e	6	6	6	6	6	6	6	6	7	9	10
k^s	10	10	10	10	10	10	10	10	10	10	10

Table 1: Equilibrium k^e and optimum k^S size of the research coalition [Poyago-Theotoky (1995)].

spillovers there is not enough cooperation. Countries focus on their individual profits when blocking entry to an additional country, rather than taking into account the social profits which are maximized when entry is granted to nearly all countries [Poyago-Theotoky (1995)].

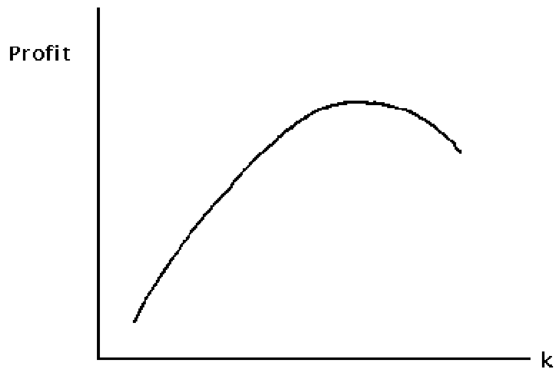


Figure 3: A schematic depiction of the coalition's profit. The profits of the coalition depend on the size of the coalition [Poyago-Theotoky (1995)]

3.4 Evaluation

Poyago-Theotoky (1995) concludes that, depending on the value of spillovers between the coalition and the non-members, three different types of equilibria exist:

- $\beta \leq 0.5$; R&D is a strategic substitute for both coalition members and non-members [Poyago-Theotoky (1995)]. Whenever the coalition increases their R&D expenses and achieves a higher cost-reduction z, the marginal profitability of the non-coalition members decreases. Their cost-reduction capability does not necessarily increase or if so at a lower rate, such that the coalition have an advantage, and vice versa [Bulow et al. (1985)].

- $0.5 \leq \beta \leq k/k+1$; R&D becomes a strategic complement for the coalition members but remains a strategic substitute for the non-cooperating countries [Poyago-Theotoky (1995)]. Whenever the coalition achieves a cost reduction z, the research effort $\bar{z}$ of the non members does not necessarily increase or remains the same, whereas whenever the non members achieve a cost reduction, the coalition profits as well [Bulow et al. (1985)].

- $k/k + 1 < \beta < 1$; R&D is a strategic complement for all coalition members [Poyago-Theotoky (1995)]. While coalition members achieve a cost reduction, the non members achieve just the same reduction of costs. According to Yi and Shin (2000, p.248), this case favours coalition formation and (P.1)-(P.4)[10] hold for β close to 1. Furthermore the results of Section 2 and Section 4.1 apply.

Finally the question on the effect of the spillover rate on the equilibrium size of the coalition remains. According to Poyago-Theotoky (1995), the profits of an individual coalition member are usually increasing and concave in k, for all values of spillovers, reaching a coalition size of $k < n$. Expanding the research coalition has two effects: As the number of members increases a given R&D expenditure is spread among countries, lowering the cost of R&D and increases per country profit. On the other hand, increasing the coalition by granting access to a member that has a lower R&D productivity and a smaller cut back of production cost means sharing the market with a less

[10] For a definition of (P.4) see Section 4.2.2

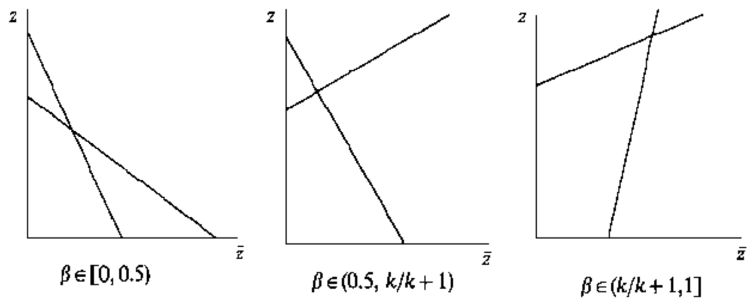


Figure 4: These graphs illustrate how cost reduction depends on the size of the positive externalities. z refers to the cost reduction of coalition members, $\bar{z}$ refers to cost reduction of non-members and β refers to the spillover rate outside the coalition [Poyago-Theotoky (1995)]

efficient co-venturer. This presses down the average profit and explains the concavity of the per country payoff.
Considering β takes the form of a strategic substitute: There are not sufficient spillovers and the gap between the coalition and the non-coalition members is quite large. Hence, allowing a non-member to accede will dreadfully press the average payoff of the coalition members. The coalition will block entry and the equilibrium size of the coalition will be a lot smaller than the optimal size.
When spillovers take the form of a strategic complements, then an increase in R&D investment of the coalition will also benefit the non-coalition members. The gap between the non-members and members is not sufficiently large and expanding the coalition will not jeopardise the per member payoff. The equilibrium size and optimal size eventually coincide.
Yi and Shin (2000) conclude:

Lemma 2. *Assumptions 1-3 hold in the linear-quadratic model of cost-reducing R&D in Cournot oligopoly for $\beta > 0,5$ and $b\gamma > 2$.*[11]

Thus, β has to take the form of strategic complements to support successful coalition formation.

Data and information of the GEOSS members rather take the form of strategic complements; national information can be used complementary and

[11] Yi and Shin (2000) provide the proof in Appendix B of their paper

also the quantity of information can lead to better policies and results, such that there is a chance that the coalition will be rather large and profitable. Nevertheless β can reflect the willingness to disseminate data and information and can take a rather low value, such that the question remains: which incentive system has to be given to increase the coalition or trigger existing members to increase the spillover rate to eventually reach a social optimal size? This question will guide the third part of the working paper.

4 Expanding Research Coalitions with Positive Spillovers

The equilibrium size of research coalitions in games with positive externalities depends on the degress of spillovers. In environmental coalitions the behaviour of free-riders is decisive for the coalition size, which is usually smaller than the socially optimal size.[12] The equilibrium derived in research coalitions is of the 'entry blocking' type. It forms where one more member decreases the payoff of the current members [Poyago-Theotoky (1995)]. As to increase the size of research coalitions various measures have been proposed. Subsidies are usually suggested, which compensate the coalition members for incurring the cost when granting access to one more member. Nevertheless, subsidies are usually assumed to be externally implemented.

In this section, I introduce some results of Carraro and Siniscalco (1995, 1997) who have introduced an endogenous possibility to increase the size of a club good coalition. Linking the research coalition to a, for example, free trade agreement, which is of exclusive nature, could compensate the initial coalition members for expanding the coalition.

Another interesting proposition stems from Yi and Shin (2000), who suggest

[12] Environmental coalitions deal equally with the production of a public good i.e. clean air, decrease environmental degradation; hence, bear the similar characteristics as the framework in Section 2. They can be equally depicted as two-stage games; where in the first stage membership is decided and in the second stage the payoff is maximised, i.e.: the optimal emission vector is decided. The public good nature of environmental coalitions makes them prone to free-riding. Whenever the reaction function of free-riders takes the orthogonal form, and the free-riders display supportive behaviour for the coalition and merely enjoy the fruits of cooperation, even full cooperation could be achieved; whereas, non-orthogonal free-riding,- whenever free-riders offset the efforts of the coalition by i.e. increasing emissions, decreases the profits of cooperation and yields a rather small coalition [Carraro and Siniscalco (1995, 1997)].

to increase the number of members by allowing the formation of multiple coalitions. To achieve this, they transform the previously assumed club good game with two different spillover rates, one for coalitions members ($\beta^c = 1$) and for outsiders ($0 \leq \beta^o \leq 1$), into a public good game by discarding the assumption that the spillover rate inside and outside the coalition varies. Hence, $\beta^c = \beta^o \equiv \beta$, the spillover rate is either equal or nearly equal. Here the typical Prisoners' Dilemma free-rider logic applies, where free-riders gain a higher payoff than coalition members and are therefore unwilling to join the coalition. Incentives have to be provided to make accession to the coalition attractive for free-riders.

4.1 Linkage of Negotiations

Carraro and Siniscalco (1995, 1997) suggest designing a negotiation mechanism in which countries do not only negotiate on the public good issue, i.e. the emission abatement, but also on another interrelated issue.
Similarly, in the previsous section Poyago-Theotoky (1995) has shown that an equilibrium coalition in a club good game on R&D cooperation is usually smaller than the socially optimal size for $\beta < 1$. The coalition members' profits decrease due to low productivity of an additional member. To increase the coalition and reach the socially optimal size of full participation, the inital members have to be compensated for the loss incurred when granting access to one additional member. This could be achieved by linking the R&D agreement to another club good agreement, i.e. a trade agreement which opens a new market for the coalition members. Besides the profit derived by nationally implemented policies and decisions taken on the environment and natural resources and the spillover rate of other countries, there exists an industry with firms who act according to the country's legislation. Suppose in each country resides one firm which produce an homogeneous good and which is granted access to the newly developed market. Further consumers' demand is stimulated by their wellbeing. As it has been subject to recent research, wellbeing is heavily linked to the natural environment with a focus on parks, forests, gardens etc.[13], whose conservation and utilization depends on the implemented policies and decisions made due the research coalition. Profits in the trade coalition are humped-shaped; initially increasing with an additional member, then decreasing. By selling more goods to more consumers

[13] Compare Newton (2007)

the profits can be increased and a strategic advantage over the non-member firm/countries can be singled out.Clearly, the more countries accede to the coalition this advantage decreases and due to more competition, the price decreases as well which affects profits.

According to Carraro and Siniscalco (1995), two negotiations are linked when signing the first agreement is conditional on signing the other one, and vice versa. The linkage thus changes the rules of the game, the strategy space and the payoff functions. Now $P^1(j_1^*)$, in the previous section $\pi_{j,c}$, is the payoff of the j_1^* countries which join the R&D agreement and $Q^1(j_1^*)$ is the payoff of the non-signatories. Similarly, $P^2(j_2^*)$ and $Q^2(j_2^*)$ are defined for the trade agreement. The payoff of the countries signing the joint agreement is $P^u(j_u^*)$, and of the non-signatories $Q^u(j_u^*)$. The set of signatories is defined as J^1, J^2, J^u and J_0^1, J_0^2, J_0^u is the set of non-signatories.
A coalition is profitable when $P^k(j_k^*) \geq 0$ for $k = 1, 2, u$ [Carraro and Siniscalco (1995)]. According to Poyago-Theotoky (1995), a stable equilibrium size coalition j^e is that size j where no member has an incentive to deviate: $\pi_{i,j}(j^e) > \pi_{i,j}(j^e - 1)$; or to let one more country accede to the coalition: $\pi_{i,j}(j^e + 1) < \pi_{i,j}(j^e)$. Poyago-Theotoky (1995) refers to this as 'entry-blocking' coalition because profits decrease when access to one addition member is granted. Carraro and Siniscalco (1995) analyze the expansion of the coalition and consider $J^1 \in J^u$:

Definition 2. *Linking two negotiations increases the dimension of the stable environmental coalition if $j_u^* > j_1^*$. The move to a larger stable coalition is profitable for the j_1^* countries belonging to the stable research coalition if:*

$P^u(j_u^*) \geq P^1(j_1^*) + P^2(j_2^*)$ *when* $J^1 \in J^u$, $J^1 \in J^2$
$P^u(j_u^*) \geq P^1(j_1^*)$ *when* $J^1 \in J^u$

The linkage occurs when it increases the welfare of the signatories vis-a-vis the case of separated negotiations. It may not be Pareto-optimal, and countries which do not sign the agreement may loose with respect to the situations in which they belonged to one of the two agreements. Carraro and Siniscalco (1995) consider the signatories of the second agreement:

Definition 3. *The welfare of countries which do not belong to the research agreement, but belong to the other one, does not decrease when the joint coalition is formed if:*

$P^u(j_u^*) \geq P^2(j_2^*)$ *when* $J^2 \in J^u$
$Q^u(j_u^*) \geq P^2(j_2^*)$ *when country* $i \in J^2$, $i \notin J^u$

To achieve Pareto-optimality, the joint coalition must not decrease the welfare of those countries who did not belong to any coalition. Q_0 is the payoff of these countries before the coalition is joined and Carraro and Siniscalco (1995) conclude:

Definition 4. *Linking two negotiations is Pareto-optimal if the conditions of Definition 2 and Definition 3 hold and if:*

$P^u(j_u^*) \geq Q_0$ *when* $J_0 \in J^u$
$Q^u(j_u^*) \geq Q_0$ *when country* $i \in J_0$, $i \notin J^u$

Proposition 1. *If* n*, the number of negotiating countries, is the dimension of* J^2 *and* J^u*, which implies that all countries join the second and the joint agreement, and if* $P^u(n) \geq P^1(j_1^*) + P^2(n)$, $j_1^* < n$*, then the linkage of the two negotiations expands the research coalition and is Pareto-optimal.*

Proof: By assumption $j_u^* = n > j_1^*$, which implies that the linkage expands the environmental coalition. $P^k(j_k^*) \geq 0$, $k = 1, 2, u$, by the profitability condition, hence, $P^u(n) \geq P^1(j_1^*) + P^2(n) > 0$. $J^u = J^2$ and J_0^1 is empty, there exists no non-signatory. This makes only following conditions relevant:
$P^u(j_u^*) \geq P^1(j_1^*) + P^2(j_2^*)$ when $J^1 \in J^u, J^1 \in J^2$
$P^u(j_u^*) \geq P^1(j_1^*)$ when $J^1 \in J^u$
$P^u(j_u^*) \geq P^2(j_2^*)$ when $J^2 \in J^u$ (Q.E.D.)

Through linkage of two issues countries in the R&D coalition are compensated for the effort to let one more country join their coalition.Due to the very simplified framework, the specific shapes of the results of the linkage in reality are unclear. However, following aspects shed light on how issue linkage could manifest in reality.
Trade effect: The trade coalition enables access to a broader market such that firms' profits, market share, and consumer surplus increase, but decreases as j approaches n. Suppose only the initial members of the R&D coalition accede to the trade coalition. Under these circumstances full cooperation can be achieved when the payoffs of the trade coalition compensate the R&D members sufficiently. If each newly entered member of the research coalition enters the trade coalition as well, the profits of the trade coalition

decrease and coalition members are not suffciently compensated for expanding the coalition further. In this case, the resulting expanded coalition might be smaller than when only initial members are in the trade coalition.

Welfare effect: The welfare effect demonstrates that research coalition with full membership maximize social and environmental welfare, which in turn has a positive influence on consumers' wellbeing and purchase capacity, which positivley influences the results of the trade coalition.

Environment effect: The environmental effect shows that an increase in production and trade harms the environment and negativly affects natural resources. On the other hand, the policies implemented by GEOSS help protect the environment.

The interplay of these effects determines the outcome of issue linkage. Linkage of negotiation is a powerful tool to adress the expansion of a coalition. There is a risk of increasing complexity and unintended consequences. Hence, the concept should preferably be applied to bilateral negotiations, when issues can be chosen carefully such that they are roughly offsetting. This requires further that countries have complementary needs, otherwise the agreement will not come into force [Cesar and de Zeeuw (1996), p.160].

4.2 Multiple Coalition Formation

Yi and Shin (2000) allow for the endogenous formation of multiple research coalitions given various rules of coalition formation. Allowing for multiple coalitions to form in the equilibrium acknowledges the heterogeneity of countries, which have different interest and might be more agreeable to the idea to form a coalition with a like-minded group of countries with i.e. similar environmental problems and research foci.

Yi and Shin (2000) assume an intra-coalition spillover rate equal to the inter-country/inter-coalition spillover rate. Hence, they discard the club good nature of a research coalition and apply the framework outlined in Section 2. The individual benefits are simply derived by internalizing the research results without giving importance to the strategic advantage. A strategic advantage emerges by appropriating private benefits due to information or research which is exclusively accessible for the coalition members. Here, the reasoning of the game changes and agents are facing a public good problem,because policies on the environment provide a public good, which inflichts equal spillovers on all agents. Apart from the fact that policies are of

public good nature, the realised projects and decisions can equally be copied by non-members without having to incur the effort of being in the coalition and sharing data. In this analysis only the sum of policies plays a role and affects the country's individual payoff. Outsiders to the coalition enjoy a higher payoff (composed by the policies implemented by the coalition members and the policies they can implement given the knowledge of the other countries). The model is in accordance with the model of Poyago-Theotoky (1995) for a spillover rate close to one, hence for strategic complements. Strategic complements still imply that the more countries are willing to share their data, the better the response will be.
Yi and Shin (2000) introduce two different membership rules for a game of multiple coalition formation and present the resulting equilibrium structures for $0.5 < \beta \leq 1$. The framework is in accordance with the assumptions outlined in Section 2.

4.2.1 Exclusive Membership Game

The idea of the so-called exclusive membership game stems from Hart and Kurz (1983) who refer to it as Δ-Game. According to Yi and Shin (2000), the idea of the game is the following: Each country announces simultaneously a list of players with whom it is willing to form a research coalition; the countries who announce exactly the same list of members belong to the same coalition. Country i's strategy is to choose a set of players S^i, a subset of $S \equiv \{P_1, P_2, ..., P_N\}$ where P_i denotes country i. Given the countries' announcements $\alpha \equiv (S^1, S^2, ...S^N)$, the resulting coalition structure is $C = \{D_1, D_2, ..., D_m\}$, where country i and j belong to the same coalition D_k if, and only if, $S^i = S^j$; that is they choose exactly the same list of players. For example, if $\alpha = (\{P_1, P_2\}, \{P_1, P_2\}, \{P_3\}, \{P_3, P_4\})$ the resulting coalition structure is $C = \{2, 1, 1\}$ and country 1's and country 2's payoff are $\pi(2; \{2, 1, 1\})$ whereas country 3's and country 4's payoff equal $\pi(1; \{2, 1, 1\})$. Country 4 cannot join country 3 without its consent, whereas country 3 can join country 4's singleton coalition [Yi and Shin (2000)].
To derive an equilibrium, Yi and Shin (2000) employ the above introduced conditions on the payoff function and further assume,- in contrast to the previous chapter, an uniform spillover rate.
The first step is to show that at least one stand-alone stable Nash equilib-

rium[14] can exist:

Proposition 2. *$C = \{n_1, n_2, ...n_m\}$ is a Nash equilibrium coalition structure if and only if it is stand-alone stable. Since $C = \{1, 1, ..., 1\}$ is stand-alone stable by definition, a Nash equilibrium coalition structure exists in this game.*[15]

Suppose C is stand-alone stable and is supported by following strategy profile: $\alpha = (S^1, S^2, ...S^N)$ where $S^1 = ... = S^{n_1} = \{P_1, ..., P_{n_1}\}$ and $S^{n_1+1} = ... = S^{n_1+n_2} = \{P_{n_1+1} = ..., P_{n_1+n_2}\}$ and $S^{t+1} = ...S^N = \{P_{t+1}, ...P_N\}$ where $t = N - \sum_{i=1}^{m-1} n_i$. In this scenario no country can join another research coalition by individual deviation. The only feasible deviation is to continue as a singleton. Since C is stand-alone stable no country can gain by leaving the coalition. Otherwise, if C is not a stable coalition structure and supported by any strategy profile, then if country j changes her announcement to $\{P_j\}$ the coalition structure turns into $C_i \backslash \{n_i\} \bigcup \{n_i - 1, 1\}$ and country j is better off due to (P.2) and $\pi(1; C_i) > \pi(n_i; C)$.
To obtain sharper predictions about stable coalition structures Yi and Shin (2000) introduce the equilibrium concept coalition-proof Nash equilibrium (CPNE)[16]. A Nash equilibrium is immune against individual deviations and a coalition-proof Nash equilibrium is immune against deviations which are self-enforcing and are not subject to further deviations. Coalition proofness imposes a consistency requirement on the game and rules out all non-credible threats [Finus and Rundshagen (2003)].
The following Lemma, proposed by Yi and Shin (2000), supports the understanding of the resulting equilibrium coalition structures.

Concerning the notation: $I(N/k)$ denotes the higher integer to N/k including N/k ($I(2.5) = I(3) = 3$) and $\{a_p, b_q, ..., h_w\} = \{a, ...a, b, ...b, h, ...h\}$ where there are p entries of a, q entries of b etc. [Yi and Shin (2000)].

Lemma 3. *$C = \{k_{m-1}, r\}$ is more concentrated than $C' = \{n_1, n_2, ..., n_{m'}\}$, where $m = I(N/k)$, $r = N - (m-1)k$, and $k \geq n_1 \geq ... \geq n_{m'}$.*[17]

Coalition structure $\{k_{m-1}, r\}$, where the number of research coalitions is given by $m = I(N/k)$ and $r = N - (m-1)k$, is the most concentrated

[14]For a definition of Nash equilibrium see Appendix A.
[15]For the detailed proof consult Yi and Shin (2000) Appendix A.
[16]See Appendix A for definition.
[17]The proof is provided in Appendix A of Yi and Shin (2000).

research coalition structure with the size of the largest coalition less than or equal to k. According to Yi and Shin (2000), following proposition states conditions which help to identify a coalition-proof Nash equilibrium:

Proposition 3. *Suppose that* $C^* \equiv \{k^*_{m^*-1}, r^*\}$ *is stand alone stable, where* $m^* = I(N/k^*)$ *and* $r^* = N - (m^* - 1)k^*$ *with* $1 \leq r \leq k^*$. *The size-*k *coalition is not stand-alone stable in any research coalition structure for all* $k = k^* + 1, ...N$. *Then in the Exclusive Membership game:*

1. C^* *is the most concentrated Nash equilibrium coalition structure under (P.1)-(P.3).*

2. C^* *is a coalition-proof Nash equilibrium structure.*

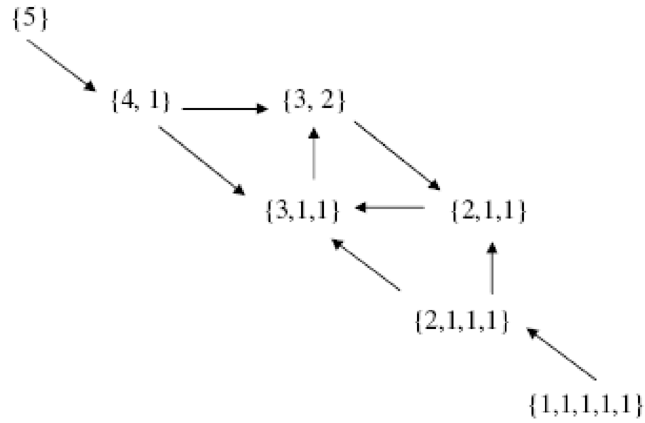
3. *If there is any other coalition-proof Nash equilibrium coalition structure, it has exactly* m^* *research coalitions and is less concentrated than* C^*.

4. *If* $r^* = k^* - 1$ *or* k^*, *then* C^* *is the unique coalition-proof Nash equilibrium coalition structure.*

A detailed proof is conducted in Appendix A of Yi and Shin (2000) and a short demonstration of *(3)* is provided in Appendix B of this paper. Focusing on the intuition, Yi and Shin (2000) conclude that *(1)* is based on the hypothesis that no research coalition with the size of the largest research coalition greater than k^* is stand-alone stable. In any Nash equilibrium coalition structure the size of the largest research coalition is less than or equal to k^*.(2)indicates that C^* constitutes a CPNE because any deviation which creates a bigger coalition than k^* is not self-enforcing. The deviation would not constitute a Nash equilibrium among the deviators. Any other deviation is not profitable due to stand-alone stability and the conditions of the profit function (P.1)-(P.3).

Nevertheless, a size-k coalition with $k > k^*$ can emerge and be stand-alone stable such that a coalition-proof Nash equilibrium may fail to exist. Yi and Shin (2000) propose following example as to illustrate a situation when a coalition-proof Nash equilibrium may fail to exist in an Exclusive Membership game:

Example 1: An arrow pointing from one coalition structure C to another coalition structure C' implies that there is one member country which becomes better off by changing its membership to some coalition in structure C'.



$\{4,1\} \to \{3,2\}$ implies that $\pi(4;\{4,1\}) < \pi(2;\{3,2\})$. This example is in accordance with (P.1)-(P.3) but violates Proposition 2, because $C^* = \{2,2,1\}$ but $\{3,1,1\}$ is stand-alone stable: no coalition member has an incentive to play as a singleton. According to this concept there are four Nash equilibria: $\{3,1,1\}$, $\{2,2,1\}$,$\{2,1,1,1\}$ and $\{1,1,1,1,1\}$. From $\{2,2,1\}$,$\{2,1,1,1\}$ and $\{1,1,1,1,1\}$ three countries could make a profitable deviation to $\{3,1,1\}$. But even $\{3,1,1\}$ does not constitute a coalition-proof Nash equilibrium structure since the singletons could join together to induce $\{3,2\}$.
Yi and Shin (2000) introduce two additional conditions on the profit function to guarantee a well-defined equilibrium $C^* = \{k^*_{m^*-1}, r^*\}$ such that a size-k coalition with $k > k^*$ is not stand-alone stable. Since theses conditions play only a limited role they are introduced in the Appendix.

4.2.2 Open Membership Game

In this game each agent announces a list of agents they want to be in a coalition with. Agents who announce the same address are in the same coalition. Again, α^i is a country's announcement. Given all countries' announcements $\alpha \equiv (\alpha^1, \alpha^2, ..., \alpha^N)$, the resulting coalition structure is $C = \{D_1, D_2, ...D_m\}$ where country i and country j belong to the same coalition if, and only if, $\alpha^i = \alpha^j$. For example, there are four countries and $\alpha = (\alpha_1, \alpha_1, \alpha_4, \alpha_3)$, the resulting coalition structure is $C = \{2,1,1\}$ where country 1 and country 2 belong to the same coalition because they have chosen the same list and country 3 and 4 play as singleton. But in this case countries 3 and 4 can join country 1 and 2 by changing their announcement from α_3 or α_4 to α_1.

Since the consent of the coalitions members is not needed to be allowed to join the coalition stand-alone stability is a necessary condition for a coalition structure to be supported as a Nash equilibrium outcome. The existence of a Nash equilibrium structure is not guaranteed in this game unless the number of countries is small [Yi and Shin (2000)].

Proposition 4. *For $N \leq 4$ a NE coalition structure exists in the Open Membership game. Under (P.1)-(P.3) the most concentrated Nash equilibrium coalition structure is the unique coalition-proof Nash equilibrium structure.*

Yi and Shin (2000) provide a proof in Appendix A of their paper. Why a Nash equilibrium may fail to exist for $N \geq 5$ is explained by previously introduced Example 1. In this case no research coalition structure can be supported as a Nash equilibrium because there is always one country who becomes better off by leaving and to join another country or to play as singleton. In this case there arises a circle among $\{3, 2\}$, $\{3, 1, 1\}$ and $\{2, 2, 1\}$. Similar to the additional conditions in Appendix B, Yi and Shin (2000) introduce a fourth condition on the profit function to prevent this circle. (P.4), which, along with conditions (P.1)-(P.3), guarantees a unique coalition-proof Nash equilibrium in the open membership game.

- (P.4) $C = \{n_1, ...n_m\}$ is stand-alone stable. If $n_1 \geq n_m + 2$, then there exists a n_j, $n_1 \geq n_j + 2$, such that $\pi(n_1; C) < \pi(n_j + 1; C')$, where $C' = C\{n_1, n_j\} \cup \{n_1 - 1, n_j + 1\}$. If the size of the largest research coalition exceeds the size of the smallest research coalition by 2 or more members, a member of the largest research coalition becomes better off by joining one of the smaller coalitions [Yi and Shin (2000)].

This conditions implies the emergence of a rather symmetric coalition structure.

Lemma 4. *(P.4) holds in the linear quadratic model of R&D competition*[18] *for $\beta > 1/2$ and $b\gamma \geq 2$.*

(P.4) also reflects the free-riding problem in coalition formation with positive externalities. A member of a larger coalition conducts more research. The country decreases her research expenditure and reduces the contribution to thw public good research by joining a smaller coalition. However, even

[18]The proof of Lemma 4 is depicted in Yi and Shin (2000) Appendix B.

though (P.4) is necessary to generate an equilibrium in this game, Yi and Shin (2000) acknowledge one drawback: (P.4) is not yet compatible with the linear-quadratic Cournot model since Assumption 1 is violated. The aggregate payoff $V(x_i, X)$ is lower under C' than under C and reduces the deviators payoff by holding the investment constant [Yi and Shin (2000)]. Finally, Proposition 4 has been established to introduce the coalition-proof Nash equilibrium under conditions (P.1)-(P.4).

Proposition 5. *Suppose that $C^{**} \equiv \{k^{**}_{m^{**}-q^{**}}, k-1^{**}_{q^{**}}\}$ is stand-alone stable, where $k^{**} = I(N/m^{**})$ and $q^{**} = m^{**}k^{**} - N(\geq 0)$. Suppose that $k_{m-q}, k-1_q$ is not stand-alone stable, where $k = I(N/m)$ and $q = mk/N$, for all $m = 1, ...m^{**} - 1$. Then in the open membership game:*

1. *Under (P.4), C^{**} is the most concentrated Nash equilibrium coalition structure and*

2. *Under $(P.1)-(P.4)$, C^{**} is the unique Nash equilibrium coalition structure.*[19]

Yi and Shin (2000) conclude that for $C = \{n_1, ..., n_m\}$, $n_1 \geq ... \geq n_m$ to be a Nash equilibrium coalition structure in the Open Membership game under (P.4), it must be that $n_1 \leq n_m + 1$ so that $C = \{k_{m-q}, k-1_q\}$ where $k = I(N/m)$, $q = mk - N$. $\{k_{m-q}, k-1_q\}$ is clearly more concentrated than $\{k_{m'-q'}, k'-1_{q'}\}$ where $m < m'$. C^{**} is the most concentrated stand-alone stable coalition structure among N symmetric coalition structures $C = \{k_{m-q}, k-1_q\}$, $m = 1, ..., N$, where $k = I(N/m)$ and $q = mk/N$. This yields $\{N\}$,$\{N/2, N/2\}$, $\{N/3, N/3, N/3\}$, $\{N/4, N/4, N/4, N/4\}$,..., $\{2, 2, ..., 2\}$, $\{2, 2, ..., 1, 1\}$, ...$\{2, 1, ..., 1, 1\}$, and finally $\{1, 1, ..., 1, 1\}$. To show that *(2)* holds Yi and Shin (2000) conclude that it is similar to Proposition 2. A group deviation to create a larger coalition is not feasible by (P.4) or by stand-alone stability.

4.2.3 Socially Optimal Coalition Structure

Proposition 6. *The grand coalition is the socially efficient coalition structure under Assumption 1 and 2.*

The entire aggregate payoff is higher under the grand coalition than under any other coalition structure. The grand coalition maximizes the entire

[19]The detailed Proof is provided in the Appendix A of Yi and Shin (2000).

aggregate payoff and consumer surplus is highest under Assumption 5 [Yi and Shin (2000)].

4.2.4 Evaluation

To accomplish a comparison of the two games, consider that $\{k_{m-1}, r\}$ denotes the most concentrated coalition structure with the largest coalition equal to k; and $\{k_{m-q}, k/1_q\}$ is the least concentrated coalition structure with m coalitions. By Proposition 2, a stand-alone stable coalition structure $C^* \equiv \{k^*_{m^*-1}, r^*\}$ is the most concentrated Nash equilibrium and the unique coalition-proof Nash equilibrium whenever $r^* = k^* - 1$ or k^*. By Proposition 4, on the Open Membership game coalition structure $C^* \equiv \{k^{**}_{m^{**}-q^{**}}, k - 1^{**}_{q^{**}}\}$ is the most concentrated stand-alone stable coalition structure.
This leads Yi and Shin (2000) to the conclusion that:

- Under Proposition 2 any Nash equilibrium coalition structure of the Open Membership game, if one exists, is (weakly) less concentrated than the most concentrated Nash equilibrium coalition structure of the Exclusive Membership game.

- Under (P.1)-(P.3) and the conditions of Proposition 3, any coalition-proof Nash equilibrium coalition structure is less concentrated than the most concentrated coalition proof Nash equilibrium coalition structure of the Exclusive Membership Game.

For both statements it is necessary to consider that stand-alone stability is a necessary condition for a Nash equilibrium to exist at all. According to Proposition 3, the equilibrium coalition structure C^* is more concentrated than any other equilibrium structure with the larger coalition of less or equal size k^*.
Further, Yi and Shin (2000) conclude that:

- Under (P.1)-(P.4) and the conditions of Proposition 2 and 4, the unique coalition-proof Nash equilibrium coalition structure of the Open Membership game is (weakly) less concentrated than any coalition-proof Nash equilibrium coalition structure of the Exclusive Membership game.

This can be deducted from the fact that $C' = \{k'_{m^*-q'}, k' - 1_{q'^*}\}$, where $k' = I(N/m^*)$ and $q' = m^*k' - N$ is less concentrated than any research coalition

structure with m^* coalitions; and, under (P.4), C' is the only candidate for a Nash equilibrium structure with m^* coalitions in the open membership game. Yi and Shin (2000) show that all in all the exclusive membership rule supports a more concentrated coalition structure as a stable outcome than the open membership rule does. Under condition (P.3) members of a small size-r^* coalition in C^* earn lower profits if they admit a new member from the size-k^*. Under assumption (P.4) a member of the size-k^* coalition wants to join the smaller coalition (this is unless $r^* = k^* - 1$ or k^* so that C^* and C^{**} coincide) and cannot be denied access due to open membership. Thus, the more concentrated C^* cannot be sustained as a Nash equilibrium outcome of the open membership game under (P.4), unless $r^* = k^* - 1$ or k^* so that C^* and C^{**} coincide.
Exclusivity of membership allows some countries to form smaller coalitions and thereby inducing other countries to form a larger coalition and provide more of the public good. This result supports Poyago-Theotoky's (1995) definition of an 'entry-blocking' coalition.
On the other hand, the Open Membership rule equalizes the coalition sizes as the members of smaller coalitions cannot block entry.

In accordance with the linear-quadratic Cournot model and conditions (P.1)-(P.4) of the profit function Yi and Shin (2000) establish two simulation for the Open and Exclusive Membership game for $N = 1$ to $N = 9$ participants and $\beta = 0.6, 0.8$ and 1. Table 2 and 3 illustrate the above stated results and show that the grand coalition is not an equilibrium outcome for $N \geq 5$ for all β and for neither of the games. High positive externalities invite free-riders to undermine the coalition's effort. Yi and Shin (2000) conclude that even without assumptions (P.1)-(P.3) the existence of a Nash equilibrium coalition structure is guaranteed in the Exclusive Membership game. For the linear-quadratic Cournot model, Table 2 lists the coalition-proof Nash equilibrium coalition structures of the Exclusive Membership game. Due to exclusivity of membership there are many Nash equilibrium coalition structures; coalition structures which are stand-alone stable. For example for $N = 6$ and $\beta = 1$ there are nine Nash equilibrium structures: $\{4, 2\}$, $\{4, 1, 1\}$, $\{3, 3\}$, $\{3, 2, 1\}$, $\{3, 1, 1, 1\}$, $\{2, 2\}$, $\{2, 2, 1, 1\}$, $\{1, 1, 1, 1, 1\}$. Further Yi and Shin (2000) conclude that as the spillover rate increases, a more concentrated coalition structure becomes stand-alone stable and a Nash equilibrium or coalition-proof Nash equilibrium outcome in both games. A higher spillover rate eliminates the underinvestment problem in a situation of non-

	$\beta = 0.6$	$\beta = 0.8$	$\beta = 1$
N=2	{1, 1}, {2}*	{1, 1}, {2}*	{1, 1}, { 2}*
N=3	{1, 1, 1}, {2, 1}, {3}*	{1, 1, 1}, {2, 1}, {3}*	{1, 1, 1}, {2, 1}, {3}*
N=4	{1, 1, 1, 1}, {2, 1, 1}, {2, 2}*, {3, 1}*	{1, 1, 1, 1}, {2, 1, 1}, {2, 2}*, {3, 1}*	{1, 1, 1, 1}, {2, 1, 1}, {2, 2}, {3, 1}, {4}*
N=5	all *C* with 3; {3, 2}*	all *C* with 3; {3, 2}*	all *C* with 3; {3, 2}*
N=6	all *C* with 3; {3, 3}*	all *C* with 3; {3, 3}*	all *C* with 4; {3, 3}*, {4, 2}*
N=7	all *C* with 3; {3, 2, 2}*, {3, 3, 1}*	all *C* with 3; {3, 2, 2}*, {3, 3, 1}*	all *C* with 4; {4, 3}*
N=8	all *C* with 3; {3, 3, 2}*	all *C* with 3; {3, 3, 2}*	all *C* with 4; {4, 4}*
N=9	all *C* with 3; {3, 3, 3}*	all *C* with 3; {3, 3, 3}*	all *C* with 3; {4, 4, 1}*

Table 2: Coalition-proof Nash equilibrium structure under Exclusive Membership rule. A coalition structure with * is a coalition-proof NE coalition structure. 'all C with k' means all coalition structures with the size of the largest research coalition less than or equal to k [compare Yi and Shin (2000)].

	$\beta = 0.6$	$\beta = 0.8$	$\beta = 1$
N=2	{2}*	{2}*	{2}*
N=3	{3}*	{3}*	{3}*
N=4	{2, 2}*	{2, 2}*	{2, 2}, {4}*
N=5	{3, 2}*	{3, 2}*	{3, 2}*
N=6	{2, 2, 2}, {3, 3}*	{2, 2, 2}, {3, 3}*	{2, 2, 2}, {3, 3}*
N=7	{3, 2, 2}*	{3, 2, 2}*	{3, 2, 2}, {4, 3}*
N=8	{2, 2, 2, 2}, {3, 3, 2}*	{2, 2, 2, 2}*, {3, 3, 2}*	{2, 2, 2, 2}, {3, 3, 2}, {4, 4}*
N=9	{3, 2, 2, 2}, {3, 3, 3}*	{3, 2, 2, 2}, {3, 3, 3}*	{3, 2, 2, 2}, {3, 3, 3}*

Table 3: Open Membership game: Nash equilibrium and coalition-proof Nash equilibrium under open Membership Rule [compare Yi and Shin (2000)].

cooperation and increases the private gains from forming research coalitions. This supports the conclusion of Poyago-Theotoky (1995), who equally derives the result that high strategic complements provide the possibility of high participation.

Given that R&D investment increases with concentration, following statement can be derived with regards to global welfare:

Proposition 7. *Under Assumption 1-3, the Exclusive Membership rule leads to higher industry R&D investment and thus higher consumer surplus than the Open Membership rule does.*

Yi and Shin (2000) add that for an analytical proof the effects of (P.4) and (P.3) are conflicting. Whenever one member deviates to a larger or equal size coalition, the deviator is worse off and the remaining members are better off. Nevertheless, their simulation results of the linear-quadratic Cournot model confirm above proposition.

5 Summary and Conclusion

The motivation for this paper was to highlight the benefits of research cooperation as well as to depict the influence and drawbacks of changing spillover rates. Firstly, I introduced the well known linear-quadratic, 2-stage Cournot model to illustrate the effects of an increasing spillover rate on research output and size of the resulting coalition. Poyago-Theotoky (1995) assumes that coalition members can internalize the fruits of their research by entirely sharing their data and information in order to take better decisions and introduce better policies. In contrast, the spillover rate from the coalition members to the non-members varies between 0 and 1. Thus, the achieved cost reduction and R&D output of coalition members will always exceed the output of non-members and also outweighs the situation where no cooperation takes place. A low spillover rate, strategic substitutes, to non-members decreases their competitiveness. In this case coalition members gain higher individual profits than in the presence of high spillovers. Consequently, full cooperation is hardly possible because coalition members are unwilling to open up their coalition to a less productive agents in apprehension that the average payoff will decrease. When spillovers take the form of strategic complements and are close to one, the competitiveness of outsiders does not lag behind significantly and a higher level of cooperation and eventually even full cooperation is possible. From a social welfare point of view, this development is desirable since the socially optimal payoff can only be achieved by the grand coalition. The increasing spillover rate reflects the trade off between a high individual payoff and low social payoff on the one hand (when the spillover rate is low), and broad participation, high social payoff but relativley small individual payoff on the other hand (when the spillover rate is high). Full cooperation is only an equilibrium outcome when $\beta = 1$.
According to this reasoning Poyago-Theotoky (1995) concludes that for any spillover rate $\beta < 1$ the size of the coalition settles at $k \leq n$; research coalitions are of entry blocking type and refuse membership to less productive

countries. To achieve a higher level of cooperation a system of incentives has to be set up to compensate the initial coalition members for allowing more countries to join the coalition or for increasing the spillover rate to one or close to one. Subsidies could be an option to compensate members of the equilibrium size coalition for the expansion of the coalition or the increasing spillover rate and to increase the private gains of coalition members. Equally it can be concluded that GEOSS needs some pioneering countries, which increase their spillover rate to a higher level to trigger the dynamics of coalition formation and eventually reach full cooperation.

On the basis of the model of Carraro and Siniscalco (1995, 1997), linkage of negotiations can be proposed as compensation mechanism for the incurred costs of expanding the coalition. This additional agreement could take the form of a trade agreement, which allows the counries to generate extra benefits.

Another proposition, which has been introduced in the second part of this discussion paper, was to change the rules of coalition formation and advocate the formation of multiple coalitions instead of only one partial coalition. Since GEOSS is composed of 42 tasks, which develop and provide monitoring systems,model and data and therefore constitute the System of Systems, the member countries are participating organisations are already grouped by interest. However, the results show that even then, full cooperation is hard to achieve. But it might be possible that by allowing the formation of several small coalitions, or tasks, more agents can be engaged to contribute to GEOSS. These concerns have been investigated by Yi and Shin (2000). They transform the linear-quadratic Cournot club good model to a linear-quadratic public good model which displays a homogenous spillover rate for coalition members as well as outsiders. Whereas Poyago-Theotoky (1995) applies varying spillover rates and speaks of an entry blocking coalition, Yi and Shin (2000) assume that non-members refuse to join the coalition because they are better off as free-riders. Yi and Shin (2000) assume a high spillover rate, with an inter-coalition spillover rate equal or nearly equal to the intra-coalition spillover rate and describe a situation when strategic complements are at work. Freely interpreted this implies that the individual payoffs are influenced by the sum of implemented policies and decisions and not by the composition of other countries research, which is reflected in the size and form of spillovers. Smaller coalitions implement fewer policies and incurr fewer costs but still internalise the gains of the higher research effort and policies of the larger coalitions. Yi and Shin (2000) introduce a set of conditions on the payoff function and introduce two games with either Exclusive or Open Membership rule. Neither of the games achieves a grand coalition for $N \geq 5$ due to high free-riding incentives. The Open Membership game,- all agents can join whichever coalition they like, leads to a rather symmetric coalition structure. Freely interpreted, this could imply that rather diversified coalitions with heterogenous agents emerge. In contrast, in the Exclusive Membership game coalitions are allowed to restrict membership, which allows them to select agents according to similar needs and ressources, for example agents who have to fight problems of desertification, or possess and manage rain forest areas. This practice allows them to concentrate their research and avoid the scattering of results by a less specialised country.

Even though these results are instructive for the design of future research agreements, they have to be interpreted with caution due to the simplified framework. The results of this discussion paper suggest that participation to GEOSS could be increased by (i) intervening in the coalition formation process and changing the rules of the formation process (e.g. by restricting membership to certain coalitions to a set of agents), (ii) offering compensations for the coalition members which contribute to the public good (e.g. offering an adequate cost recovery system), or (iii) linking GEOSS to an external agreement which allows members to generate additional benefits. These measures require the intervention of an external, coordinating institution with enforcement or sanctioning powers. This is not the case since participation to GEOSS is voluntary and non-legally binding. Consequently, full participtaion to GEOSS depends on the willingness of a set of pioneering countries and organisations who fully engage in the negotiations and release their data and information. These agents are aware of the fact that their effort and trust can contribute to greater social welfare.

6 APPENDIX

A Equilibrium Concepts

To define an equilibrium coalition structure, Finus and Rundshagen (2003) introduce two well known equilibrium concepts: Nash equilibrium and the coalition-proof Nash equilibrium.

Definition 5. *Nash Equilibrium Coalition Structure:*
Let $G = \{P, \sum = \{\sum_i\}_{i \in P}, \overline{\pi}(C(\sigma)) = \{\pi(n_i; C)\}_{i \in P}\}$ *be the first stage of the coalition formation game with countries* $i \in P$*, strategy vectors* $\sigma \in \sum$*, which resembles a proposal for a coalition, the resulting coalition structure* C *and vectors of payoff function* $\overline{\pi}$*. Let* $\widetilde{\boldsymbol{C}}(n^S, \sigma)$ *be the set of coalition structure that a subgroup of countries* n^S *can induce if the remaining countries* $j \in P \backslash n^S$ *play* σ_j*. For a fixed strategy vector* σ *defines the reduced game for a subgroup* n^S *as* $G^S_\sigma = \{n^S, \{\sum_i\}_{i \in n^S}, \{\pi(\widetilde{n}_i; \widetilde{\boldsymbol{C}}(n^S, \sigma)\}_{i \in n^S}\}$.
Then σ^* *is called a Nash equilibrium (NE) with the resulting Nash equilibrium coalition structure* C^* *if no singleton* $n^S = \{i\}$ *can increase her payoff by inducing another coalition structure:*

$$C^*(\sigma^*) \textit{ is a NE if } \forall\, i \in P \textit{ and } \forall \widetilde{C} \in \widetilde{\boldsymbol{C}}(\{i\}, \sigma^*) : \pi(n_i; C^*) \geq \pi(\widetilde{n}_i; \widetilde{C})$$

A NE requires that a coalition structure is immune to deviations by single countries. A stand-alone stable coalition structure constitutes a NE coalition structure. Finus and Rundshagen (2003) have established following definition for coalition-proof Nash equilibrium coalition structure helps to obtain sharper predictions on equilibrium coalition structures. Coalition-proofness rules out non-credible deviations, such that a coalition structure can only be challenged by self-enforcing deviations. Coalition-proofness considers deviations of subgroups of countries but also includes the special case of deviations by singletons, such that a CPNE can be considered as subset of NE.

Definition 6. *Coalition-proof Nash equilibrium Coalition Structure:*
For $P = \{1\}$ α_i *is a coalition-proof Nash equilibrium if, and only if, it is a Nash equilibrium. Assuming that* $|P| = n > 1$ *and that coalition-proof Nash equilibrium coalition structures have been defined for all* $m < n$*. Then:*
α *is self-enforcing if, and only if, for all* $n^S \subset P$*,* $n^S \neq I$*,* α_{n^S} *is a coalition proof Nash equilibrium of* G^S_α
α^* *is a coalition proof Nash equilibrium of* G *with the coalition-proof coalition*

structure C^* if, and only if, it is self-enforcing and there does not exist another self-enforcing strategy α' such that $\pi(n_i(\alpha'); C(\alpha')) \geq \pi(n_i^*, C^*) \forall i \in P$ and $\pi(n_i(\alpha'), C(\alpha')) > \pi(n_i^*, C^*)$ for at least one i

B Coalition Formation

Exclusive Membership Game

To show that the equilibrium of the exclusive membership game can be well-defined Yi and Shin (2000) introduce two additional conditions; the detailed proof can be found in Yi and Shin (2000) Appendix A.

- (P.5) $C = \{n_1, ...n_m\}$, $C' = C\backslash\{n_i, n_j\} \in \{n_i - 1, n_j + 1\}$, $\hat{C} = C\backslash\{n_k, n_l\} \in \{n_k + n_l\}$, and $\hat{C}' = \hat{C}\backslash\{n_i, n_j\} \in \{n_i - 1, n_j + 1\}$, where $n_1 \geq ... \geq n_m$ and $n_i \geq n_j + 2$. Then $\pi(n_k + n_l; \hat{C})/\pi(n_k; C) > \pi(n_k + n_l; \hat{C}')/\pi(n_k; C')$.

A change in the coalition structure which increases concentration increases profitability of the merger of coalition s not involved in the change of the coalition structure.

- (P.6) $C = \{n_1, ...n_m\}$ and $C_i = C\backslash\{n_i\} \in \{n_i - 1, 1\}$, $n_1 \geq ... \geq n_m$, $i = 1, ..., m$. If $\pi(n - 1; C) \geq \pi(n_1; C_1) \geq \pi(1; C_1)$, then $\pi(n_i; C) \geq \pi(1; C_i)$ for all $i = 2, ..., m$.

If the largest coalition is stand-alone stable, then all other coalitions in the coalition structure are stand-alone stable.

To demonstrate point *(3)* of Proposition 2 Yi and Shin (2000) assume a coalition structure with more and smaller or equal sized coalitions, which constitutes a Nash equilibrium coalition structure: $C = \{n_1, n_2, ..., n_m\}$ with $k^* \geq n_1 \geq ... \geq n_m$, $m > m^*$ and i^* such that $\sum_{j=i^*}^{m} n_j \geq r^* > \sum_{j=1^*+1}^{m} n_j$; and show that all countries can engage in a profitable and self-enforcing group deviation to $C^* \equiv \{k^*_{m^*-1}, r^*\}$. The last r^* countries are better off because $\pi(r^*; C^*) \geq \pi(1; C^*_r) \geq \pi(n_m; C) \geq \pi(n_j; C)$, $j = i^*, ..., m$ and $C^*_r = \{C^*\backslash\{r^*\} \cup \{r^* - 1, 1\} = \{k^*_{m^*-1}, r^* - 1, 1\}$. The first inequality follows from stand-alone stability of C^*; the second inequality from (P.1)-(P.3); the third inequality follows (P.2) which states that or small coalitions always earn a higher payoff than the coalition members. The $(m^*-1)k^*$ countries are better off because $\pi(k^*;C) \geq \pi(1;C_k^*) \geq \pi(1;C^* - k4) \geq \pi(n_{i^*};C) \geq \pi(n_j;C)$ where $j = 1, ..., i^* - 1$ and $C_k^* = C^* \backslash \{k^*\} \cup \{k^* -, 1\} = \{k_{m^*-2}^*, k^* - 1, 1, r^*\}$ and $C_{k4}^* = C_k^* \backslash \{r^*\} \cup \{r^* - \sum_{j=i^*+1}^m n_j, n_{i^*+1}, ..., n_m\}$, which is less concentrated than C_k^*. The first inequality follows again from stand-alone stability of C^*; the second inequality from (P.1), because if a coalition structure becomes more concentrated countries who are not involved in the change of the coalition structure and remain free-riders earn higher payoffs; the third inequality follows from (P.1)-(P.3); and the fourth inequality follows (P.2). C^* Pareto dominates C and all countries can make a profitable and self-enforcing deviation to C^*. Yi and Shin (2000) conclude that if there exists any other coalition-proof Nash equilibrium coalition structure, it must have exactly m^* research coalitions.

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