Conflicts between Intragenerational and Intergenerational Justice in the Use of Ecosystem Services

Der Fakultät Nachhaltigkeit der Leuphana Universität Lüneburg

zur Erlangung des Grades

Doktorin der Wirtschafts-, Sozial- und Politikwissenschaften

- *Dr. rer. pol.* -

vorgelegte kumulative Dissertation von

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geboren am 1. Juni 1983 in Groß-Gerau

Eingereicht am: 27. September 2012

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Tag der Disputation: 17. Dezember 2012

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Acknowledgements

Foremost, I am very grateful to my doctoral supervisor, Prof. Dr. Stefan Baumgärtner, for the intellectual support and guidance he showed me during all stages of my dissertation writing. The joint work and many discussions substantially helped me to conduct this dissertation. I am thankful to my second advisor, Prof. Dr. Christian Becker, for sharing his philosophical knowledge on justice and sustainability, and for helpful comments. Further, I thank my third advisor, Prof. Dr. Jörn Fischer, for agreeing to review this thesis.

I would like to thank my present and former colleagues David Abson, Anna Magdalena Biehler, John-Oliver Engler, Joachim Fünfgelt, Nikolai Hoberg, Roland Olbrich, Sebastian Strunz and Klara Helene Stumpf for valuable discussions and for creating such an enjoyable working atmosphere. Furthermore, I want to thank the team of the research project EIGEN for constructive feedback during our meetings.

Our student research assistant Nikolai Huckle conducted the numerical simulation and created the graphs for the modeling paper – therewith, making the model solutions accessible. The team of the Agrar Koordination, particularly Sandra Blessin, brought my attention to the Philippine farmer network MASIPAG and the impact evaluation study on the network. This caused me to choose MASIPAG as the case study object of my dissertation. Elisabeth Cruzada, MASIPAG national coordinator, proved to be a reliable contact person regarding questions on the MASIPAG network and the evaluation study.

Furthermore, I would like to thank my "Mentee-group", Katharina Hetze, Melanie Mergler and Judith Moll, for their companionship throughout my doctoral studies. The mutual sharing of experiences and inspiring meetings helped me write this dissertation.

Last but not least, I wish to thank my parents, Birgit Bernhard and Manfred Glotzbach, and many friends for their support and encouragement. Particularly, I thank Christian Sievers for his love, his patience, and for always inspiring me with confidence.

Introduction

1 Motivation

1.1 Sustainability: Ideal theory and non-ideal politics

The guiding principle of sustainability comprises two objectives of justice (WCED 1987: 43): global justice between different people of the present generation (*intragenerational justice*), and justice between people of different generations (*intergenerational justice*). International sustainability policy attaches equal normative importance to both objectives of justice. Accordingly, environmental philosophers ethically justify that people living today and people living in the future have equal rights to certain basic goods, including ecosystems and their services (e.g. Feinberg 1981, Visser't Hooft 2007). Whereas ideal theories of sustainability and justice do not recognize interdependencies between intragenerational and intergenerational justice, conflicts ('trade-offs') in attaining the justices possibly arise in the design and implementation of sustainability policy. Identifying and preventing such conflicts is fundamental to devise an ethically legitimate, politically consistent and actually effective sustainability policy. This dissertation systematically investigates conflicts between intragenerational and intergenerational justice in the use of ecosystem services.

1.2 Ecosystem services and injustice

Human wellbeing depends on the services provided by ecosystems, such as provision of food, purification of water, protection from soil erosion, and provision of recreation sites. Yet, humans substantially degrade world's ecosystems, and therewith cause the loss of important ecosystem services (MEA 2005: 26ff.). This problem was already recognized in 1980 in the World Conservation Strategy (IUCN 1980). Since then, the idea of a *sustainable* use and conservation of ecosystems and their services has been on the political agenda (MEA 2005, TEEB 2010, UN 1992, UNEP 2012, WCED 1987) and has been posing an ongoing challenge to international, national and local sustainability policy. The idea of sustainability demands to use ecosystem services in accordance with the two objectives of *intragenerational justice* and *intergenerational justice*. Reality, however, is far from attaining these objectives: Both today's global poor and future persons are, resp. will be, disproportionately affected by the loss of vital ecosystem services (MEA 2005: 62, 85). Especially severe affected are the rural poor who directly depend on local ecosystem services for food, income and health. As the report on the Millennium Ecosystem Assessment (MEA) points out, "the pattern of 'winners' and 'losers' associated with ecosystem changes (…) has not been adequately taken into account in management decisions" (ib. 62).

1.3 Research gap

The political discourse on the relationship between the objectives of intra- and intergenerational justice in the use of ecosystem services ('justice relationship') is blurred. Some argue that a globally just distribution of access to ecosystem services is a necessary precondition to achieve justice with respect to future generations (cf. e.g. Goodland 1992: 40, Sachs 2001: 2ff., WBGU 2004: 55ff., 97ff.). Others state that the satisfaction of the elementary needs of the world's poor inevitably implies the long-term degradation of ecosystems (cf. e.g. Visser't Hooft 2007: 84, Roemer 2007: 226). The political discourse lacks a common normative understanding of justice in ecosystem-use and a systematic reflection on the actual 'justice relationship', such as on the factors that cause conflicts between the two justices.

The vagueness of the political sustainability discourse regarding the 'justice relationship' encounters two research gaps:

1. The specific questions of justice linked to the governance of access to, and use of, ecosystem services have not been discussed thoroughly within the distributive justice literature in general and the environmental justice literature in specific. Also, the scientific justice literature tends to focus either on intragenerational justice (cf. the discussion on environmental justice, e.g. by Schlosberg 2007 and Schroeder et al. 2008) or on intergenerational justice (cf. the discussion on environmental sustainability, e.g. by Goodland 1995 and Neumayer 1999).
2. Although several authors (e.g. Adams et al. 2004, Langhelle 2000 and Wissenburg 2006) discussed possible conflicts between intragenerational and intergenerational justice in ecosystem use, they rather investigated them for specific contexts (e.g. for the relationship between biodiversity conservation and poverty eradication through protected areas, Adams et al. 2004). Thus, possible conflicts and synergies in attaining the two justices have not been analyzed systematically and generally.

1.4 Research questions

In this dissertation, I approach the outlined research gaps regarding the 'justice relationship' along three central questions:

- What conception(s) of justice can adequately address the distribution of access rights to ecosystem services?
- How must sustainability policy be designed to enhance both intragenerational and intergenerational justice in the use of ecosystem services?
- (How) Can economics be helpful for characterizing and assessing trade-offs between the two justices?

I investigate these questions both generally and by the example of a case study, the MASIPAG farmer network in the Philippines.

1.5 Research papers

This cumulative dissertation comprises the following five papers:

[1] Glotzbach, S., forthcoming. Ecosystem services and distributive justice. Considering access rights to ecosystem services in theories of distributive justice. *Ethics, Policy & Environment* ('Justice Paper').

[2] Baumgärtner, S., S. Glotzbach, N. Hoberg, M. F. Quaas and K. H. Stumpf 2012. Economic analysis of trade-offs between justices. *Intergenerational Justice Review*, 1/2012, 4-9 ('Trade-off Paper').

[3] Glotzbach, S. and S. Baumgärtner 2012. The relationship between intragenerational and intergenerational ecological justice. *Environmental Values*, 21(3), 331–355 (‘Relationship Paper’).

[4] Baumgärtner, S., S. Glotzbach and M. F. Quaas 2012. The relationship between intragenerational and intergenerational justice in the use of ecosystems and their services. An ecological-economic model. Manuscript (‘Modeling Paper’).

[5] Glotzbach, S., forthcoming. Reconciling intragenerational and intergenerational environmental justice in Philippine agriculture: The MASIPAG farmer network. *Ethics, Policy & Environment* (‘MASIPAG Paper’).

1.6 Original contribution

This dissertation makes an original contribution to the scientific discourse on sustainability and ecosystem services in three ways:

- The *systematic and general investigation of possible conflicts between the objectives of intragenerational and intergenerational justice* is of high political relevance and exceeds the latest state of international research.
- The *specific research focus on ecosystem services* is innovative: I explicitly outline how the use of ecosystem services is connected to questions of intragenerational and intergenerational justice, and reason why access rights to ecosystem services are suitable instruments of justice to tackle injustices in ecosystem use. From the subject matter of ecosystem services and their characteristics (e.g. the multiple temporal and spatial scales of generation, provision and use of ecosystem services), specific implications follow both for developing a conception of justice that addresses the use of ecosystem services and for analyzing the ‘justice relationship’ in real-world contexts. I explicitly introduce and discuss these implications.
- The *methodological approach* employed to investigate the ‘justice relationship’ allows for a comprehensive analysis: Whereas former studies either operated at the conceptual level (e.g. Dobson 1998, Ott and Döring 2008), or at the modeling level (Roemer and Veneziani 2007), or at the case study level (e.g. Adams et al. 2004), I simultaneously analyze the ‘justice relationship’ at the three levels of concept, model and case study.

The introduction contains four further sections. In Section 2, I present the methodological framework linking the research papers. Particularly, I introduce the distinction between the normative and the positive analysis of the ‘justice relationship’, and three levels of scientific analysis which are concept, model and case study. In Section 3, I present the results of the five research papers, and discuss their original contribution and limitations. In Section 4, I discuss four cross-cutting issues which concern the linkages between the single research papers. In Section 5, I conclude.

2 Methodological framework

2.1 Normative and positive analysis of the justice relationship

As outlined in the motivation, research challenges arise both regarding the normative foundation of the 'justice relationship' and regarding the attainment of the two justices in policy implementation. In this dissertation, I combine a normative and a positive analysis of the relationship between intra- and intergenerational justice in the use of ecosystem services.

The *normative analysis* serves the explication, justification and reflection of the norms underlying the 'justice relationship'. I conduct the normative analysis as follows: The 'Justice Paper' reasons that the two justices should be considered as societal objectives of equal normative rank, and argues for a specific conception of environmental justice that addresses the distribution of access rights to ecosystem services. The 'Trade-off Paper' introduces efficiency in attaining intragenerational and intergenerational justice as a *secondary* normative objective – that is, efficiency is not a societal desirable objective in its own right, but with regard to attaining certain *primary* objectives of justice which are societal desirable in their own right.

The *positive analysis* serves the description of the 'justice relationship' in the sustainability discourse and in practical contexts, as well as the provision of explanations on the determinants of the 'justice relationship'. I conduct the positive analysis as follows: The 'Relationship Paper' describes the scientific and political discourse on the 'justice relationship' along the three hypotheses of independency, facilitation and rivalry. The 'Relationship Paper' and the 'Trade-off Paper', respectively, identify certain determining factors of the 'justice relationship'. An ecological-economic modeling ('Modeling Paper') and a case study analysis ('MASIPAG Paper') investigate the possible resp. empirically observable impact of the identified determining factors on the 'justice relationship'.

2.2 Methodological approach: concepts – model – case study

To analyze the 'justice relationship', I apply the "comprehensive multi-level approach" (CML-approach)[1] as developed by Baumgärtner et al. (2008). According to the CML-approach, I investigate the 'justice relationship' simultaneously on three levels: (i) concepts, (ii) models and (iii) case studies. I choose the CML-approach as methodological approach of this dissertation for three reasons:

- The CML-approach allows integrating concepts, methods and theories of different scientific disciplines. Thereby, it can *combine different disciplinary approaches* (from political philosophy, economics, ecology, and social sciences) to comprehensively investigate the 'justice relationship'.
- The CML-approach allows *connecting the general norm of environmental justice and general explanations* for the occurrence of rivalry, independency or facilitation in the 'justice relationship' *to specific real-world contexts*.

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[1] Baumgärtner et al. (2008: 384) propose the CML-approach as a general and unifying methodology for ecological economics.

- It allows *integrating rational reasoning* (particularly philosophical argumentation, concept building and formation of hypotheses) *with empirical evidence* in concrete cases.

In the following, I outline how the levels of concept, model and case study are employed to investigate the 'justice relationship'.

Concepts

According to the CML-approach, a concept is defined as "an intellectual figure – a norm, a notion or a mechanism – that is part of the basic construction of the world by a scientific community" (ib. 388). The main concepts discussed in the 'Justice Paper' are the norm *environmental justice* and the notion *ecosystem services*.

The norm *justice* is a basic concept in political philosophy referring to the mutual claims of members of a community of justice from the standpoint of impartiality and equal consideration (e.g. Gosepath 2007: 82). The norm *environmental justice* in its broadest meaning reasons "how environmental goods and bads are to be distributed among human beings, within and across societies at any one time, and between generations across time" (Baxter 2005: 6). I specify the norm environmental justice to philosophically reason and describe a conception of justice that links the ideas of intragenerational and intergenerational justice to the distribution of access rights to ecosystem services.

The notion *ecosystem services* is an interdisciplinary concept that emerged at the interface between ecology and economics. Explicitly introduced by Ehrlich and Ehrlich (1981), the notion describes the dependence on ecosystems of people and society for sustaining human life and wellbeing. In the research papers, I draw upon two specific conceptions of ecosystem services: the 'MEA framework' and the 'fund-service-approach'. The MEA defines ecosystem services as "the benefits people obtain from ecosystems" (MEA 2005: 40), and classifies them along functional lines in provisioning, regulating, cultural and supporting services. The 'MEA framework' is fruitful for investigating the 'justice relationship' as it emphasizes the linkages between ecosystem services, human wellbeing and drivers of change in ecosystems. The 'fund-service-approach' describes ecosystem services in terms of natural capital: Ecosystem services are defined as all benefits that living ecosystem funds (e.g. animals or trees) and non-living ecosystem funds (e.g. soil or air) contribute to human wellbeing (Ott and Döring 2008: 219ff., cf. also Faber, Manstetten and Proops 1995: 44ff., Georgescu-Roegen 1971: 224ff.). The 'fund-service-approach' is helpful for understanding intragenerational trade-offs in the provision of different ecosystem services by one ecosystem fund, as well as intergenerational trade-offs between the present consumption of ecosystem services and the conservation of ecosystem funds for future persons.

The 'Trade-off Paper' introduces the norm *efficiency* in relation to the norm justice. Referring to Robbins' (1932) definition of economics, we define *efficiency* as the "non-wastefulness in the use of scarce resources that have alternative uses as means to attain given normative objectives". Hence, a situation is efficient with regard to two normative objectives of justice if it is not possible in a given system to better attain one objective of justice without worsening the attainment of the other objective of justice. Whereas intragenerational and intergenerational environmental justice are primary normative objectives, efficiency is conceptualized as a secondary normative objective: An efficient situation regarding the two objectives of justice is claimed to be good, because scarce resources are allocated in a way that produces a higher degree of attainment of one or both justices as compared to an inefficient situation.

Beyond its characteristic as a norm, *(in)efficiency* is proposed as an explanation for the occurrence of rivalry, independency or facilitation in the 'justice relationship'. The very definition of efficiency implies that there is rivalry between two objectives of justice in an efficient situation, and that there is independency or facilitation between two objectives of justice in an inefficient situation. Hence, a 'justice relationship' of rivalry can occur only if scarce resources are used efficiently; a 'justice relationship' of facilitation or independency can occur only if scarce resources are used inefficiently.

In the 'Relationship Paper', we derive a further explanation for the occurrence and extent of rivalry, independency or facilitation in the 'justice relationship'. As the result of a qualitative content analysis of the political and scientific sustainability discourse, we reveal certain *determinants* which act upon the 'justice relationship'. These determinants are quantity and quality of ecosystem services, population development, substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions.

Model

The CML-approach views a model as "an abstract representation of a system under study, explicitly constructed for a certain purpose, and based on the concepts within a scientific community's basic construction of the world that are considered relevant for the purpose" (Baumgärtner et al. 2008: 389). In the 'Modeling Paper', we build an *ecological-economic model* that aims to represent the 'justice relationship' against the backdrop of given societal circumstances. The main elements of the 'justice relationship' depicted in the model include a renewable resource stock that provides two different ecosystem services, the determinants of the 'justice relationship' (represented as model parameters) and indicators for intragenerational and intergenerational environmental justice, respectively (derived from the specific conception of environmental justice as developed in the 'Justice Paper'). Hence, the norm *environmental justice*, the notion *ecosystem services* and the explanation of the 'justice relationship' by certain *determinants* have been operationalized and related to each other in a coherent model. The purpose of this model is to provide a tool that allows investigating how different policies and changes in societal circumstances may impact on the 'justice relationship'. As the ecological-economic model is a *generic* model, it allows creating insights into the 'justice relationship' both at a general level (i.e. valid for a large class of systems) and for specific real-world systems (ib. 389f.).

Case study

According to the CML-approach, a case study is a "descriptive, explorative and prospective study of a concrete real-world situation, including its practical context and its determining factors, for the purpose of generating and testing hypotheses" (Baumgärtner et al. 2008: 390). The 'MASIPAG Paper' is an investigation of the *Philippine farmer network MASIPAG* regarding its impact on intragenerational and intergenerational environmental justice in peasant rice-farming systems. The study analyses a real-world situation, the situation of MASIPAG farmers as compared to non-member rice farmers in their environmental, social, economic, institutional and political context. The purpose of the case study is to provide evidence for the influence of the *determinants* on the 'justice relationship'. Using a comparative, interdisciplinary approach, I investigate whether certain facilitation-specific properties of the *determinants* (as revealed in the 'Relationship Paper') have been present in the MASIPAG farming systems, but not in the conventional reference systems. Beyond, the MASIPAG case study serves testing whether the conception of *environmental justice* (as developed in the 'Justice Paper') can be meaningfully applied to assess the degree of intragenerational and intergenerational environmental justice in a concrete real-world case.

2.3 Methodological classification of the research papers

Figure 1 classifies the single research papers along the two dimensions of the methodological framework: the distinction between three levels of scientific analysis which are concept, model and case study (x-axis), and the distinction between the normative and the positive analysis of the 'justice relationship' (y-axis). The 'Trade-off Paper' contributes to both the normative and the positive analysis of the 'justice relationship' as the concept *efficiency* constitutes both a norm and an explanation for the occurrence of rivalry in the 'justice relationship'.

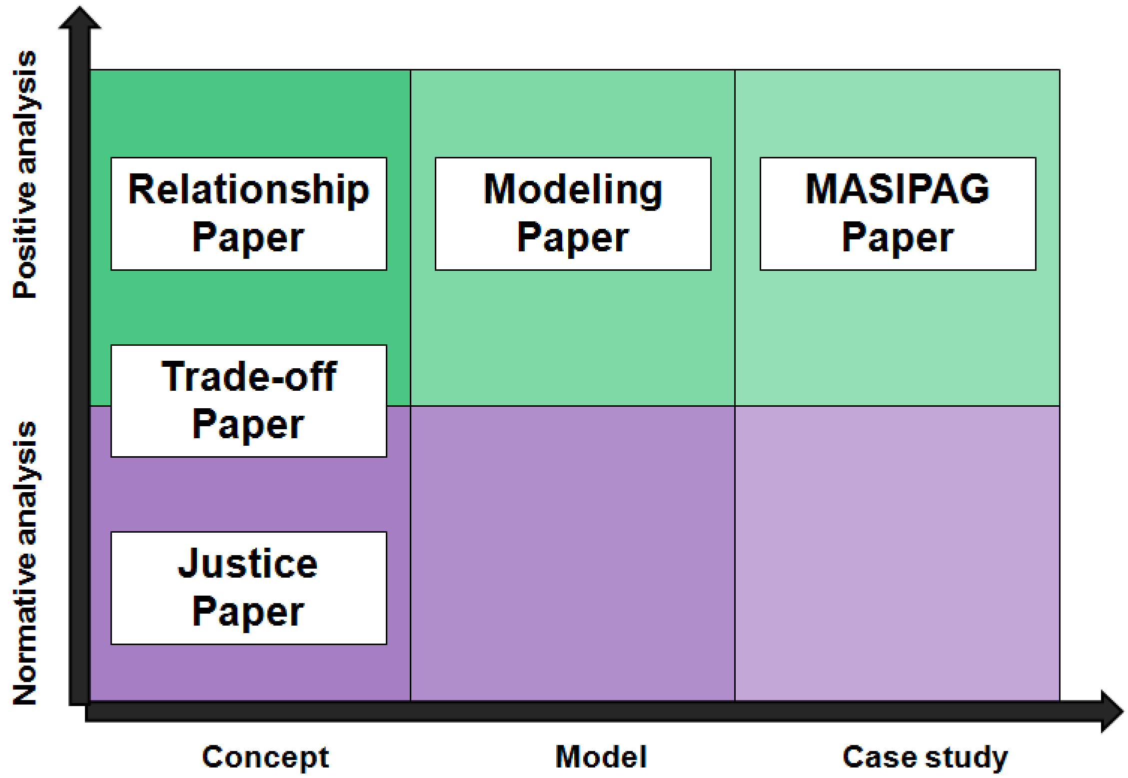

Figure 1: Methodological classification of the research papers along two dimensions: the distinction between three levels of scientific analysis (concept, model and case study), and the distinction between the normative and positive analysis of the 'justice relationship'.

3 Results

In the first paper, **"Ecosystem services and distributive justice. Considering access rights to ecosystem services in theories of distributive justice"**, I propose a conception of environmental justice that addresses the distribution of access rights to ecosystem services. As the life perspectives of both today's poor and future persons are severely, and disproportionately, affected by the increasing loss of ecosystem services (MEA 2005: 62), human use of ecosystem services raises fundamental questions of intragenerational and intergenerational justice. Yet, the specific issues of justice linked to the use of ecosystem services have not been explicitly discussed in the environmental justice literature.

In this paper, I explicitly reason why theories of distributive justice should, in order to tackle injustices concerning the use of ecosystems, focus on access rights to ecosystem services as objects of distribution. Then, I work out three specific demands that a theory of distributive justice should fulfil to adequately cope with the distribution of access rights to ecosystem services. These demands are (i) global and intertemporal extension of the community of justice, (ii) institutional agents as claim addressees, and (iii) includability of ecosystem services as objects of distribution. Subsequently, I face "A Theory of Justice" by John Rawls (1971) with the identified demands, and verify that the theory can be consistently extended to meet the demands. Based on the Rawlsian theory, I derive a *principle of environmental justice*: *Inequalities in the distribution of access rights to all vital ecosystem services are to be to the greatest benefit of the least-advantaged members of the present and actual future generations*. In terms of the principle, 'vital ecosystem services' are ecosystem services required to exert human basic capabilities; 'benefit' measures how access rights to ecosystem services impact on a set of human basic capabilities. The *principle of environmental justice* constitutes a philosophically founded criterion for assessing the distributional effects of social institutions on access rights to ecosystem services. It marks an ideal of environmental justice that institutions should seek for, and needs to be specified for particular ecological-economic systems and policy areas.

The original contribution of this paper is to link the concept of ecosystem services to theories of distributive justice. Generally, I show that the distribution of access rights to ecosystem services is a suitable instrument to tackle injustices in the use and conservation of ecosystems. Specifically, I propose a *principle of environmental justice* that characterizes an intra- and intergenerational just distribution of access rights to ecosystem services. One limitation of the paper emerges from proving solely for the Rawlsian theory that it can fulfil the identified demands on a conception of environmental justice. Other conceptions of environmental justice, based on different theories of distributive justice, may be equally possible. Yet, the paper introduces general demands on a conception of environmental justice, and outlines that the developed conception of environmental justice based on Rawls' theory can be complemented by a conception of 'the environmentally just person' based on virtue ethics. The second limitation is due to the 'ideal character' of the developed conception of environmental justice: The ideal *principle of environmental justice* potentially faces the problem of assessing non-ideal states of the world (cf. Section 4.2).

In the second paper, **"Economic analysis of trade-offs between justices"**, we outline how economics can help to assess trade-offs between intragenerational and intergenerational justice – or generally, between different justices of equal normative rank. Based on Robbins' (1932) definition of economics, we introduce the criterion of *efficiency* to characterize the attainment of different justices of equal normative rank: a situation is efficient with regard to the justices if it is not possible in a given system to improve on one justice without doing worse on another justice. This criterion of efficiency constitutes a secondary normative objective as it claims that it is good to use scarce resources efficiently to attain the primary objectives of justices. The mere definition of efficiency implies that there is rivalry between two objectives of justice in an efficient situation, and that there is independency or facilitation between two objectives of justice in an inefficient situation.

In the paper, we build the economic analysis of inter- and intragenerational justice on three assumptions: (i) The two justices are of equal normative rank; (ii) the degree of attainment of both justices can be measured; (iii) for a given system, the outcome of using scarce resources in terms of the measures of the two justices can be described. Based on these assumptions, economic analysis of inter- and intragenerational justice can make three genuine contributions: (1) It can describe which outcomes are feasible in achieving the two objectives of justice in a given system, i.e. it can depict the 'opportunity set' of politics; (2) it can identify the 'opportunity cost' of achieving one justice to a higher degree in terms of less achievement of the other justice; (3) it can identify how a change in the system determinants (including natural, technological and institutional factors) changes the 'opportunity set'.

The original contribution of this paper is to relate the normative criterion of efficiency to the occurrence of rivalry, independency and facilitation in the 'justice relationship', and to demonstrate how economics can help to assess trade-offs between intragenerational and intergenerational justice – namely, by proving whether an existing outcome is 'truly' efficient, and by identifying the opportunity costs of moving from one efficient outcome to another. The outlined economic analysis of trade-offs between justices could be further elaborated as follows: Regarding conceptual precision, future research could refine the definition of *efficiency* (particularly by clarifying whether it is the use of the instruments of justice or an allocation that is defined to be efficient in terms of attaining the two justices), and could explicitly define *feasibility* with regard to attaining intra- und intergenerational justice in a given system. Regarding the application to concrete real-world cases, an economic analysis of trade-offs between justices faces the challenge to handle imprecise or incomplete information on the 'opportunity set' of politics (i.e. assumption (iii) as described in the former paragraph is not given in many real-world situations). Thus, further research needs to tackle the question how an economic analysis of trade-offs between justices can cope with uncertainty about the 'opportunity set' of politics, or with knowledge that is limited to a small segment of the 'opportunity set'.

In the third paper, **"The relationship between intragenerational and intergenerational ecological justice"**, we describe and analyze the political and scientific sustainability discourse on the relationship between intragenerational and intergenerational justice in the use of ecosystem services. Several studies already noted possible conflicts between intragenerational and intergenerational justice in ecosystem use (e.g. Adams et al. 2004, Langhelle 2000 and Wissenburg 2006). However, the 'justice relationship' has not been analyzed systematically and explicitly relating to the objectives of intragenerational and intergenerational justice. Three hypotheses about the 'justice relationship' are logically possible, and indeed held in the political and scientific sustainability discourse: (1) Achieving one objective may not have any effect on the chances to also achieve the other one (*independency*); (2) achieving one objective may make it easier to also achieve the other one (*facilitation*); (3) achieving one objective may make it more difficult to also achieve the other one (*rivalry*).

We evaluate important political documents on sustainable development as well as the scientific literature from various disciplines – encompassing natural resource management, ecosystem ecology, neoclassical and ecological economics, political science on environment and development issues, environmental ethics as well as interdisciplinary analyses – in terms of these hypotheses. Applying the method of qualitative content analysis (Mayring 2000), we first extract the core statements and arguments in the literature and assign them to the different hypotheses, and then identify the fundamental *determinants* which are used to argue in favour of the different hypotheses. These *determinants* are quantity and quality of ecosystem services, population development, substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions.

The original contribution of this paper is to systematically describe and analyze the political and scientific sustainability discourse regarding the 'justice relationship'. Generally, we illustrate that different (and mutually exclusive) hypotheses about the 'justice relationship' – independency, facilitation and rivalry – are held in the sustainability discourse. We reveal that different assumptions on the six *determinants* lead to different hypotheses. The *determinants* are assumed to impact on the 'justice relationship' as follows: The higher the intrinsic growth rate of renewable resources, the smaller the population growth rate, the greater the substitutability of ecosystem services, the higher the rate of technological progress, the more effective the institutional restriction of ecosystem use and the greater the political scope for redistribution of environmental property rights, the less likely is the occurrence of rivalry in the 'justice relationship'.

A limitation of this discourse analysis emerges from the induction and definition of the underlying determinants. While we explicitly outline how different assumptions on the *determinants* support different hypotheses on the 'justice relationship', we cannot prove the completeness of the revealed determinants. Further, we choose the specification of the single determinants with a view to cover the main arguments expressed in the sustainability discourse. Different specifications of the determinants not explicitly discussed in the sustainability discourse, for example the distinction between technological development in the manufacturing sector and in resource harvesting, would possibly allow for a more differentiated view on the 'justice relationship' (cf. Section 4.3).

In the fourth paper, **"The relationship between intragenerational and intergenerational justice in the use of ecosystems and their services. An ecological-economic model"**, we present an ecological-economic model that depicts the 'justice relationship' against the backdrop of given societal circumstances. Although conflicts between intragenerational and intergenerational justice in the use of ecosystems and their services may arise in sustainability policy, little research has been conducted on simultaneous modeling of intragenerational and intergenerational problems in renewable resource use. Therefore, we build a model that represents crucial interdependencies between the objectives of intragenerational and intergenerational justice in ecosystem-service use.

In the two-period model, human individuals maximize their utility from a manufactured consumption good and two ecosystem services delivered by a renewable resource stock, a consumptive and a non-consumptive ecosystem service. The policy instrument (*instrument of justice*) is the assignment of first- and second-generation utilization rights to the renewable resource stock by a social planner. The given societal circumstances are depicted by certain s*ystem determinants*: the quantity of ecosystem services (i.e. the total endowment with the renewable resource stock and its intrinsic growth rate), the quality of ecosystem services (consumptivity, rivalry in consumption and excludability from consumption), population development, substitutability of ecosystem services (both between manufactured-good consumption and aggregate ecosystem-service consumption, and between a consumptive and a non-consumptive ecosystem service), technological progress (in the manufacturing sector and in resource harvesting), and political restrictions on the assignment of resource utilization rights. The degree of intragenerational (resp.: intergenerational) justice in ecosystem-service use is measured in terms of the Rawlsian Difference Principle regarding the individual utilities attained by the first-generation individuals (resp.: the first- and second-generation individuals).

In the model analysis, we define *efficiency* in the assignment of resource utilization rights in terms of attaining the two justices. Applying the method of numerical simulation, we identify efficient and inefficient assignments of resource utilization rights for a specific ecological-economic system, and illustrate how *(in)efficiency* is related to the occurrence of rivalry, independency and facilitation in the 'justice relationship'. Further, we show by means of numerical simulation how the use of the *instrument of justice* (i.e. different assignments of resource utilization rights to generation 1 and 2) and a change in certain *system determinants* impact on the set of feasible outcomes in terms of intra- and intergenerational environmental justice ('opportunity set') – and thereby on the occurrence of rivalry, independency and facilitation in the 'justice relationship'.

The contribution of this paper is twofold: First, it systematically represents the main elements of the 'justice relationship' and their interactions in an ecological-economic model – including the determinants of the 'justice relationship' and a differentiated description of ecosystem services (i.e. regarding mode of production, substitutability, excludability from use, consumptivity and rivalry in consumption). Second, the paper illustrates that this model can be used as a tool to explore political paths that consistently and effectively improve on both intragenerational and intergenerational environmental justice.

As the model analysis is limited to a numerical simulation by the example of a specific ecological-economic system, there is need for a comprehensive and general model analysis of the 'justice relationship' based on the introduced model. In future research, the *numerical simulation* could be conducted more comprehensively – by comparing the 'opportunity sets' for a broad range of specific ecological-economic systems, or by investigating the impact of each system determinant, respectively, on the 'opportunity set' of a specific ecological-economic system. Further, and more importantly, an *analytical model analysis* should be conducted to produce general model solutions – first, on how the use of the instrument of justice impacts on the occurrence of rivalry, independency and facilitation in the 'justice relationship', and second, on how a change in one (or several) system determinants impacts on the 'justice relationship'.

In the fifth paper, **"Reconciling intragenerational and intergenerational environmental justice in Philippine agriculture: The MASIPAG farmer network"**, I investigate facilitation between intragenerational and intergenerational environmental justice in peasant agricultural systems by the example of the Philippine farmer network MASIPAG – a network of more than 35.000 small-scale rice farmers located all over the Philippines. MASIPAG has been established in 1986 on a rice conference which discussed the negative impacts of the Green Revolution on Philippine rice farmers, and aims for giving the farmers control over agricultural diversity, agricultural production and associated knowledge. MASIPAG farmers breed their own rice varieties from the old traditional rice varieties, employ a communal seed bank, enhance their on-farm diversity, farm without artificial fertilizers and pesticides, and revive traditional labor-sharing practices.

Two specific objectives of justice arise from the *conception of environmental justice* (as developed in the 'Justice Paper') to the management of agricultural systems: (1) the improvement of access for today's rural poor to vital ecosystem services regarding *intragenerational environmental justice*; and (2) the sustenance of critical ecosystem funds to enable future persons access to vital ecosystem services regarding *intergenerational environmental justice*. In the case study analysis, I comparatively assess the situation of MASIPAG and conventional rice farmers' households regarding these two objectives of justice – drawing on comprehensive evaluation data on 280 MASIPAG and conventional rice farmers' households, respectively, regarding food security, health outcomes and livelihood, corn yields and productivity, various environmental outcomes, farmer knowledge and empowerment (MASIPAG 2009).

Based on a normative framework that focuses on inequalities in the basic capabilities of present and future Philippine rice farmers in terms of access rights to ecosystem services, I prove that MASIPAG could simultaneously enhance both justices for its farmer members as compared to conventional farmers. This indicates a 'justice relationship' of facilitation in the MASIPAG farming systems. Then, I investigate whether the determinants of the 'justice relationship' (as identified in the 'Relationship Paper') can explain this facilitation. I find that an enhanced provision of regulating ecosystem services and on-farm diversity (*quantity of ecosystem services*), the 're-substitution' of artificial fertilizers and pesticides by free and more effective regulating ecosystem services (*substitutability of ecosystem services*), the enhancement of *ecological efficiency* through broad adoption of organic farming, a seed collection of traditional rice varieties as a managed community asset and institutional structures fostering farmer empowerment (*institutions*) have (probably) promoted both intragenerational and intergenerational environmental justice in the MASIPAG systems. The determinants *population development* and *political restrictions* cannot explain facilitation in the MASIPAG farming systems.

The specific contribution of this paper is twofold: First, it illustrates how the *principle of environmental justice* can be applied to assess real-world situations in terms of intragenerational and intergenerational environmental justice. Second, it provides empirical evidence for the explanation (as stated in the 'Relationship Paper') that certain properties of the *determinants* induce a 'justice relationship' of facilitation.

Generally, I found that a 'justice relationship' of facilitation occurred in the MASIPAG farming systems, and that the determinants are fruitful categories to explain this facilitation. Yet, the findings are limited due to the chosen method of case study analysis. In the analysis of the MASIPAG network, I compare two groups, agricultural systems of MASIPAG farmers and non-member farmers, regarding the attainment of environmental justice. Although the groups are similar regarding several important characteristics (including farm size, household size and land ownership), they may deviate in other characteristics that make some farmers more likely to join the MASIPAG network. In contrast, the method of field experiments, such as conducted in international development research (cf. e.g. Duflo et al. 2006), could minimize the problem of differences between the two groups by randomly assigning individuals to a treatment group (i.e. the group who receives the intervention) and a control group (i.e. the group who does not receive the intervention) before starting the intervention. A second limitation of this case study analysis is the focus on certain properties of the *determinants* that are relevant to the MASIPAG farming systems. Therefore, the case study analysis can (only) prove some specific lines of argument stated in the sustainability discourse regarding the *determinants*, e.g. whether (local seed collections as) managed community assets promote a 'justice relationship' of facilitation. Further research on real-world cases, particularly the comparison of different case studies and the conduction of field experiments, could help to clarify whether and how a change in the *determinants* can induce facilitation in the 'justice relationship'.

4 Discussion

In this section, I discuss four cross-cutting issues concerning the linkages between the single research papers.

4.1 Distinguishing environmental justice from ecological justice

To describe a conception of justice that links the ideas of intragenerational and intergenerational justice to the distribution of access rights to ecosystem services, I use both the term *ecological justice* (in the 'Relationship Paper') and the term *environmental justice* (in all other research papers). The reference to both terms in my research papers is due to the ambiguous use of the terms in the scientific literature. Whereas Leist (2005: 3) states that *ecological justice* concerns the relations between humans[2], globally and intergenerationally,

[2] Leist (2005: 3) also discusses the relations between humans and animals which are part of human society under the term *ecological justice*.

Low and Gleeson (1998: 2) state that ecological justice concerns “the relations between humans and the rest of the natural world”. *Environmental justice*, in its core meaning, concerns the unequal distribution of environmental burdens and hazards (such as exposition to toxic waste and air pollution) between different contemporary societal groups, with particular reference to ethnic groups and poor people (e.g. Schlosberg 2007). Issues of intergenerational justice in ecosystem use are prominently discussed referring to the concept of *environmental sustainability* (e.g. in Goodland 1995 and Neumayer 1999).

Whereas most conceptions and definitions of ecological justice (also) concern the distribution of environmental goods resp. bads between humans and non-human entities of nature, environmental justice clearly concerns the distribution of environmental goods resp. bads between humans. Therefore, I conclude that the conception of justice regarding the use of ecosystem services (as developed in the ‘Justice Paper’) can be classified as a specific *conception of environmental justice*. The environmental goods in the *conception of environmental justice* are access rights to ecosystem services. As generation, provision and use of many ecosystem services happens at different spatial and temporal scales, expanding the community of justice beyond a national community becomes necessary. Thus, I refer to Brian Baxter (2005: 6) who defines that environmental justice is about “how environmental goods and bads are to be distributed among human beings, within and across societies at any one time, and between generations across time”.

4.2 Measuring environmental justice

To make intragenerational and intergenerational environmental justice measurable in the ecological-economic model and the case study, I translate the *principle of environmental justice* into *indicators for intragenerational and intergenerational environmental justice*, respectively. In the following, I describe and discuss three relevant issues concerning the measurement of environmental justice in the research papers.

One principle of environmental justice – two indicators

The principle of environmental justice – which claims that inequalities in the distribution of access rights to all vital ecosystem services are to be to the greatest benefit of the least-advantaged members of the present and actual future generations – encompasses both the objective of intragenerational environmental justice and the objective of intergenerational environmental justice. As the ecological-economic model and the case study analysis aim at investigating the relationship between the two objectives of justice, the principle of environmental justice needs to be divided into two *separate* principles – one of intragenerational and one of intergenerational environmental justice – and subsequently to be translated into two different indicators.

The ‘benefit’ of the least-advantaged

The principle of environmental justice assesses inequalities in the distribution of access rights to ecosystem services in terms of the ‘benefit’ of the least-advantaged. In the *conception of environmental justice*, I relate ‘benefit’ to the degree up to which human basic capabilities can be attained with the provided set of ecosystem services. I adopt this definition of ‘benefit’ to measure environmental justice in the case study: The indicator set for intragenerational (resp.

intergenerational) environmental justice measures how the MASIPAG network influences a certain set of human basic capabilities available to present (resp. future) rice farmers. The measurement in terms of capabilities recognizes that MASIPAG farmers intrinsically value the freedom to decide on their agricultural management. To allow the depiction of 'benefit' in the ecological-economic model, we measure 'benefit' in the model in terms of individual utility.

Ideal theory and non-ideal states of affairs

The *principle of environmental justice*, just as the Rawlsian principles of justice, marks an 'ideal' of environmental justice that institutions should seek for. This ideal, if comprising different dimensions of valuation (such as the degree of attainment of different human basic capabilities), potentially faces the problem to assess non-ideal states of affairs in terms of environmental justice (cf. Sen 2009: 16). In the ecological-economic modeling, this problem is avoided as intra- and intergenerational environmental justice are measured in one dimension of valuation, individual utility. Both the ideal of intra- and intergenerational environmental justice can be described, and different non-ideal states of affairs can be compared in terms of individual utility. In the case study analysis, the comparative assessment of MASIPAG and conventional farming systems produces an unambiguous solution as the different dimensions of evaluation, i.e. the single indicators constituting the two indicator sets, *all* show the same ranking in terms of intragenerational and intergenerational environmental justice, respectively.

4.3 The determinants of the justice relationship

In this subsection, I clarify two issues relevant for describing the determinants of the 'justice relationship': The distinction of the determinants in terms of instruments of justice and system determinants, and the depiction of the determinants in the model and the case study.

Distinguishing instruments of justice and system determinants

The determinants (as described in the 'Relationship Paper') are differentiated into *instruments of justice* and *system determinants* in the 'Trade-off Paper': The *instruments of justice* are the means used by the claim addressees to satisfy the legitimate claims of justice, whereas the *system determinants* are the (natural, technological, institutional, etc.) factors that characterize a given context. The ecological-economic model further clarifies this differentiation: The *instrument of justice* is the assignment of first- and second-generation resource utilization rights by a social planner; the *system determinants* are the model parameters which are given for a specific system and cannot be changed by the social planner (such as the initial endowment with the renewable resource). In the case study, the specific *instruments of justice* employed by the MASIPAG network are technological innovations (environmentally sound and agrobiodiversity-based farming practices) and institutional innovations (communal seed banks, farmer-led rice breeding and training activities) at the household and community level, whereas the *system determinants* are, among others, population development and political restrictions on the redistribution of agricultural land.

Depiction of the determinants in model and case study

Different specifications of the *determinants* may lead to different conclusions on how (and whether) the *determinants* influence the 'justice relationship'. Therefore, I point out some specifics on their depiction in the ecological-economic model and the case study analysis.

In the model, we depict several *determinants* more differentiated than being outlined in the 'Relationship Paper': *Substitutability of the ecosystem service* is described by two parameters, one measuring substitutability between manufactured-good consumption and aggregate ecosystem-service consumption, and one measuring substitutability between a consumptive and a non-consumptive ecosystem service; *technological development* is described by two rates of technological progress, one in the manufacturing sector and one in resource harvesting; *quality of the ecosystem service* is described by the distinction between a consumptive and a non-consumptive ecosystem service, and by the degree of rivalry in, and excludability from, consumption of the non-consumptive ecosystem service. These differentiations made in the model allow analyzing the impact of the determinants on the 'justice relationship' more precisely. By contrast, the determinants *institutions* and *political restrictions* only relate to the assignment of resource utilization rights in the model, whereas these determinants relate to a range of different institutions, including legal structures, formal and informal markets, management rules for common goods and informal networks, in the political and scientific discourse.

In the case study analysis, I put the *determinants* into concrete terms. This implies a concentration on certain properties of the determinants that are relevant to the investigated agricultural systems. For instance regarding *institutions*, I focus on management rules for community assets and the empowerment of the local population, and regarding *political restrictions*, I focus on political resistance against agrarian reform implementation.

4.4 Efficiency as general condition of facilitation in the MASIPAG case study

Following the argumentation in the 'Trade-off Paper', facilitation in the attainment of intra- and intergenerational environmental justice can only occur if the instruments of justice are used inefficiently in the initial situation. This raises a question relevant for the case study analysis: Is the general process behind facilitation in the MASIPAG farming systems the transition from an inefficient to a (more) efficient use of the instruments of justice? Generally, the use of the instruments of justice is *efficient* if it is not possible in a given system to better attain one objective of justice without worsening the attainment of the other objective of justice. The specific *instruments of justice* employed by the MASIPAG network are technological innovations (i.e. the adoption of environmentally sound and agrobiodiversity-based farming practices) and institutional innovations (i.e. the establishment of a communal seed collection, farmer-led rice breeding and training activities) in agricultural management at the household and community level. The degree of attainment of intragenerational and intergenerational environmental justice is measured in terms of the respective indicator sets.

Indeed, the MASIPAG way of agricultural management is more efficient than the conventional way of agricultural management: MASIPAG farming systems have provided enhanced ecosystem services (i.e. higher agro-biodiversity, better soil fertility, more effective biological control and better knowledge in plant breeding) and less environmental impacts (i.e. soil erosion, pesticide and fertilizer use) than conventional farming systems under equal rice yield – thereby, increasing indicator values of both intragenerational and intergenerational environmental justice. Hence, *inefficiency* in the conventional farming systems was a general condition for a 'justice relationship' of facilitation in the MASIPAG farming systems.

5 Conclusion

Investigating the 'justice relationship' in real-world contexts presupposes clarity on the underlying norms. Conflicts between intragenerational and intergenerational justice in the use of ecosystem services can occur only if the two justices are of equal normative rank. Also, assessing the 'justice relationship' in a specific real-world system requires reference to a conception of justice that particularly addresses the use of ecosystem services. In the 'Justice Paper', I therefore reasoned why intragenerational and intergenerational environmental justice should be considered as objectives of equal normative importance, and proposed a philosophically founded conception of environmental justice that links the ideas of intragenerational and intergenerational justice to the use of ecosystems services.

As a result of a literature review on the scientific and political sustainability discourse, I found that the actual 'justice relationship' is multifarious and multilayered. In real-world situations, three relationships may hold in the attainment of intragenerational and intergenerational environmental justice: rivalry, independency or facilitation. Particularly, I revealed two explanations for the occurrence and extent of rivalry, independency or facilitation in the 'justice relationship'. The first explanation, derived from the very definition of *efficiency* in terms of attaining the two justices, states that *(in)efficiency* in the use of the instruments of justice decides on the occurrence of rivalry, independency or facilitation. The second explanation, derived from the political and scientific sustainability discourse, states that certain *determinants* influence the 'justice relationship'. The results of the ecological-economic modeling and the case study analysis largely substantiate these explanations. Regarding *(in-)efficiency* as determining factor of the 'justice relationship', further research should elaborate how the outlined economic analysis of trade-offs between justices can be applied to concrete real-world cases where information on the 'opportunity set' of politics is imprecise or incomplete. Regarding the *determinants* of the 'justice relationship', further research, particularly the comparison of different case studies and the conduction of field experiments, should clarify whether the determinants are complete and sufficiently specific, and how the determinants interact to produce a certain 'justice relationship'.

The economic analysis of trade-offs between justices opens a new perspective on conflicts between intragenerational and intergenerational environmental justice: Conflicts in terms of 'true' rivalry indicate an efficient use of the instruments of justice – that is, an outcome on the 'justice possibility frontier'. Hence, in a situation of conflict between the two justices a higher degree of one or both justices has been attained as compared to a situation of independency or facilitation between the justices. This implies that a 'justice relationship' of rivalry may be the inevitable outcome of an effective sustainability policy.

Players in international sustainability policy should explicitly discuss on their ideas of intragenerational and intergenerational justice in the use of ecosystem services, and should strive for a common understanding of environmental justice. If facing conflicts between intragenerational and intergenerational environmental justice, sustainability policy should thoroughly prove (1) whether there is a situation of 'true' rivalry, and (2), in case of 'true' rivalry, whether a feasible change in the determinants can improve on one or both justices and thereby reduce the existing conflict. Recognizing these suggestions would enrich political debate about the ethics of sustainable development, and would probably improve the consistency and effectiveness of sustainability policy.

6 References

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Overview of the included papers

Title of Ph.D. thesis: Conflicts between intragenerational and intergenerational justice in the use of ecosystem services

My cumulative Ph.D. thesis comprises the following five papers:

[1] Glotzbach, S., forthcoming. Ecosystem services and distributive justice. Considering access rights to ecosystem services in theories of distributive justice. *Ethics, Policy & Environment.*

[2] Baumgärtner, S., S. Glotzbach, N. Hoberg, M. F. Quaas and K. H. Stumpf 2012. Economic analysis of trade-offs between justices. *Intergenerational Justice Review*, 1/2012, 4-9.

[3] Glotzbach, S. and S. Baumgärtner 2012. The relationship between intragenerational and intergenerational ecological justice. *Environmental Values*, 21(3), 331–355.

[4] Baumgärtner, S., S. Glotzbach and M. F. Quaas 2012. The relationship between intragenerational and intergenerational justice in the use of ecosystems and their services. An ecological-economic model. Manuscript.

[5] Glotzbach, S., forthcoming. Reconciling intragenerational and intergenerational environmental justice in Philippine agriculture: The MASIPAG farmer network. *Ethics, Policy & Environment*.

On the following pages, I specify the authors' contributions to the papers and the papers' publication status as required by the guideline for cumulative dissertations "Promotionskommissionen Dr. phil, Dr. rer. pol. und Dr. rer. nat. der Fakultät Nachhaltigkeit, *Richtlinie zur kumulativen Dissertation*, beschlossen am 15. Januar 2012 (Dr. phil.) / 23. Januar 2012 (Dr. rer. pol.) / 24. Januar 2012 (Dr. rer. nat.)", in the following termed "the guideline".

Table: Authors' contributions to the papers and papers' publication status (according to §16 of the guideline)

Paper #	Short title	Specific contributions of all authors	Author status	Weighting factor	Publication status	Conference contributions
[1]	Ecosystem services and distributive justice		Sole author	1	Accepted for publication in *Ethics, Policy & Environment* (international peer-reviewed journal, indexed in SCOPUS)	GFÖ 2010 DRZE 2011 ISEE 2011 ESEE 2011* ISEE 2012
[2]	Economic analysis of trade-offs between justices	SB: motivation and question of the paper SB, SG, NH, MFQ, KHS: discussion of conclusions, writing of revisions in all parts SB: coordination, writing of introduction and conclusion KHS: writing of section 2 SG: writing of section 3 NH, BG: writing of section 4 MFQ, NH: drawing of the graphs	Co-author with important contribution	0,5	Published in *Intergenerational Justice Review* (international peer-reviewed journal, indexed in DOAJ)	
[3]	Relationship between intragenerational and intergenerational ecological justice	SG, SB: question of the paper SB, SG: logic of the argument SG: qualitative content analysis SG, SB: writing of the manuscript	First author with predominant contribution	1	Published in *Environmental Values* IF: 1.372 (in 2011)	ISEE 2010
[4]	Ecological- economic model	SB, SG: question of the paper SB, SG: outline of the paper SB, SG, MFQ: model design SG, SB: model solution SG, SB: writing of the manuscript	Co-author with equal contribution	1	Manuscript	
[5]	The MASIPAG farmer network		Sole author	1	Accepted for publication in *Ethics, Policy & Environment* (international peer-reviewed journal, indexed in SCOPUS)	BIOECON 2011 TEEB 2012 ISEE 2012
			Sum:	4,5		

Explanations and list of abbreviations

Specific contributions of all authors

KHS = Klara H. Stumpf, MFQ = Martin F. Quaas, NH = Nikolai Hoberg, SB = Stefan Baumgärtner, SG = Stefanie Glotzbach.

Author status

according to §12b of the guideline:

Sole author [Allein-Autorenschaft] = Own contribution amounts to 100%.

First author with predominant contribution [Überwiegender Anteil] = Own contribution exceeds the contribution of the co-author(s) and amounts to at least 35%.

Co-author with equal contribution [Gleicher Anteil] = Own contribution equals the contribution of the co-authors and amounts to at least 25%.

Co-author with important contribution [Wichtiger Anteil] = Own contribution amounts to at least 20%, and it is no predominant or equal contribution.

Co-author with minor contribution [Geringer Anteil] = Own contribution amounts to less than 20%.

Weighting factor

according to §14 of the guideline:

Sole author [Allein-Autorenschaft]	1
First author with predominant contribution [Überwiegender Anteil]	1
Co-author with equal contribution [Gleicher Anteil]	1
Co-author with important contribution [Wichtiger Anteil]	0,5
Co-author with minor contribution [Geringer Anteil]	0

Publication status

IF= ISI Social Sciences Citation Index – Impact Factor

DOAJ= Directory of Open Access Journals, http://www.doaj.org/

Conference contributions (acronym, society, date, venue, website)

BIOECON 2011	BIOECON Conference, September 11-13, 2011, Geneva (Switzerland), http://www.bioecon-network.org/pages/13th_2011.html
DRZE 2011	Deutsches Referenzzentrum für Ethik in den Biowissenschaften, „Interdisciplinary Study Days Biodiversity. Concept and Value", March, 21-25, 2011, Bonn (Germany), http://www.drze.de/drze-events/study-days-2011
ESEE 2011	European Society for Ecological Economics, June 14–17, 2011, Istanbul (Turkey), http://www.esee2011.org
GFÖ 2010	Gesellschaft für Ökologie, August 30- September 03, 2010, Gießen (Germany), http://www.gfoe-giessen-2010.de
ISEE 2010	International Society for Ecological Economics, August 22–25, 2010, Oldenburg/Bremen (Germany), http://www.isee2010.org
ISEE 2011	International Society for Environmental Ethics, June 14-17, 2011, Nijmegen (Netherlands), http://conference.science.ru.nl/isis_isee/ISEE2011
ISEE 2012	International Society for Ecological Economics, June 16–19, 2012, Rio de Janeiro (Brazil), http://www.isee2012.org
TEEB 2012	TEEB Conference 2012, March, 19-22, 2012, Leipzig (Germany), http://www.teeb-conference-2012.ufz.de

* Paper accepted for presentation but not presented

Declaration (according to §16 of the guideline)

Ich versichere, dass alle in diesem Anhang gemachten Angaben jeweils einzeln und insgesamt vollständig der Wahrheit entsprechen.

Paper 1: Ecosystem services and distributive justice. Considering access rights to ecosystem services in theories of distributive justice

Forthcoming in *Ethics, Policy & Environment*

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Abstract: As the increasing loss of ecosystem services severely affects life perspectives of today's poor and future persons, governing access to, and use of, ecosystem services in an intragenerational and intergenerational just way is an urgent issue. Therefore, I argue that theories of distributive justice should consider the distribution of access rights to ecosystem services. I work out three specific demands that a theory of distributive justice should fulfill to adequately cope with the distribution of access rights to ecosystem services, and show that Rawls' "A Theory of Justice" (1971) can be consistently extended to meet the identified demands.

Keywords: ecosystem services, distributive justice, environmental justice, global justice, intergenerational justice.

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1 Introduction

Climate regulation, flood protection, pollination, fertile soils, clean freshwater - the Earth's ecosystems provide a large variety of socially, economically and culturally valuable services to humans (TEEB 2010). Yet, humans degrade today's ecosystems faster than ever and cause the loss of important ecosystem services (MEA 2005: 26ff.). The harmful effects of diminishing ecosystem services appear either as negative externalities, as in the case of climate change or soil erosion, or as a loss of access to natural resources, as in the case of fish, fertile land or fresh water. Today's poor, women and indigenous communities as well as future generations are, respectively will be, disproportionately affected by the negative externalities of ecosystem degradation and by loss of access to essential ecosystem services (ib. 62). Thus, the human use of ecosystems and its services raises fundamental questions of intragenerational and intergenerational justice. However, the specific questions of justice linked to the governance of access to, and use of, ecosystem services have not been discussed thoroughly within the distributive justice literature in general and the environmental justice literature in specific.

In this paper, I justify that theories of distributive justice should consider the distribution of access rights to ecosystem services - both among persons of the present generation and between persons of the present and future generations. This poses specific challenges to the environmental justice discourse which addresses the unequal distribution of environmental burdens and hazards between different contemporary societal groups (e.g. Bryant 1995, Schlosberg 2007)[1]: (1) The choice of the *objects of distribution* needs to be discussed explicitly. I define the objects of distribution generally as the "what?" of distribution according to Dobson (1998: 63), and as the instruments used to fulfill legitimate claims for justice (i.e., the "objects of distribution" fall together with the "instruments of justice", cf. Baumgärtner et al. 2011). In the context of environmental justice, the objects of distribution are the components of nature which are considered as instruments to satisfy legitimate claims for environmental justice. I explicitly reason why access rights to ecosystem services are adequate and sufficient objects of distribution to address injustices in the use and conservation of ecosystems. (2) The scope of theories of environmental justice needs to be extended to tackle questions of global and intertemporal justice simultaneously within one theory. Presently, literature on justice with regard to ecosystem use and conservation tends to focus either on the intragenerational dimension (the environmental justice discourse, e.g. by Schlosberg 2007 and Schroeder et. al. 2008) or on the intergenerational dimension (the ecological sustainability discourse, e.g. by Goodland 1995 and Neumayer 1999) although these dimensions are interconnected (cf. Glotzbach and Baumgärtner 2012). (3) Theories of distributive justice need to be reconsidered for their suitability to address the distribution of access rights to ecosystem services. I work out three specific demands that a theory of distributive justice should fulfill to adequately cope with the distribution of rights to

[1] David Schlosberg (2007) has illustrated that - while political theorists have focused on "justice as distribution" - activists in the environmental justice movement claim distributive justice combined with individual and social recognition as well as participation. Still, I focus on the aspect of distribution in this paper.

ecosystem services. Subsequently, I show that the "A Theory of Justice" by John Rawls (1971) can, by interpreting and extending it in a consistent way, meet the demands.

In the following I use the term *conception of environmental justice*, resp. *principle of environmental justice*, to describe a conception of distributive justice that specifically addresses the distribution of access rights to ecosystem services, resp. the principle(s) of justice following from such a conception of environmental justice.

The paper is structured into six sections. In Section 2, I reason that theories of distributive justice should, in order to tackle injustices related to the use of ecosystems, focus on access rights to ecosystem services as objects of distribution. In Section 3, I identify three specific demands that a theory of distributive justice should fulfill to adequately cope with the distribution of access rights to ecosystem services. In Section 4, I hypothesize that Rawls' "A Theory of Justice" (1971) is an appropriate theory for deriving a conception of environmental justice, and prove this hypothesis by facing his theory with the identified demands. In Section 5, I apply the Rawlsian theory to the distribution of access rights to ecosystem services to derive a principle of environmental justice. In Section 6, I give a conclusion.

2 Rights to ecosystem services as objects of distribution

In this section, I argue that access rights to ecosystem services are particularly suitable objects of distribution to address injustices in the use and conservation of ecosystems. My argumentation is structured along three questions: (1) Why focussing on *ecosystem services*? (2) What does *distribution* mean with regard to ecosystem services? (3) Why distributing *access rights* to ecosystem services?

(1) The notion ecosystem service, as used in this paper, encompasses all benefits that living ecosystem funds (e.g. animals or trees) and non-living ecosystem funds (e.g. soil or air) contribute to human wellbeing (cf. Faber, Manstetten and Proops 1995: 44ff., Georgescu-Roegen 1971: 224ff., MEA 2003: 53). Using the example of the ecosystem “coral reef”, I explain why one should choose *ecosystem services* as core objects of distribution with regard to a conception of environmental justice.

Starting at the ecosystem level, it seems not purposeful to distribute a coral reef itself among different persons. Individual claims to a just use or conservation of a coral reef usually refer to certain components of and processes within the coral reef ecosystem: Claim holders may call for access to its rich fish stocks or the permission to dive and enjoy the beauty of the coral reef; they may claim to conserve the coral reef as spawning area for fish, as shoreline protection from strong currents or because of the high biodiversity it supports. The concept of ecosystem services includes all such ecosystem components and processes that humans value. Thereby, the concept is not restricted to according nature solely instrumental value - the category of cultural ecosystem services[2] also allows according nature aesthetic intrinsic value,

[2] The MEA (2003:57) divides ecosystem services into four categories: provisioning, regulating, cultural and supporting services. Cultural ecosystem services include among others spiritual, religious, educational and aesthetic values, sense of place and recreation.

Heimat value and sacredness (cf. Krebs 1999: 66). Changes in all types of ecosystem services affect human well-being in multiple ways. For instance, changes in access to fish stocks impact on security of livelihoods of coastal inhabitants, and changes in shoreline protection impact their security against natural disasters. The resulting well-being itself cannot be (re)distributed among different persons as it is bound to the access to certain ecosystem services. This implies that governing access to ecosystem services can serve as an instrument of justice that directly influences human wellbeing. Summarizing the two aspects, ecosystem services encompass all ecosystem components and processes that humans value and at the same time constitute effective instruments to influence human wellbeing insofar as it is connected with ecosystems. Therefore, ecosystem services are particularly suitable objects of distribution to address injustices in the use of ecosystems

(2) To explain what *distribution* can mean with regard to ecosystem services, it is necessary to make two distinctions: (i) between divisible ecosystem services characterized by rivalry in consumption and indivisible ecosystem services characterized by non-rivalry in consumption; (ii) between distribution among presently living humans (“intragenerational distribution”) and distribution among humans of different generations (“intergenerational distribution”).

(i) Divisible ecosystem services characterized by rivalry in consumption (e.g. food, fresh water) can be distributed in the “classical” sense, i.e. a certain quantity of the total quantity of an ecosystem service (e.g. a bucket of clean fresh water, a hand of rice) or of its underlying productive funds (e.g. a parcel of fertile agricultural area, rice seeds) can be allocated to different humans. Ecosystem services characterized by non-rivalry in consumption (e.g. erosion control, climate regulation) can be – and insofar they are also characterized by non-excludability from use must be – provided to whole communities at the same time. Distributing such ecosystem services can only mean providing a specific quality of the ecosystem service to a community (e.g. a certain level of flood regulation or a certain level of climate regulation provided by a forest).

(ii) Intragenerational distribution relates to the access to a specific quantity or quality of ecosystem services. Across generations only an indirect distribution of access rights to ecosystem services is possible via the sustenance of “productive” ecosystems. Therefore, intergenerational distribution relates to the passing on of (critical) ecosystem funds (e.g. viable fish populations, fertile soils) - as a prerequisite for the access to ecosystem services of future persons.

(3) Why distributing *access rights* to ecosystem services and not ecosystem services itself? The access right to an ecosystem service is more comprehensive than the corresponding ecosystem service because it constitutes the normative background of a concrete distribution and can actually be distributed - whereas many ecosystem services (e.g. climate regulation or clean fresh water) are presently not (sufficiently) available for "distribution" to all claim holders (Leist 2005: 1).

3 Demands on a conception of environmental justice

A conception of environmental justice should fulfill specific demands to adequately cope with the distribution of access rights to ecosystem services. In this Section, I develop and discuss three specific demands which are (i) the global and intertemporal extension of the community of justice, (ii) institutional agents as claim addressees, and (iii) includability of ecosystem services as objects of distribution.

3.1 Global and intertemporal extension of the community of justice

The *community of justice* comprises all holders and addressees of legitimate claims for justice (Baumgärtner et al. 2011, Dobson 1998: 64). In the following, I give three reasons why a conception of environmental justice demands extending the community of justice to include a global community across generations. The reasons are based on the assumption that the provision and use of ecosystem services create global and intertemporal social relations which give rise to legitimate claims for justice.

First, the modes of generation and provision of many ecosystem services produce the necessity to extent the community of justice beyond a national community, both spatially and temporally. Whereas some ecosystem services are provided at the same spatial and temporal scale as the ecosystem that generates them (e.g. the provision of wood by a forest ecosystem), others are provided at a completely different scale as the generating system (Elmquist et. al. 2010). Examples include pollination, which is provided at local scale, but depends on the maintenance of viable populations of pollinators on the landscape level, as well as climate regulation, a service provided at global scale and with time delay, but generated locally by carbon sequestration in organic matter (ib.). Hence, human action towards local ecosystems (e.g. the clear cut of a forest) can affect the provision of ecosystem services at the other end of the globe and in remote future (e.g. climate impacts due to failing global climate regulation).

Second, provision and use of ecosystem services are separated spatially as a consequence of globalization. International trade, global division of labor and the operating principles of multinational corporations often go along with specific patterns of production and consumption: Harms associated with ecosystem service provision are distributed to the countries of the global South, whereas benefits from ecosystem service use are distributed to the countries of the global North.

Third, modern technology (e.g. nuclear power plants, GMO technology, and potentially Geo-Engineering) has enormously extended human impact on ecosystems. Today's introduction of such technologies can irreversibly affect future states of ecosystems and their potential to provide ecosystem services to future persons (cf. Jonas 1988: 8f., 54).

As humans impact on the provision and use of ecosystem services and thereby create global and intertemporal social relations that give rise to potentially legitimate claims for justice, a conception of environmental justice needs to tackle the question how these relations across time and space should be governed in a "just" way.

3.2 Institutional agents as claim addressees

The *claim addressees* are the agents within the community of justice who must ensure that legitimate claims for justice asserted by the *claim holders* are fulfilled (Baumgärtner et al. 2011). I will give both positive and normative arguments why societal institutions and its agents should be the claim addressees once the claims concern access rights to ecosystem services.

One *positive reason* is the cognitive, emotional and motivational overload of individuals. No single individual can overview all consequences of her own environmental behavior - because of the temporally and spatially aggregated impacts on ecosystems of myriad independent decisions, the complexity of ecosystem processes and the interdependency of different ecosystem services. As societal institutions (e.g. eco-labelling) exert an orientation function, they can help to value individual environmental behaviour (Kopfmüller 2001: 106). Further, emotional and motivational barriers impede constraining one’s own behaviour for the sake of persons at the other end of the globe and in remote future. Societal institutions (e.g. environmental legislation) can possibly reduce the psychological gap between the motivation to accept moral rules and the motivation to act in accordance with them (Birnbacher 2006: 21). From an economic point of view, most ecosystem services are viewed either as common-pool goods or as public goods, resulting in overuse (in case of common-pool goods) or insufficient provision (in case of public goods) of ecosystem services. To repair this market failure, the intervention by societal institutions and rules (e.g. property rights, laws, taxes or community management) is demanded. From a governance point of view, most impacts on the delivery and distribution of ecosystem services evade an individual's immediate sphere of activity. The governance function of institutions facilitates the coordination of different agents, where cumulative effort for the conservation and provision of ecosystem services is needed (e.g. in the case of global climate regulation and global biodiversity conservation). All these reasons point to societal institutions and its agents as the appropriate claim addressees. By focusing on societal institutions and institutional agents one needs to bear in mind that it is the individual actors, their norms and their conduct who shape societal institutions and who ultimately comply with or reject institutional rules.

The *normative reason* for choosing institutions as claim addressees is founded on the communitarian value of ecosystem services. Faber and Petersen (2008) use the term institutional justice (“Ordnungsgerechtigkeit”) to describe a structure of a community that enables its members to lead a good life in the best possible way. Hence, institutional justice demands creating conditions that enable a good life in a community. The provision of ecosystem services, at least of the essential and non-substitutable ones, could be defined as a necessary condition for realizing a good life in a community. Transferring the argumentation by Faber and Petersen to environmental justice, societal institutions would need to ensure the provision of vital ecosystem services to all members of a community. As national institutions which govern the use of ecosystem services influence the possibilities for a good life of people living in other nations and in the future (cf. Section 3.1), its global and intertemporal impacts need to be considered (Pogge 1989: 256).

3.3 Includability of ecosystem services as objects of distribution

As I have argued in Section 2, access rights to ecosystem services should be the objects of distribution to adequately address injustices related to the use and conservation of ecosystems. Most theories of distributive justice only refer to certain objects of distribution. For example, Rawls' theory is concerned with the distribution of primary social goods, i.e. “things that men are presumed to want whatever else they want” (Rawls 1999a: 230). Thus, it needs to be investigated whether ecosystem services can fall into the restricted category of objects treated by the theory under consideration, e.g. whether access rights to ecosystem services can fall into the category of primary social goods.

4 Rawls’ “Theory of Justice” and the demands on a conception of environmental justice

To develop a philosophically founded conception of environmental justice, it is instructive to build on established theories of distributive justice. Theories, which shall contribute to build a philosophically founded conception of environmental justice, need to be reconsidered for whether they can fulfill the demands elaborated in the previous Section 3. I hypothesize that the “A Theory of Justice” by John Rawls (1971) is an appropriate theory for deriving a conception of environmental justice, and prove this hypothesis by facing Rawls’ theory with the three demands on a conception of environmental justice.

4.1 Rawls: global and intertemporal extension of the community of justice

Rawls’ theory is a contract theory considering the question of a just basic structure of society, which includes the political constitution and the principal elements of the social and economic system. Its focus is on the development of certain principles of justice that should guide societal institutions in the distribution of primary social goods. His theory is characterized by an impartial perspective: Rawls introduces an original position in which the contract partners decide on principles of justice from behind a veil of ignorance, neither knowing their specific place in society nor what makes them different from other individuals regarding natural assets and abilities nor what conception of a good life they hold. The imaginary original position serves the purpose of deducing, justifying and revising fair and generally agreeable principles of justice. In this original position, the contract partners commonly agree on two principles of justice (ib. 53): (1) equal rights to the most extensive set of equal basic liberties; (2) social and economic inequalities are only allowed (a) if they are to the benefit of the least advantaged, and (b) if societal positions and offices are accessible to all.

Rawls chooses the members of a nation state, i.e. a "society (…) as a closed system isolated from other societies" (Rawls 1999a: 8), to be the community of justice. Can his theory be extended in a consistent and coherent way to include a global community of justice and future persons and, thereby, meet the first demand on a conception of environmental justice?

The original position and a global community

In general, two basic conditions are claimed to constitute and delimitate the community of justice (cf. e.g. Leist 2005: 11f.; Pogge 1989: 262ff.): (i) *reciprocity*, defined either as a significant web of mutual social relations or as social relations characterized by mutual advantage; and (ii) *moral equality*, based e.g. on human dignity.

On one site, Rawls draws on *reciprocity* as the defining condition of the community of justice for he assumes “that those who engage in social cooperation choose together, in one joint act, the principles [of justice, author’s note]” (Rawls 1999a: 10). As Samuel Freeman (2006: 38) points out, social cooperation in the Rawlsian framework is only possible within a “basic structure of society” constituted by social institutions such as a legal system, competitive markets and private property (Rawls 1999a: 6). On the other hand, Rawls accounts with his original position for the *moral equality* of all humans: “For in this situation [the original position, author’s note] men have equal representation as moral persons who regard themselves as ends” (ib. 157). He uses the veil of ignorance to construct an impartial situation that secures a morally equal treatment of all contract partners. The discussion about extending Rawls’ domestic original position to a global one bears on this inner tension between reciprocity and moral equality as the defining condition of a community of justice.

Rawls himself rejects a global original position in which representative members of a world society decide upon a global basic structure of institutions. Instead, he constructs in his book "The Law of Peoples" (1999b) a second original position containing delegates from different nations who decide on principles of international law. Criticism of Rawls’ international original position and of the principles of justice derived from it concentrates on three aspects: The lack of reference to a globally just distribution of primary goods, the priority of national decisions and the assumed analogy between individuals and states in the original position (Hayden 2002: 89; Pogge 1989: 240). Because of these significant objections against Rawls' international original position, I investigate the potential of a global original position.

The first question that arises is why Rawls himself did reject a global original position. Freeman (2006: 53) points to a certain kind of reciprocity, i.e. democratic social and political cooperation within the basic institutions of society, which Rawls assumes as constitutive for a community of justice that decides on the distribution of primary social goods. This kind of reciprocity would not exist at the international level: “Given the central role that cooperation and reciprocity play in Rawls’s system, the absence of the rule of law at an international level is not merely a “practical” difficulty. It plays a central role in determining what individuals can reasonably expect of one another under such circumstances” (Heath 2005: 7f., cf. also Freeman 2006). Charles Beitz (1979), the first who proposed extending the Rawlsian original position to the global level, holds against the reciprocity-argument that the present absence of a global basic structure is no obstacle against a global original position: “Ideal theory prescribes standards that serve as goals of political change in the nonideal world, assuming that a just society can, in due course, be achieved. The ideal cannot be undermined simply by pointing out that it cannot be achieved at present” (ib. 156).

Proponents of a global original position refer to moral equality as a central feature of the Rawlsian original position. They argue that morally equal treatment of all presently living humans would require a global original position. Excluding economic, social and natural contingencies in the original position, but not compensating for contingencies related to the country of birth (e.g. the unequal distribution of natural resources) would be an indication of moral arbitrariness in Rawls' contract theory – as it would imply unequal moral treatment of humans inhabiting different countries (Beitz 1979, Pogge 1989: 247). The demand for a global original position based on the mutual appreciation as morally equal persons would remain valid if international social cooperation is insufficient to constitute a global basic structure (Leist 2005: 79). I assume this to be a convincing argument for a global original position.

The original position and future people

In intergenerational relations (i.e. social relations between persons of different generations) the lack of reciprocity reveals as much more fundamental than in intragenerational relations. The non-concurrency of existence of the present and future generations makes mutual communication and cooperation impossible. Instead, intergenerational relations are characterized by radical asymmetry in power (Dobson 1998: 103; Leist 2005: 24ff., Rawls 1999a: 254). But, as I have argued with regard to a global original position, the domestic community of justice can be consistently extended drawing upon moral equality of all humans as defining feature of a community of justice. In this paragraph, I analyze how far the condition of moral equality allows extending the original position to include future persons. Starting from Rawls' domestic original position in which the members of a nation state are assembled, I investigate whether and how this original position can be consistently extended to also represent future persons. In doing so, I refer to three models discussed by Rawls:

1) The assembly in the original position contains only self-interested contemporaries (Rawls 1999a: 121, 254f.).
2) The assembly in the original position contains only contemporaries, but they represent family lines that have an interest in the wellbeing of their descendants (*ib.* 255).
3a) The assembly in the original position contains all individuals who exist, have existed and will exist (ib. 120).
3b) The assembly in the original position contains representatives from the present and actual future generations (Richards 1983, in De-Shalit 1995: 110).

In model 1, there are only persons who know that they are contemporaries, but who do not know which generation they belong to in the original position. As they could not affect the saving decisions of previous generations, they would acknowledge the principle that no one has to save for posterity (Rawls 1999a: 255). The persons' knowledge about them being contemporaries would prevent the representation of future persons' interests in the decisions of contemporaries.

In model 2, the assembly members are contemporaries who represent family lines and, therewith, care about the wellbeing of their descendants (ib.). This is the solution proposed by Rawls. By rejecting the motivation assumption of purely self-interested persons in this model, Rawls breaks his contractualist reasoning. He introduces altruistic interests of the assembly members and a *particular* conception of a good life (i.e. the idea of the family and of emotional familiar ties) which is not consistent with Rawls' fundamental conception of the original position (De-Shalit 1995: 105ff.). Therefore, I assess his solution as unconvincing.

Model 3a, an assembly of all persons who will live at some time, is rejected by Rawls because this conception would "cease to be a natural guide to intuition" (Rawls 1999a: 120). Although Rawls wants to show principles of justice for an ideal society and stresses that the original position is a "purely hypothetical situation" (ib. 104), his objection is reasonable. Another argument against model 3a can be derived from the assumption of endogenous population development: If the number and individuality of future persons fully depends on actions of the present generation, there can only be possible future individuals. At least two significant objections are raised against attributing moral rights to possible future individuals: the „non-identity-problem" (e.g. Schwartz 1978, Parfit 1987) and the "non-existence" argument (e.g. Beckermann 2006, Partridge 2008: 4). The non-identity-problem questions the assumption that individuals of the present generation can harm future individuals. The actions of the present generation (e.g. the choice between different environmental policies) would not only determine the future environment, but also which individuals will come into existence. If the very existence of a future individual is necessarily associated with a certain present action, the future individual could neither be harmed nor benefited by this action (Parfit 1987; Page 2008: 10f.). Ott (2003: 43) clarifies that the validity of the non-identity-problem "rests on the distinction between person-dependent and person-independent moral principles". Person-independent principles would relate to a future person, i.e. a "future human being who owns such features that are (or will be) constitutive of personhood", whereas person-dependent principles would relate to a future individual, i.e. a "particular future person" (ib. 42). The non-identity-problem would be a person-dependent moral principle (ib. 44). As the (possible) future individuals in the original position of model 3a are behind a veil of ignorance and, hence, do not know about their particular abilities and their concept of the good, it seems sufficient to assume future *persons*. Therefore, the non-identity-problem can be rejected within the context of the Rawlsian original position. The non-existence argument refers to the potentiality of future persons and says that *possible* persons do not have any interests at all and, therewith, do not have moral rights until they come into existence (Parfit 1987: 359, Partridge 2008: 5). The argument can only be rejected if we assume that solely real future persons are represented in the original position.

Model 3b slightly differs from model 3a as it makes weaker assumptions about future generations. It takes the assumption made by Richards (1983, in De-Shalit 1995: 110) that the assembly only contains *real* future persons, who are concerned with the circumstances of their existence, but not their existence itself. More specifically, Model 3b only assumes that there will be at least one future generation with at least one future person living and being characterized by the same human features as present persons. As the assembly decides on abstract and generally agreeable principles of justice, it is not important to know the exact number of generations and of future people in the original position. Model 3b only refers to *real* future persons (i.e. persons who will actually live in the future) and, therefore, the non-existence argument is not relevant. Hence, this model can consistently represent future persons in the original position.

Although Rawls restricts the community of justice to a national community of contemporaries, his original position can - based on the moral equality of all present and real future humans - be consistently extended to include a global community of justice across the present and future generations.

4.2 Rawls: Institutional agents as claim addressees

Rawls assumes that the primary subject of justice is "the basic structure of society, or more exactly, the way in which the major social institutions distribute fundamental rights and duties and determine the division of advantages from social cooperation" (Rawls 1999a: 6). In Rawls’ theory it is institutions and the institutional agents who govern the distribution of primary social goods. Hence, it is institutions that must ensure that justified claims for primary goods are met. Institutional agents are the claim addressees in Rawls’ theory.

4.3 Rawls: Includability of ecosystem services as objects of distribution

Rawls’ theory derives principles of justice for the distribution of primary social goods. For addressing the distribution of access rights to ecosystem services based on the Rawlsian theory, it is crucial whether ecosystem services can fall into the category of primary social goods. Rawls does not discuss natural resources and intact ecosystems as part of his list of primary goods. Nevertheless, all attempts to relate Rawls' theory to the environment show that ecosystems and its services need to be included, at least to some extent, in a list of primary goods (e.g. Dobson 1998: 125; Visser’t Hooft 2007: 88).

Rawls defines primary social goods as “a class of goods that are normally wanted as parts of rational plans of life which may include the most varied sorts of ends” (Rawls 1999a: 230), and assigns rights, liberties, opportunities, income and wealth to the category of primary goods (ib. 54). Primary goods are derived from the general assumptions about rationality and the requirements of social life (ib. 223). As persons in the original position know "the general facts about human society" (ib. 119), it can be assumed that they know about their basic needs and about their dependence on essential and non-substitutable ecosystem services to fulfill them. Therefore, persons in the original position will commonly regard essential and non-substitutable ecosystem services as primary social goods.

The question whether ecosystem services which are not essential for human survival are primary goods is less obvious. It can only be answered by thickening Rawls’ “thin theory” of the good (ib. 348). A promising way to do this is by interpreting primary goods as things that enable the exertion of *basic capabilities* - substantive freedoms that people can achieve with certain primary goods (Sen 1982: 368). Amartya Sen (2009: 248) argues that the value of the environment to humans lies not only in the fulfilment of basic needs, but rather in “the opportunities it offers to people”. The capability approach shifts attention to what primary goods do to humans, and hence to a thicker conception of the good life (ib.). The instrumental value of (essential) ecosystem services to human basic capabilities has been described by Holland (2008) as follows: “Being able to have a good health and nourishment requires that ecological systems function at a level that can sustain the provision of soil, water, and atmospheric temperature that enable agricultural production and the absorption of human produced waste (pollution). Similarly, the adequacy of human shelter is partly contingent upon the extent to which whole ecological systems can maintain the chemical composition of the atmosphere in a way that stabilizes temperatures and ensures environmental change occurs on time scales to which humans can adapt" (ib. 323). Also several cultural ecosystem services are required to exert certain basic capabilities. For instance, one can argue that exerting the basic capability "senses, imagination, and thoughts" (Nussbaum 2006: 77) requires the possibility of spiritual experience of nature and of religious practices attached to environmental monuments (Holland 2008: 323). Martin Seel's "three aspects of a good life" (1991: 311ff.) constitute a conception of basic capabilities that explicitly refers to cultural ecosystem services. Also Martha Nussbaum's list of "central human capabilities" (2006:76ff.) contains a capability related to cultural ecosystem services, the capability of "being able to live with concern for and in relation to animals, plants, and the world of nature" (ib. 77). Generally, it seems reasonable to argue that all ecosystem services which provide vital resources or conditions to human basic capabilities possess the characteristics of primary social goods. Hence, what ecosystem services fall into the category of primary goods depends on the list of human basic capabilities, and the level of generality of these basic capabilities.[3]

The distribution of social primary goods underlies the Rawlsian principles of justice decided behind the veil of ignorance. Rawls' first principle of justice refers to a system of basic liberties of citizenship - negative liberties, including freedom of thought, liberty of conscience, freedom of the person and political liberty (Rawls 1999a: 177). Rawls' second principle of justice refers to the distribution of all further primary social goods: the fair equality of opportunity principle as one part of the second principle refers to opportunities to societal positions and offices, the difference principle as the other part of the second principle refers to income and wealth (ib. 80). As rights to access ecosystem services are positive rights to tangible goods, they fall into the second subcategory and under the difference principle.

5 From Rawls' "A Theory of Justice" to a principle of environmental justice

A consequent extension of Rawls' original position contains representatives from the present and (at least one) actual future generation(s) behind a complete veil of ignorance. The representatives regard ecosystem services that provide essential resources or conditions for the fulfillment of basic capabilities as primary social goods. Hence, the representatives would decide on the following abstract principle of justice regarding access rights to ecosystem services, termed *principle of environmental justice*:[4]

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[3] Even if the assembly members would - behind the veil of ignorance - know that certain ecosystem services are vital for realizing the basic capabilities of many, but not all contract partners, they would probably decide upon distributing such ecosystem services *as if* these would be primary goods. As the veil of ignorance excludes all knowledge of likelihoods, only the distribution according to the difference principle would ensure them against the eventuality of lacking a good life because of the absence of certain ecosystem services.

[4] Thomas Pogge (1989: 247) has argued that the same principles of justice would be decided in the global original position as in the domestic original position. There seems to be no reason, why different principles of justice should be decided in a "cross-generational and global" original position.

Inequalities in the distribution of access rights to all vital ecosystem services are to be to the greatest benefit of the least-advantaged members of the present and actual future generations.

The term 'vital' relates to the ecosystem services which are required for exerting human basic capabilities. The term 'benefit' relates to the degree up to which the basic capabilities can be attained with the provided set of ecosystem services. Here, I assume that the degree of attainability of different capabilities cannot be aggregated to a single index. This would not be consistent with the capability approach which assumes that "a life that is worthy of the dignity of the human being" requires attaining a minimum threshold of each human basic capability for each person (Nussbaum 2006: 70).

Whether future persons have access to sufficient vital ecosystem services to fulfill their basic capabilities crucially depends – besides the ecosystem funds passed on to future generations - on future population size. Therefore, Brian Barry (1999: 109) suggests that "the size of future population should be brought within the scope of the principle of responsibility". This implies that the current institutional agents should address the stabilization of population size to fully implement the principle of environmental justice.

Lifting the veil of ignorance

The principle of environmental justice is decided in the original position behind a veil of ignorance. After lifting the veil of ignorance, three challenges arise. First, the principle of environmental justice needs to be specified for particular human-nature-systems and policy areas, considering uncertainty with regard to the future. Second, the specified principle needs to be implemented by social institutions. The principle can mark the overall aim of environmental justice that institutions should seek for, but it does not reveal institutional transformation processes necessary to achieve it. Third, individuals need to support and accept institutions which implement the principle of environmental justice. According to Rawls, the members of the community of justice have a twofold duty: "first, we are to comply with and to do our share to just institutions when they exist and apply to us; and second, we are to assist in the establishment of just arrangements when they do not exist" (Rawls 1999: 293f.). Whereas the principle of environmental justice is favorable to all rational and self-interested persons behind the veil of ignorance, it becomes adverse to some persons after lifting it. Therefore, justice as a virtue needs to be an integral part of a conception of environmental justice in terms of responsibility for establishing und sustaining just institutions. Rawls himself assumes moral persons who are "capable of having (and are assumed to acquire) a sense of justice, a normally effective desire to apply and to act upon the principles of justice" (ib. 442). Therewith, he develops a more encompassing idea of the human as a relational and responsible person, whereas in the original position the persons only show one of their characteristics as humans, their rationality. Rawls' idea of the human therefore allows for complementing his conception of institutional justice with a conception of an *environmentally just person* based on virtue ethics (cf. e.g. Becker 2011).

6 Conclusion

In this paper, I propose a conception of environmental justice that addresses the distribution of access rights to ecosystem services. I worked out three specific demands that a theory of distributive justice should fulfill to adequately cope with the distribution of access rights to ecosystem services: (i) global and intertemporal extension of the community of justice, (ii) institutional agents as claim addressees, and (iii) includability of ecosystem services as objects of distribution. I verified that Rawls' "A Theory of Justice" (1971) is an appropriate theory for deriving a conception of ecological justice. Rawls' original position can be extended to include representatives from the present and future generations, who decide on the distribution of access rights to ecosystem services. They would agree on the following principle of environmental justice: Inequalities in the distribution of access rights to all vital ecosystem services are to be to the greatest benefit of the least-advantaged members of the present and actual future generations.

Although Rawls' theory can be consistently expanded to meet all demands on a conception of environmental justice, it has two shortcomings: its mere focus on primary social goods as objects of distribution and its focus on pure institutional justice. The first can be addressed by interpreting Rawls' primary goods as necessary resources and conditions for realizing certain basic capabilities of a good life, as applied in this paper. The second can be addressed by complementing the developed conception of institutional justice with a conception of "the environmentally just person" based on virtue ethics.

The principle of environmental justice integrates the intragenerational and the intergenerational dimension of environmental justice, and constitutes a philosophically founded criterion for assessing the distributional effects of social institutions on access rights to ecosystem services. Investigating what institutional changes are needed to approach the principle of environmental justice, and how the principle can be translated into context-specific indicators, presents a challenge to interdisciplinary and transdisciplinary sustainability sciences.

7 Acknowledgements

I wish to thank Stefan Baumgärtner, Christian Becker, Klara H. Stumpf and two anonymous referees as well as the participants of the Eighth Annual Meeting of the *International Society for Environmental Ethics* and the participants of the *Interdisciplinary Study Days. Biodiversity – Concept and Value* for critical discussion and valuable comments. Financial support from the German Federal Ministry of Education and Research (BMBF) under grants 01UN1011A/B is gratefully acknowledged.

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Paper 2: Economic analysis of trade-offs between justices

Intergenerational Justice Review 1/2012, 4-9.

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Abstract: We argue that economics – as the scientific method of analysing trade-offs – can be helpful (and may even be indispensable) for assessing the trade-offs between intergenerational and intragenerational justice. Economic analysis can delineate the "opportunity set" of politics with respect to the two normative objectives of inter- and intragenerational justice, i.e. it can describe which outcomes are feasible in achieving the two objectives in a given context, and which are not. It can distinguish efficient from inefficient uses of instruments of justice. It can identify the "opportunity cost" of attaining one justice to a higher degree, in terms of less achievement of the other. We find that, under very general conditions, (1) efficiency in the use of instruments of justice implies that there is rivalry between the two justices and the opportunity cost of either justice is positive; (2) negative opportunity costs of achieving one justice exist if there is facilitation between the two justices, which can only happen if instruments of justice are used inefficiently; (3) opportunity costs of achieving one justice are zero if the two justices are independent of each other, which is the case in the interior of the opportunity set where instruments of justice are used inefficiently.

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1 Introduction

Justice is a multifarious normative idea about the quality of relationships among members of society. One may argue that there are many "justices", insofar as different parts of society, different types of relationships, or different substantive areas are addressed. The overall societal goal ("vision") of sustainability particularly addresses two justices: (i) justice between presently living persons ("intragenerational justice"), and (ii) justice between members of present and future generations ("intergenerational justice"). [1,2]

With two (or more) different justices as normative objectives of equal rank, it may be that there exists a trade-off between them, that is, performing better with regard to one objective implies performing worse with regard to the other one. In particular, it may be that fostering intragenerational justice makes it more difficult to attain intergenerational justice, and vice versa. Such a trade-off at the level of normative objectives of equal rank – if it exists – asks for societal resolution. The question is: How to act in the face of different justices? Important examples for such a trade-off include government spending on social welfare vs. investment in public infrastructure and education, or the exploitation vs. conservation of non-renewable natural resources.

In this essay, we argue that economics – as the scientific method of analyzing trade-offs – can be helpful (and may even be indispensable) for assessing the trade-offs between different justices. We understand economics as being defined by its method, rather than by its substance matter or by some normative objective[3], and we sketch how to employ this method to analyse trade-offs between justices. An important contribution that economics can make to this analysis is to introduce the secondary normative criterion of *efficiency* which characterises the non-wasteful use of scarce resources to attain the primary normative objectives of justice: a situation is efficient with regard to different objectives if it is not possible to improve on one objective without doing worse on another one. Being derived from primary normative objectives, the criterion of efficiency itself makes a normative claim: it is good to use scarce resources efficiently to attain intra- and intergenerational justice; it is wrong to use scarce resources inefficiently for that purpose.

This approach of using economics as a method to study the efficient use of scarce resources in the attainment of rivaling normative objectives of justice[4] opens an innovative perspective on what the role of economics should be (as a method) in the discussion of justice, and on how to bridge the gap – systematically and rigorously – between ideal theory and non-ideal politics.

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[1] WCED 1987.

[2] In addition, some conceptions of sustainability also include justice towards nature as a third normative objective of equal rank.

[3] This is the standard interpretation of modern economics according to Robbins 1932. For an encompassing discussion of this and other interpretations of economics, see Hausman 2007.

[4] This approach, as applied to the three justices included in the vision of sustainability – intra- and intergenerational justice as well as justice towards nature – has been called "sustainability economics" (Baumgärtner and Quaas 2010, Baumgärtner 2011).

2 Specifying justice(s)

To inform our understanding of intra- and intergenerational justice, the abstract and general concept of justice needs to be further specified. We take justice to generally refer to the mutual claims of members of the community of justice from the standpoint of impartiality.[5] This minimum definition leaves ample room for very different, and sometimes much contested, conceptions of justice. Each of them can be described more precisely by specifying a number of elements in a "syntax of justice".[6,7] In the following, we specify the essential elements of the syntax to clarify the conceptions of inter- and intragenerational justice.

The community of justice. Justice refers to mutual claims[8] within a community of justice. We term those holding a particular claim the *claim holders*, and those responsible for the fulfillment of the claim the *claim addressees*.[9] Intragenerational justice entails claims held by currently living persons (claim holders) towards other currently living persons (claim addressees). Intergenerational justice entails claims held by persons living in the future ("future generations", claim holders) towards persons living today (claim addressees).[10] It is not necessary that such a claim is explicitly put forward by the claim holder (which may be impossible in the case of intergenerational justice). What matters is that a legitimate claim might be formulated by someone speaking for the claim holder.

Positive and negative claims. Generally, claims can be positive, i.e. defining an entitlement to a certain good,[11] or negative, i.e. demanding freedom from harm.[12] Claims are considered legitimate if they could be agreed on from the standpoint of impartiality and equal consideration. For example, intergenerational justice claims could be specified as a positive claim of future generations to certain stocks and systems, such as a democratic political system, a stock of manufactured capital and critical knowledge, or intact ecosystems, implying a responsibility of the present generation to pass on these stocks and systems in a good state to future generations. Future generations may also have a negative claim: not to be harmed by any activities of the presently living generation, e.g. through increasing systemic risks caused by a dysfunctional global financial system or through nuclear waste left over as a

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[5] E.g. Gosepath 2007: 82.

[6] Baumgärtner / Glotzbach / Stumpf 2011.

[7] This "syntax" is our approach to structure what has been called the different "dimensions" (Pogge 2006, Dobson 1998, see also Ott and Döring 2008) of the concept of justice. It allows fully specifying a particular conception of justice.

[8] Young 1994, Ott and Döring 2008: 59 et seqq.

[9] The delineation of the community of justice, especially the question of who is to be included as a claim holder, can be drawn according to different criteria such as reciprocity, dignity, ability to experience pain, etc. (e.g. Baumgärtner, Glotzbach and Stumpf 2011).

[10] The third justice often included in sustainability conceptions, justice towards nature, refers to claims held by "nature", e.g. higher non-human animals capable of experiencing pain or of pursuing goals, against humanity. Thus, the claim holders differ, while the claim addressees belong to the group of currently living persons in all three cases. While intra- and intergenerational justice reflect an anthropocentric idea of justice, according to which nature matters to humans exclusively because of its instrumental value, the idea of justice towards nature assigns an intrinsic value to nature (Baumgärtner and Quaas 2010: Sec. 2), so that "nature" becomes a claim holder in its own right.

[11] "Goods" should be understood in a wide sense.

[12] cf. Baumgärtner / Glotzbach / Stumpf 2011.

by-product of present electricity production. Intragenerational justice claims include the positive claim for satisfaction of basic needs, and the negative claim that one's freedoms should not be harmed (human rights).

Judicandum. We use the term *judicandum* to describe that which is to be judged as just or unjust. Judicanda can be agents, actions, institutions or states of the world.[13] When discussing inter- and intragenerational justice, the judicanda could be the actions of currently living persons (and the consequences of these actions, such as, say, the distribution of certain primary goods), as the claim addressees of both justices belong to the current generation.

Instruments of justice. We use the term *instrument of justice* to describe that which is to be used to satisfy the legitimate claims of justice. In many conceptions of justice, these will be objects of distribution (answers to the question "What is distributed?"[14]), but the satisfaction of legitimate claims could also be achieved via, say, institutional reform to ensure procedural justice. So, the question here is *how* legitimate claims are addressed. For example, one instrument of intergenerational justice could be the investment in public goods such as education and infrastructure, or the distribution of stocks of non-renewable resources between different generations. The aim of intragenerational justice could, for example, require institutional reform of international trade rules ("fairness").

Metric for the judgment. For statements about the degree of attainment of a normative objective, there must be some way to measure the justice of the judicanda: one needs a *metric* to judge whether, and to what extent, a judicandum is just or unjust. For this metric, different informational bases have been proposed, such as e.g. capabilities, primary goods, or utility.[15] It is possible to use different metrics for inter- and intragenerational justice.

In sum, judging a certain judicandum as inter- or intragenerationally just according to a metric requires first to specify the positive and negative claims of claim holders in present and future generations against claim addressees in the present generation, which are to be satisfied by certain instruments of justice.

As we discuss two different justices, both of which demand the fulfillment of legitimate claims through the use of instruments of justice by the same addressee, a non-trivial decision problem arises for this addressee – the present generation. We therefore need to have a closer look at the possible relationships of these two justices.

3 Relationships between justices

Generally, the two justices are related both on the "value" side and the "production" side.[16] On the value side, the relationship refers to the desirability, from a societal point of view, of

[13] Pogge 2006: 863.
[14] *Sensu* Dobson 1998: 73 et seqq.
[15] Cf. Pogge 2006: 868.
[16] LeGrand 1990: 555.

attaining one justice relative to the other one. For example, society may be willing to trade-off one justice against the other[17], or one justice might strictly dominate the other. In this essay, we build on the minimal and very general premise, widely held in the literature,[18] that both intra- and intergenerational justice are considered by society as desirable normative objectives of equal rank. Beyond that, we do not further discuss the value side.

On the production side, the relationship refers to the feasible outcomes of the use of instruments of justice, that is, combinations of degrees of attainment of both justices. Here, what is feasible is determined by the structure and functioning of the given system, based on natural resource endowments, technology, institutions, etc. The set of all feasible combinations in terms of the two justices is called the "opportunity set". It describes society's options for choice, which are independent of what society considers desirable. That is, the production side and the value side are independent of each other.

Scientific analysis and political implementation have shown that, in general, three relationships may hold on the production side between intra- and intergenerational justice:[19]

(1) **Independency**: The objectives of intra- and intergenerational justice can be achieved independently, that is, attaining one objective to a higher degree does not necessitate any change in the degree to which one attains the other one.[20]
(2) **Facilitation**: Achieving one objective supports achieving the other one, that is, attaining one objective to a higher degree induces a higher degree of attainment of the other one.[21,22]
(3) **Rivalry**: A fundamental rivalry (or "trade-off") exists between the objectives of intra- and intergenerational justice, that is, attaining one objective to a higher degree necessarily reduces the degree to which one attains the other one.[23]

For illustration, we give examples from different contexts. Independency is an assumption frequently made in ecological, environmental and resource economics.[24] For example, cap-and-trade systems for greenhouse gas emissions imply that the overall intergenerational impact on global climate can be governed independently of the initial intragenerational distribution of emission certificates.[25] Facilitation is prominently stated with regard to the provision of public goods. For instance, public investment in education or the improvement of public transportation systems may simultaneously benefit today's poor and future persons. Rivalry is often assumed when the possibility of intragenerational redistribution of access

[17] Barry 1965: Sec. 1.
[18] E.g. Dobson 1998: 3 et seqq., Ott / Döring: 2008, Visser´t Hooft 2007: 56, WCED 1987: 43.
[19] Here, we extend the argument from Glotzbach and Baumgärtner (in press, Sec. 3) which originally refers to justice with regard to the use and conservation of ecosystems.
[20] Independency does not need to be symmetric: achieving one objective may be independent of achieving the other one, but not vice versa.
[21] This relationship is similar to the concept of "joint production" in economics, which means that the production of a wanted good necessarily gives rise to additional outputs (cf. Baumgärtner et al. 2006).
[22] This facilitation may be one-way, or the other way, or a mutual facilitation between the achievement of the two objectives.
[23] Like independency and facilitation, rivalry does not need to be symmetric.
[24] E.g. Dasgupta and Heal: 1979.
[25] E.g. Perman et al.: 2003: 219 et seqq.

rights to rival resources is heavily limited. In such cases, meeting the legitimate claims of the poor to the resource possibly reduces the total resource stock passed on to future generations and, thereby, may be at the expense of intergenerational justice. For example, if the government spends a higher share of tax revenue to increase social support of the poor without being able to enforce higher taxes on the rich, the government has less revenue to invest in public infrastructure and education.

A host of specific **determinants** – natural, technological and institutional factors – impact on the production relationship between intra- and intergenerational justice, for example because they influence the availability and effectiveness of the instruments of justice. Thereby, they affect which relationship holds. Two examples for such determinants are population development and political restrictions. In many countries of the global North, a population development characterised by higher life expectancy and lower birth rates challenges the existing social security systems. A potential trade-off among the goal to reduce old-age poverty (intragenerational justice), and the goal to avoid an unacceptable high financial burden on the young generation (intergenerational justice) may occur. Political restrictions limit the political scope for redistribution of resources within a society. If, for instance, the political scope for redistribution of wealth within a society is tight due to resistance against introduction of an inheritance tax, the situation of the poor can only be improved by increasing public expenditures and, thereby, possibly adding to public debt in the long-term – therefore causing a trade-off between inter- and intragenerational justice.

Regarding the production relationship between intra- and intergenerational justice in the use and conservation of ecosystem services, Glotzbach and Baumgärtner (2012: Section 4) found that the determinants impacting on this relationship are the quantity and quality of ecosystem services, population development, the substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions. The determinant substitutability of ecosystem services, for instance, influences the character of the relationship between the justices as follows: If an ecosystem service is substitutable by human-made goods and services, an overexploitation of the ecosystem service by members of the present generation to increase intragenerational justice can be compensated by sufficient investment in other forms of physical, social and human capital to secure intergenerational justice – the relationship between the justices is one of independency or facilitation. If an ecosystem service is non-substitutable, an overexploitation of the ecosystem service by members of the present generation to increase intragenerational justice cannot be compensated and, hence, reduces the degree of intergenerational justice – the relationship between the justices is one of rivalry.

In sum, the opportunity set, which embodies information on the production relationships between the two justices in all feasible outcomes, crucially depends on a number of fundamental context-specific determinants.

4 Scarcity, economic efficiency, and opportunity costs

Irrespective of which production relationship holds between inter- and intragenerational justice, society has to make a decision on how to use some instruments of justice in the attainment of these objectives. Very often, the use of instruments of justice means employing scarce resources that may be used in alternative ways.[26] This is where the key contribution of economics to the study of societal problems comes in: How to use scarce resources efficiently in the attainment of some objectives? According to a classical definition, economics "studies human behaviour as a relationship between [given] ends and scarce means which have alternative uses".[27] With this definition, economists generally understand efficiency as non-wastefulness in the use of "scarce means" to attain some "ends" that humans pursue in their actions. In this understanding, ends are open-ended: they are not determined by economics as a method. In principle, it could be any ends that humans pursue. Here, we focus on intra- and intergenerational justice as two primary normative objectives that humans pursue.[28] Then, drawing on the common definition of efficiency by Pareto (1906),[29] one can define efficiency as follows: "An allocation of resources is efficient if it is impossible to move toward the attainment of one social objective without moving away from the attainment of another objective".[30]

The minimal assumption needed to define efficiency in this way is that, for each justice, the metric of justice allows a distinction to be made between a higher and a lower degree of attainment of the respective justice. In particular, it is neither necessary to assume cardinality of each metric nor commensurability of the two justices.[31] Thus, this notion of efficiency and the subsequent analysis are very general.

If efficiency is related in this manner to some primary normative objectives, it acquires the status of a secondary normative objective.[32,33] This means, it is good to use resources efficiently; it is wrong to use them inefficiently. In this perspective, the contribution of economics to the study of societal problems lies in characterising the (in)efficient use of scarce means in the attainment of multiple primary normative objectives. For this purpose, economics provides a broad set of methods to analyse, display and empirically verify the relationships between these objectives.

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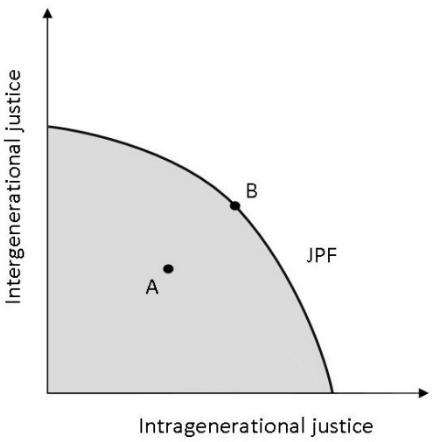
[26] Scarcity is generally considered as central to many important problems of justice (Dobson 1998: 12).
[27] Robbins 1932: 15.
[28] This goes beyond what economists usually consider as ends (cf. Baumgärtner 2011). Traditionally, economics has been concerned with the end of an ever better satisfaction of human needs and wants. This end can be further specified and operationalised as individual utilities (microeconomics), or as policy goals such as low inflation and low unemployment (macroeconomics).
[29] According to the original criterion of Pareto (1906), which assesses allocations based on the well-being of individual persons, an allocation of resources is *efficient* if no one can be made better off (in terms of this person's individual utility) without making anyone else worse off (in terms of the other person's individual utility).
[30] LeGrand 1990: 559.
[31] A *cardinal* metric is one that preserves orderings uniquely up to linear transformations; *commensurability* of justices means that the metric of both justices is in the same units.
[32] LeGrand 1990: 560.
[33] Here, we study the relationship, including a potential trade-off, between two primary normative objectives. There is also a discussion on the so-called "equity-efficiency trade-off" (surveyed by e.g. Putterman et al. 1998), where equity and efficiency are treated as normative objectives of equal rank. But efficiency – in contrast to equity – cannot serve as a primary normative objective, so that this trade-off is irrelevant (LeGrand 1990: 566).



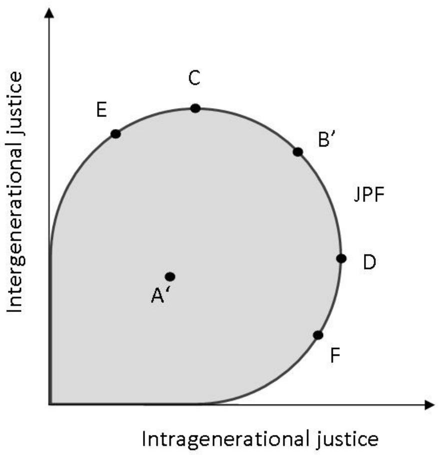


Figure 1: Rivalry and independency

Figure 2: Rivalry, facilitation, and independency

Figures 1 and 2 illustrate the opportunity set and efficiency in attaining the two normative objectives of intra- and intergenerational justice. The axes indicate the degree of attainment of inter- and intragenerational justice, respectively, based on the respective metrics of justice. Thus, each point in the diagram represents an outcome of the use of the instruments of justice. In Figure 1, the shaded area depicts all feasible outcomes in the given context, that is, for given resource endowment, technology, institutions, and the like ("opportunity set"). The curve JPF ("justice possibility frontier") denotes its frontier. Outcomes to the northeast of this curve are not feasible in the given context. Point A represents an outcome where the instruments of justice are used in an inefficient manner as more intergenerational justice could be achieved without sacrificing intragenerational justice. In contrast, the use of the instruments of justice in point B is efficient as no higher degree of attainment of one justice is feasible without reducing the other one. Generally, all outcomes below the JPF-curve correspond to inefficient uses of the instruments of justice, whereas all outcomes on the curve correspond to efficient uses of these instruments.

Obviously, in point B there is rivalry between intragenerational and intergenerational justice: attaining one to a higher degree necessarily reduces the degree to which one attains the other one. This loss can be measured by the concept of "opportunity cost". The opportunity cost of increasing, say, intragenerational justice is the corresponding minimal loss of intergenerational justice. In contrast, in point A there is independency between intragenerational and intergenerational justice: attaining one to a higher degree does not necessitate any change in the degree to which one attains the other one. Hence, there are no opportunity costs of increasing one or the other justice. Generally, in all efficient outcomes, i.e. on the JPF-curve, there is rivalry between the two justices and, thus, positive opportunity costs. In all inefficient outcomes, i.e. under the JPF-curve, there is independency between the two justices and, thus, zero opportunity costs.

For example, the opportunity set of Figure 1 may refer to the use of a non-renewable natural resource such as oil or gas: the resource may be exploited today for social welfare policy (intragenerational justice); alternatively, it may be conserved for future generations (intergenerational justice).

In a different context, the opportunity set may look as in Figure 2. The shaded area again depicts all outcomes that are feasible in this context ("opportunity set"), with the JPF-curve as its frontier. As in Figure 1, outcomes A' and B' correspond to an inefficient and an efficient use, respectively, of the instruments of justice. Obviously, all points on the JPF-curve between C and D represent outcomes of efficient uses of the instrument of justice, because no higher degree of attainment of one justice is feasible without reducing the other one. These outcomes are characterised by rivalry between the two justices and positive opportunity costs of either justice.

Outcome E is inefficient, but as it lies on the JPF, attaining intergenerational justice to a higher degree starting from this point necessarily also leads to a higher degree of intragenerational justice. That is, in outcome E there is facilitation between the two justices. But facilitation is not symmetric: attaining a higher degree of intragenerational justice, starting again from point E, does not necessarily induce a higher degree of intergenerational justice. Hence, the opportunity cost of increasing intergenerational justice is negative: increasing intergenerational justice does not incur a loss, but a gain, of intragenerational justice, and the opportunity cost of increasing intragenerational justice is zero. In outcome F, the situation is reversed: attaining intragenerational justice to a higher degree facilitates attaining intergenerational justice to a higher degree, but not vice versa; hence, the opportunity cost of increasing intragenerational justice is negative, while the opportunity cost of increasing intergenerational justice is zero. Generally, all (inefficient) uses of instruments of justice along increasing parts of the JPF correspond to outcomes where attaining one justice to a higher degree facilitates attaining the other one, but not vice versa, so that the former has negative opportunity cost, while the latter has zero opportunity cost.

For example, the opportunity set of Figure 2 may refer to government spending on education, where a broader educational base decreases income inequality within a generation (intragenerational justice), and at the same time increases prospects for economic growth over time (intergenerational justice).

As the figures and examples illustrate, the shape of the opportunity set may differ from context to context, and with it the relationships between the two justices.[34] As the opportunity set is fundamentally determined by natural resource endowment, technology, institutions, etc. (cf. Section 3), a change in these fundamental determinants may change the opportunity set and the relationships between the two justices. For example, with given endowment of a non-

[34] In addition to the two fundamental shapes of the opportunity set discussed here, other shapes are imaginable. For example, the justice possibility frontier may be linearly downward sloping, implying constant opportunity costs in all efficient outcomes. It may also be convex (resulting e.g. from increasing returns to scale in the use of instruments of justice), and the frontier may not even intersect but asymptotically approach the axes. This would imply that the opportunity costs of one justice may rise to infinity. Yet, all insights into the relationships between the two justices and efficiency that are essential for our main line of argument can already be obtained from the two shapes of the opportunity set presented here. We therefore refrain from discussing additional shapes in detail.

renewable resource, technical progress in resource extraction would shift the JPF-curve in Figure 1 outwards.

5 Conclusion

Robbins' (1932) definition of economics delimits the contribution of economics to the study of normative questions. It does not lie in determining what ends to pursue or in developing the means to achieve a normative objective. Rather, the focus of economic analysis is on efficiency, i.e. non-wastefulness in the use of scarce resources that have alternative uses as means to attain given normative objectives. Thus, in contexts where there is no scarcity or no alternatives exist, economics does not lend itself to the discussion of normative questions. Yet, many questions of justice arise under conditions of scarcity and involve the freedom to make choices. Such questions can be discussed in economic terms.

Economic analysis of inter- and intragenerational justice builds on three fundamental, and rather weak, assumptions:

(1) On the "value" side, the two justices are considered by society to be of equal rank.

(2) For each justice, one can measure the degree to which one attains this justice. This measurement does not need to be cardinal but may be ordinal, and the two justices do not need to be commensurable but the two metrics may be in different units.

(3) For a given context – specified by natural, technological, institutional factors, etc. – one can describe the outcome of using scarce resources (as instruments of justice) in terms of these measures of the two justices.

With these assumptions, the genuine and original contribution of an economic analysis of justice is threefold:

(1) Economic analysis can delineate the "opportunity set" of politics with respect to the two normative objectives of inter- and intragenerational justice, i.e. it can describe which outcomes are feasible in achieving the two objectives in a given context, and which are not. The opportunity set includes information on whether the production relationship between the two justices in some outcome is one of rivalry (i.e. trade-off), independency, or facilitation; and it distinguishes efficient from inefficient allocations of scarce resources.

    As efficiency, when related to the primary normative objectives of intergenerational and intragenerational justice, is a secondary normative objective, one conclusion for policy-making is straightforward: instruments of justice should be used efficiently; they should not be used inefficiently.

    One important conclusion about the production relationship between intra- and intergenerational justice follows directly from the very definition of efficiency. In outcomes of efficient resource use there is always rivalry between the different justices – attaining one justice to a higher degree necessarily reduces the degree to which the other is attained. In contrast, in outcomes of inefficient resource use there is either independency between the two justices – the level of attainment of one justice can be improved without doing worse on the other one, or even both can be improved – or facilitation – improving the level of attainment of one justice necessarily also improves the other one.[35]

(2) Based on the opportunity set, economic analysis can identify the "opportunity cost" of attaining one justice to a higher degree, in terms of less achievement of the other. Positive opportunity costs of achieving one justice exist if there is rivalry between the two normative objectives of intergenerational and intragenerational justice; negative opportunity costs of achieving one justice exist if there is facilitation between the two justices; opportunity costs are zero if there is independency between the two justices. Generally, negative and zero opportunity costs indicate inefficiency in the allocation of resources, while positive opportunity costs indicate an efficient resource allocation.

(3) Economic analysis can identify how the opportunity set changes as its determinants – natural, technological, institutional factors, etc. – change. In particular, it can study how the occurrence and extent of rivalry, independency or facilitation in the relationship between the two justices changes as underlying determinants change. Hence, it may suggest how to manage these underlying determinants in order to decrease the degree of rivalry and to increase the degree of independency or facilitation.

The economic analysis presented here cannot determine which of the efficient outcomes on the justice possibility frontier is preferable. Moving from one efficient outcome to another means incurring opportunity costs – i.e. furthering the degree of attainment of one normative objective at the cost of the other one. Depending on how the relationship between the two normative objectives is shaped on the "value side", it might well be acceptable to incur these costs – for example, burdening the presently living with a small tax that would prevent future generations from huge damage.

So, economic analysis can give no clear guidance on how to decide among efficient outcomes – i.e. in the case of rivalry between objectives. Its contribution lies in pointing out clearly inefficient outcomes, and in identifying the opportunity costs of moving from one efficient outcome to another.

These insights can help make an informed decision about how to use scarce resources that have alternative uses to attain the two normative objectives of inter- and intragenerational justice in a non-wasteful manner. This seems to be a valuable contribution for societies facing decisions about the use of scarce resources in view of different normative objectives of equal rank. Of course, this would not make hard decisions easy, but at least efficiently difficult.

6 Acknowledgements

We thank Joachim Fünfgelt, Michael Schefczyk, the editors and two anonymous reviewers for helpful comments. Financial support from the German Federal Ministry of Education and Research (BMBF) under grants 01UN1011A/B is gratefully acknowledged.

[35] In the (inefficient) interior of the opportunity set there is always independency; and facilitation can only occur on the inefficient part of the justice possibility frontier.

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Paper 3: The relationship between intragenerational and intergenerational ecological justice

Environmental Values 21(3), 331–355.

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Abstract: The principle of sustainability contains two objectives of justice regarding the conservation and use of ecosystems and their services: (1) global justice between different people of the present generation ("*intra*generational justice"); (2) justice between people of different generations ("*inter*generational justice"). Three hypotheses about their relationship – independency, facilitation and rivalry – are held in the political and scientific sustainability discourse. Applying the method of qualitative content analysis to important political documents and the scientific literature, we reveal six determinants underlying the different hypotheses: quantity and quality of ecosystem services, population development, substitutability of ecosystem services, technological progress, institutions and political restrictions.

Keywords: sustainable development, ecosystem services, intragenerational justice, intergenerational justice, ecological justice, sustainability research.

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1 Introduction

Do we have to make a hard choice between fighting today's poverty and preserving the environment for future generations? Or are there conditions which enable to foster both intragenerational and intergenerational justice?

Global justice between different people of the present generation (*intragenerational justice*) and justice between people of different generations (*intergenerational justice*) are the great ideas underlying the politics of sustainable development.[1] These ideas of justice are the core normative guidelines with regard to the sustainable use and conservation of the services provided by ecosystems, such as food and fresh water production, flood protection and erosion control. As it could be philosophically justified that people living today and people living in future have equal rights to use ecosystems and their services (cf. e.g. Feinberg 1981, Tremmel 2008, Visser't Hooft 2007), the impacts of political institutions and instruments on both intragenerational and intergenerational justice have to be considered.

The political discourse about the relationship between the aim of a juster distribution of rights to ecosystem services between countries of the global North and the global South as well as within countries and the aim to preserve ecosystems for future generations is blurred. Is a globally just distribution of access to ecosystem services a necessary precondition to achieve justice with respect to future generations? Or the other way round, does the satisfaction of the elementary needs of the world's poor inevitably imply the long-term degradation of ecosystems?

Possible conflicts between intragenerational and intergenerational justice have already been noted (e.g. by Adams et al. 2004, Langhelle 2000, Wissenburg 2006), but analyzed rather specifically, such as for the relationship between the conservation of biodiversity and the eradication of poverty through protected areas (cf. Adams et al. 2004), and not directly referring to the fundamental objectives of intragenerational and intergenerational ecological justice. Our study investigates the relationship between intragenerational and intergenerational ecological justice in a systematic manner as a clarification of this relationship is of high importance for devising an ethically legitimate, politically consistent and actually effective sustainability policy.

Three hypotheses about the relationship between the objectives of intragenerational and intergenerational ecological justice are logically possible: (1) Achieving one objective may not have any effect on the chances to also achieve the other one (*independency*). (2) Achieving one objective may make it easier to also achieve the other one (*facilitation*). (3) Achieving one objective may make it more difficult to also achieve the other one (*rivalry*). We evaluate important political documents on sustainable development as well as the scientific literature from various disciplines in terms of these hypotheses, applying the method of qualitative content analysis (Mayring 2000).

[1] Sustainable development as defined by the Brundtland-Report is "a development that meets the needs of the present without compromising future generations to meet their own needs" (WCED 1987: 43).

As a first step of evaluation, we assign the core statements and arguments to one of the hypotheses, thereby systematically revealing the lines of reasoning supporting each of the three hypotheses. In a second step, we identify the assumptions which are used to argue in favour of each hypothesis. These assumptions concern the following underlying determinants: the quantity and quality of ecosystem services, population development, substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions. These determinants impact on the relationship between intragenerational and intergenerational ecological justice and, therefore, influence which hypothesis holds true. The higher the intrinsic growth rate of renewable resources, the smaller the population growth rate, the greater the substitutability of ecosystem services, the higher the rate of technological progress, the stricter the institutional restriction of ecosystem use and the greater the political scope for redistribution of environmental property rights, the less likely is a conflict between the objectives of intragenerational and intergenerational justice.

The paper is organized as follows. In Section 2, we discuss why ecosystem services are a core object of intragenerational and intergenerational justice in sustainability policy. In Section 3, we specify our selection of literature and method of text analysis, introduce the three logically possible hypotheses and describe the main arguments given in the literature to support each of these hypotheses. In Section 4, we extract and discuss the determinants underlying the argumentations. In Section 5, we conclude with consequences for sustainability policy and perspectives for sustainability research.

2 Ecosystems and justice

Humans vitally depend on the Earth's ecosystems, which deliver a large variety of economically, socially and culturally valuable services to them (Costanza et al. 1997b, Sukhdev and Kumar 2008). A common definition by the Millennium Ecosystem Assessment (MEA) describes ecosystem services as "the benefits people obtain from ecosystems" (MEA 2003: 53). They are classified along functional lines in provisioning, regulating, cultural and supporting services. Ecosystems *provide* materials to humans such as food, fiber and freshwater, and create benefits by *regulating* ecosystem processes including climate regulation, air quality maintenance, erosion control and pollination. Furthermore, people obtain non-material benefits from ecosystems through *cultural* services such as recreation, aesthetic experiences and spiritual enrichment in natural or cultivated landscapes. Necessary for the production of the mentioned ecosystem services are *supporting* services: soil formation processes, cycling of nutrients and water, primary production and production of atmospheric oxygen. Changes in all types of ecosystem services affect human well-being in multiple ways: through impacts on secure and adequate livelihoods, on health, on safe access to natural resources and on security against natural and human-made disasters, on good social relations and on freedoms available to people.

Ecosystems are degrading faster than ever (MEA 2005: 26ff.). This is accompanied by the loss of important ecosystem services such as climate regulation, flood protection and water purification. The harmful effects of diminishing ecosystem services affect especially the poor, who have lost access to essential ecosystem services disproportionately with their degradation (MEA 2005: 62, Sukhdev and Kumar 2008: 15ff.). The scarcer the availability of ecosystem services, the more urgent becomes the question of their just distribution. Especially the human-caused global warming has placed the question of intragenerational and intergenerational justice in the centre of political debate. Whereas the industrialized countries in the global North bear the main responsibility for human-induced climate warming, the poor people in the countries of the global South and future generations are worst affected by its harming impacts. Further important societal problems of intragenerational and intergenerational justice are the rapid and irreversible loss of biodiversity (cf. e.g. Adams et al. 2004), the shortage of fresh water and the overfishing of oceans.

The imperative of sustainability regarding the conservation and use of ecosystems and their services is widely accepted in today's international policies (e.g. UN 1992, WCED 1987). *Intragenerational and intergenerational justice* are, in general, taken as constituent for the guiding principle of sustainable development (Kopfmüller et al. 2001, Langhelle 2000: 298, Ott and Döring 2004: 58f., WCED 1987: 43).[2] This raises the question of how the idea of intragenerational and intergenerational justice can specifically be applied to the use and conservation of ecosystems. In the remainder of this section, we elaborate on the specific link between justice and ecosystems, yielding a conception that we call *ecological justice*.

In his "Nicomachean Ehics" the Greek philosopher Aristotle (1998: Book 5) makes a fruitful distinction between two forms of justice: *general justice* and *particular justice*. Whereas general justice is about the "lawful", that is, the basic institutions of a just political system, particular justice deals with what is "fair", that is, the aversion or correction of unjust gains caused by acts of overreaching. Aristotle further divides particular justice in the distribution of divisible goods (*distributive justice*) and the rectification of voluntary transactions (*justice in exchange*) and involuntary transactions such as theft and assault (*corrective justice*). This classification can be meaningfully applied to the conservation and use of ecosystem services.

Distributive justice requires that the recipients of justice have common claims to scarce goods. Because natural ecosystems are not created by any particular human or any group of humans, it seems plausible that ecosystems and their services are the common property of humankind, and that every present and future person has a legitimate claim to use them (Helm and Simonis 2001, Schlosberg 2004).[3] A commonly mentioned premise for the application of distributive justice is the scarcity of the object of distribution (e.g. Hume 1975: Chapter 3), which is certainly given for ecosystem services. Furthermore, distributive justice can be regarded as the most comprehensive type of particular justice as it does not depend on transactions or prior caused environmental harm (Leist 2005: 1). Whereas corrective justice is orientated towards individually caused environmental harm, the most pressing environmental problems, such as human-caused climate change and biodiversity loss, are caused by a vast

[2] The modern concept of sustainable development refers fundamentally to three relationships of the human being: the relationship to contemporaries, to future generations and to nature (cf. Becker 2009: 23ff.). In this paper we leave aside the dimension of justice towards nature.

[3] Nozick (1974: 175) proceeds on the assumption that the original nature was owned by nobody before individual property rights have been invented.

number of polluters and need to be tackled before the worst consequences will appear. By applying principles of distributive justice, collectively caused ecosystem degradation and precautionary ecosystem preservation can be addressed. As a result, there are many good reasons for taking distributive justice as a core principle of ecological justice.[4] In fact, in most contributions to the political and scientific literature relevant for this analysis, “justice” is (implicitly) meant to be distributive justice.

The abstract and general idea of ‘distributive justice’ needs to be further specified. According to Dobson (1998: Chap. 3), every conception of distributive justice has to specify the objects, the community and the basic principle of justice. In our proposed conception of ecological justice the *objects of justice* are ecosystem services. For intragenerational justice, this basically implies the distribution of rights to enjoy the benefits produced by ecosystems and the distribution of duties to conserve ecosystems as well as to pay or compensate for the harms caused by ecosystem degradation. Intergenerational justice with regard to ecosystem services can only mean sustaining the potential of ecosystems to produce ecosystem services in the future (Dobson 1998: 131).[5] Thus, the objects of justice in the intergenerational context are the duties to preserve stocks of natural capital, which deliver ecosystem services to future people.

The *community of justice* comprises all recipients of ecological distributive justice. Humans’ present and local action towards nature affects the provision of ecosystem services at the other end of the globe and in the remote future. Thus, the central question is whether the community of justice can be extended to the *global* human community and *future* generations. This question can be affirmed by referring to the moral equality of all people (Feinberg 1981, Kant 1949: 59, Rawls 1973: 179, UN General Assembly 1948: Article 1), which implies the necessity to guarantee rights to essential ecosystem services.

The third component for building a conception of ecological justice is the *basic principle of justice*, that is, the principle of distribution. Rawls’ influential “Theory of Justice” (1971) appears as a fruitful starting point to derive such a principle. The “Theory of Justice” bears on the distribution of basic freedoms and basic goods. Ecosystem services can be subsumed under these categories (Dobson 1998: 125., Visser’t Hooft 2007: 88ff.). Furthermore, Rawls’ original position, in which everyone decides on the principles of justice from behind a *veil of ignorance,* offers the potential to extend the community of justice to include all people living at present and living in future (Beitz 1979, Hayden 2002, Langhelle 2000, Pogge 1989, Tremmel 2008). A consequent extension of this original position would produce the following intragenerational (or: intergenerational) principle of distribution: Access rights to vital ecosystem services have to be distributed in such a way that they are to the greatest benefit of the least-advantaged members of the present generation (or: across the present and all future generations). We interpret *benefit*, based on the "capability"-approach

[4] The implementation of distributive justice presupposes a stable political system, which is itself based on certain principles of justice (i.e., iustitia universalis), such as the protection of the universal human rights.

[5] Sustaining ecosystems and complying with ecological limits can also be viewed as a "precondition for intergenerational justice" (Langhelle 2000: 318).

by Sen (1982), as the valued possibilities to live a good life, which are set by access rights to ecosystem services.

Bringing together these three elements, we define *ecological justice* as an intragenerational and intergenerational distributive justice, which is about distributing rights to ecosystem services and duties to conserve stocks of natural capital according to the Rawlsian principles of justice, including all present and future people as recipients of justice. Whereas *intragenerational ecological justice* relates to global justice between different people of the present generation regarding the distribution of rights to access ecosystem services and of the benefits arising out of their utilization, *intergenerational ecological justice* relates to justice between people of different generations regarding the duties to conserve intact ecosystems for future generations. For instance, both objectives of ecological justice are expressed in the UN-Convention on Biological Diversity (1992: Article 1), which explicitly aims at both the “conservation of biological diversity“, which can be interpreted as the aim of intergenerational ecological justice, and the “equitable sharing of the benefits arising out of the utilization“, which can be interpreted as the aim of intragenerational ecological justice.

3 Survey of the literature

In the political and scientific discourse, there is a multitude of views on how the establishment of global intragenerational and intergenerational ecological justice relate to each other. Our literature survey includes important political documents on sustainable development (among others, WCED 1987, UN 1992, UN 2002, UN/DESA 1992) as well as the scientific literature from various disciplines, encompassing natural resource management, ecosystem ecology, neoclassical and ecological economics, political science on environment and development issues, environmental ethics as well as interdisciplinary analyses.[6] The selection of literature is based on two criteria: (i) a broad covering of all scientific disciplines dealing with ecological justice, and (ii) the political importance of documents on sustainable development. We considered all aspects of the literature concerning the relation between intragenerational and intergenerational ecological justice.

In most of the selected political and scientific documents links between poverty and environmental degradation are explored in general (cf. UN 2002, WBGU 2004, WCED 1987) whereas the hypotheses under study here specifically focus on justice with regard to ecosystem services. Therefore, the question arises whether the extent of poverty can be equated with a measure of intragenerational ecological justice, and whether the extent of ecosystem degradation can be equated with a measure of intergenerational ecological justice. Certainly, the conservation of non-substitutable and vital ecosystem services is generally regarded as a necessary precondition for safeguarding the basic rights of future generations. Therefore, we view environmental degradation with harmful impacts on future generations as an indicator of intergenerational injustice. The report "World in Transition – Fighting Poverty through Environmental Policy" of the German Advisory Council on Global Change (WBGU

[6] We searched the databases *Web of Science* and *Google Scholar* for the key words "ecological justice"; "environmental justice"; and "ecosystem" or "environment" combined with "justice", "sustainable development", "sustainability", "intragenerational justice" or "intergenerational justice" – both in English and German language.

2004) shows that links exist between a lack of access to ecosystem services and multiple dimensions of poverty, encompassing income poverty, disease and malnutrition as well as lack of education and social stability. Likewise, the MEA-report illustrates how the constituents of human well-being depend on the provision of ecosystem services (MEA 2003: 78), and the TEEB-Report illustrates the links between ecosystem services and the Millennium Development Goals (Sukhdev and Kumar 2008: 21). Nevertheless, a lack of access to ecosystem services is one important cause of poverty, but not an equivalent to poverty. Therefore, we try to focus on those parts of the texts that directly deal with access and user rights to ecosystems.

Three relationships between the objectives of intragenerational and intergenerational ecological justice are logically possible: independency, facilitation and rivalry. The following hypotheses are constructed to express these logical relationships:

- *Independency-hypothesis*: The objectives of intragenerational and intergenerational ecological justice can be reached independently, that is, achieving one objective does not have any effect on the chances to also achieve the other one.
- *Facilitation-hypothesis*: Achieving one objective makes it easier to also achieve the other one. This facilitation may be one-way, or the other way, or a mutual facilitation between the achievement of the two objectives.
- *Rivalry-hypothesis*: A fundamental rivalry (trade-off) exists between the objectives of intragenerational and intergenerational ecological justice, that is, achieving one objective makes it more difficult to also achieve the other one.

To evaluate the selected literature, we apply the method of qualitative content analysis (Mayring 2000). As a first step of analysis, we extract the core statements and arguments found in the selected literature about the relationship between intragenerational and intergenerational ecological justice and assign them to the different hypotheses, thereby systematically revealing the lines of reasoning supporting each of the three hypotheses (Sections 3.1–3.3). In a second step of analysis, we identify the assumptions about the fundamental determinants which are used to argue in favour of each hypothesis (Section 4).

3.1 Independency-hypothesis

The independency-hypothesis states that the objectives of intragenerational and intergenerational ecological justice can be reached independently, that is, achieving one objective does not have any effect on the chances to also achieve the other one. This hypothesis cannot be found explicitly in empirical studies or political documents. However, it is an implicit assumption, or a consequence of more fundamental assumptions, made in many economic conceptualizations and models.

In the environmental-and-resource-economics literature, sustainability is commonly defined as the maintenance over an infinite time horizon of a further specified measure such as, for example, the total capital stock, the natural capital stock, per capita consumption, welfare, or a vector of such measures (Arrow et al. 2004, Atkinson et al. 1997, Costanza et al. 1997a, Hanley et al. 1997, Perman et al. 2003). Thereby, sustainability is reduced to its intergenerational dimension. In contrast, economic theories and analyses of distributive justice (surveyed, e.g. by Roemer 1996) solely refer to the present. By this separation, environmental and resource economics eludes the analysis of possible interdependencies between intragenerational and intergenerational justice.

Contributions to ecological economics regard both objectives of justice as highly important and acknowledge that interactions may occur in the implementation of them. Nevertheless, ecological economics stresses the conservation of ecosystems for future generations in the context of sustainable development. Sustainability is conceptualised with reference to concepts such as ecological carrying capacity or ecological resilience[7] (cf. Atkinson et al. 1997: 119ff., Costanza et al. 1997a: 3), leading to notions of "strong" sustainability (Pearce et al. 1989, Daly and Cobb 1989, Ekins et al. 2003, Ott and Döring 2004).

Also, some basic models and results of welfare economics support the independency-hypothesis. They imply that the overall intergenerational impact of human economic action towards nature is independent of the initial distribution to different individuals of rights to use ecosystems. As a prominent example, cap-and-trade systems for formerly open-access ecosystem services, such as the atmospheric sink function for greenhouse gas emissions, are assumed to work accordingly. The cap, that is, the overall volume of greenhouse gases allowed to be emitted into the atmosphere in each year, would be decisive of intergenerational distributive justice. The initial endowment of individuals with emission certificates would be decisive of intragenerational distributive justice. Economists suppose that all initial allocations of emission certificates would equally ensure the compliance with the set cap of greenhouse gases (e.g. Perman 2003: 219ff.).[8] Thus, intergenerational and intragenerational justice could be governed independently. An important presumption underlying this insight is the existence of a perfect and decentralised private ownership market economy without any externalities or transaction costs.

To sum up, implicitly the independency-hypothesis is underlying many concepts and models in the context of sustainability in ecological, environmental and resource economics.

3.2 Facilitation-hypothesis

The facilitation-hypothesis states that achieving one of the objectives of intragenerational and intergenerational justice makes it easier to also achieve the other one. It represents a core belief of important political documents on sustainable development, for example, the *Brundtland-Report* (WCED 1987) and the *Report of the United Nations' World Summit on Sustainable Development* (UN 2002). The hypothesis points to two possible causal connections between intragenerational and intergenerational justice, specified by variant A and B, respectively. A third variant C is based on the simultaneous existence of both causal links.

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[7] Resilience is commonly defined as „the potential of a particular configuration of a system to maintain its structure/function in the face of disturbance, and the ability of the system to re-organize following disturbance-driven change" (Holling and Wagner 2003).

[8] This says nothing about up to what extent the welfare-optimal level of ecosystem utilization can guarantee the preservation of intact ecosystems in the long-term and thereby intergenerational justice.

3.21 Facilitation-hypothesis A: The achievement of intragenerational ecological justice facilitates intergenerational ecological justice

According to facilitation-hypothesis A, an increase of justice to future generations is a positive side effect of a juster intragenerational distribution of rights to ecosystem services today. The literature contains three chains of reasoning resulting in this hypothesis. One chain of reasoning focuses on poverty-induced ecosystem degradation and recommends poverty reduction by means of human-made substitutes for ecosystem services, increases in ecological efficiency through technological progress, population control or education as a means to achieve greater intragenerational justice, which is at the same time to the benefit of future generations. The second line of argument states that a redistribution of environmental property rights can be established in a way that facilitates the preservation of ecosystems. A third line of reasoning says that international agreements on ecosystem preservation to the benefit of future generations are facilitated if the agreements are accepted as "fair" by all negotiating, that is, contemporary, parties. In the following, the three chains of reasoning are described in detail.

The first line of argument states that a reduction of extreme poverty without increases in overall ecosystem use addresses a major cause of long-term environmental degradation and, thereby, facilitates intergenerational justice. The Brundtland-Report (WCED 1987) identifies poverty as a cause of ecosystem degradation because "those who are poor and hungry will often destroy their immediate environment in order to survive: They will cut down forests; their livestock will overgraze grasslands; they will overuse marginal land; and in growing numbers they will crowd into congested cities. The cumulative effect of these changes is so far-reaching as to make poverty itself a major global scourge" (WCED 1987: 28). Likewise, it is pointed out that local communities living in extreme poverty are often forced to apply management methods with negative long-term impacts on ecosystems (Adams et al. 2004, WBGU 2004: 79). Poverty-driven environmental stress brought about soil erosion of 20% of vegetation-covered land in countries of the global South (WBGU 2004: 77). Poor rural communities usually possess only marginal land and are, therefore, forced to migrate. This poverty-environment-loop led to deforestation and soil erosion in mountain areas in Central America and to desertification in arid regions of Africa resulting from overgrazing by livestock (WBGU 2004: 72). The rapid rise in population is generally considered as a factor speeding up poverty-driven irreversible degradation of ecosystems (e.g. WCED 1987: Chapter 1).

But how can poverty be addressed in a way that, at the same time, reduces pressure on ecosystems? The Brundtland-Commission argues that this would be possible through increases in ecological efficiency, development of environmentally sound technologies and especially technology transfers into the countries of the global South (WCED 1987: 25). Advocates of an efficiency revolution consider a four- to tenfold increase of material and energy efficiency possible (e.g. Harrison 1992, von Weizäcker et al. 1995). The German Advisory Council on Global Change points to technological leapfrogging, that is, overleaping of resource-consumptive stages of development, as a key strategy to reduce poverty without rising ecosystem degradation (WBGU 2004: 97ff.), and the Agenda 21 suggests a transfer of environmentally sound technology (UN/DESA 1992: Chapter 34). According to this line of reasoning, environmentally sound substitutes for ecosystem services, for instance the use of solar cookers instead of fuel-wood in Africa, and efficiency increases through technological progress und technology transfer, such as improved irrigation systems to use fresh water more efficiently, are crucial measures to address poverty and ecosystem degradation simultaneously.

Two further strategies are mentioned to reduce poverty in a way that favors ecosystem preservation: controlling population development and improving education (e.g. MEA 2005: 92ff., UN/DESA 1992: Section 4, WBGU 2004: 55ff.). Appropriate training measures would equip poor people with knowledge about the links between ecosystem processes and their own livelihood and with capabilities to adapt to a changing environment. Thereby, education measures could reduce the poors' vulnerability to changing environmental conditions and lay the foundations for adopting and advancing environmentally sound technologies (WBGU 2004: 55f.).

The second line of argument supporting facilitation-hypothesis A runs as follows. A transfer of user rights to ecosystems from the countries of the global North to the countries of the global South would create greater intragenerational justice. At the same time, it would reduce total environmental stress because sufficient user rights to ecosystems to secure their livelihood would allow the poor to afford an environmentally sound management of their local ecosystems.

Advocates of this argumentation regard the overuse of local ecosystems by the poor to survive from day to day as only one side of the coin. The other side would be the massive consumption of global natural resources and the overuse of, in many cases global, ecosystem services by the industrialized countries (Bartelmus 1994: 11, Visser't Hooft 2007: 18, Sachs 2001: 75). The investigation of the causes of human-induced global ecological problems, including global warming, fresh water shortage and pollution, soil degradation, loss of biological diversity and air pollution, revealed that the negative impacts of poverty on the environment are overestimated. Industrialization and high levels of well-being are a much greater issue (WBGU 2004: 4). If intragenerational justice was achieved by *redistributing* user rights to ecosystem services between countries of the global North and countries of the global South, this would not be to the harm of future generations (Costanza et al. 1997b: 16, Goodland 1992: 40, Kopfmüller et al. 2001: 107, Sachs 2001: 2ff.). But does this kind of redistribution really *reduce* absolute pressure on ecosystems? Would rural communities stop degrade their local ecosystems, which are the basis of their own present and future income, if their user rights to ecosystems are expanded by means of redistribution? The answer to this question depends, besides sufficient user rights to ecosystems to secure a livelihood, on many institutions including well-functioning credit, product and labor markets, effective monitoring of rules, proper enforcement of policies and secure land tenure (Ruijs et al. 2008: 9).

The third line of argument, why the achievement of intragenerational justice can facilitate intergenerational justice, is based on the observation that only international agreements on ecosystem conservation which are preceived as beneficial and intragenerationally "fair" by all parties are politically feasible (Sachs 2001: 94ff., Lange et al. 2010). By employing game theory, it can be shown that a win-win-situation is a precondition for a successful self-enforcing international environmental agreement which facilitates intergenerational ecological justice (e.g. Elsasser 2002).

3.22 Facilitation-hypothesis B: The achievement of intergenerational ecological justice facilitates intragenerational ecological justice

Facilitation-hypothesis B is logically possible, but we found no arguments supporting this hypothesis in the literature. Facilitation-hypothesis B is included in facilitation-hypothesis C, which states that one cannot argue that intragenerational justice is facilitated by realizing intergenerational justice without arguing that intergenerational justice is facilitated by realizing intragenerational justice. Someone who argues in favour of facilitation-hypothesis C, thus, holds that both facilitation-hypotheses A and B are correct.

3.23 Facilitation-hypothesis C: There is a mutual facilitation between the achievement of intragenerational and intergenerational ecological justice

The core content of facilitation-hypothesis C is that many human-made environmental problems, threatening the lives and well-being of future generations, vitally affect the access to essential ecosystem services of the world's poor already today (MEA 2003: 71ff., Tremmel 2008: 63, WCED 1987). It would, therefore, prove advantageous for today's poor as well as for future generations to tackle these environmental problems.

Global climate change is a prime example, being a presently acute as well as a long-ranging global environmental problem. The industrialized countries in the global North are largely responsible for human-induced climate change. In contrast, its harmful impacts first of all affect poor people in countries of the global South as well as future generations. The poorest are worst affected because their livelihoods directly depend on their natural environment, and they are in a far worse position to adapt to changing climate conditions and extreme weather events (IPCC 2007). Already today, global warming exacerbates the water crises in Southern Africa and Western Sahel, affects food production and food security, just as it fosters the spread of infectious diseases like malaria (IPCC 2007., WBGU 2004: 65ff.). The effects of global warming jeopardize and undermine human rights (such as the right to physical integrity) of the poor people living today and will further deepen global injustice concerning the access to ecosystem services in the decades to come (Neefjes 1999: 253). Slowing down climate change would, therefore, help both fulfil the rights of future generations to live under stable climate conditions and favor intragenerational justice today.

The situation is very similar for biological diversity. The drastic loss of biological diversity carries long-term risks, such as the loss of ecosystem resilience, as it threatens food, income and health security of rural communities in the global South at present whereas intact ecosystems with their great diversity of species and breeds are supermarket, property market and pharmacy to poor rural communities (Sukhdev and Kumar 2008: 15ff.). Put positively, the protection of intact ecosystems, and the restoration of degraded ones, proves advantageous to the well-being of today's poor people as well as to the well-being of future generations by enhancing the delivery of vital ecosystem services now and in the future (WCED 1987: 19ff., MEA 2003: 3ff., Sukhdev and Kumar 2008).

3.3 Rivalry-hypothesis

The rivalry-hypothesis states that a fundamental rivalry (trade-off) exists between the objectives of intragenerational and intergenerational ecological justice, so that achieving one objective makes it more difficult to also achieve the other one. In other words, the quantity and quality of existing ecosystem services are insufficient to fulfil both the justified claims of present and future people. More intragenerational ecological justice would imply less intergenerational justice, and vice versa. The creation of protected areas to preserve intact ecosystems for future generations often negatively impacts on today’s poverty as it closes land use options to poor rural communities (Adams et al. 2004). Vice versa, it is assumed that the vital needs of the poor in the global South, especially for ecosystem services characterized by rivalry in use, such as food, fuel and freshwater, can only be met at the expense of long-term ecological interests (Visser’t Hooft 2007: 84, Roemer 2007: 226). Alleviating poverty by securing sufficient access of today’s poor to ecosystem services, would, according to this hypothesis, cause an increasing overall degradation of ecosystems, thereby reducing the availability of ecosystem services to future generations.

This chain of reasoning does not consider an intragenerational redistribution of environmental property rights, neither within nations nor between industrialized countries and countries of the global South. If fundamental intragenerational redistribution of environmental property rights is impeded by political restrictions or simply not taken into account (as in WCED 1987), intragenerational justice can only be achieved by extending the poors’ rights to use ecosystems. This would inevitably lead to ongoing environmental degradation to the disadvantage of future generations. Hence, extending today’s poors’ user rights to ecosystems without reducing them elsewhere is inevitably at the cost of future generations. Obviously, this conflict intensifies if the countries of the global South claim environmental property rights which do not only guarantee subsistence level but also allow for the same opportunities to economic development than were enjoyed by countries with earlier development. It is claimed as highly unlikely that ecosystem degradation can be stopped solely through technological progress if most of the world’s population is to reach the resource consumption level of today’s industrialized countries (Ekins 1993, Wissenburg 2006: 429). Goodland illustrates this dilemma as a conflict between two realisms:”On the one hand political realism rules out income redistribution and population stability as politically difficult, if not impossible; therefore the world economy has to expand by a factor of five or ten in order to alleviate poverty. On the other hand ecological realism accepts that the global economy has already exceeded the sustainable limits of the global ecosystem and that a fivefold to tenfold expansion of anything remotely resembling the present economy would simply speed us from today’s longrun unsustainability to imminent collapse” (Goodland 1992: xiii).

Whereas advocates of facilitation-hypothesis A (according to which the achievement of intragenerational ecological justice facilitates intergenerational ecological justice) presume a stabilization of population number as well as either an intragenerational redistribution of environmental property rights or a decoupling of environmental pressure from economic growth, advocates of the rivalry hypothesis challenge exactly these premises (e.g. Dobson

1998: 134, Goodland 1992: 42, Sachs 2001: 88). Supporters of the rivalry hypothesis question the predominant Western model of development and the associated patterns of production and consumption. To reduce the conflict between the objectives of intragenerational and of intergenerational justice, they point out pathways to resource-conserving prosperity models. These give priority to the adaptation of material and energy flows to the regenerative capacity of ecosystems and raise the question of "How much is enough/too much?" (Kopfmüller et al. 2001: 107, Sachs 2001: 197).

4 The underlying determinants

A more fundamental analysis of the arguments used to support the three hypotheses reveals that they draw on specific assumptions about underlying determinants. These determinants are the quantity and quality of ecosystem services, population development, substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions.

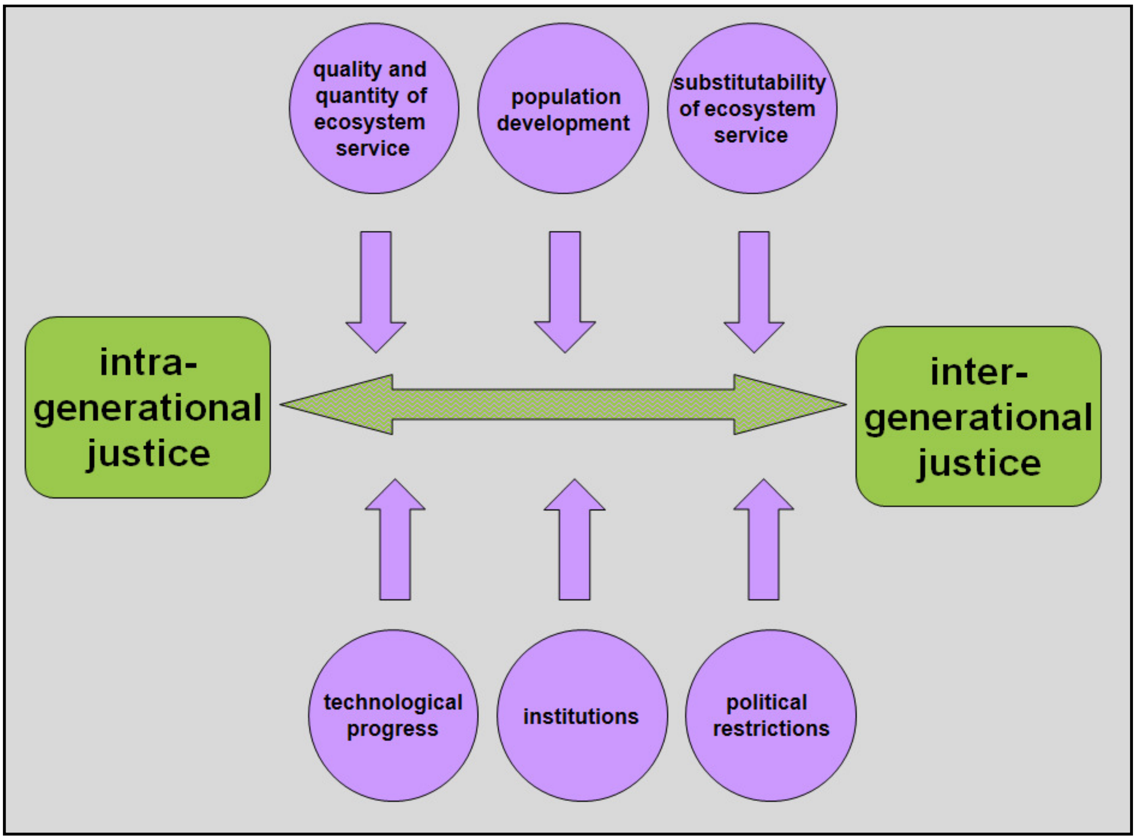

Figure 1: Six underlying determinants affect the relationship between the objectives of intragenerational and intergenerational ecological justice: the quantity and quality of ecosystem services, population development, substitutability of ecosystem services, technological progress, institutions and political restrictions.

The analysis of the arguments for each of the three hypotheses shows that different assumptions regarding the underlying determinants lead to different hypotheses. Hence, the determinants act upon the relationship between intragenerational and intergenerational ecological justice and, thereby, influence which hypothesis holds true (cf. Figure 1). Clarifying the impact of the underlying determinants on the objectives of intragenerational and intergenerational ecological justice is of high importance for sustainability policy, which can strive to change these determinants to prevent and solve goal conflicts.

4.1 Quantity and quality of ecosystem services

The *quantity* of ecosystem services refers to the *amount* of ecosystem services produced by today's ecosystems as well as to the *intrinsic growth rate* of renewable resources, which determines the potential amount of delivered provisioning ecosystem services in the future. The quantity of ecosystem services determines, inter alia, whether and to what extent there is a rivalry between meeting the justified claims on ecosystem services of people living at present and meeting such claims of future people. For instance, the rivalry-hypothesis holds true if the quantity of ecosystem services is insufficient to realise both intragenerational and intergenerational ecological justice.

We describe the *quality* of ecosystem services with reference to two fundamental and distinctive characteristics: *rivalry/non-rivalry in consumption* and *excludability/non-excludability from use*. *Rivalry in consumption* means that the use of an ecosystem service by one person does diminish another person's ability to use the same service. An example is the provisioning service of food production. One unit of food consumed by one person cannot be consumed by another person anymore. Many regulating and cultural ecosystem services are characterized by *non-rivalry in consumption*, that is, their use by one person does not diminish another person's ability to use the same service. Examples include climate stabilization or aesthetic beauty of a landscape. *Non-excludability from use* means that within the current social, legal and economic order no one can be excluded from using the service. For example, the services climate regulation and flood protection prove advantageous not only to people who contributed to their delivery, such as through preservation of bogs or reforestation, but also to many other persons locally and globally who cannot be excluded from benefiting from these services. *Positive externalities* spring from ecosystem services that are characterized by non-rivalry in use and non-excludability from use. The provision of ecosystem services by one person has a direct positive impact on the well-being of other persons.

The basic models and results of welfare economics supporting the independency-hypothesis presuppose that ecosystem services, characterized by rivalry in consumption and non-excludability from consumption, can be made excludable by an institutional arrangement, such as privatization or implementation of a cap-and-trade-system. Facilitation-hypothesis C is essentially based on the assumption of positive externalities springing from the preservation or restoration of ecosystems to today's poor and to future generations. Advocates of the rivalry-hypothesis refer to ecosystem services characterized by rivalry in consumption. The present overuse of such services would lead to the depletion of the delivering stocks (e.g. fish populations and forests) and the degradation of supporting and regulating services (e.g. the loss of erosion control) with harmful consequences for future people.

4.2 Population development

The determinant *population growth* refers to the *growth rate of human population* in total as well as to the spatial *distribution of demographic development* at present and projected into the future.[9]

In the context of facilitation-hypothesis A, it is assumed that controlling population development in countries of the global South is a means to achieve greater intragenerational justice, which at the same time reduces poverty-induced ecosystem degradation and, thereby, facilitates intergenerational ecological justice. Conversely, the promotion of intragenerational ecological justice can reduce poverty and, thereby, slow down population growth (Neefjes 1999: 257, Thompson 1992, WCED 1987: 98), what again takes human pressure from ecosystems. In this sense, the WCED argues that almost "any activity that increases well-being and security lessens people’s desires to have more children than they and national ecosystems can support" (WCED 1987: 98). In contrast, the rivalry-hypothesis presupposes that population cannot be controlled at a stable number, but grows to a number which does not allow to fulfil the justified claims on ecosystem services of all people living at present and living in the future in relation to the delivered quantity of ecosystem services. [10]

4.3 Substitutability of ecosystem services by human-made goods and services

A definition of *substitutability* requires a measure according to which there is no change when an ecosystem service is replaced by a human-made good or service. Whereas in environmental and resource economics social welfare or individual utility is commonly used as the measure to define substitutability, contributions to ecological economics define substitutability predominantly as the availability of functional substitutes for every single individual. In case of many vital ecosystem services, such as the provision of clean fresh water, a non-substitutability according to both evaluation criteria must be assumed. Neither basic human needs nor the specific function of the ecosystem service for human well-being are substitutable. In the following, we understand substitutability with reference to the functional substitutability of ecosystem services by human-made goods and services.

Examples that illustrate substitutability of ecosystem services by human-made goods and services include the various ecosystem services delivered by a forest: Its water regulation service could be substituted by building a system of reservoirs and embankments, its filtering of fresh water could be substituted by a desalination plant, its recreational service could be substituted by an artificial forest, a yoga course or a theme park, the provision of wood as fuel or construction material could be substituted by the use of solar cookers or by plastics. For each service it has to be examined whether the human-made alternative really substitutes for the functions delivered by the ecosystem service to each affected individual. For the whole forest ecosystem it has to be examined whether human-made alternatives can adequately substitute for all delivered ecosystem services.

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[9] The UN-Department of Economic and Social Affairs prognosticates between 7,7 and 10,7 billion people in 2050 (UN/DESA 2005). For the most part population growth is predicted to occur in poor regions, especially in the biggest cities (WBGU 2004: 89).

[10] There is a considerable body of empirical evidence that conflicts with the paradigm – used in both lines of argument discussed in this Section – that population growth causes poverty and environmental degradation (Attfield 1998).

The more ecosystem services are regarded as substitutable, the less harmful is a present overexploitation of ecosystems to the realization of justice to future generations, as long as the present generation sufficiently invests in other forms of (physical, social and human) capital. In the context of facilitation-hypothesis A, one line of argument assumes substitutability: Environmentally sound functional substitutes for ecosystem services, such as the use of solar cookers instead of fuel-wood in Africa, are pointed out as a means to achieve greater intragenerational justice, which at the same time facilitates intergenerational ecological justice. In contrast, advocates of the rivalry-hypothesis primarily relate the quantity and quality of delivered ecosystem services to the number of present and future people. Thereby they implicitly assume a limited substitutability of ecosystem services.

4.4 Technological progress

We define *technological progress* as the rate of increase in ecological efficiency, realized by innovation of new technologies, or by means of technology and knowledge transfer of already existing technologies.

There are specific assumptions about technological progress made in the context of facilitation-hypothesis A. Technological progress is mentioned as a strategy to reduce global intragenerational injustice in a way that also facilitates the preservation of ecosystems to the benefit of future generations. Advocates of an efficiency revolution consider a four- to tenfold increase of material and energy efficiency possible (e.g. Harrison 1992, von Weizäcker et al. 1995). The Brundtland-Report points out the importance of technological efficiency increases in industrialized countries and technology transfer into the global South (WCED 1987: 24ff.). The WBGU terms two key strategies to realize intragenerational justice through economic growth of the countries in the global South without rising ecosystem degradation: technological leapfrogging, that is, skipping resource-consumptive stages of development, and dematerialization, that means decoupling the consumption of natural resources from economic growth (WBGU 2004: 97ff.).

In contrast, advocates of the rivalry-hypothesis assume a decoupling of total ecosystem pressure from economic growth by means of technological progress to be highly unlikely, especially if most of the world’s population is to reach the resource consumption level of today’s industrialized countries (Ekins 1993). This would entail a conflict between the objectives of intragenerational and intergenerational justice. In addition, efficiency increases can stimulate further demand and, thus, raise total consumption of ecosystem services (cf. e.g. Sorrell 2007).

4.5 Institutions

Sustainability-relevant *institutions* are all mechanisms which structure and govern human use of ecosystem services at all levels of society (Vatn 2005: 6). They encompass the legal structure, formal and informal markets, agencies of government, interpersonal networks as well as the rules and norms guiding their behavior (Arrow et al. 2004: 149, Vatn 2005: 6ff.). Relevant institutions in the context of ecosystem use include private property or user-rights to ecosystems and the rules regulating their distribution, as well as management rules for common goods, and sanctions securing compliance with them.

The basic models and results of welfare economics supporting the independency-hypothesis are grounded on institutional arrangements (e.g. the assignment of property rights or the implementation of cap-and-trade-systems) which exclude non-authorized users from the consumption of formerly open-access ecosystem services. Institutions are also of importance in the context of facilitation-hypothesis A: Private property or user rights to local ecosystems for the world's poor are mentioned as a precondition for realizing intragenerational ecological justice and facilitating intergenerational ecological justice. For example the MEA and WBGU recommend the institutionalization of rights to use ecosystem services, which enable the poor to satisfy their basic needs and assure a livelihood, as a means to reduce poverty-driven ecosystem degradation (MEA 2003:81, WBGU 2004:4).

An important issue for establishing such institutional arrangements is who carries the transaction costs[11] for contracting, implementing, monitoring and controlling the transactions made under some institution. In a market economy transaction costs depend on the regulation of liability rules, which distribute responsibilities and, thus, serve as a starting point for negotiations. The success of market solutions, based on private user rights to ecosystem services, may be limited by excessive transaction costs. Theory and empirical results indicate that a full liability rule[12] decreases the extent of market failure from negative environmental externalities stronger than a zero liability rule, and that it redistributes income in favor of the negatively affected party (Norgaard and Hall 1974, Randall 1972).

Whether securing sufficient user rights to ecosystems really stops the poor degrading their local ecosystems, further depends on many other institutions, including well-functioning credit, product and labor markets, effective monitoring of rules, proper enforcement of policies and secure land tenure (Ruijs et al. 2008: 9) as well as the empowerment of the local population to participate in decisions concerning their local ecosystems (WBGU 2004: 4, Stoll-Kleemann 2005 and WRI 2008: 47ff.).

4.6 Political restrictions

We define *political restrictions* as the limits to an alteration of political institutions, such as agreements or laws, at any level – from the local to the global level. Political restrictions are an expression of existing power relations. For example, a redistribution of property rights to private land may be impossible due to effective resistance of those parts of society who would loose from the redistribution.

Advocates of facilitation-hypothesis A argue with the underlying assumption that there are no or only slight global political restrictions. Both a redistribution of environmental property rights and the recognition of the claims of the global South to reach enforceable environmental agreements are based on the possibility to fundamentally alter political institutions. On the contrary, proponents of the rivalry-hypothesis consider political

[11] Following Randall (1972: 176), we define transaction costs as the "costs of making and enforcing decisions. Included are the costs of obtaining information, establishing one's bargaining position, bargaining and arriving at a group decision, and enforcing the decision made".

[12] Under full liability rule the environmental property rights are initially assigned to the (potential) pollutees, under zero liability rule they are initially assigned to the polluter.

restrictions to be tight and, therefore, a redistribution of rights to ecosystem services to be politically difficult if not impossible.

5 Conclusion

Our investigation shows that the relationship between intragenerational and intergenerational ecological justice is multifarious and multilayered. Whether the elementary needs for ecosystem services of the world's poor can be satisfied and at the same time intact ecosystems for future generations be preserved, crucially depends on certain determinants: the quantity and quality of ecosystem services, population development, substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions.

The influence of these determinants can be summarized as follows: The higher the intrinsic growth rate of renewable resources, the smaller the population growth rate, the greater the substitutability of ecosystem services, the higher the rate of technological progress, the stricter the institutional restriction of ecosystem use and the greater the political scope for redistribution of environmental property rights, the less likely is a conflict between the objectives of intragenerational and intergenerational justice.

The different (and mutually exclusive!) hypotheses about the relationship between intragenerational and intergenerational ecological justice – independency, facilitation and rivalry – reflect positions in realpolitik and hinder developing common objectives and agreements. Scientists, political advisors, politicians and the public need to be aware of, and explicitly discuss, the conflicting opinions about the determinants underlying these positions and their impacts on both intragenerational and intergenerational justice. Furthermore, sustainability policy needs to recognize that there are differences between specific ecosystem services, for example between biodiversity and climate regulation, in terms of substitutability, reversibility, actual quality and quantity. Whereas political restrictions are an inherent attribute of political power structures and the quality and quantity of ecosystem services are given, sustainability policy could strive to change the determinants population development, substitutability, technological progress and institutions in an integrated way.

The literature survey raises two questions for further research. There are different concepts of intragenerational and intergenerational ecological justice underlying the discussions in the literature. Yet, they are rarely introduced explicitly. Therefore, one question for further research is which concepts of ecological justice underlie important political documents on sustainable development (especially UN 1992 und WCED 1987). The political debate about the ethics of sustainable development could be further enriched by a philosophical explication and justification of global intragenerational and intergenerational ecological justice. The other question concerns the issue of political implementation: How must political institutions and instruments be designed to facilitate intragenerational and intergenerational justice simultaneously?

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The relationship between intragenerational and intergenerational justice in the use of ecosystems and their services. An ecological-economic model.

Manuscript, September 24, 2012

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Abstract: Conflicts between intragenerational and intergenerational justice in the use of ecosystems and their services may arise in sustainability policy. However, there is little research on simultaneous modeling of intragenerational and intergenerational problems in renewable resource use. In this paper, we present a model that depicts the relationship between intragenerational and intergenerational justice in the use of ecosystem services ('justice relationship') against the backdrop of given societal circumstances. Based on this model, we characterize efficiency in the assignment of resource utilization rights in terms of attaining the two justices. Further, we numerically simulate how different assignments of resource utilization rights and certain system determinants impact on the 'justice relationship'.

Keywords: ecological-economic model, efficiency, environmental justice, ecosystem services, equity, facilitation, distribution, independence, intragenerational, intergenerational, natural capital, rivalry, trade-off

JEL-classification: D63, Q20, Q56, Q57

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1 Introduction

Realizing a sustainable use and conservation of ecosystems and their services is a major challenge for human society (MEA 2005, TEEB 2010a, UK-NEA 2011, UN/DESA 1992, UNEP 2012). Its implementation in global, national and local sustainability policy demands to account for the variety of *ecosystem services*: They can be provisioning, regulating, cultural or supporting services; substitutable and non-substitutable by human-made goods and services; excludable or non-excludable from use; consumptive or non-consumptive; rival or non-rival in consumption. Intragenerational trade-offs in the provision of different ecosystem services by one renewable resource stock (e.g. between wood provision and recreational services provided by a forest), as well as intergenerational trade-offs between the consumption of ecosystem services by today's persons and the conservation of renewable resource stocks for future persons (e.g. between present provision of agricultural goods and the maintenance of fertile soils for future agricultural production) may occur (cf. TEEB 2010b: 81ff.). These potential trade-offs ask for careful recognition of the linkages between renewable resource stocks and the provision of multiple ecosystem services.

The societal objective of *sustainability* in the use of ecosystem services refers to two different justices of equal normative rank: *intragenerational justice* and *intergenerational justice*. In the design and implementation of sustainability policy, these two justices potentially conflict. Generally, three relationships in the attainment of the two justices ('justice relationships') occur in real-world contexts: independency, facilitation and rivalry (Glotzbach and Baumgärtner 2012).

Although considerable research has modeled problems of intergenerational justice in renewable resource use (specifically under the maximin-criterion in the spirit of Rawls' second principle of justice, e.g. Cairns and Tian 2010, Martinet 2007), rather less attention has been paid to simultaneous investigation of intragenerational and intergenerational problems in renewable resource use (cf. e.g. Roemer and Veneziani 2007). In this paper, we introduce an ecological-economic model that provides the basis for a systematic investigation of the 'justice relationship' against the backdrop of given societal circumstances. The model does not serve the overall analysis of justice, but focuses on environmental justice – that is, justice in the distribution of access rights to ecosystem services.

In the two-period ecological-economic model, human actors maximize their individual utility from a manufactured consumption good and two ecosystem services delivered by a renewable resource stock, a consumptive ecosystem service (i.e. a resource harvest) and a non-consumptive ecosystem service. The policy instrument (*instrument of justice*) is the assignment of first- and second-generation utilization rights to the renewable resource stock by a social planner. The given societal circumstances (such as the available amount of renewable resource stock and given political restrictions on the assignment of resource utilization rights) characterize a specific ecological-economic system and are depicted by certain s*ystem determinants*. The degree of intragenerational (resp.: intergenerational) justice in ecosystem-service use is measured in terms of the Rawlsian Difference Principle regarding the individual utilities attained by the first-generation individuals (resp.: the first- and second-generation individuals). The ecological-economic model is a *generic* model – that is, it allows creating insights into the 'justice relationship' both at a general level for a large class of systems, and for specific real-world systems (cf. Baumgärtner et al. 2008: 389f.).

Based on the developed generic ecological-economic model, we conduct initial steps of model analysis. First, we prove the plausibility of the model by analyzing how the model parameters impact on the indirect utility functions of present and future individuals. The model parameters are the quantity of ecosystem services (i.e. the total endowment with the renewable resource stock and its intrinsic growth rate), the quality of ecosystem services (consumptivity, rivalry in consumption and excludability from consumption), population development, substitutability of ecosystem services (both between manufactured-good consumption and aggregate ecosystem-service consumption, and between a consumptive and a non-consumptive ecosystem service), technological progress (in the manufacturing sector and in resource harvesting), institutions (i.e. the assignment of resource utilization rights) and political restrictions on this assignment. Second, we define *efficiency* in terms of the model – that is, efficiency in the assignment of first- and second-generation resource utilization rights regarding the objectives of intragenerational and intergenerational environmental justice. Applying the method of numerical simulation, we identify efficient and inefficient assignments of resource utilization rights for a specific ecological-economic system, and illustrate how *(in)efficiency* is related to the occurrence of rivalry, independency and facilitation in the 'justice relationship'. Third, we illustrate based on a numerical simulation how the use of the *instrument of justice* (i.e. different assignments of first- and second-generation resource utilization rights) and a change in certain *system determinants* impact on the occurrence of rivalry, independency and facilitation in the 'justice relationship'. With these first steps of model analysis, we demonstrate that the introduced model is a valuable tool to explore political paths that consistently and effectively improve on both intragenerational and intergenerational environmental justice.

The paper is organized as follows. In Section 2, we lay the normative foundation – by discussing environmental justice, the three possible relationships between intra- and intergenerational environmental justice, and their determinants. In Section 3, we introduce the ecological-economic model. In Section 4, we present the results of the model analysis. In Section 5, we discuss these results and conclude by identifying further research questions.

2 Normative foundations: environmental justice, determinants, and efficiency

In this paper, we apply the ideas of intragenerational and intergenerational justice to the use of ecosystems and their services. Whereas the 'classical' environmental justice discourse (cf. e.g. Schlosberg 2007) investigates the unequal distribution of environmental burdens and hazards between different contemporary societal groups, we more broadly assume that **environmental justice** is about "how environmental goods and bads are to be distributed among human beings, within and across societies at any one time, and between generations across time" (Baxter 2005: 6). A conception of environmental justice that specifically addresses the intragenerational and intergenerational distribution of access rights to ecosystem services is proposed by Glotzbach (forthcoming). We draw on this conception to derive model indicators for intragenerational and intergenerational environmental justice. The conception builds on John Rawls' "A Theory of Justice" (1971). It extends Rawls' impartial original position – by including representatives from the present and future generations as contract partners, and access rights to ecosystem services in Rawls' category of primary social goods – and, consequently, deduces a *principle of intragenerational (resp.: intergenerational) environmental justice*: Access rights to ecosystem services have to be distributed in such a way that they are to the greatest benefit of the least-advantaged members of the present generation (resp.: across the present and future generations) (Glotzbach, forthcoming). From these principles, we derive indicators that measure the degree of intragenerational and intergenerational environmental justice in the model system. The model indicators depict the 'benefit of the least-advantaged' in terms of individual utility.

In real-world systems, three '**justice relationships**' may hold in the attainment of intragenerational and intergenerational environmental justice (Glotzbach and Baumgärtner 2012: 337):

(1) **Independency**: The objectives of intra- and intergenerational environmental justice can be achieved independently, that is, attaining one objective to a higher degree does not necessitate any change in the degree of attainment of the other objective.
(2) **Facilitation**: Achieving one objective of environmental justice supports achieving the other one, that is, attaining one objective to a higher degree induces a higher degree of attainment of the other objective.
(3) **Rivalry**: A fundamental rivalry ("trade-off") exists between the objectives of intra- and intergenerational environmental justice, that is, attaining one objective to a higher degree necessarily reduces the degree of attainment of the other objective.

All three relationships do not need to be symmetric (Baumgärtner et al. 2012: notes 20, 22, 23): The achievement of one objective of justice may be independent, favorable resp. rival regarding the achievement of the other objective of justice, but not vice versa.

Independency, facilitation and rivalry in the 'justice relationship' hold true under different assumptions on certain **determinants** of the 'justice relationship' (Glotzbach and Baumgärtner 2012: Sec. 4). These *determinants* are the quantity of ecosystem services, the quality (i.e., rivalry in and excludability from use) of ecosystem services, population development, substitutability of ecosystem services by human-made goods and services, technological progress, institutions and political restrictions (ib.). They were revealed as the result of a qualitative content analysis of the political and scientific sustainability discourse. The ecological-economic model serves to better understand how the determinants influence the occurrence and extent of rivalry, independency or facilitation in the 'justice relationship'. In the model, we differentiate the determinants in an *instrument of justice* and several *system determinants*: The *instrument of justice* is the assignment of first- and second-generation resource utilization rights by the social planner; the *system determinants* are the model parameters (such as the initial endowment with the renewable resource stock) which cannot be controlled by the social planner, but which are given for a specific ecological-economic system. In a numerical simulation, we investigate how the use of the instrument of justice and a change in certain system determinants, respectively, impact on the occurrence and extent of rivalry, independency or facilitation in the 'justice relationship'.

Further, the occurrence of rivalry, independency or facilitation in the 'justice relationship' is related to the condition of **(in-)efficiency** (Baumgärtner et al. 2012). The use of instruments of justice is defined to be *efficient* if it is not possible in a given system to better attain one objective of justice without worsening the attainment of the other objective of justice (ib. 6). Hence, *efficiency* assesses the use of instruments of justice in terms of attaining the two objectives of intra- and intergenerational environmental justice within a community. The three 'justice relationships' are related to efficiency as follows: An efficient use of the instruments of justice implies a 'justice relationship' of rivalry; an inefficient use of the instruments of justice implies a 'justice relationship' of facilitation or independence (ib. 8). Because of this relation, we define efficiency in terms of the ecological-economic model and identify by method of numerical simulation efficient and inefficient assignments of resource utilization rights for a specific ecological-economic system.

3 Model description

There are two time periods $t = 1, 2$ and two non-overlapping generations. Generation 1 lives at time $t = 1$ and comprises two individuals A and B; generation 2 lives at time $t = 2$ and comprises $2n$ identical individuals C, where $n>0$ is the population growth rate.

There are four goods: a manufactured consumption good, a renewable resource stock (e.g. a forest stand), a provisioning ecosystem service which is consumptive, i.e. the harvest of which diminishes the resource stock (e.g. timber provision), and a non-consumptive ecosystem service. The manufactured consumption good and the consumptive ecosystem service are private goods. As for the non-consumptive ecosystem service, we study two alternative variants of the model: (a) the ecosystem service is a private good characterized by intragenerational rivalry in, and excludability from, consumption (e.g. provision of non-timber forest products such as fruits, berries, mushrooms etc.); (b) the ecosystem service is a pure public good characterized by intragenerational non-rivalry in, and non-excludability from, consumption (e.g. a regulating service such as erosion control or climate regulation, or a cultural service such as aesthetic satisfaction or recreation). Let the parameter $\nu \in \{0,1\}$ denote the degree of rivalry/excludability, where $\nu = 1 \; (\nu = 0)$ means that the non-consumptive ecosystem service is a pure private good (public good).

The manufactured consumption good is assumed to be exogenously provided. At $t = 1$, the total endowment is Y_1, and each individual i consumes an equal share:

$$Y^i = \frac{Y_1}{2} \quad \text{for} \quad i = A, B \, . \tag{1}$$

Due to autonomous technological progress in the manufacturing sector, the total endowment with the manufactured consumption good increases by a rate $\mu > 0$ from $t = 1$ to $t = 2$. Hence, the amount of the manufactured good consumed by individual C in $t = 2$ is given by

$$Y^C = \frac{\mu Y_1}{2n} . \tag{2}$$

Initially, i.e. at $t = 1$, there is a total endowment R_1 with the renewable resource stock. Individual i (with $i = A, B$) possesses utilization rights to an amount $R^i \geq 0$ of the resource stock with

$$R^A + R^B \leq R_1 . \tag{3}$$

He harvests an amount H^i of the consumptive ecosystem service by means of a linear harvest technology that converts one unit of the resource stock R^i into one unit of H^i, subject to

$$0 \leq H^i \leq R^i \quad \text{for} \quad i = A, B . \tag{4}$$

The non-consumptive ecosystem service S^i is provided by the non-converted resource stock in proportion to the stock size:

$$S^i = R^i - H^i + (1-\nu)\left(R_1 + R^j - R^A - R^B - H^j\right) \tag{5}$$

for $i = A, B$; $j \neq i$.

According to Equation (5), if (a) the non-consumptive ecosystem service is a private good, $\nu = 1$, S^i is provided by the non-converted resource stock possessed by individual i (with $i = A, B$): $S^i = R^i - H^i$. If (b) the non-consumptive ecosystem service is a pure public good, $\nu = 0$, S^i is provided by the total of the non-converted resource stock in $t = 1$: $S^i = R_1 - \left(H^A + H^B\right)$.

The non-converted resource stock naturally regenerates with an intrinsic resource growth rate $\omega > 0$. As harvest of H^i does diminish the resource stock, but consumption of S^i does not, the total resource stock R_2 in $t = 2$ depends on the harvested amount $H^A + H^B$ of the consumptive ecosystem service in $t = 1$:

$$R_2 = \omega\left(R_1 - H^A - H^B\right). \tag{6}$$

At time $t = 2$, representative individual C of generation 2 possesses utilization rights to an amount $R^C \geq 0$ of the remaining resource stock with

$$R^C \leq \frac{R_2}{2n} . \tag{7}$$

He harvests an amount H^C of the consumptive ecosystem service. Due to autonomous technical progress in the harvest technology, he can convert one unit of the resource stock R^C into $\gamma > 0$ units of H^C. If $\gamma > 1$, the resource efficiency of the linear harvest technology improves from $t = 1$ to $t = 2$, that is, a greater amount of the consumptive ecosystem service can be harvested through converting the same amount of the resource stock. Hence, harvesting in $t = 2$ is subject to

$$0 \leq H^C \leq \gamma R^C \, . \tag{8}$$

The level of the non-consumptive ecosystem service, S^C, is given by

$$S^C = [\, 1 + (1-\nu)(2\, n - 1)] \left(R^C - \frac{H^C}{\gamma} \right) + (1-\nu)\left(R_2 - 2\, n\, R^C\right). \tag{9}$$

According to Equation (9), if (a) the non-consumptive ecosystem service is a private good, $\nu = 1$, S^C is provided by the non-converted resource stock possessed by the representative individual C : $S^C = R^C - H^C/\gamma$; if (b) the non-consumptive ecosystem service is a pure public good, $\nu = 0$, S^C is provided by the total of the non-converted resource stock in $t = 2$: $S^C = R_2 - 2\, n\, H^C/\gamma$.

Individual i (with $i = A, B, C$) has preferences for the consumption of the manufactured consumption good Y^i, the consumptive ecosystem service H^i and the non-consumptive ecosystem service S^i as represented by the utility function

$$U^i = U\left(Y^i, H^i, S^i\right) = \left[\left(Y^i\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^i\right)^{\frac{\theta-1}{\theta}} + \left(S^i\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} . \tag{10}$$

In this nested CES-utility function, overall utility is characterized by a constant elasticity of substitution $\sigma > 0$ between the manufactured consumption good, Y^i, and the utility from aggregate ecosystem-service consumption, and the utility from aggregate ecosystem-service consumption is characterized by a constant elasticity of substitution $\theta > 0$ between the consumptive and the non-consumptive ecosystem service, H^i and S^i. For $\theta \to 0$ ($\theta \to \infty$), the consumptive and the non-consumptive ecosystem service are perfect complements (substitutes) in consumption; For $\sigma \to 0$ ($\sigma \to \infty$), the manufactured good and aggregate ecosystem services are perfect complements (substitutes) in consumption.

Individual i chooses the levels of H^i and S^i so as to maximize his individual utility U^i (Equation (10)) subject to ecological, technological and institutional feasibility:

$$\max_{H^i,\, S^i} U^i = U\left(Y^i, H^i, S^i\right) \text{ subject to (1), (4), (5) for } i = A, B\,, \tag{11}$$

$$\max_{H^C,\, S^C} U^C = U\left(Y^C, H^C, S^C\right) \text{ subject to (2), (6), (8), (9).} \tag{12}$$

In variant (a) of the model, where the non-consumptive ecosystem service is a private good, the maximization problems (11) of individuals A and B are independent of each other. In contrast, in variant (b) of the model, where the non-consumptive ecosystem service is a public good, the maximization problems (11) of individuals A and B are interdependent through constraint (5) on how the amount of the public ecosystem service depends on the non-converted resource stock. For this case, we assume that both individuals act simultaneously and the solution is the Nash equilibrium of the non-cooperative game. The solution to optimization problems (11) and (12), i.e. the individually optimal extent of ecosystem service consumption for a given vector $\boldsymbol{R} = \left(R^A,\ R^B, R^C\right)$ of resource utilization rights, is denoted by $H^{i*}(\boldsymbol{R})$ and $S^{i*}(\boldsymbol{R})$. Individual i thus achieves the utility level

$$V^i(\boldsymbol{R}) = U\ (Y^i, H^{i*}(\boldsymbol{R}), S^{i*}(\boldsymbol{R})) \quad \text{for } i = A, B, C\,, \tag{13}$$

where V^i is the indirect utility function derived from utility function (10) through optimization problem (11) resp. (12).

A social planner assigns first- and second-generation utilization rights $\boldsymbol{R} = \left(R^A,\ R^B, R^C\right)$ with the objective of achieving a maximum of intragenerational and intergenerational environmental justice and taking into account individuals' optimizing behavior ((11), (12), (13)). The ideal of intragenerational and of intergenerational environmental justice – as derived from the Rawlsian Difference Principle – is achieved by choosing $\boldsymbol{R}$ so as to maximize the minimum actually realized utility level V^i of individuals $i = A, B$, and of individuals $i = A, B, C$, respectively:

$$\max_R\ AJ\ (\boldsymbol{R}) \tag{14}$$

$$\max_R\ EJ\ (\boldsymbol{R}) \tag{15}$$

where

$$AJ\ (\boldsymbol{R}) = \min\ [V^A(\boldsymbol{R}),\ V^B(\boldsymbol{R})] \tag{16}$$

$$EJ\ (\boldsymbol{R}) = \min\ [V^A(\boldsymbol{R}),\ V^B(\boldsymbol{R}),\ V^C(\boldsymbol{R})] \tag{17}$$

are indicators for intragenerational environmental justice and for intergenerational environmental justice, respectively, for a given distribution of resource utilization rights $\boldsymbol{R}$. In assigning resource utilization rights, the social planner is limited

by physical feasibility as given by the equations (3), (6) and (7),

by a political constraint on intragenerational distribution within generation 1,

$$\underline{\chi} \leq \left(\frac{R^A}{R^B}\right) \leq \overline{\chi}\,, \tag{18}$$

by a political constraint on intergenerational distribution,

$$\underline{\pi} \leq \left(R^A + R^B\right) \leq \overline{\pi}\,, \tag{19}$$

and by a political constraint on access to the remaining resource stock by generation 2,

$$\underline{\xi} \leq R^C \leq \overline{\xi}\,. \tag{20}$$

The exact time structure of decision making is as follows. At $t = 0$, the social planner assigns resource utilization rights $\boldsymbol{R}$ to members of generation 1 and 2. At $t = 1$, first-generation individuals $i\ (i = A, B)$ maximize their utility U^i (optimization problem (11)). At $t = 2$, second-generation individuals C maximize their utility U^C (optimization problem (12)).

In this model, the six *determinants* of the relationship between intragenerational and intergenerational justice in the use of ecosystem services (cf. Section 2) are captured by the following model parameters: The determinant "institutions" is described by the assignment of utilization rights $\boldsymbol{R}$. The "quality of ecosystem service" is described by the distinction between the consumptive ecosystem service and the non-consumptive ecosystem service, and by the degree ν of rivalry in, and excludability from, consumption of the non-consumptive ecosystem service. The "quantity of ecosystem service" is described by the initial endowment R_1 with the renewable resource stock and its intrinsic growth rate ω. The "population development" is described by the population growth rate n. The "substitutability of the ecosystem service" is described by the parameters σ, which measures substitutability between manufactured-good consumption and aggregate ecosystem-service consumption, and θ, which measures substitutability between the consumptive and the non-consumptive ecosystem service. The "technological development" is described by the rates μ and γ of technological progress in the manufacturing sector and in resource harvesting, respectively. The "political restrictions" are described by constraints (18), (19) and (20) on the intra- and intergenerational assignment of resource utilization rights by the social planner.

4 Model analysis and results

In the following model analysis, we proceed in three steps: First, we analytically derive the general model solutions for model variant (a) and model variant (b), respectively. Second, we analyze the impact of each model parameter on the indirect utility functions of present and future individuals using the method of comparative statics. Third, we define the normative objective of efficiency, and assess the model solutions in terms of efficiency for a specific ecological-economic system using the method of numerical simulation.

4.1 General model solutions

Model variant (a): S^i is a private good ($\nu = 1$)

The model in variant (a) has the following general solutions:

$$H^{i*} = \frac{R^i}{2}, \tag{21}$$

$$S^{i*} = \frac{R^i}{2}, \tag{22}$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \tag{23}$$

$$H^{C*} = \frac{R^C}{\left(\gamma^{-\theta} + \gamma^{-1}\right)}, \tag{24}$$

$$S^{C*} = \left(1 - \frac{1}{\gamma^{1-\theta} + 1}\right) R^C , \tag{25}$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} . \tag{26}$$

Proof. See Appendix A.1.

Model variant (b): S^i is a pure public good ($\nu = 0$)

The model in variant (b) has the following general solutions:

For **model variant (b1)**, i.e. $R^i \geq \frac{R_1}{3}$ with $i = A, B$,

$$H^{i*} = \frac{R_1}{3}, \tag{27}$$

$$S^{i*} = \frac{R_1}{3}, \tag{28}$$

$$V^{i*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}} \frac{1}{3} R_1 \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{29}$$

$$H^{C*} = \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \quad \text{if} \quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R^C, \tag{30a}$$

$$H^{C*} = \gamma R^C \quad \text{if} \quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C, \tag{30b}$$

$$S^{C*} = \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right) \frac{\omega R_1}{3} \quad \text{if} \quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R, \tag{31a}$$

$$S^{C*} = \frac{\omega R_1}{3} - 2\, n\, R^C \quad \text{if} \quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C, \tag{31b}$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{32a}$$

if $\frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R^C$,

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega R_1}{3} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{32b}$$

if $\frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C$.

For **model variant (b2)**, i.e. $R^i < \frac{R_1}{3}$ and $R^j \geq \frac{R_1}{3}$ with $i, j = A, B$ and $i \neq j$,

$$H^{i*} = R^i \,, \tag{33}$$

$$H^{j*} = \frac{R_1 - R^i}{2} \,, \tag{34}$$

$$S^{i,j*} = \frac{R_1 - R^i}{2} \,, \tag{35}$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1 - R^i}{2}\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} , \tag{36}$$

$$V^{j*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}} \left(R_1 - R^i\right) \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} , \tag{37}$$

$$H^{C*} = \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \quad \text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R^C , \tag{38a}$$

$$H^{C*} = \gamma R^C \quad \text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C , \tag{38b}$$

$$S^{C*} = \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right) \frac{\omega\left(R_1 - R^i\right)}{2} \quad \text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R^C , \tag{39a}$$

$$S^{C*} = \frac{\omega\left(R_1 - R^i\right)}{2} - 2\, n\, R^C \quad \text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C , \tag{39b}$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{40a}$$

$$\text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R^C ,$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2} - 2\, n\, R^C \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

$$\text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C . \tag{40b}$$

For **model variant (b3)**, i.e. $R^i < \frac{R_1}{3}$ with $i = A, B$ and $i \neq j$,

$$H^{i*} = R^i , \tag{41}$$

$$S^i = R_1 - \left(R^i + R^j\right) , \tag{42}$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - \left(R^i + R^j\right)\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} , \tag{43}$$

$$H^{C*} = \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \quad \text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \leq \gamma R^C , \tag{44a}$$

$$H^{C*} = \gamma R^C \qquad \text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} > \gamma R^C , \tag{44b}$$

$$S^{C*} = \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right) \omega\left(R_1 - \left(R^i + R^j\right)\right) \qquad \text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \le \gamma R^C , \tag{45a}$$

$$S^{C*} = \omega\left(R_1 - \left(R^i + R^j\right)\right) - 2\, n\, R^C \qquad \text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} > \gamma R^C , \tag{45b}$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{46a}$$

$$\text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \le \gamma R^C ,$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right) - 2\, n\, R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{46b}$$

$$\text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} > \gamma R^C .$$

Proof. See Appendix A.2.

4.2 Impact of the model parameters on the indirect utility functions

This subsection describes the impact of the model parameters – that is, the initial endowment Y_1 with the manufactured consumption good, the initial endowment R_1 with the renewable resource stock, the individual endowment R^i (for $i = A, B$) and R^C with utilization rights to the renewable resource stock, the intrinsic growth rate ω of the renewable resource stock, the population growth rate n, the "substitutability-parameters" σ and θ, the rate μ of technological progress in the manufacturing sector, and the rate γ of technological progress in resource harvesting – on the indirect utility functions V^i (for $i = A, B$) and V^C. A marginal increase in the value of the respective model parameter implies a marginal increase (+), decrease (-) or no change (0) in the value of the indirect utility functions for the respective model variants (MV) as follows:

Table 1: Impact of a marginal increase in the value of the particular model parameter on the values of V^i (for $i = A, B$) and V^C

<table>
<tr><th rowspan="3">Model parameter</th><th colspan="12">Impact of model parameter on V^i (for $i = A, B$) and V^C</th></tr>
<tr><th colspan="2">MV (a)</th><th colspan="3">MV (b1)</th><th colspan="4">MV (b2)</th><th colspan="3">MV (b3)</th></tr>
<tr><th>V^i</th><th>V^C</th><th>V^i</th><th colspan="2">V^C</th><th>V^i</th><th>V^j</th><th colspan="2">V^C</th><th>V^i</th><th colspan="2">V^C</th></tr>
<tr><td>Y_1</td><td>+</td><td>+</td><td>+</td><td colspan="2">+</td><td>+</td><td>+</td><td colspan="2">+</td><td>+</td><td colspan="2">+</td></tr>
<tr><td>R_1</td><td>0</td><td>0</td><td>+</td><td colspan="2">+</td><td>+</td><td>+</td><td colspan="2">+</td><td>+</td><td colspan="2">+</td></tr>
<tr><td>R^i ($i = A, B$)</td><td>+</td><td>0</td><td>0</td><td colspan="2">0</td><td>+</td><td>−</td><td colspan="2">−</td><td>+</td><td colspan="2">−</td></tr>
<tr><td>R^C</td><td>0</td><td>+</td><td>0</td><td>0</td><td>+</td><td>0</td><td>0</td><td>0</td><td>+</td><td>0</td><td>0</td><td>+</td></tr>
<tr><td>ω</td><td>0</td><td>0</td><td>0</td><td colspan="2">+</td><td>0</td><td>0</td><td colspan="2">+</td><td>0</td><td colspan="2">+</td></tr>
<tr><td>n</td><td>0</td><td>−</td><td>0</td><td>−*</td><td>−</td><td>0</td><td>0</td><td>−*</td><td>−</td><td>0</td><td>−*</td><td>−</td></tr>
<tr><td>σ</td><td>−</td><td>−**</td><td>−</td><td colspan="2">−</td><td>−</td><td>−</td><td colspan="2">−</td><td>−</td><td colspan="2">−</td></tr>
<tr><td>θ</td><td>−</td><td>−</td><td>−</td><td colspan="2">−</td><td>−</td><td>−</td><td colspan="2">−</td><td>−</td><td colspan="2">−</td></tr>
<tr><td>μ</td><td>0</td><td>+</td><td>0</td><td colspan="2">+</td><td>0</td><td>0</td><td colspan="2">+</td><td>0</td><td colspan="2">+</td></tr>
<tr><td>γ</td><td>0</td><td>+*</td><td>0</td><td>+*</td><td>+</td><td>0</td><td>0</td><td>+*</td><td>+</td><td>0</td><td>+*</td><td>+</td></tr>
</table>

* *for* $\theta < 1$
** *for* $\sigma > 1$

Proof. See Appendix A.3 for model variant (a); see Appendix A.4 for model variant (b).

The non-shaded cells in Table 1 indicate solutions obtained by comparative statics; the grey-shaded cells indicate solutions obtained by numerical simulation. As there are two general model solutions in the model variants (b1), (b2) and (b3) (cf. Section 4.1), the left cell refers to general model solution a and the right cell refers to general model solution b, respectively. If the impact of the model parameters on both of the general model solutions is the same in terms of (+), (-) and 0, the impact is indicated in a single cell.

The results regarding the impact of the respective model parameters on the indirect utility functions (as presented in Table 1) indicate the plausibility of the introduced ecological-economic model.

4.3 Definition and analysis of efficiency

Referring to a classical definition of economics by Robbins[1] (1932: 15), we generally characterize efficiency as non-wastefulness in the use of “scarce means” that have alternative uses to attain societally desired “ends”. These “ends” are not determined by Robbins' definition of economics. Accordingly, LeGrand (1990: 559) suggests that efficiency refers to primary “social objectives”. Taking up the definition of efficiency by LeGrand (1990: 559), we define the use of instruments of justice to be efficient if it is not possible in a given system to better attain one primary social objective without worsening the attainment of the other primary social objective. In the model, the primary social objectives are intragenerational and intergenerational environmental justice. We presume that the two justices are normative objectives of equal rank regarding societal desirability. In terms of the formal model (Section 3), we define efficiency as follows:

Definition:[2]

A feasible assignment $\mathbf{R} = \left(R^A,\ R^B, R^C\right)$ of resource utilization rights is efficient if and only if there exists no other feasible assignment $\mathbf{R}' = \left(R^{A'},\ R^{B'}, R^{C'}\right)$ for which

AJ ($\mathbf{R}'$) > AJ ($\mathbf{R}$) and EJ ($\mathbf{R}'$) ≥ EJ ($\mathbf{R}$) or,

EJ ($\mathbf{R}'$) > EJ ($\mathbf{R}$) and AJ ($\mathbf{R}'$) ≥ AJ ($\mathbf{R}$).

An assignment of resource utilization rights **R** is feasible if the social planner can implement the assignment subject to four constraints: physical feasibility (equations (3), (6) and (7)), the political constraint on χ intragenerational distribution of resource utilization rights within generation 1 (equation (18)), the political constraint π on intergenerational distribution of resource utilization rights (equation (19)) and the political constraint ξ on access to the renewable resource stock by generation 2 (equation (20)). The set of all feasible assignments of resource utilization rights is the *policy set.*

The normative criterion of efficiency considered here is different from the criterion of ‘Pareto-efficiency’[3] which is commonly used in economics. Whereas ‘Pareto-efficiency’ assesses allocations in terms of the well-being of individual persons, efficiency as considered here assesses the use of instruments of justice in terms of attaining the two objectives of intra- and intergenerational environmental justice. As this criterion of efficiency is derived from the Rawlsian difference principle, which involves a maximin-optimization, the relation between $V^i(\boldsymbol{R})$ for $i = A, B, C$ and $AJ(\boldsymbol{R})$ resp. $EJ(\boldsymbol{R})$ is nontrivial – and, hence, there exists no trivial connection between *efficiency* and ‘Pareto-efficiency’. ‘Pareto-efficiency’ is not relevant to assess the *policy set* in terms of environmental justice. Thus, we focus on efficiency in the following numerical analysis.

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[1] Lionel Robbins (1932: 15) constitutes that economics “studies human behaviour as a relationship between ends and scarce means which have alternative uses”.

[2] In this definition, it is a regulation that is defined to be efficient and not an allocation (which is the usual entity to be defined as efficient).

[3] According to the original criterion of efficiency by Vilfredo Pareto (1906), an allocation is ‘Pareto-efficient’ if it is not possible in a given system to improve on one person's individual utility without worsening the individual utility of any other person.

Numerical simulation

To illustrate efficiency in terms of the model, we depict the outcomes of different feasible assignments of resource utilization rights in terms of intra- and intergenerational environmental justice for a specific ecological-economic system – that is, for specific values of the *system determinants* Y_1, R_1, ω, n, σ, θ, μ, γ, $\underline{\chi}$, $\overline{\chi}$, $\underline{\pi}$, $\overline{\pi}$, $\underline{\xi}$ and $\overline{\xi}$. The diagrams in Figures 1-4 show for each model variant, respectively, how the *policy set* is assessed in terms of intragenerational environmental justice (AJ) and intergenerational environmental justice (EJ). The x-axis measures the degree of attainment of AJ, the y-axis the degree of attainment of EJ. Each cross in the diagrams represents the outcome of a specific assignment of resource utilization rights included in the policy set.

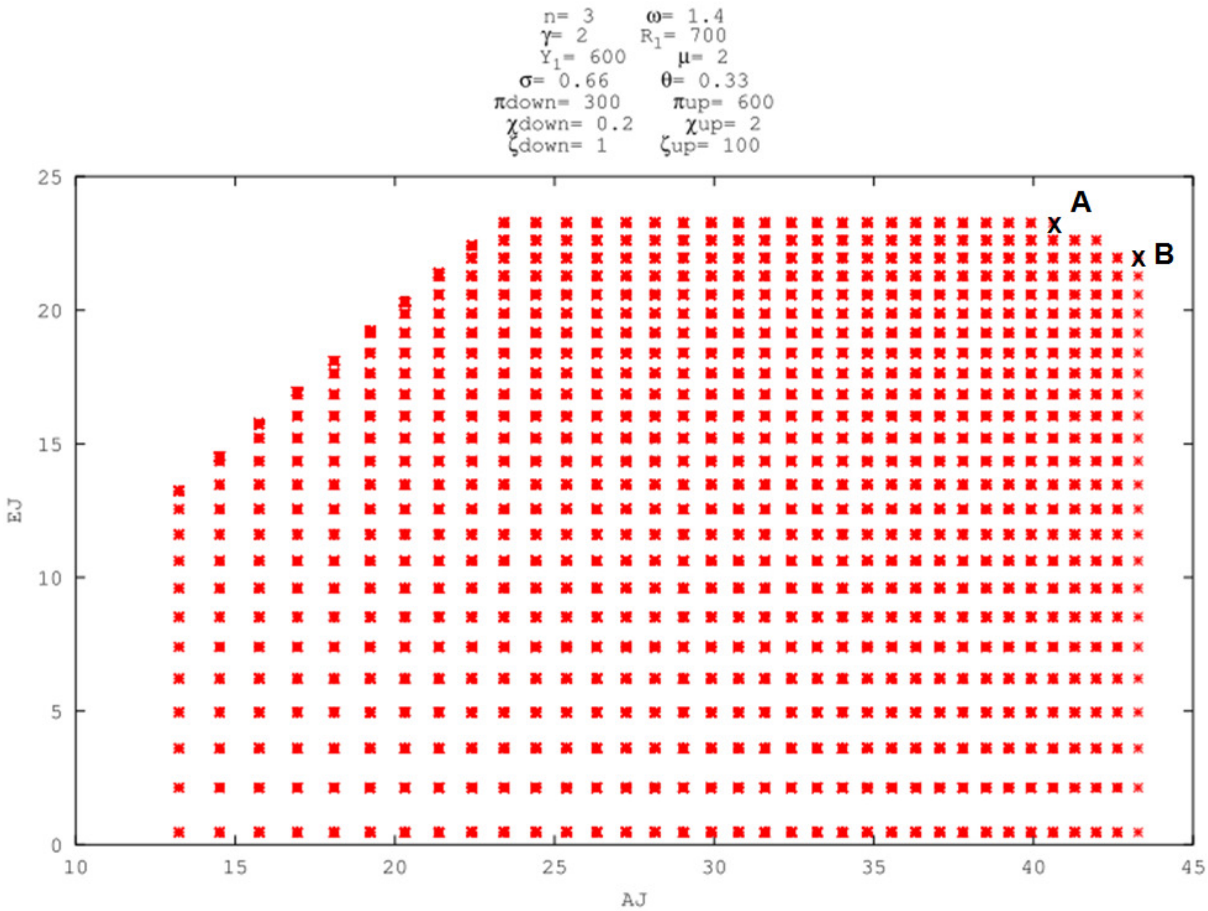

Figure 1: The opportunity set for a specific ecological-economic system in model variant (a)

In model variant (a), (b2) and (b3), respectively, all outer outcomes build a curve, the 'justice possibility frontier' (JPF) (cf. Figure 1, 3 and 4, respectively). The area on and interior of the JPF-curve indicates the set of feasible outcomes in the given context ('opportunity set') – that is, for given system determinants. Outcomes outside of the JPF-curve are not feasible in the given context. All outcomes on the JPF-curve between the crosses A and B in Figure 1, 3 and 4, respectively, indicate *efficient* assignments of resource utilization rights: From these outcomes a higher degree of one justice cannot be attained without worsening the degree of attainment of the other justice. All further outcomes on and below the JPF-curve indicate *inefficient* assignments of resource utilization rights. In model variant (b1), there is only one *efficient* assignment of resource utilization rights included in the policy set: This efficient assignment produces outcome C in Figure 2.

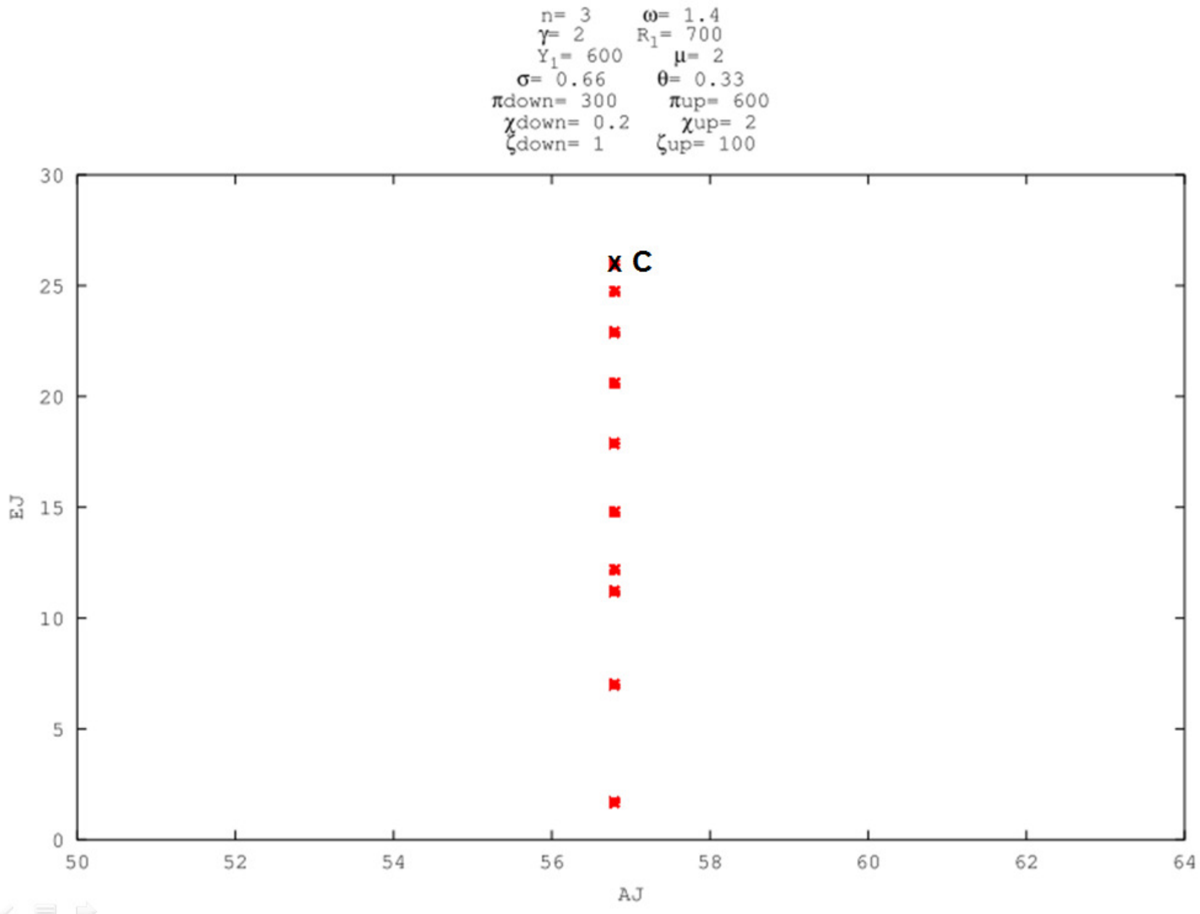

Figure 2: The opportunity set for a specific ecological-economic system in model variant (b1)

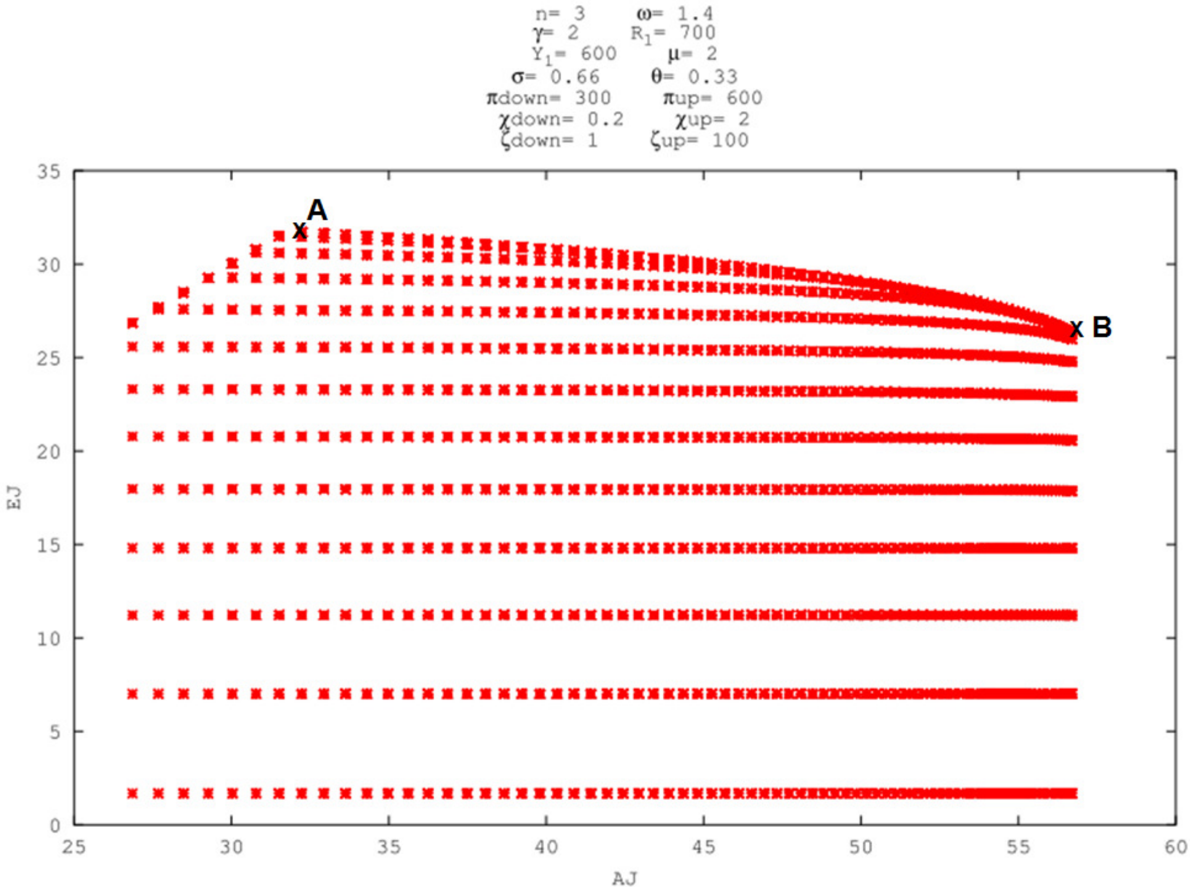

Figure 3: The opportunity set for a specific ecological-economic system in model variant (b2)

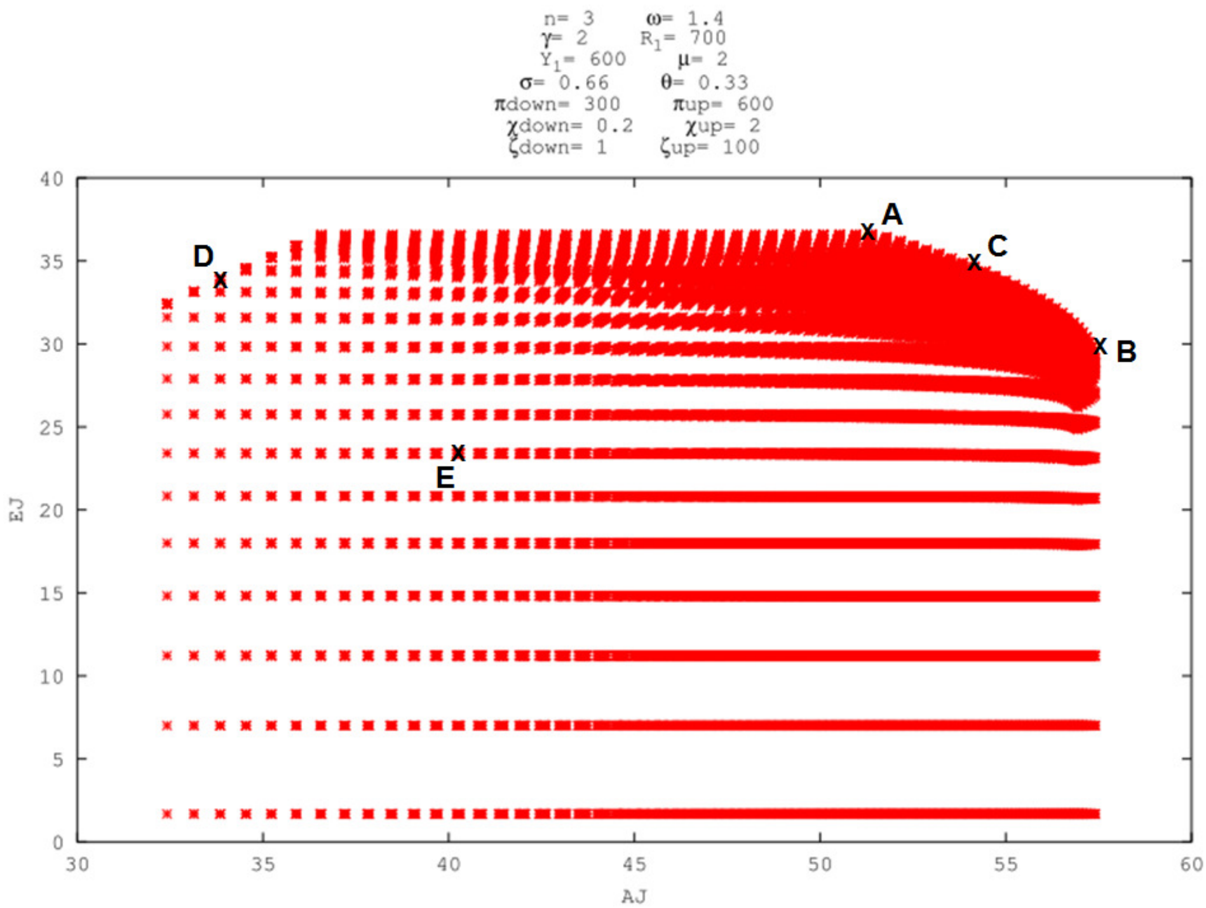

Figure 4: The opportunity set for a specific ecological-economic system in model variant (b3)

In all *efficient* outcomes, *rivalry* between intragenerational and intergenerational environmental justice necessarily occurs (Baumgärtner et al. 2012: 8). An example is outcome C in Figure 4: Improving on EJ from this point would necessarily reduce the degree of attainment of AJ, and vice versa. In all *inefficient* outcomes, either *independency* or *facilitation* between intragenerational and intergenerational environmental justice occurs (ib.). For instance, in outcome D in Figure 4 there is facilitation between the two justices: As outcome D is located on the JPF-curve, improving on EJ from this point necessarily also increases the degree of AJ.[4] In outcome E in Figure 4 there is independency between the two justices: Improving on AJ from outcome E does not necessitate any change in the degree of attainment of EJ, and vice versa.

A **change in the system determinants** may alter the opportunity set and therewith the shape of the JPF-curve (ib.: 7). Figures 5 and 6 give two examples on how a change in a particular system determinant shifts the JPF-curve in the specific ecological-economic system under study: An increase in the initial endowment R_1 with the renewable resource stock stretches the JPF-curve in model variant (b3) both westwards and outwards to the northeast (cf. Figure 5). Thus, the social planner can, with the available policy set, attain outcomes which show

[4] This facilitation is not symmetric: Improving on AJ from point E does not necessarily also increase the degree of EJ.

higher values in terms of both AJ and EJ. An increase in the rate γ of technological progress in resource harvesting shifts the JPF-curve in model variant (a) northwards (cf. Figure 6). This change allows the social planner to attain, with the available policy set, outcomes which show higher values in terms of EJ and equally high values in terms of AJ.

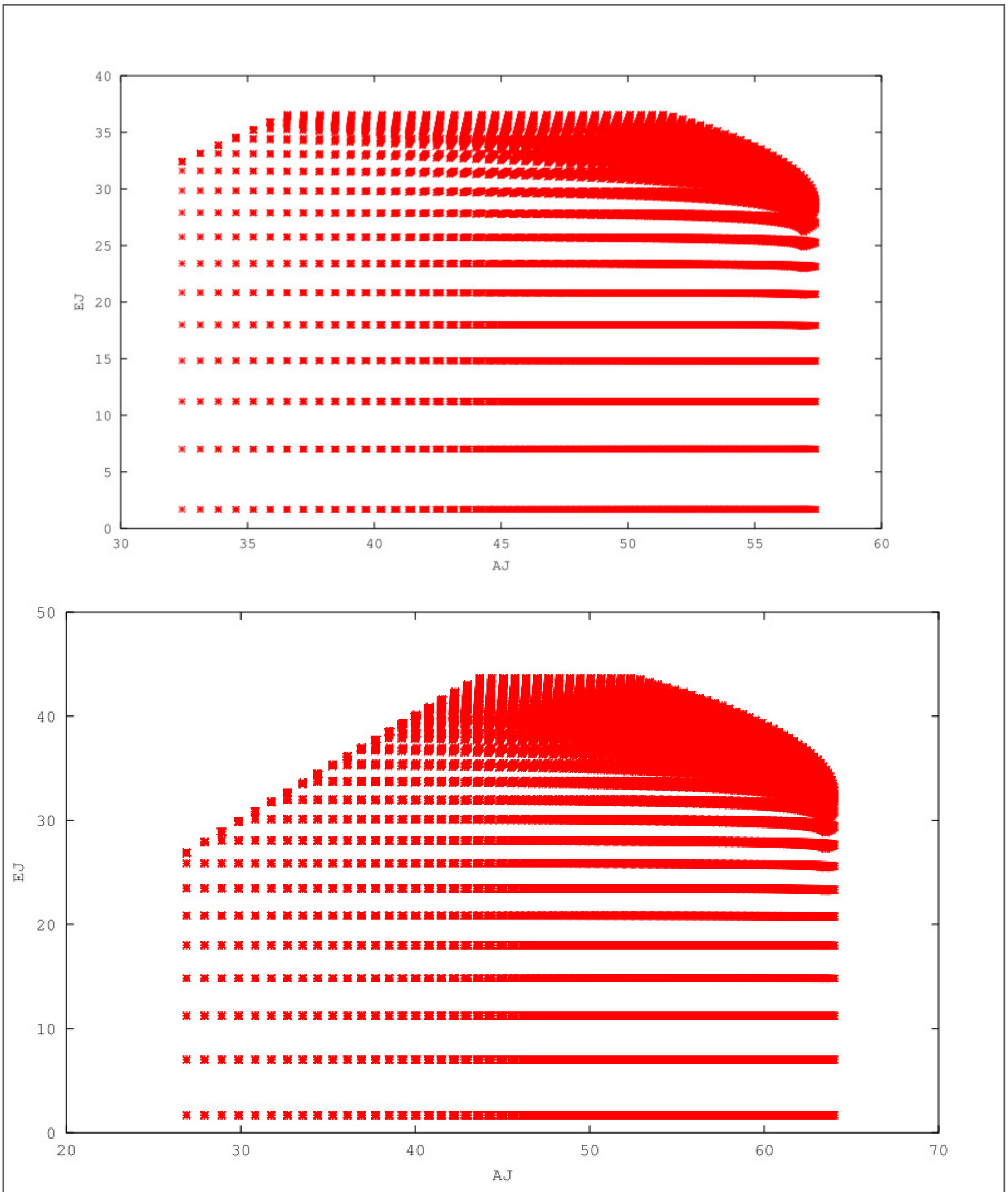

Figure 5: Alteration in the opportunity set for an increase in the initial endowment with the renewable resource stock (from $R_1 = 700$ to $R_1 = 850$) in model variant (b3)

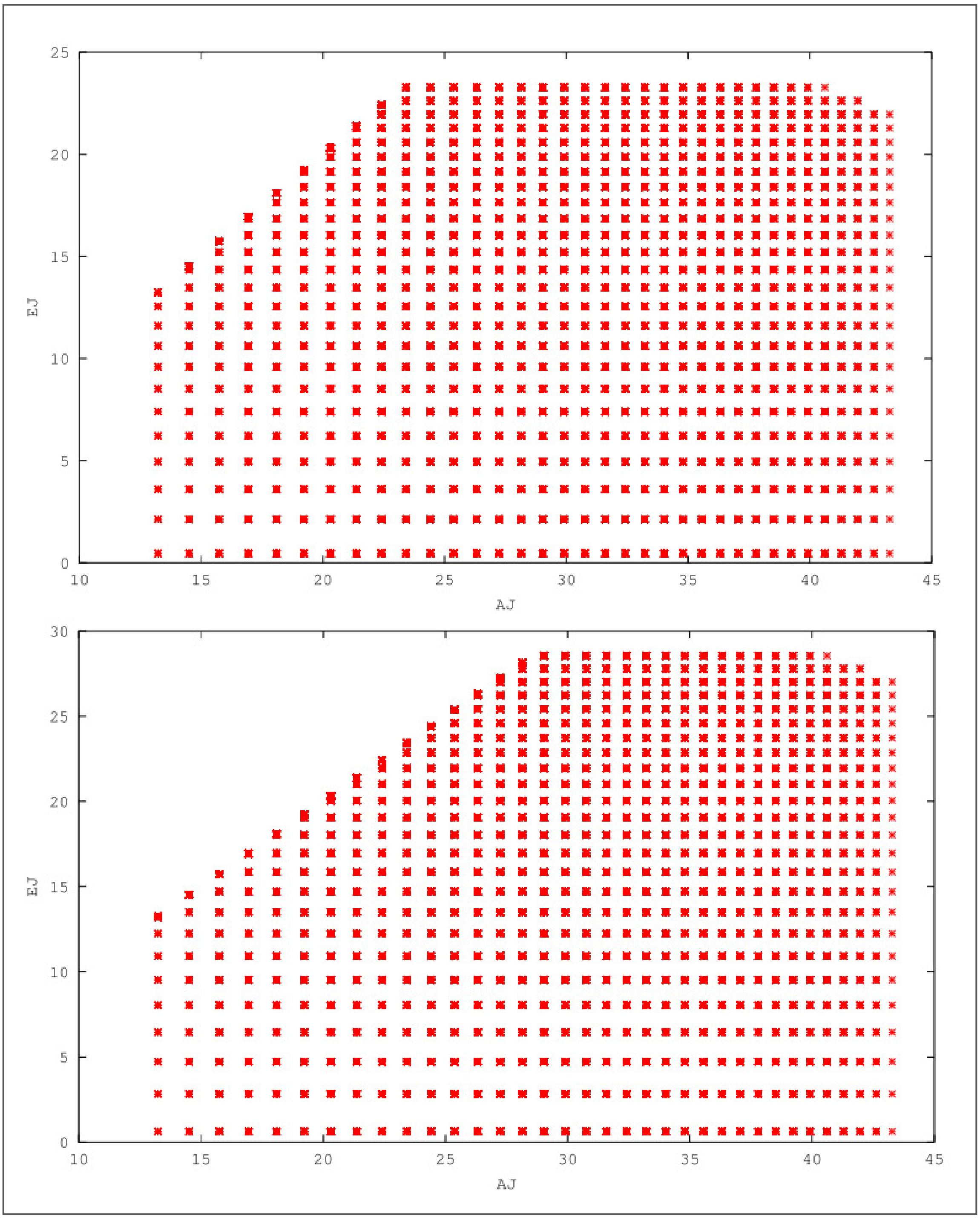

Figure 6: Alteration in the opportunity set for an increase in the rate of technological progress in resource harvesting (from $\gamma = 2$ to $\gamma = 5$) in model variant (a)

5 Discussion and conclusion

In this paper, we developed an ecological-economic model that depicts the relationship between intragenerational and intergenerational justice in the use of ecosystem services against the backdrop of given societal circumstances. The model includes a differentiated description of ecosystem services (e.g. in terms of substitutability, excludability from use, consumptivity and rivalry in consumption) and certain *determinants* of the 'justice relationship'. Particularly, we distinguished two model variants: In model variant (a), the non-consumptive ecosystem service is a private good; in model variant (b), the non-consumptive ecosystem service is a pure public good. Further, we differentiated the determinants into an instrument of justice and several system determinants: The *instrument of justice* is the assignment of resource utilization rights to generation 1 and 2 by a social planner. The use of the *instrument of justice* decides on *(in)efficiency* – and, thereby, on the occurrence of rivalry, independency and facilitation in the 'justice relationship'. The *system determinants* set the context of a specific ecological-economic system and cannot be regulated by the social planner. The values of the *system determinants* decide on the *opportunity set* of feasible outcomes in terms of intragenerational and intergenerational environmental justice – and therewith on the shape of the *justice possibility frontier*.

The main contribution of this paper is the introduction of a generic ecological-economic model as a tool to systematically analyze the interdependencies between the objectives of intragenerational and intergenerational justice in ecosystem-service use. In future research, an *analytical model analysis* should be conducted to produce general model solutions – first, by analyzing how the use of the *instrument of justice* (i.e. the assignment of first- and second-generation resource utilization rights) impacts on the occurrence of rivalry, independency and facilitation in the 'justice relationship'; second, by analyzing how a change in one (or several) *system determinants* impacts on the shape of the justice possibility frontier – and, therewith, on the occurrence of rivalry, independency, facilitation in the 'justice relationship'. Using the method of numerical simulation, we illustrated possible findings regarding these two steps of model analysis. The numerical examples demonstrate that the introduced model is a valuable tool to explore political paths that consistently and effectively improve on both intragenerational and intergenerational environmental justice.

6 Acknowledgements

We are grateful to Ralf Döring, Larry Karp, Max Stöven, Klara Stumpf, Rudi Voss and Hans-Peter Weikard for critical discussion, to our student assistant Nikolai Huckle for conducting the numerical simulation und producing the graphs, and to the German Federal Ministry of Education and Research for financial support under grant 01UN1011A.

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Appendix

Appendix A.1: Proof of model variant (a)

For model variant (a) follows from (5) inserting in (10)

$$U^i = U\left(H^i\right) = \left[\left(Y^i\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^i\right)^{\frac{\theta-1}{\theta}} + \left(R^i - H^i\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad \text{for } i = A, B\,,$$

$$\max_{H^i} U^i = U\left(H^i\right) \quad \leftrightarrow \quad \frac{d\,U^i\left(H^i\right)}{d\left(H^i\right)} = 0\,,$$

$$0 = \frac{\sigma}{\sigma-1}\left[\left(Y^i\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^{i*}\right)^{\frac{\theta-1}{\theta}} + \left(R^i - H^{i*}\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(H^{i*}\right)^{\frac{\theta-1}{\theta}} + \left(R^i - H^{i*}\right)^{\frac{\theta-1}{\theta}} \right)^{-\frac{\theta}{(\theta-1)\sigma}} \left[\frac{\theta-1}{\theta}\left(H^{i*}\right)^{-\frac{1}{\theta}} - \frac{\theta-1}{\theta}\left(R^i - H^{i*}\right)^{-\frac{1}{\theta}} \right],$$

$$0 = \left(H^{i*}\right)^{-\frac{1}{\theta}} - \left(R^i - H^{i*}\right)^{-\frac{1}{\theta}},$$

$$\left(H^{i*}\right)^{-\frac{1}{\theta}} = \left(R^i - H^{i*}\right)^{-\frac{1}{\theta}},$$

$$H^{i*} = R^i - H^{i*}\,,$$

$$H^{i*} = \frac{R^i}{2} \quad \text{for } i = A, B\,. \tag{21}$$

For model variant (a) follows from inserting (21) in (5)

$$S^{i*} = R^i - \frac{R^i}{2} = \frac{R^i}{2} \quad \text{for } i = A, B\,. \tag{22}$$

From inserting (21) and (22) in (13) follows

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\frac{R^i}{2}\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R^i}{2}\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad \text{for } i = A, B\,,$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2\left(\frac{R^i}{2}\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta}}\left(R^i\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{i*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}} \left(R^i \right) \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad \text{for } i = A, B\,. \tag{23}$$

For model variant (a) follows from inserting (9) in (10)

$$U^C = U\left(H^C\right) = \left[\left(Y^C\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^C\right)^{\frac{\theta-1}{\theta}} + \left(R^C - \frac{H^c}{\gamma} \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$\max_{H^C} U^C = U\left(H^C\right) \;\leftrightarrow\; \frac{d\,U^C\left(H^C\right)}{d\left(H^C\right)} = 0\,,$$

$$0 = \frac{\sigma}{\sigma-1} \left[\left(Y^C\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^{C*}\right)^{\frac{\theta-1}{\theta}} + \left(R^C - \frac{H^{c*}}{\gamma} \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\theta-1}} \frac{\theta}{\theta-1}\,\frac{\sigma-1}{\sigma}$$

$$\left(\left(H^{C*}\right)^{\frac{\theta-1}{\theta}} + \left(R^C - \frac{H^{c*}}{\gamma} \right)^{\frac{\theta-1}{\theta}} \right)^{-\frac{\theta}{(\theta-1)\sigma}} \left[\frac{\theta-1}{\theta}\left(H^{C*}\right)^{-\frac{1}{\theta}} - \frac{1}{\gamma}\,\frac{\theta-1}{\theta}\left(R^C - \frac{H^{C*}}{\gamma} \right)^{-\frac{1}{\theta}} \right],$$

$$0 = \left(H^{C*}\right)^{-\frac{1}{\theta}} - \frac{1}{\gamma}\left(R^C - \frac{H^{C*}}{\gamma} \right)^{-\frac{1}{\theta}},$$

$$\frac{1}{\gamma}\left(R^C - \frac{H^{C*}}{\gamma} \right)^{-\frac{1}{\theta}} = \left(H^{C*}\right)^{-\frac{1}{\theta}},$$

$$\gamma^{\theta}\left(R^C - \frac{H^{C*}}{\gamma} \right) = H^{C*}\,,$$

$$\gamma^{\theta}\; R^C - \gamma^{\theta-1}\; H^{C*} = H^{C*}\,,$$

$$\gamma^{\theta}\; R^C = \left(1 + \gamma^{\theta-1}\right) H^{C*}\,,$$

$$H^{C*} = \frac{R^C}{\left(\gamma^{-\theta} + \gamma^{-1}\right)}. \tag{24}$$

For model variant (a) follows from inserting (24) in (9)

$$S^C = R^C - \frac{R^C}{\left(\gamma^{-\theta} + \gamma^{-1}\right)\gamma},$$

$$S^{C*} = \left(1 - \frac{1}{\gamma^{1-\theta} + 1} \right) R^C\,. \tag{25}$$

From inserting (24) and (25) in (13) follows

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left[\left(\frac{R^C}{\left(\gamma^{-\theta} + \gamma^{-1}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(\left(1 - \frac{1}{\gamma^{1-\theta}+1} \right) R^C \right)^{\frac{\theta-1}{\theta}} \right] \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^C\right)^{\frac{\theta-1}{\theta}} \left[\left(\frac{1}{\gamma^{-\theta} + \gamma^{-1}} \right)^{\frac{\theta-1}{\theta}} + \left(\frac{\gamma^{1-\theta}}{\gamma^{1-\theta}+1} \right)^{\frac{\theta-1}{\theta}} \right] \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\gamma^{-\theta} + \gamma^{-1}} \right)^{\frac{\theta-1}{\theta}} + \left(\frac{\gamma^{1-\theta}}{\gamma^{1-\theta}+1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}. \qquad (26)$$

Appendix A.2 : Proof of model variant (b)

For **model variant (b1)**, i.e. $R^i \geq \frac{R_1}{3}$ with $i = A, B$ and $i \neq j$,
follows from inserting (5) in (10)

$$U^i = U\left(H^i\right) = \left[\left(Y^i\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^i\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - H^i - H^j\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

$$\max_{H^i} U^i = U\left(H^i\right) \quad \leftrightarrow \quad \frac{d\,U^i\left(H^i\right)}{d\left(H^i\right)} = 0,$$

$$0 = \frac{\sigma}{\sigma-1} \left[\left(Y^i\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^{i*}\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - H^{i*} - H^j\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\theta-1}} \frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(H^{i*}\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - H^{i*} - H^j\right)^{\frac{\theta-1}{\theta}} \right)^{-\frac{\theta}{(\theta-1)\sigma}} \left[\frac{\theta-1}{\theta}\left(H^{i*}\right)^{-\frac{1}{\theta}} - \frac{\theta-1}{\theta}\left(R_1 - H^{i*} - H^j\right)^{-\frac{1}{\theta}} \right],$$

$$0 = \left(H^{i*}\right)^{-\frac{1}{\theta}} - \left(R_1 - H^{i*} - H^j\right)^{-\frac{1}{\theta}},$$

$$R_1 - H^{i*} - H^j = H^{i*},$$

$$H^{i*} = \frac{R_1 - H^j}{2},$$

$$H^{i*} = \frac{R_1 - H^{j*}}{2},$$

$$H^{j*} = \frac{R_1 - H^{i*}}{2} \quad \leftrightarrow \quad H^{i*} = R_1 - 2H^{j*},$$

$$R_1 - 2H^{j*} = \frac{R_1 - H^{j*}}{2} \quad \leftrightarrow \quad H^{j*} = \frac{R_1}{3},$$

$$H^{i*} = \frac{R_1 - \frac{R_1}{3}}{2} = \frac{R_1}{3},$$

$$H^{i*} = H^{j*} = \frac{R_1}{3}. \tag{27}$$

For model variant (b) follows from inserting (27) in (5)

$$S^{i*} = R_1 - \left(\frac{R_1}{3} + \frac{R_1}{3}\right) = \frac{R_1}{3}. \tag{28}$$

From inserting (27) and (28) in (13) follows

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\frac{R_1}{3}\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1}{3}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad \text{for } i = A, B,$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2\left(\frac{R_1}{3}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2\,3^{\frac{1-\theta}{\theta}}\left(R_1\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

$$V^{i*} = \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\frac{1}{3}R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}. \tag{29}$$

For **model variant (b2)**, i.e. $R^i < \frac{R_1}{3}$ and $R^j \geq \frac{R_1}{3}$ with $i, j = A, B$ and $i \neq j$,

$$H^{i*} = R^i, \tag{33}$$

$$H^{j*} = \frac{R_1 - H^{i*}}{2} \quad \leftrightarrow \quad H^{i*} = R_1 - 2H^{j*},$$

$$R_1 - 2H^{j*} = R^i,$$

$$H^{j*} = \frac{R_1 - R^i}{2}. \tag{34}$$

For model variant (b) follows from inserting (33) and (34) in (5)

$$S^{i,j*} = R_1 - \left(R^i + \frac{R_1 - R^i}{2} \right) ,$$

$$S^{i,j*} = \frac{R_1 - R^i}{2} \ . \tag{35}$$

From inserting (33) and (35) in (13) follows

$$V^{i*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i \right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1 - R^i}{2} \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} . \tag{36}$$

From inserting (34) and (35) in (13) follows

$$V^{j*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\frac{R_1 - R^i}{2} \right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1 - R^i}{2} \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} ,$$

$$V^{j*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(2 \left(\frac{R_1 - R^i}{2} \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} ,$$

$$V^{j*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta}} \left(R_1 - R^i \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} ,$$

$$V^{j*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}} \left(R_1 - R^i \right) \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} . \tag{37}$$

For **model variant (b3)**, i.e. $R^i < \frac{R_1}{3}$ with $i = A, B$ and $i \neq j$,

$$H^{i*} = R^i \ . \tag{41}$$

For model variant (b) follows from inserting (41) in (5)

$$S^{i*} = R_1 - \left(R^i + R^j \right). \tag{42}$$

From inserting (41) and (42) in (13) follows

$$V^{i*} = \left[\left(\frac{Y_1}{2} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i \right)^{\frac{\theta-1}{\theta}} + \left(R_1 - \left(R^i + R^j \right) \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} . \tag{43}$$

For model variant (b) follows from inserting (9) in (10)

$$U^C = U\left(H^C\right) = \left[\left(Y^C\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^C\right)^{\frac{\theta-1}{\theta}} + \left(R_2 - \frac{2nH^c}{\gamma}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

$$\max_{H^C} U^C = U\left(H^C\right) \leftrightarrow \frac{dU^C\left(H^C\right)}{d\left(H^C\right)} = 0,$$

$$0 = \frac{\sigma}{\sigma-1}\left[\left(Y^C\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(H^{C*}\right)^{\frac{\theta-1}{\theta}} + \left(R_2 - \frac{2nH^{c*}}{\gamma}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\theta-1}} \frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(H^{C*}\right)^{\frac{\theta-1}{\theta}} + \left(R_2 - \frac{2nH^{c*}}{\gamma}\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}} \left[\frac{\theta-1}{\theta}\left(H^{C*}\right)^{-\frac{1}{\theta}} - \frac{2n}{\gamma}\frac{\theta-1}{\theta}\left(R_2 - \frac{2nH^{c*}}{\gamma}\right)^{-\frac{1}{\theta}}\right],$$

$$0 = \left(H^{C*}\right)^{-\frac{1}{\theta}} - \frac{2n}{\gamma}\left(R_2 - \frac{2nH^{c*}}{\gamma}\right)^{-\frac{1}{\theta}},$$

$$\left(\frac{2n}{\gamma}\right)^{-\theta}\left(R_2 - \frac{2nH^{c*}}{\gamma}\right) = H^{C*},$$

$$\left(\frac{2n}{\gamma}\right)^{-\theta} R_2 - \left(\frac{2n}{\gamma}\right)^{1-\theta} H^{C*} = H^{C*},$$

$$R_2 = \left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right] H^{C*},$$

$$H^{C*} = \frac{R_2}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}. \tag{47}$$

For model variant (b) follows from inserting (47) in (9)

$$S^{C*} = R_2 - \frac{2n}{\gamma\left(\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right)} R_2,$$

$$S^{C*} = \left(1 - \frac{2n}{\left[\gamma^{1-\theta}(2n)^{\theta} + 2n\right]}\right) R_2,$$

$$S^{C*} = \left(1 - \frac{1}{\gamma^{1-\theta}(2n)^{\theta-1} + 1}\right) R_2,$$

$$S^{C*} = \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right) R_2 \; . \tag{48}$$

From inserting (47) and (48) in (13) follows

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\frac{R_2}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(\left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right) R_2 \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} ,$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R_2\right)^{\frac{\theta-1}{\theta}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right] \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} ,$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(R_2\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} . \tag{49}$$

For **model variant (b1)**, i.e. $R^i \geq \frac{R_1}{3}$ with $i = A, B$ and $i \neq j$,

inserting (27) in (6), and then (6) in (47), (48) and (49), respectively, produces the solutions

$$H^{C*} = \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \quad \text{if} \quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma R^C , \tag{30a}$$

$$H^{C*} = \gamma R^C \qquad \text{if} \quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma R^C , \tag{30b}$$

$$S^{C*}=\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)\frac{\omega R_1}{3}\quad \text{if}\quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}\leq \gamma R^C, \tag{31a}$$

$$S^{C*}=\frac{\omega R_1}{3}-2\,n\,R^C \qquad \text{if}\quad \frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}> \gamma R^C, \tag{31b}$$

$$V^{C*}=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{32a}$$

if $\frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}\leq \gamma R^C$,

$$V^{C*}=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{32b}$$

if $\frac{\omega R_1}{3\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}> \gamma R^C$.

For **model variant (b2)**, i.e. $R^i<\frac{R_1}{3}$ and $R^j\geq\frac{R_1}{3}$ with $i,j=A,B$ and $i\neq j$, inserting (33) and (34) in (6), and then (6) in (47), (48) and (49), respectively, produces the solutions

$$H^{C*}=\frac{\omega\left(R_1-R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}\quad \text{if}\quad \frac{\omega\left(R_1-R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}\leq \gamma R^C, \tag{38a}$$

$$H^{C*}=\gamma R^C \qquad \text{if}\quad \frac{\omega\left(R_1-R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]}> \gamma R^C, \tag{38b}$$

$$S^{C*} = \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right) \frac{\omega\left(R_1 - R^i\right)}{2} \quad \text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma\, R^C , \tag{39a}$$

$$S^{C*} = \frac{\omega\left(R_1 - R^i\right)}{2} - 2\,n\,R^C \quad \text{if} \quad \frac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma\, R^C , \tag{39b}$$

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{40a}$$

if $\dfrac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} \leq \gamma\, R^C$,

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma\, R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2} - 2\,n\,R^C \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{40b}$$

if $\dfrac{\omega\left(R_1 - R^i\right)}{2\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]} > \gamma\, R^C$.

For **model variant (b3)**, i.e. $R^i < \dfrac{R_1}{3}$ with $i = A, B$ and $i \neq j$,

inserting (41) in (6), and then (6) in (47), (48) and (49), respectively, produces the solutions

$$H^{C*} = \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \quad \text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \leq \gamma\, R^C , \tag{44a}$$

$$H^{C*} = \gamma\, R^C \quad \text{if} \quad \frac{\omega\left(R_1 - \left(R^i + R^j\right)\right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} > \gamma\, R^C , \tag{44b}$$

$$S^{C*} = \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right) \omega \left(R_1 - \left(R^i + R^j \right) \right) \quad \text{if} \quad \frac{\omega \left(R_1 - \left(R^i + R^j \right) \right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \le \gamma R^C , \tag{45a}$$

$$S^{C*} = \omega \left(R_1 - \left(R^i + R^j \right) \right) - 2\, n\, R^C \quad \text{if} \quad \frac{\omega \left(R_1 - \left(R^i + R^j \right) \right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} > \gamma R^C , \tag{45b}$$

$$V^{C*} = \left[\begin{array}{l} \left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\omega \left(R_1 - \left(R^i + R^j \right) \right) \right)^{\frac{\sigma-1}{\sigma}} \\ \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1} \frac{\sigma-1}{\sigma}} \end{array} \right]^{\frac{\sigma}{\sigma-1}} \tag{46a}$$

if $\dfrac{\omega \left(R_1 - \left(R^i + R^j \right) \right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \le \gamma R^C$,

$$V^{C*} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C \right)^{\frac{\theta-1}{\theta}} + \left(\omega \left(R_1 - \left(R^i + R^j \right) \right) - 2\, n\, R^C \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1} \frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{46b}$$

if $\dfrac{\omega \left(R_1 - \left(R^i + R^j \right) \right)}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} > \gamma R^C$.

Appendix A.3: Impact of the model parameters on the indirect utility functions for model variant (a)

Table 1: Impact of a marginal increase in the value of the particular model parameter on the values of V^i (for $i = A, B$) and V^C

Model parameter	Impact of model parameter on V^i (for $i = A, B$) and V^C								
	MV (a)		MV (b1)		MV (b2)			MV (b3)	
	V^i	V^C	V^i	V^C	V^i	V^j	V^C	V^i	V^C
Y_1	+	+	+	+	+	+	+	+	+
R_1	0	0	+	+	+	+	+	+	+
$R^i\ (i = A, B)$	+	0	0	0	+	–	–	+	–
R^C	0	+	0	0 / +	0	0	0 / +	0	0 / +
ω	0	0	0	+	0	0	+	0	+
n	0	–	0	–* / –	0	0	–* / –	0	–* / –
σ	–	–**	–	–	–	–	–	–	–
θ	–	–	–	–	–	–	–	–	–
μ	0	+	0	+	0	0	+	0	+
γ	0	+*	0	+* / +	0	0	+* / +	0	+* / +

* for $\theta < 1$
** for $\sigma > 1$

The non-shaded cells in Table 1 indicate solutions obtained by comparative statics; the grey-shaded cells indicate solutions obtained by numerical simulation.

Solutions obtained by comparative statics

Impact of the model parameters on V^i (equation (23)):

$$\frac{dV^{i*}}{dY_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\sigma-1}{\sigma}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2} \quad > 0,$$

$$\frac{dV^{i*}}{dR_1} = 0 ,$$

$$\frac{d\,V^{i*}}{d\,R^{i}} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\sigma-1}{\sigma}\left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{-\frac{1}{\sigma}} 2^{\frac{1}{\theta-1}}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{-\frac{1}{\sigma}} 2^{\frac{1}{\theta-1}} \quad > 0\,,$$

$$\frac{d\,V^{i*}}{d\,R^{C}} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\omega} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,n} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\theta} = -\frac{\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}} \ln 2}{(\theta-1)^2\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}}\right]}$$

$$= -\frac{\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(2^{\frac{1}{\theta-1}}\left(R^{i}\right)\right)^{\frac{\sigma-1}{\sigma}} \ln 2}{(\theta-1)^2} \quad < 0\,,$$

$$\frac{d\,V^{i*}}{d\,\mu} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\gamma} = 0\,.$$

Impact of the model parameters on V^C (equation (26)):

$$\frac{dV^{C*}}{dY_1} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1} \frac{\sigma-1}{\sigma}$$

$$\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n}$$

$$= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n} > 0,$$

$$\frac{dV^{C*}}{dR_1} = 0,$$

$$\frac{dV^{C*}}{dR^i} = 0,$$

$$\frac{dV^{C*}}{dR^C} = \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1}$$

$$\left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \frac{\sigma-1}{\sigma} \left(R^C\right)^{-\frac{1}{\sigma}}$$

$$= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(R^C\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}$$

$$\left[\left(\gamma^{-\theta} + \gamma^{-1}\right)^{\frac{1-\theta}{\theta}} + \left(1+\gamma^{\theta-1}\right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \left(R^C\right)^{-\frac{1}{\sigma}} > 0,$$

$$\frac{dV^{C*}}{d\omega} = 0,$$

$$\frac{dV^{C*}}{dn} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1} \frac{\sigma-1}{\sigma}$$

$$\left(\frac{\mu Y_1}{2n} \right)^{-\frac{1}{\sigma}} \left(-\frac{\mu Y_1}{2n^2} \right)$$

$$= -\left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n} \right)^{-\frac{1}{\sigma}}$$

$$\frac{\mu Y_1}{2n^2} < 0 \,,$$

$$\frac{dV^{C*}}{d\mu} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}$$

$$\frac{\sigma}{\sigma-1} \frac{\sigma-1}{\sigma} \left(\frac{\mu Y_1}{2n} \right)^{-\frac{1}{\sigma}} \frac{Y_1}{2n}$$

$$= \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n} \right)^{-\frac{1}{\sigma}} \frac{Y_1}{2n} > 0 \,,$$

$$\frac{dV^{C*}}{d\gamma} = \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1} \frac{\theta}{\theta-1} \frac{\sigma-1}{\sigma}$$

$$\left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{-\frac{\theta}{(\theta-1)\sigma}} \left[\begin{array}{l} \frac{1-\theta}{\theta} \left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-2\theta}{\theta}} \left(-\theta \gamma^{-\theta-1} - \gamma^{-2} \right) \\ + \frac{1-\theta}{\theta} \left(1 + \gamma^{\theta-1} \right)^{\frac{1-2\theta}{\theta}} (\theta-1) \gamma^{\theta-2} \end{array} \right]$$

$$= \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(R^C \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \left(R^C \right)^{\frac{\sigma-1}{\sigma}}$$

$$\left[\left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-\theta}{\theta}} + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-\theta}{\theta}} \right]^{-\frac{\theta}{(\theta-1)\sigma}} \left[\begin{array}{l} \left(\gamma^{-\theta} + \gamma^{-1} \right)^{\frac{1-2\theta}{\theta}} \left(\theta \gamma^{-\theta-1} + \gamma^{-2} \right) \\ + \left(1 + \gamma^{\theta-1} \right)^{\frac{1-2\theta}{\theta}} (1-\theta) \gamma^{\theta-2} \end{array} \right]$$

$$> 0 \quad for \quad \theta < 1 \,.$$

Solutions obtained by numerical simulation

In **MV (a)**, we conducted the numerical simulation for the following parameter values: $Y_1 = 600$; $R_1 = 500$; $R^A = 230$; $R^B = 210$; $R^C = 8$; $\omega = 0{,}4$; $n = 3$; $\mu = 2$; $\gamma = 2$.

Impact of σ on V^i (equation (23)) and V^C (equation (26)):
$\sigma = (0{,}1\ ;\ 1{,}5)$ for $\theta = 0{,}5$ and $\theta = 1{,}5$, respectively.

Impact of θ on V^i (equation (23)):
$\theta = (0{,}1\ ;\ 1{,}5)$ for $\sigma = 0{,}5$ and $\sigma = 1{,}5$, respectively.

The validity of the numerical solutions as presented in Table 1 is only proven for these parameter values.

Appendix A.4.: Impact of the model parameters on the indirect utility functions for model variant (b)

Table 1: Impact of a marginal increase in the value of the particular model parameter on the values of V^i (for $i = A, B$) and V^C

Model parameter	Impact of model parameter on V^i (for $i = A, B$) and V^C											
	MV (a)		MV (b1)			MV (b2)				MV (b3)		
	V^i	V^C	V^i	V^C		V^i	V^j	V^C		V^i	V^C	
Y_1	+	+	+	+		+	+	+		+	+	
R_1	0	0	+	+		+	+	+		+	+	
R^i ($i = A, B$)	+	0	0	0		+	–	–		+	–	
R^C	0	+	0	0	+	0	0	0	+	0	0	+
ω	0	0	0	+		0	0	+		0	+	
n	0	–	0	–*	–	0	0	–*	–	0	–*	–
σ	–	–**	–	–		–	–	–		–	–	
θ	–	–	–	–		–	–	–		–	–	
μ	0	+	0	+		0	0	+		0	+	
γ	0	+*	0	+*	+	0	0	+*	+	0	+*	+

$*$ *for* $\theta < 1$

$**$ *for* $\sigma > 1$

The non-shaded cells in Table 1 indicate solutions obtained by comparative statics; the grey-shaded cells indicate solutions obtained by numerical simulation.

Solutions obtained by comparative statics

For **model variant (b1)**, i.e. $R^i \geq \frac{R_1}{3}$ with $i = A, B$ and $i \neq j$,

the model parameters impact on V^i (equation (29)) as follows:

$$\frac{dV^{i*}}{dY_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\frac{1}{3}R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\sigma-1}{\sigma}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\frac{1}{3}R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2} > 0,$$

$$\frac{d\,V^{i*}}{d\,R_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\sigma-1}{\sigma}\left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{-\frac{1}{\sigma}} 2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{-\frac{1}{\sigma}} 2^{\frac{\theta}{\theta-1}}\,\frac{1}{3} \quad > 0\,,$$

$$\frac{d\,V^{i*}}{d\,R^i} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,R^C} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\omega} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,n} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\theta} = \frac{1}{\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}}}\left(\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}} \left(-\frac{1}{(\theta-1)^2}\right)\ln 2\right)$$

$$= -\frac{\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(2^{\frac{\theta}{\theta-1}}\,\frac{1}{3}\,R_1\right)^{\frac{\sigma-1}{\sigma}} \ln 2}{(\theta-1)^2} \quad < 0\,,$$

$$\frac{d\,V^{i*}}{d\,\mu} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\gamma} = 0\,.$$

Impact of the model parameters on V^C (equation (32a)):

$$\frac{d\,V^{C*}}{d\,Y_1}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu}{2n}$$

$$=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu}{2n}>0\,,$$

$$\frac{d\,V^{C*}}{d\,R_1}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\frac{\sigma-1}{\sigma}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega R_1}{3}\right)^{-\frac{1}{\sigma}}\frac{\omega}{3}$$

$$=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega R_1}{3}\right)^{-\frac{1}{\sigma}}\frac{\omega}{3}>0\,,$$

$$\frac{d\,V^{C*}}{d\,R^{i}}=0\,,$$

$$\frac{d\,V^{C*}}{d\,R^{C}}=0\,,$$

$$\frac{d\,V^{C*}}{d\,\omega}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega R_1}{3}\right)^{-\frac{1}{\sigma}}\left(\frac{R_1}{3}\right)$$

$$=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega R_1}{3}\right)^{-\frac{1}{\sigma}}\left(\frac{R_1}{3}\right)>0,$$

$$\frac{d\,V^{C*}}{d\,n}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\left(\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\left(-\frac{\mu Y_1}{2n^2}\right)+\frac{\sigma-1}{\sigma}\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}\right.$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left.\left[\frac{\theta-1}{\theta}\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}}\left(-\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]^2}\right)\left(\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\frac{2}{\gamma}+\frac{2}{\gamma}\right)+\frac{\theta-1}{\theta}\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}}\left(\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right]^2}\right)(\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\frac{n}{\gamma}\right]\right)$$

$$
= \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}}
$$

$$
\left(\frac{\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \left(-\frac{\mu Y_1}{2n^2}\right) + \left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\ldots} \right.
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}} \left(-\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]^2}\right) \left(\theta \left(\frac{2n}{\gamma}\right)^{\theta-1} \frac{2}{\gamma} + \frac{2}{\gamma}\right) \right.
$$

$$
\left. \left. + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{-\frac{1}{\theta}} \left(\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1\right]^2}\right) (\theta - 1) \left(\frac{2n}{\gamma}\right)^{\theta-2} \frac{n}{\gamma} \right] \right)
$$

$$
< 0 \quad for \quad \theta < 1,
$$

$$\frac{dV^{C*}}{d\mu}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}>0\,,$$

.

$$\frac{d\,V^{C*}}{d\,\gamma}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\frac{\theta}{\theta-1}\,\frac{\sigma-1}{\sigma}\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left[\begin{array}{l}\frac{\theta-1}{\theta}\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}}\left(-\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right)^{2}}\right)\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\left(-\frac{2n}{\gamma^{2}}\right)\\ +\frac{\theta-1}{\theta}\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}}\left(\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right)^{2}}\right)(\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\left(-\frac{2n}{\gamma^{2}}\right)\end{array}\right]$$

$$= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}$$

$$\left(\frac{\omega R_1}{3}\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{-\frac{1}{\theta}} \left(- \frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right)^2} \right) \theta \left(\frac{2n}{\gamma}\right)^{\theta-1} \left(-\frac{2n}{\gamma^2}\right) \right.$$
$$\left. + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{-\frac{1}{\theta}} \left(\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1\right)^2} \right) (\theta-1) \left(\frac{2n}{\gamma}\right)^{\theta-2} \left(-\frac{2n}{\gamma^2}\right) \right]$$

$$> 0 \quad for \quad \theta < 1 .$$

Impact of the model parameters on V^C (equation (32b)):

$$\frac{dV^{C*}}{dY_1} = \frac{\sigma}{\sigma-1} \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega R_1}{3} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma-1}{\sigma} \left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n}$$

$$= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega R_1}{3} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n} \quad > 0 ,$$

$$\frac{d\,V^{C*}}{d\,R_1}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\omega}{3}$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\omega}{3}\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,R^i}=0\,,$$

$$\frac{d\,V^{C*}}{d\,\omega}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{R_1}{3}$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\frac{\omega R_1}{3}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{R_1}{3}\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,n}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\begin{array}{l}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\left(-\frac{\mu Y_1}{2n^2}\right)+\quad\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\\ \frac{\theta-1}{\theta}\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\left(-2\,R^C\right)\end{array}\right]$$

$$=-\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu Y_1}{2n^2}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{-\frac{1}{\theta}}2\,R^C\right]$$

$$<0\,,$$

$$\frac{d\,V^{C*}}{d\,\mu}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,\gamma}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\gamma\,R^C\right)^{-\frac{1}{\theta}}R^C$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\,R_1}{3}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\gamma\,R^C\right)^{-\frac{1}{\theta}}R^C\quad>0\,.$$

For **model variant (b2)**, i.e. $R^i < \frac{R_1}{3}$ and $R^j \geq \frac{R_1}{3}$ with $i, j = A, B$ and $i \neq j$,

the model parameters impact on V^i (equation as follows (36)):

$$\frac{d\,V^{i*}}{d\,Y_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1-R^i}{2}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\sigma-1}{\sigma}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1-R^i}{2}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2} > 0\,,$$

$$\frac{d\,V^{i*}}{d\,R_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1-R^i}{2}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1-R^i}{2}\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}} \frac{\theta-1}{\theta}\left(\frac{R_1-R^i}{2}\right)^{-\frac{1}{\theta}}\frac{1}{2}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1-R^i}{2}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(\frac{R_1-R^i}{2}\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left(\frac{R_1-R^i}{2}\right)^{-\frac{1}{\theta}}\frac{1}{2} > 0\,,$$

$$\frac{d\,V^{i*}}{d\,R^C} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\omega} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,n} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\mu} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\gamma} = 0\,.$$

Impact of the model parameters on V^j (equation (37)):

$$\frac{dV^{j*}}{dY_1}=\frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma-1}{\sigma}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}$$

$$=\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}\quad>0,$$

$$\frac{dV^{j*}}{dR_1}=\frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma-1}{\sigma}\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{-\frac{1}{\sigma}}2^{\frac{1}{(\theta-1)}}$$

$$=\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{-\frac{1}{\sigma}}2^{\frac{1}{(\theta-1)}}\quad>0,$$

$$\frac{dV^{j*}}{dR^i}=\frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma-1}{\sigma}\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{-\frac{1}{\sigma}}\left(-2^{\frac{1}{(\theta-1)}}\right)$$

$$=-\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(2^{\frac{1}{(\theta-1)}}\left(R_1-R^i\right)\right)^{-\frac{1}{\sigma}}2^{\frac{1}{(\theta-1)}}\quad<0,$$

$$\frac{dV^{j*}}{dR^C}\quad=0,$$

$$\frac{dV^{j*}}{d\omega}\quad=0\ ,$$

$$\frac{dV^{j*}}{dn}\quad=0,$$

$$\frac{d\,V^{j*}}{d\,\theta} = -\frac{\left(\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{(\theta-1)}}\left(R_1 - R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \left(2^{\frac{1}{(\theta-1)}}\left(R_1 - R^i\right)\right)^{\frac{\sigma}{\sigma-1}} \ln 2}{(\theta-1)^2 \left(\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{(\theta-1)}}\left(R_1 - R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right)}$$

$$= -\frac{\left(\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(2^{\frac{1}{(\theta-1)}}\left(R_1 - R^i\right)\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}} \left(2^{\frac{1}{(\theta-1)}}\left(R_1 - R^i\right)\right)^{\frac{\sigma}{\sigma-1}} \ln 2}{(\theta-1)^2} < 0\,,$$

$$\frac{d\,V^{j*}}{d\,\mu} = 0\,,$$

$$\frac{d\,V^{j*}}{d\,\gamma} = 0\,.$$

Impact of the model parameters on V^C (equation (40a)):

$$\frac{d\,V^{C*}}{d\,Y_1} = \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1}\,\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n}$$

$$= \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n} > 0\,,$$

$$
\frac{d\,V^{C*}}{d\,R_1}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}
$$

$$
\frac{\sigma-1}{\sigma}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{-\frac{1}{\sigma}}\frac{\left(R_1-R^i\right)}{2}
$$

$$
=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{-\frac{1}{\sigma}}\frac{\left(R_1-R^i\right)}{2}\quad>0,
$$

$$\frac{d\,V^{C*}}{d\,R^{i}}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^{i}\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\frac{\sigma-1}{\sigma}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega\left(R_1-R^{i}\right)}{2}\right)^{-\frac{1}{\sigma}}\left(-\frac{\omega}{2}\right)$$

$$=-\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^{i}\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega\left(R_1-R^{i}\right)}{2}\right)^{-\frac{1}{\sigma}}\left(-\frac{\omega}{2}\right)<0,$$

$$\frac{d\,V^{C*}}{d\,R^{C}}=0,$$

$$
\frac{d\,V^{C*}}{d\,\omega}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{-\frac{1}{\sigma}}\frac{\left(R_1-R^i\right)}{2}
$$

$$
=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{-\frac{1}{\sigma}}\frac{\left(R_1-R^i\right)}{2}\quad>0\,,
$$

$$\frac{dV^{C*}}{dn}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\left(\begin{array}{l}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\left(-\frac{\mu Y_1}{2n^2}\right)+\frac{\sigma-1}{\sigma}\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}\\
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}\\
\left[\begin{array}{l}\frac{\theta-1}{\theta}\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}}\left(-\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]^2}\right)\left(\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\frac{2}{\gamma}+\frac{2}{\gamma}\right)\\
+\frac{\theta-1}{\theta}\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}}\left(\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right]^2}\right)(\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\frac{n}{\gamma}\end{array}\right]\end{array}\right)$$

$$= \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}}$$

$$\left(\frac{\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \left(-\frac{\mu Y_1}{2n^2}\right) + \left(\frac{\omega\left(R_1 - R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}} \left[\begin{array}{l} \left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}} \left(-\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right]^2}\right) \left(\theta \left(\frac{2n}{\gamma}\right)^{\theta-1} \frac{2}{\gamma} + \frac{2}{\gamma}\right) \\ + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{-\frac{1}{\theta}} \left(\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1\right]^2}\right) (\theta - 1) \left(\frac{2n}{\gamma}\right)^{\theta-2} \frac{n}{\gamma} \end{array} \right]} \right)$$

$$< 0 \quad for \quad \theta < 1,$$

$$\frac{d\,V^{C*}}{d\,\mu}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}\,\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}>0\,,$$

$$\frac{d\,V^{C*}}{d\,\gamma}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}\left(\frac{\omega\left(R_1-R^i\right)}{2}\right)^{\frac{\sigma-1}{\sigma}}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left[\begin{array}{l}\frac{\theta-1}{\theta}\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}}\left(-\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right)^{2}}\right)\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\left(-\frac{2n}{\gamma^{2}}\right)\\ +\frac{\theta-1}{\theta}\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}}\left(\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right)^{2}}\right)(\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\left(-\frac{2n}{\gamma^{2}}\right)\end{array}\right]$$

$$= \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2} \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}$$

$$\left(\frac{\omega\left(R_1 - R^i\right)}{2} \right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{-\frac{1}{\theta}} \left(- \frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right) \right)^2} \right) \theta \left(\frac{2n}{\gamma}\right)^{\theta-1} \left(-\frac{2n}{\gamma^2} \right) \right.$$
$$\left. + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{-\frac{1}{\theta}} \left(\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1 \right)^2} \right) (\theta - 1) \left(\frac{2n}{\gamma}\right)^{\theta-2} \left(-\frac{2n}{\gamma^2} \right) \right]$$

$$> 0 \quad for \quad \theta < 1 .$$

Impact of the model parameters on V^C (equation (40b)):

$$\frac{d V^{C*}}{d Y_1} = \frac{\sigma}{\sigma - 1} \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2} - 2\, n\, R^C \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}$$

$$\frac{\sigma - 1}{\sigma} \left(\frac{\mu Y_1}{2n} \right)^{-\frac{1}{\sigma}} \frac{\mu}{2n}$$

$$= \left[\left(\frac{\mu Y_1}{2n} \right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1 - R^i\right)}{2} - 2\, n\, R^C \right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n} \right)^{-\frac{1}{\sigma}} \frac{\mu}{2n} \quad > 0 ,$$

$$\frac{d\,V^{C*}}{d\,R_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\theta}{\theta-1}\,\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}} \frac{\theta-1}{\theta}\left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\omega}{2}$$

$$= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}} \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\omega}{2} > 0\,,$$

$$\frac{d\,V^{C*}}{d\,R^i} = \frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\theta}{\theta-1}\,\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}} \frac{\theta-1}{\theta}\left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{-\frac{1}{\theta}}\left(-\frac{\omega}{2}\right)$$

$$= -\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}} + \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}} \left(\frac{\omega\left(R_1-R^i\right)}{2} - 2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\omega}{2} < 0\,,$$

$$\frac{d\,V^{C*}}{d\,\omega}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\,\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\left(R_1-R^i\right)}{2}$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\frac{\left(R_1-R^i\right)}{2}\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,n}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\begin{array}{l}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\left(-\frac{\mu Y_1}{2n^2}\right)+\quad\frac{\theta}{\theta-1}\,\frac{\sigma-1}{\sigma}\\ \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\\ \frac{\theta-1}{\theta}\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{-\frac{1}{\theta}}\left(-2\,R^C\right)\end{array}\right]$$

$$=-\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\begin{array}{l}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu Y_1}{2n^2}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\\ \left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{-\frac{1}{\theta}}2\,R^C\end{array}\right]\quad<0\,,$$

$$\frac{d\,V^{C*}}{d\,\mu}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,\gamma}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\gamma R^C\right)^{-\frac{1}{\theta}}R^C$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\frac{\omega\left(R_1-R^i\right)}{2}-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\gamma R^C\right)^{-\frac{1}{\theta}}R^C\quad>0\,.$$

For **model variant (b3)**, i.e. $R^i<\frac{R_1}{3}$ with $i=A,B$ and $i\neq j$,

the model parameters impact on V^i (equation (43)) as follows:

$$\frac{d\,V^{i*}}{d\,Y_1}=\frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(R^i\right)^{\frac{\theta-1}{\theta}}+\left(R_1-\left(R^i+R^j\right)\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma-1}{\sigma}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}$$

$$=\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(R^i\right)^{\frac{\theta-1}{\theta}}+\left(R_1-\left(R^i+R^j\right)\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(\frac{Y_1}{2}\right)^{-\frac{1}{\sigma}}\frac{1}{2}\quad>0\,,$$

$$\frac{d\,V^{i*}}{d\,R_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - \left(R^i + R^j\right)\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - \left(R^i + R^j\right)\right)^{\frac{\theta-1}{\theta}} \right)^{-\frac{\theta}{(\theta-1)\sigma}} \frac{\theta-1}{\theta}\left(R_1 - \left(R^i + R^j\right)\right)^{-\frac{1}{\theta}}$$

$$= \left[\left(\frac{Y_1}{2}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - \left(R^i + R^j\right)\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(R^i\right)^{\frac{\theta-1}{\theta}} + \left(R_1 - \left(R^i + R^j\right)\right)^{\frac{\theta-1}{\theta}} \right)^{-\frac{\theta}{(\theta-1)\sigma}} \left(R_1 - \left(R^i + R^j\right)\right)^{-\frac{1}{\theta}} \quad > 0\,,$$

$$\frac{d\,V^{i*}}{d\,R^C} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\omega} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,n} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\mu} = 0\,,$$

$$\frac{d\,V^{i*}}{d\,\gamma} = 0\,.$$

Impact of the model parameters on V^C (equation (46a)):

$$\frac{dV^{C*}}{dY_1} = \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu}{2n}$$

$$= \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}} \left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu}{2n} > 0,$$

$$
\frac{d\,V^{C*}}{d\,R_1}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}
$$

$$
\frac{\sigma-1}{\sigma}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{-\frac{1}{\sigma}}\omega
$$

$$
=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{-\frac{1}{\sigma}}\omega\quad>0\,,
$$

$$
\frac{d\,V^{C*}}{d\,R^{i}} = \left[\left(\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}} \right) \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1}
$$

$$
\frac{\sigma-1}{\sigma} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{-\frac{1}{\sigma}} (-\omega)
$$

$$
= - \left[\left(\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}} \right) \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}
$$

$$
\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)} \right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{-\frac{1}{\sigma}} \omega \quad < 0 ,
$$

$$
\frac{d\,V^{C*}}{d\,R^{C}} = 0 ,
$$

$$\frac{dV^{C*}}{d\omega} = \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}} \frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{-\frac{1}{\sigma}} \left(R_1 - \left(R^i + R^j\right)\right)$$

$$= \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}} \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{-\frac{1}{\sigma}}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \left(R_1 - \left(R^i + R^j\right)\right) > 0,$$

$$\frac{dV^{C*}}{dn}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\Bigg(\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\left(-\frac{\mu Y_1}{2n^2}\right)+\frac{\sigma-1}{\sigma}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\Bigg[\frac{\theta-1}{\theta}\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}}\left(-\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]^2}\right)\left(\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\frac{2}{\gamma}+\frac{2}{\gamma}\right)$$

$$+\frac{\theta-1}{\theta}\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}}\left(\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right]^2}\right)(\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\frac{n}{\gamma}\Bigg]\Bigg)$$

$$= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \left(-\frac{\mu Y_1}{2n^2}\right) + \left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}} \left(-\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right]^2}\right) \left(\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\frac{2}{\gamma}+\frac{2}{\gamma}\right) + \left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}} \left(\frac{1}{\left[\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right]^2}\right) (\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\frac{n}{\gamma} \right] \right)$$

$$< 0 \quad for \quad \theta < 1,$$

$$\frac{dV^{C*}}{d\mu}=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$=\left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}>0,$$

$$\frac{dV^{C*}}{d\gamma}=\left[\begin{array}{l}\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+{}^{\frac{\sigma-1}{\sigma}}\\ \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\end{array}\right]^{\frac{1}{\sigma-1}}\frac{\sigma}{\sigma-1}$$

$$\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}}+\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left[\begin{array}{l}\frac{\theta-1}{\theta}\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}}\left(-\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta}+\left(\frac{2n}{\gamma}\right)\right)^{2}}\right)\theta\left(\frac{2n}{\gamma}\right)^{\theta-1}\left(-\frac{2n}{\gamma^2}\right)\\ +\frac{\theta-1}{\theta}\left(1-\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1}+1}\right)^{-\frac{1}{\theta}}\left(\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta-1}+1\right)^{2}}\right)(\theta-1)\left(\frac{2n}{\gamma}\right)^{\theta-2}\left(-\frac{2n}{\gamma^2}\right)\end{array}\right]$$

$$
= \left[\frac{\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}}}{\left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}} \right]^{\frac{1}{\sigma-1}}
$$

$$
\left(\omega\left(R_1 - \left(R^i + R^j\right)\right)\right)^{\frac{\sigma-1}{\sigma}} \left[\left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{\frac{\theta-1}{\theta}} + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{\frac{\theta-1}{\theta}}\right]^{-\frac{\theta}{(\theta-1)\sigma}}
$$

$$
\left[\begin{array}{l} \left(\frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)}\right)^{-\frac{1}{\theta}} \left(-\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta} + \left(\frac{2n}{\gamma}\right)\right)^2}\right) \theta \left(\frac{2n}{\gamma}\right)^{\theta-1} \left(-\frac{2n}{\gamma^2}\right) \\ + \left(1 - \frac{1}{\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1}\right)^{-\frac{1}{\theta}} \left(\frac{1}{\left(\left(\frac{2n}{\gamma}\right)^{\theta-1} + 1\right)^2}\right) (\theta - 1) \left(\frac{2n}{\gamma}\right)^{\theta-2} \left(-\frac{2n}{\gamma^2}\right) \end{array} \right]
$$

$$
> 0 \quad for \quad \theta < 1 .
$$

Impact of the model parameters on V^C (equation (46b)):

$$
\frac{dV^{C*}}{dY_1} = \frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right) - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}
$$

$$
\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n}
$$

$$
= \left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}} + \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}} + \left(\omega\left(R_1 - \left(R^i + R^j\right)\right) - 2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}
$$

$$
\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}} \frac{\mu}{2n} \quad > 0 ,
$$

$$\frac{d\,V^{C*}}{d\,R_1}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\omega$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\omega\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,R^i}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}$$

$$\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\left(-\omega\right)$$

$$=-\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma\,R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}$$

$$\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\omega\quad<0\,,$$

$$\frac{d\,V^{C*}}{d\,\omega}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}$$

$$\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\left(R_1-\left(R^i+R^j\right)\right)$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}$$

$$\left(R_1-\left(R^i+R^j\right)\right)\quad>0\,,$$

$$\frac{d\,V^{C*}}{d\,n}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\begin{array}{l}\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\left(-\frac{\mu Y_1}{2n^2}\right)+\quad\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}\\ \left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\\ \frac{\theta-1}{\theta}\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\left(-2\,R^C\right)\end{array}\right]$$

$$=-\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left[\begin{array}{l}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{\mu Y_1}{2n^2}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\\ \left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{-\frac{1}{\theta}}\,2\,R^C\end{array}\right]\quad<0\,,$$

$$\frac{d\,V^{C*}}{d\,\mu}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\frac{\sigma-1}{\sigma}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\left(\frac{\mu Y_1}{2n}\right)^{-\frac{1}{\sigma}}\frac{Y_1}{2n}$$

$$>0\,,$$

$$\frac{d\,V^{C*}}{d\,\gamma}=\frac{\sigma}{\sigma-1}\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\frac{\theta-1}{\theta}\left(\gamma R^C\right)^{-\frac{1}{\theta}}R^C$$

$$=\left[\left(\frac{\mu Y_1}{2n}\right)^{\frac{\sigma-1}{\sigma}}+\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}$$

$$\left(\left(\gamma R^C\right)^{\frac{\theta-1}{\theta}}+\left(\omega\left(R_1-\left(R^i+R^j\right)\right)-2\,n\,R^C\right)^{\frac{\theta-1}{\theta}}\right)^{-\frac{\theta}{(\theta-1)\sigma}}\left(\gamma R^C\right)^{-\frac{1}{\theta}}R^C\quad>0\,.$$

Solutions obtained by numerical simulation

In **MV (b1)**, we conducted the numerical simulation for the following parameter values: Y_1= 600; R_1= 500; R^A = 230; R^B = 210; R^C = 8 / 5[5]; ω= 0,4; n= 3; μ= 2; γ= 2; for the four combinations $(\sigma,\theta=0{,}5)$, $(\sigma,\theta=1{,}5)$, $(\sigma=1{,}5\ and\ \theta=0{,}5)$ and $(\sigma=0{,}5\ and\ \theta=1{,}5)$ of the substitutability parameters, respectively.

Impact of R^C on V^C (equation (32b)): R^C = (0,5 ; corner value[6])

Impact of σ on V^i (equation (29)) and V^C (equations (32a) and (32b)):
σ= (0,1 ; 1,5) for θ= 0,5 and θ= 1,5, respectively.

[5] As there are two general model solutions for V^C in the model variants (b1), (b2) and (b3), the left value refers to general model solution a and the right value refers to general model solution b, respectively.
[6] The 'corner value' is the maximum possible value of R^C which fulfils the precondition for equation (32b), equation (40b) and equation (46b), respectively (cf. Section 4.1).

Impact of θ on V^i (equation (29)) and V^C (equations (32a) and (32b)):
θ= (0,1 ; 1,5) for σ= 0,5 and σ= 1,5, respectively.

In **MV (b2)**, we conducted the numerical simulation for the following parameter values: Y_1 = 600; R_1 = 500; R^A = 130; R^B = 220; R^C = 8 / 5[7]; ω= 0,4; n= 3; μ = 2; γ= 2; for the four combinations $(\sigma, \theta = 0{,}5), (\sigma, \theta = 1{,}5)$, $(\sigma = 1{,}5 \textit{ and } \theta = 0{,}5)$ and $(\sigma = 0{,}5 \textit{ and } \theta = 1{,}5)$ of the substitutability parameters, respectively.

Impact of R^i on V^i (equation (36)): R^i = (20 ; 160)

Impact of R^C on V^C (equation (40b)): R^C = (0,5 ; corner value[8])

Impact of σ on V^i (equation (36)), V^j (equation (37)) and V^C (equations (40a) and (40b)):
σ= (0,1 ; 1,5) for θ= 0,5 and θ= 1,5, respectively.

Impact of θ on V^i (equation (36)) and V^C (equations (40a) and (40b)):
θ= (0,1 ; 1,5) for σ= 0,5 and σ= 1,5, respectively.

In **MV (b3)**, we conducted the numerical simulation for the following parameter values: Y_1 = 600; R_1 = 730 / 1500[9]; R^A = 210; R^B = 160; R^C = 20 / 5[10]; ω= 0,4; n= 3; μ = 2; γ= 2; for the combinations $(\sigma, \theta = 0{,}5), (\sigma, \theta = 1{,}5)$, $(\sigma = 1{,}5 \textit{ and } \theta = 0{,}5)$ and $(\sigma = 0{,}5 \textit{ and } \theta = 1{,}5)$ of the substitutability parameters, respectively.

Impact of R^i on V^i (equation (43)): R^i = (160; 499); R_1 = 1500

Impact of R^C on V^C (equation (46b)): R^C = (0,5 ; corner value[11])

Impact of σ on V^i (equation (43)) and V^C (equations (46a) and (46b)):
σ= (0,1 ; 1,5) for θ= 0,5 and θ= 1,5, respectively.

Impact of θ on V^i (equation (36)) and V^C (equations (46a) and (46b)):
θ= (0,1 ; 1,5) for σ= 0,5 and σ= 1,5, respectively.

The validity of the numerical solutions as presented in Table 1 is only proven for these parameter values.

[7] Cf. footnote 5
[8] Cf. footnote 6
[9] Cf. footnote 5
[10] Cf. footnote 5
[11] Cf. footnote 6

Paper 5: Reconciling intragenerational and intergenerational environmental justice in Philippine agriculture: The MASIPAG farmer network

Forthcoming in *Ethics, Policy & Environment*

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Abstract: The normative aim of environmental justice poses two challenges to the management of agricultural systems: (1) improvement of access for today's rural poor to vital ecosystem services ("intragenerational environmental justice"); and (2) sustenance of critical ecosystem funds to enable future persons access to vital ecosystem services ("intergenerational environmental justice"). The paper investigates whether, and how, these justices have been simultaneously enhanced by the Philippine farmer network MASIPAG. It compares evaluation data on MASIPAG and conventional farming systems within a normative framework based on the justice conceptions by Rawls and Sen, and analyses the impact of certain determinants on both justices.

Keywords: environmental justice, ecosystem services, agriculture, agro-biodiversity, Philippines.

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1 From world agriculture to the Philippine farmer network MASIPAG

MASIPAG, a network of Philippine rice farmers, demonstrates that it is possible to bring about an agriculture that *both* improves food security, income and health of the rural poor *and* environmental sustainability – and that it is resource-poor farmers who can foster such an agriculture bottom-up. MASIPAG farmers breed their own rice varieties from the old traditional rice varieties, collect and share them, enhance their on-farm diversity, farm without artificial fertilizers and pesticides, and revive traditional labor-sharing practices – thereby, regaining self-determination in their agricultural management (MASIPAG 2009). Until today, MASIPAG farmers have cultivated more than 2000 rice varieties, adapted to the specific local environmental conditions and competitive with the high yielding varieties of international research institutes in yield (ib. 55f.). In 2009, MASIPAG counted approx. 35.000 farmer members (ib. 13). Though MASIPAG is a network of rice farmers, scientists and non-governmental organizations, its institutional structure gives the priority to farmers in decision making structures at all levels, and is based on self-organized groups of MASIPAG families, the people's organizations (ib. 67ff.).

Apparently, the MASIPAG network has locally solved two major problems that today's world agriculture faces: failure in combating hunger and environmental degradation. First, most of the almost a million undernourished people[1] live in rural areas and are highly dependent on agriculture, grazing, and hunting for subsistence (MEA 2005: 47). Second, total increases in agricultural yield and livestock have entailed ecosystem degradation: losses in other valuable ecosystem services (including pest control, pollination and erosion control, ib.) and critical ecosystem funds[2] (such as fertile soils). These problems in the management of agricultural systems point to fundamental questions of intragenerational and intergenerational justice.

Intragenerational justice (i.e., justice between different persons of the present generation), and intergenerational justice (i.e., justice between members of the present and future generations) are the core normative guidelines underlying the vision of sustainable development. It is widely agreed in the international political discourse on sustainable development (cf. the famous Brundtland-definition, WCED 1987: 43) and the philosophical discourse on the rights of future people (cf. e.g. Feinberg 1981, Visser't Hooft 2007) that both justices have equal moral weight – and that (sustainability) policy should consider them equally.

To link the ideas of intragenerational and intergenerational justice to the use and conservation of ecosystems and its services, I introduce the term *environmental justice*. Whereas the scientific environmental justice discourse primarily addresses the unequal distribution of environmental burdens and hazards between different contemporary societal groups (cf. Bryant 1995, Schlosberg 2007), my definition deviates in two aspects: It focuses on injustices in the use and conservation of ecosystems, and it encompasses the

[1] 925 million people were undernourished in October 2010 according to the United Nations Food and Agriculture Organization (FAO 2010: 8).

[2] In terms of natural capital, ecosystem funds are the components of ecosystems which generate ecosystem services (Egan-Krieger 2009). They can be distinguished in living funds (e.g. animals or trees) and non-living funds (e.g. soil or a forest ecosystem, ib.).

intergenerational dimension alongside the intragenerational dimension. To discuss issues of intergenerational justice in ecosystem use, the concept of "environmental sustainability" is prominently used in the sustainability literature (e.g. in Dobson 1998). I here apply the term *environmental justice* to clearly frame that I take up the justice-perspective and focus on the legitimate claims of present *and* future persons. Two specific objectives arise from this understanding of environmental justice to the management of agricultural systems: (1) the improvement of access of today's rural poor to vital ecosystem services, especially to a sufficient quantity and quality of food and fresh water, regarding *intragenerational environmental justice*; and (2) the sustenance of critical ecosystem funds to enable future persons access to vital ecosystem services regarding *intergenerational environmental justice*.

In political implementation, the two justices may conflict. For instance, increases in agricultural productivity and income of the agrarian poor may imply soil degradation, depletion of water reservoirs and the loss of cultural landscapes with high agrobiodiversity. But there may also be synergies between both justices. The results of an impact evaluation on the MASIPAG farmer network point to such synergies: MASIPAG farmers could improve their food security, health outcomes and livelihood, as well as the ecological state of their farmland (MASIPAG 2009).

In this paper, I aim to prove the validity of two hypotheses: (1) *Facilitation* between the objectives of intragenerational and intergenerational environmental justice occurred in the MASIPAG farming systems – that is, attaining one justice to a higher degree induced a higher degree of attainment of the other justice; (2) facilitation in the MASIPAG farming systems can be explained by certain *determinants of the relationship between intra- and intergenerational environmental justice* (Glotzbach and Baumgärtner 2012). These determinants are (a) quantity and quality of ecosystem services, (b) population development, (c) substitutability of ecosystem services by human-made goods and services, (d) ecological efficiency, (e) institutions and (f) political restrictions.

To prove both hypotheses, I draw on the results of a comprehensive impact evaluation of the MASIPAG network, and apply a comparative approach – i.e., I compare the situation in MASIPAG farming systems with the situation in conventional farming systems. To prove hypothesis (1), I develop a normative framework – based on the "A Theory of Justice" by John Rawls (1971) and the "Capability-Approach" by Amartya Sen – to assess the impact of the MASIPAG network in terms of intragenerational and intergenerational environmental justice (Section 2). Applying the normative framework, I build an indicator set measuring intragenerational environmental justice and one measuring intergenerational environmental justice, respectively, and then identify the degree of attainment of both justices in the MASIPAG farming systems as compared to the conventional reference systems by means of the indicator sets (Section 3). In doing so, I assume that a higher degree of attainment of both justices in MASIPAG systems indicates facilitation. To prove hypothesis (2), I analyze whether certain facilitation-specific properties of the determinants have been present in the MASIPAG farming systems, but not in the conventional farming systems (Section 4). Finally, I summarize the results of this case study analysis and discuss possible implications for fostering environmental justice in (Philippine) agriculture (Section 5).

2 Assessing the impact of MASIPAG within a normative framework

Poverty among Philippine farmers in prevalent: The latest Philippine poverty statistics for the basic sector (NSCB 2006) indicate that poverty incidence[3] among farmers was 44% in 2006 – more than twice as high as poverty incidence among the "urban poor" and among "migrant and formal sector workers". The distribution of land ownership in Philippine agriculture is characterized by sharp inequalities which are gradually tackled by a comprehensive land redistribution program.

The MASIPAG farmer network has been established in 1986 on a rice conference which discussed the negative impacts of the Green Revolution on Philippine rice farmers (MASIPAG 2009: 6f.). The Green revolution caused most rice farmers to convert their cultivation from traditional rice varieties to the chemically-dependent, genetically uniform high-yielding varieties of the International Rice Research Institute. Subsequently, many farmers became indebted and lost the self-determination in their agricultural management. Therefore, the MASIPAG network was founded "primarily to break the control of local and multinational fertilizer and pesticide companies, multi-lateral rice research institutes and distribution cartels over the rice industry" (MASIPAG 2007). Accordingly, MASIPAG aimed for giving the farmers control over agricultural diversity, agricultural production and associated knowledge (ib.). A normative framework to assess the MASIPAG network in terms of environmental justice should, therefore, address farmer empowerment as an objective of justice in its own.

How can the impact of the MASIPAG network in terms of intragenerational and intergenerational environmental justice, respectively, be adequately assessed? In the following, I argue that Rawls' "A Theory of Justice" (1971) connected with Sen's "Capability Approach" is a promising foundation for a normative framework of assessment.

With his contract theory, John Rawls develops certain principles of justice that should guide societal institutions (i.e., primarily the political constitution and the social and economic system) in the distribution of primary social goods (i.e., rights, liberties, opportunities to societal positions, income and wealth). To deduce and justify fair and generally agreeable principles of justice, Rawls introduces an original position characterized by impartiality (Rawls 1999: 118ff.): The contract partners decide on principles of justice from behind a "veil of ignorance", neither knowing their specific place in society (e.g. whether they are big landlords or poor tenant farmers) nor their natural assets nor their conception of a good life. Rawls argues that the contract partners would commonly agree on two principles of justice in this imaginary original position: (1) "Each person is to have an equal right of the most extensive total system of equal basic liberties compatible with a similar system of liberty for all" (ib. 266). (2) "Social and economic inequalities are to be arranged so that they are both: (a) to the greatest benefit of the least advantaged, consistent with the just savings principle, and (b) attached to offices and positions open to all under conditions of fair equality of opportunity" (ib.).

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[3] Poverty incidence is conceptually defined as the number of poor people (in a specific basic sector) divided by the total number of people (in a specific basic sector), based on an annual per capita poverty threshold of 13.348 pesos in 2006 (NSCB 2006, NSCB 2009).

Rawls' principles of justice serve the assessment of institutions in terms of their realized impacts (ib. 48). His "difference principle"[4] which regulates social and economic inequalities in income and wealth focuses on the situation of the least advantaged group within a society (ib. 81ff.). Rawls also recognizes that future people have legitimate claims towards the present generation and complements the difference principle by a "just savings principle" (ib. 251ff.). He arrives at the just savings principle through replacing the assumption that the contract partners in the original position are purely self-interested persons by the assumption that the contract partners are contemporaries who represent family lines and, therewith, care about the wellbeing of their descendants (ib. 255). Beside the solution presented by Rawls, the original position offers the potential to extend the community of justice to include representatives from the present and future generations (cf. Richards 1983, in De-Shalit 1995: 110). To address ecosystem services in the context of Rawls theory, access rights to ecosystem services must fall into Rawls' list of primary social goods – that is, "a class of goods that are normally wanted as parts of rational plans of life which may include the most varied sorts of ends" (Rawls 1999: 230). I assume that people in the original position will commonly regard access rights to vital ecosystem services as primary social goods (cf. e.g. Dobson 1998: 125, Visser't Hooft 2007: 88). Food, fresh water and (to some extent) agrobiodiversity are such vital ecosystem services that should be included in Rawls' category of primary goods as they are necessary means to satisfy the basic need for nutritious food and fresh water. As ecosystem-service access refers to tangible goods, it would fall under the difference principle that regulates social and economic inequalities.

With the proposed extensions, Rawls' theory can provide a philosophical foundation to assess the MASIPAG network in terms of environmental justice: It would assess how MASIPAG impacts on inequalities in the distribution of access to vital ecosystem services, considering both today's rural poor and future people. Still, Rawls' theory neglects two aspects of relevance for the MASIPAG case. The first aspect is the context-specific value of regulating and cultural ecosystem services for the farmers' wellbeing: These ecosystem services enable a secure supply with sufficient, safe and nutritious food. For instance, enhanced biological control, instead of pesticide and herbicide use, allows for pollution-free crop yields, and practical knowledge in plant breeding improves the performance of the farmer's rice selections. The second aspect is the intrinsic value of freedoms: MASIPAG farmers aim for freedom to decide on their agricultural management and for independence from fertilizer and pesticide companies, rice research institutes and the rice industry.

The "Capability Approach" (CA) by the economist and philosopher Amartya Sen recognizes these aspects – by highlighting the context-specific relation between primary goods and human wellbeing, and the intrinsic value of freedoms (Sen 1982: 367f., Sen 1999: 36). The notion "basic capabilities" describes a person's ability to do certain basic things (Sen 1982: 367). Capabilities are alternative combinations of feasible "functionings" - that is doings and beings constitutive for human wellbeing, including „such elementary things as being adequately nourished, being in good health, avoiding escapable morbidity and premature

[4] The difference principle says that social and economics inequalities should be to the greatest expected benefit of the least advantaged (Rawls 1999: 65ff.).

mortality, etc., to more complex achievements such as being happy, having self-respect, taking part in the life of the community“ (Sen 1992: 39).

The main elements of the CA are illustrated in Figure 1 with regard to the situation of Philippine peasant rice farmers. *Resources* (such as leased or owned agricultural land, fresh water access and machinery) are converted into a *capability set* which describes “those ways of life (bundles of functionings) that are feasible for the person” (Leßmann 2011: 43). *Individual conversion factors* (personal features such as the physical condition and skills in farming methods) and the *social context* (e.g. agrarian reform legislation and exposure to climate change) influence which capabilities an individual farmer can achieve with certain resources. The individual farmer makes a choice between different bundles of functionings (e.g. between conventional and MASIPAG farming methods). The result of this choice manifests in achieved functionings (including the farmer’s achievement of food security, health and livelihood).

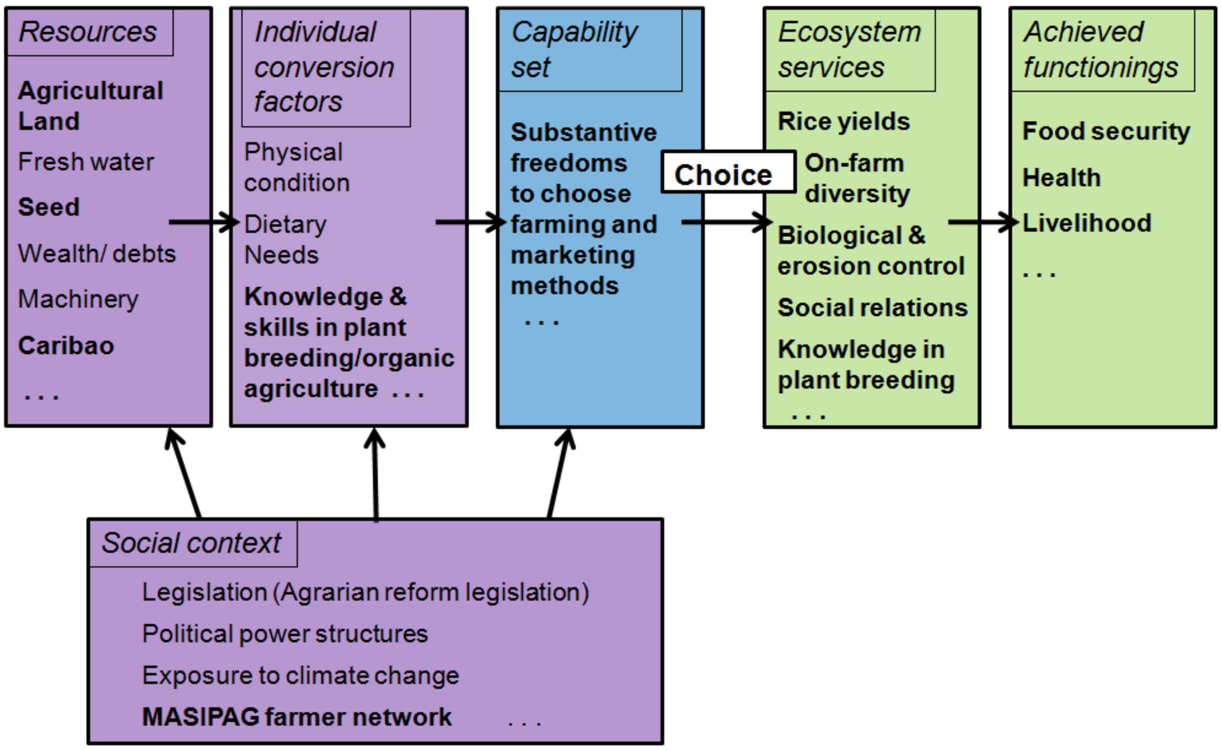

Figure 1: The situation of Philippine (MASIPAG) rice farmers within the context of the Capability Approach (based on Leßmann 2011: 53)

The bold expressions in Figure 1 indicate how the MASIPAG network (potentially) impacts on the achieved functionings of its farmer members: The MASIPAG network is part of the social context of an individual Philippine rice farmer and provides for its members training facilities in plant breeding, access to a communal seed bank and communal support. If a farmer decides to become a member of MASIPAG, he receives access to the communal seed bank (resources), attains knowledge and skills in seed selection, plant breeding and organic agriculture (individual conversion factors) – and, therewith, gains freedoms regarding his agricultural management (i.e., the choice between the MASIPAG and the conventional way of farming). The choice in favor of the MASIPAG way of farming implies changes in the provision of ecosystem services (among others in on-farm diversity, biological and erosion control, communal labor, cf. Table 3). Enhanced ecosystem-service provision substantially impacts on, or even determines, the achieved functionings: Enhanced regulating ecosystem services improve the resilience of crop yields (food security), higher on-farm diversity promotes a more diverse diet (health outcomes), and practical knowledge in plant breeding makes the farmer independent from purchase of seeds (livelihood). In addition, enhanced ecosystem-service provision (potentially) influences the future resource availability (such as the soil fertility of the farmland and the available varieties of rice seeds).

To assess the impact of MASIPAG in terms of intragenerational (resp. intergenerational) environmental justice, I construct a normative framework that connects Rawls' "A Theory of Justice" with Sen's CA. This normative framework focuses on inequalities in the basic capabilities which are determined by access rights to ecosystem-services: The MASIPAG network is assessed to be intragenerationally (resp. intergenerationally) just if it improves the situation of present (resp. future) Philippine rice farmers regarding these basic capabilities.

3 Measuring environmental justice in MASIPAG farming systems

Quantitative data from MASIPAG farmers' households, conversion farmers' households and conventional farmers' households on food security, health outcomes and livelihood, corn yields and productivity, various environmental outcomes, farmer knowledge and empowerment were collected in the context of an impact evaluation of the MASIPAG network - funded and commissioned by the German Catholic development organization Misereor. The results have been published in 2009 in the book "Food Security and Farmer Empowerment: A study of the impacts of farmer-led sustainable agriculture in the Philippines" (MASIPAG 2009). The study team - Lorenz Bachmann, freelance consultant specialized in agriculture and rural development, Elizabeth Cruzada, the former national coordinator of MASIPAG, and Sarah Wright, lecturer in geography and development studies - conducted interviews with 280 MASIPAG farmers' households and 280 conventional farmers' households as reference group (ib. 9). Both groups were comparable in farm size (about 1,5 ha, ib. 13).

In the following, I use the evaluation data to assess the impact of MASIPAG on attaining intragenerational (resp. intergenerational) environmental justice. First, I derive indicators of intragenerational (resp. intergenerational) environmental justice based on the outlined normative framework. After that, I identify the respective indicator values for MASIPAG and conventional farming systems, and compare them. Finally, I conclude whether facilitation between the justices occurred in the MASIPAG farming systems.

3.1 Measuring intragenerational environmental justice

In the intragenerational dimension, there are data available on health outcomes, food security and livelihood. These data quantify the achievement of three functionings - being able to have good health, being able to have food security, being able to make a livelihood - by MASIPAG farmers' families and conventional farmers' families. They indicate the alternative bundles of functionings feasible for Philippine rice farmers with the MASIPAG way of farming and the conventional way of farming, respectively. Hence, I choose an *indicator set for intragenerational environmental justice* that consists of three indicators: food security, health outcomes and livelihood. An increase in the value of one indicator - with the values of the others not getting worse – is defined to indicate an increase in attainment of intragenerational environmental justice.

Table 1: Indicator set measuring intragenerational environmental justice

Indicators of intragenerational environmental justice	**Indicator values**		**Comparison of indicator values**
	MASIPAG farming systems	**conventional farming systems**	
food security (perceived changes 2000-2007)	88% (better/much better) 2% (worse)	39% (better/much better) 18% (worse)	+
health outcomes (perceived changes 2000-2007)	83% (better/much better) 4% (worse)	29% (better/much better) 16% (worse)	+
livelihood [5] (per ha farmland)	51.448 pesos	32.062 pesos	+ *

The indicators *food security* and *health outcomes* measure the changes in food security (MASIPAG 2009: 22) resp. health status (ib. 29) from 2000-2007 as perceived by the farmers. The indicator *livelihood* measures the gross agricultural income less the production costs and less the value of farm products consumed by the household, and is specified as mean value per household and ha (ib. 45). Table 1 lists the three indicators and the corresponding indicator values for the investigated MASIPAG farming systems and conventional reference systems. The last column "comparison" relates the indicator values for MASIPAG and conventional farming systems: The sign + indicates higher values for MASIPAG farming systems than for conventional farming systems in the dimension of the corresponding indicator. The MASIPAG systems show higher values regarding all three indicators. Within the chosen normative framework, intragenerational environmental justice has been attained to a higher degree in MASIPAG farming systems than in conventional farming systems.

3.2 Measuring intergenerational environmental justice

In the intergenerational dimension, the basic capabilities of future MASIPAG and conventional farmers set by ecosystem-service access cannot be measured directly. What can be measured are two fundamental elements influencing the capability set of future Philippine

[5] The indicator livelihood was tested for statistical significance. * indicates highly significant differences (MASIPAG 2009: 45).

rice farmers: the maintenance of the MASIPAG institutional structure (*social context*) and the future ecological state and available quantity of the agricultural land (*resources*).

Intergenerational justice presupposes sustaining a just institutional structure of a community (Petersen 2009). If MASIPAG is sustained in its structure and methods over the next decades, future farmers will have the “freedom” to choose the MASIPAG way of farming, and, therewith, can improve resource availability (access to the MASIPAG seed bank) and individual conversion factors (access to knowledge and training in plant breeding and organic agriculture). Hence, the *maintenance of the MASIPAG network* is introduced as a first indicator of intergenerational environmental justice.

The future *ecological state of the farmland* impacts on future food production. Certain ecosystem services (such as on-farm diversity, maintenance of soil fertility, and tolerance of crops to pests and diseases) support productivity and resilience of food provision - and, hence, indicate a good ecological state of the agro-ecosystem. By contrast, certain human impacts (such as pesticide and herbicide use) impair the ecological state of the farmland. Based on the data available, I choose six *ecosystem indicators* that describe the present ecological state of the farmland: *on-farm diversity*, *maintenance of soil fertility*, *biological control*, *erosion control*, *abandonment of chemical fertilizer*, and *abandonment of pesticide and herbicide use*. If the MASIPAG network is sustained in its institutional structure, the present value of the ecosystem indicators in MASIPAG farming systems can reveal trends for its future value in MASIPAG farming systems.

The quantity of agricultural land available to future Philippine rice farmers depends on the family size of future farmers and the size of farmland owned or leased by a future farmers’ family. Hence, I introduce a *farmland indicator* which measures average size of farmland divided by average household size. Intertemporal stability or increase of this quotient is introduced as an indicator of intergenerational environmental justice.

Combining the indicators, I define that an increase in attainment of intergenerational environmental justice occurs if the following conditions are given: (a) the *maintenance of the MASIPAG network* (for MASIPAG farming systems), *and* (b) an increased value of one or several *ecosystem indicators* - with all other ecosystem indicators staying constant – *and* (c) a constant or increased value of the *farmland indicator*.

Several facts are indicative of the long-term *maintenance of the MASIPAG network*: First and foremost, MASIPAG exists and expands in its original approach and structure for nearly three decades, and under various changes of leadership. Second, there is high internal satisfaction with the work of MASIPAG among its farmer members (MASIPAG 2009: 76). MASIPAG farmers show a high degree of involvement in the organization, as leaders in people’s organizations, farmer trainers or committee members (ib. 72). Third, reputation of the MASIPAG network beyond its own farmer members is relatively high as compared with reputation of government agencies and other non-governmental organizations (ib. 79).

The indicator *on-farm diversity* is twofold, measuring the number of rice varieties grown per farm (ib. 88) and the number of crop types grown per farm (ib. 25). The indicators *maintenance of soil fertility, biological control and erosion control* measure the changes in soil fertility (ib. 94), in tolerance of crops to pests and diseases (ib. 93) and in soil erosion (ib. 93), respectively, from 2000-2007 as observed by the farmers. The *farmland indicator* measures the cut mean of farm size (for farmers in the 0-4 ha group) divided by average number of household members (ib. appendix 2).

Table 2: Indicator set measuring intergenerational environmental justice

Indicators of intergenerational environmental justice	Indicator values: MASIPAG farming systems	Indicator values: conventional farming systems	Comparison of indicator values
On-farm diversity[6]			
number of rice varieties	4,8	1,6	+ *
number of crop types	45	30	+ *
Maintenance of soil fertility (observed changes 2000-2007)	84% (better) 2% (worse)	3% (better) 53% (worse)	+
Biological control (observed changes 2000-2007)	81% (better) 3% (worse)	13% (better) 41% (worse)	+
Erosion control (observed changes 2000-2007)	59% (reduction in erosion) 6% (increase in erosion)	6% (reduction in erosion) 32% (increase in erosion)	+
Abandonment of chemical fertiliser	100%	15%	+
Abandonment of pesticide and herbicide use	100%	20%	+
Farmland indicator (average farm size divided by average household size)	1,23 ha/5,4 = 0,23 ha (2000) 1,47 ha/5,0 = 0,29 ha (2007)	1,23 ha/5,4= 0,23 ha (2000) 1,49 ha/5,1= 0,29 ha (2007)	+/-

Table 2 lists the indicators of intergenerational ecological justice and the corresponding indicator values for the MASIPAG and conventional farming systems. The sign + in the column "comparison" indicates higher values for MASIPAG systems than for conventional systems in the dimension of the corresponding indicator, the sign +/- indicates similar values for MASIPAG and conventional farming systems. The MASIPAG systems show higher values than conventional systems regarding all ecosystem indicators, and an increased value of the *farmland indicator* from 2000-2007. The long-term *maintenance of the MASIPAG network* can be reasonably assumed. Within the chosen normative framework, intergenerational environmental justice has been attained to a higher degree in MASIPAG farming systems than in conventional farming systems.

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[6] The indicator on-farm diversity was tested for statistical significance. * indicates highly significant differences (MASIPAG 2009: 25, 88).

3.3 Facilitation between the justices

Generally, three relationships between intragenerational and intergenerational environmental justice may occur: (1) independency, i.e. achieving one objective has no effect on the chances to also achieve the other one, (2) facilitation, i.e. achieving one objective makes it easier to also achieve the other one, and (3) rivalry, i.e. achieving one objective makes it more difficult to also achieve the other one (Glotzbach and Baumgärtner 2012). The simultaneous enhancement of both justices in the investigated MASIPAG farming systems points to facilitation.

4 Determinants of facilitation in MASIPAG farming systems

What factors enabled to simultaneously foster intragenerational and intergenerational justice in the MASIPAG farming systems? To investigate the determinants of facilitation in the MASIPAG systems, I apply an interdisciplinary explanation attempt to the case study. This explanation attempt condenses the findings of an investigation on the general relationship between intragenerational and intergenerational justice in the use of ecosystem services (Glotzbach and Baumgärtner 2012). Three hypotheses about this relationship are held in the political and scientific sustainability discourse: independency, facilitation, and rivalry (ib.). A qualitative content analysis of political documents on sustainable development and the scientific literature revealed that (at least) six determinants are underlying the different hypotheses: (a) quantity and quality of ecosystem services, (b) population development, (c) substitutability of ecosystem services by human-made goods and services, (d) ecological efficiency, (e) institutions, and (f) political restrictions – and that specific properties of each determinant are connected to facilitation. In the following, I investigate whether the facilitation-specific properties of the determinants have been present in the MASIPAG farming systems, but not in the conventional reference systems.

4.1 Quantity and quality of ecosystem services

The determinant analysis revealed the following argumentation about the impact of the determinant *quantity of ecosystem services* on facilitation: Increasing the quantity of ecosystem services that improve the state of critical ecosystem funds may simultaneously enhance the access of today's poor and future persons to ecosystem services (cf. e.g. Sukhdev & Kumar 2008: 15ff.; WCED 1987: 19ff.). Here, the property of the determinant *quantity of ecosystem service* assumed to favor facilitation is the *increase* in quantity of an *ecosystem service that benefits today's poor people and restores/protects critical ecosystem funds*. This property is present in the investigated MASIPAG farming systems. MASIPAG farmers have increased the ecosystem services on-farm diversity, maintenance of soil fertility, biological control and erosion control (cf. Table 3).

As agro-biodiversity is assumed to be a critical ecosystem fund itself, and the ecosystem services maintenance of soil fertility, erosion control and biological control improve the state of critical ecosystem funds of the agro-ecosystem (i.e., nutrient-rich soils and the presence of natural enemies of crop pests), they enhance the accessibility of ecosystem services by future persons.

Table 3: Ecosystem-service provision in MASIPAG and conventional farming systems

Ecosystem service	Ecosystem-service provision in	
	MASIPAG farming systems	**conventional farming systems**
Rice yields (in kg/ha) [7]	3.424 (2007) 3.374 (2000)	3.478 (2007) 3.570 (2000)
On-farm diversity: number of rice varieties number of crop types grown per farm	4,8** 45**	1,6 30
Maintenance of soil fertility (observed changes 2000-2007)	84% (better) 2% (worse)	3% (better) 53% (worse)
Biological control (observed changes 2000-2007)	81% (better) 3% (worse)	13% (better) 41% (worse)
Erosion control (observed changes 2000-2007)	59% (reduction) 6% (increase)	6% (reduction) 32% (increase)
Knowledge in plant breeding[8] (employment of verification trials of rice seed)	70%	3%
Social relations: [9] involvement in communal labor development of marketing groups	32% 6-16%	18% 1%

The determinant *quality of ecosystem services* refers to two fundamental properties: rivalry/non-rivalry in consumption and excludability/non-excludability from use. The determinant analysis showed that the following relationship between the quality of ecosystem services and facilitation is stated: Ecosystem services which are *non-rival in consumption* and *non-excludable from use* (e.g. climate regulation and flood protection) may produce positive external effects on both today's poor and future people. All ecosystem services increased under the MASIPAG approach are characterized by non-rivalry in consumption. The

[7] The differences in rice yield between MASIPAG and conventional farmers are not statistically significant (MASIPAG 2009: 55). Also the trends, a slight decline for conventional farmers and a slight increase for MASIPAG farmers from 2000-2007, are not statistically significant (ib. 56).

[8] In verification trials MASIPAG farmers test different varieties of rice seeds for its performance under local conditions: first on a local "trial farm", then on their own farms (ib. 74). Thereby, they learn to observe how the rice plant grows and reproduces, what influences growth of different varieties, and which variety performs best under specific local conditions.

[9] Involvement in communal labour refers to a "communal system of labour traditionally used in different parts of the Philippines where people come together to work on each other's projects – either as pure reciprocal labour or sometimes for a portion of the harvest" (ib. 80). The development of marketing groups means the formation of marketing or producer cooperatives (ib. 81).

excludability from free access to (different varieties of) rice seed has been reduced insofar as the MASIPAG network has established communal seed banks: All MASIPAG members provide seeds of their locally bred rice varieties to the communal seed collection and in return can access the seed collection.

4.2 Population Development

The determinant analysis revealed the following argumentation on the impact of *population development* on facilitation: Decreasing population numbers in countries of the global South would give poor people enhanced access to ecosystem services – inducing a higher degree of intragenerational justice - and would at the same time alleviate poverty-induced ecosystem degradation - thereby facilitating intergenerational environmental justice (cf. e.g. WCED 1987: chap. 1, MEA 2005: 92ff.). Hence, two properties of the determinant population development are assumed to induce facilitation: (a) a *decrease of total population numbers among the rural poor* in the present, and (b) *incidence of poverty-induced ecosystem degradation*.

Regarding the first property, I use the farmers' household size as measure of population development relevant for the MASIPAG case study. The available data on the development of MASIPAG and conventional farmers' household size show no significant differences (MASIPAG 2009: appendix 2): For the period 2000-2007, the average household size of both MASIPAG farmers (from 5,4 household members in 2000 to 5,0 household members in 2007) and conventional farmers (from 5,4 household members in 2000 to 5,1 household members in 2007) has decreased. Hence, the decrease in average household size cannot explain why facilitation occurred specifically in MASIPAG systems. Regarding the second property, the evaluation results do not indicate any poverty-induced ecosystem degradation. To conclude on the determinant population development, the two facilitation-specific properties have not been present in the MASIPAG farming systems and, therefore, cannot explain facilitation.

4.3 Substitutability of ecosystem services by human-made goods and services

The determinant *substitutability* refers to the functional substitutability of ecosystem services by human-made goods and services in terms of attaining basic capabilities. Hence, full substitutability indicates that there is no change in the farmers' basic capabilities when an ecosystem service is replaced by a human-made good or service. Substitutability is assumed to produce facilitation if the following properties are present: (a) *Full substitutability of ecosystem services by human made goods and services* is possible; and (b) the *substitutes are environmentally sound*, that is, they do not degrade vital ecosystem funds as much as the consumption of the substituted ecosystem service (cf. Glotzbach and Baumgärtner 2012).

Both properties are not fulfilled for the investigated farming systems. First, the MASIPAG evaluation results indicate that human-made goods cannot fully substitute for at least two regulating ecosystem services: Chemical fertilizers have not achieved the same effects as ecosystem-based measures (such as animal manure, agro-forestry, green manure, azolla and rice straw recycling) in terms of soil fertility from 2000-2007 (cf. Table 3); pesticide and herbicide use have not achieved the same effects as biological control (enhanced by alternative pest management) in terms of tolerance of crops to pests and diseases (ib.). Second, chemical fertilizers and pesticide use are clearly more harmful to vital ecosystem funds than measures of organic agriculture. However, the MASIPAG approach reverses the management practice to substitute for ecosystem services by artificial inputs: MASIPAG farmers enhance essential regulating ecosystem services such as maintenance of soil fertility and biological control. These "re-substitutions" point to another mechanism of facilitation linked to substitutability: The re-substitution of a human-made substitute by the restoration resp. enhancement of the previously substituted ecosystem service may lead to facilitation on condition that the human-made good can only partly substitute for the ecosystems service or does greater harm to vital ecosystem funds than the ecosystem service.

4.4 Ecological efficiency

Referred to farming systems in the Philippines, the determinant ecological efficiency describes the ratio of environmental impacts (including soil erosion, pesticide and fertilizer use) resp. ecosystem-service provision (such as on-farm diversity and soil fertility) to unit rice yield. The determinant analysis showed that an increase in ecological efficiency - by innovation of new technologies, or by means of technology and knowledge transfer of already existing technologies - is assumed to be the facilitation-specific property of the determinant ecological efficiency (cf. e.g. UN-DESA 1992: Section 4, WCED 1987: 25).

MASIPAG farmers could actually improve the ecological efficiency of their farming methods: Under similar quantities of rice yield, MASIPAG systems provided enhanced ecosystem services and caused less environmental impacts than conventional systems (cf. Table 3). This ecological-efficiency gain has been realized by transfer of existing knowledge and training in seed selection, plant breeding and organic agriculture from farmer to farmer, and by broad adoption of environmentally sound farming methods - encompassing elimination of chemical fertilizers and pesticides, sound soil management techniques, alternative pest management, participatory and on-farm breeding activities as well as higher on-farm diversity (MASIPAG 2009: 85ff.).

4.5 Institutions

The determinant *institutions* is defined to include all societal mechanisms which structure and govern human use of ecosystem services. The determinant analysis showed that institutions are generally assumed to favour facilitation if they are *effective* in both stopping ecosystem degradation, and in allowing the (rural) poor better resp. more secure access to ecosystem services. More specifically, certain institutional structures would promote facilitation: *private property or user rights* to securely access ecosystem services, *management rules for community assets* and the *empowerment* of the local population to participate in decisions concerning their local ecosystems (cf. e.g. WRI 2008: 47ff.).

The MASIPAG network possesses two facilitation-specific institutional structures: agro-biodiversity as a managed community asset and institutional structures that foster empowerment of its farmer members. First, MASIPAG has established a seed collection of traditional rice varieties as a *community asset*. The farmers who joined the founding conference of the MASIPAG network donated the first 47 traditional rice varieties to a communal seed collection, and developed the first MASIPAG rice varieties in a farmer-scientist-partnership. Today, the community seed banks hold more than 2000 local varieties and farmer-bred lines. All MASIPAG members provide seeds of their locally cultured rice varieties to the seed banks. This institutional arrangement gives MASIPAG farmers managed access to a high diversity of rice seeds. Second, *empowerment*, specified as increasing strength of MASIPAG farmers to participate in decisions concerning their own agro-ecosystems, is promoted by the network's institutional structure – that is, its farmer-led approach at all levels of the organization, especially in the rice breeding program and the training by farmers for farmers (ib. 67ff.).

4.6 Political restrictions

Political restrictions are defined as limits to an alteration of societal institutions. They express existing power relations. The main political restriction relevant to the investigated farmers' families is the resistance of big landlords against agrarian reform implementation, that is, against the transfer of large private agricultural lands - and with that access rights to ecosystem services - to tenant farmers and farm workers. The determinant analysis revealed the assumption that the *absence or reduction of political restrictions* would allow for facilitation (cf. e.g. Goodland 1992: 40). Hence, facilitation in MASIPAG farming systems could be explained in two ways: (a) There has been some *scope for redistribution of agricultural land* to the benefit of (tenant) peasant farmers, but only MASIPAG farmers took advantage of these redistribution possibilities; (b) the MASIPAG network could *reduce political restrictions on land redistribution* for its farmer members whereas conventional farmers could not.

The first explanation does not apply for the MASIPAG case study as the political restrictions on land redistribution in the Philippines are tight. To clarify this, I make a brief excursus into Philippine land reform. Historically, as legacy of the Spanish and American colonial periods, the Philippines were characterized by sharp inequalities in the distribution of land ownership (Fuwa 2000: 26ff.). Consequently, cycles of rural insurgencies and subsequent partial land reform occurred (ib. 1). Land reform has been on national political agenda at least since the early 20th century, and reform legislation has gradually expanded the (legal) scope for land redistribution over time (ib.). The latest legislations, the Comprehensive Agrarian Reform Law[10] (CARP) from 1988 and the Comprehensive Agrarian Reform Program Extension with Reforms Law[11] (CARPER) from 2009, build the legal basis for the most comprehensive land redistribution program in Philippine history, and regulate the transfer of public land and private agricultural lands from the big landlords to landless farmers. With CARP(ER) landless farmers have gained the right to acquire up to 3 ha of a landlord's land, on condition that they have tilled this land before as tenant farmers or regular farm workers. CARP has been criticized to suffer "from legal loopholes, budgetary shortage, and lack of adequate administrative capacities, which hinder swift and massive land redistribution" (ib. 75). For instance, land used for industrial purposes, for fish farming and as

[10] Republic Act No. 6657 (http://www.lawphil.net/statutes/repacts/ra1988/ra_6657_1988.html, accessed May 21, 2012)
[11] Republic Act No. 9700 (http://www.lawphil.net/statutes/repacts/ra2009/ra_9700_2009.html, accessed May 21, 2012)

pastureland did not fall within the scope of CARP. As a consequence, several landlords signed over their land to a company, or declared it as pastureland or land for fish farming. In addition, farmers who have claimed their right to land through CARP reform were often exposed to physical and legal harassments by their landlords (Narjes and Dürselen 2008).[12] Hence, prolonging and evasion of reform implementation indicate the strong political force of the landlords on national political dynamics (Fuwa 2000: 49) and on the individual farmer's capacity to claim land rights. The political restrictions on land reform implementation are reflected in the evaluation data on land ownership: 38% of the MASIPAG farmers and 45% of the conventional farmers under study did not own any of their tilled farmland in 2007 (MASIPAG 2009: Appendix 2). With the CARPER law the legal basis for land redistribution has been strengthened: For instance, any conversion of irrigated or irrigable land is prohibited (CARPER, Section 24), and the penalties on unlawful land conversion are harsher (CARPER, Section 25). Still, CARPER implementation faces the challenge to enforce redistribution of private agricultural lands with strong resistance.

The second explanation that the MASIPAG network could reduce political restrictions on land redistribution for its farmer members is not supported by the evaluation data on land access by MASIPAG and conventional farmers in 2000 and 2007: Both MASIPAG and conventional farmers in the survey gained access to additional land - without significant difference in the degree of gain in land access (MASIPAG 2009: Appendix 2). To summarize, facilitation in the MASIPAG farming systems cannot be explained by the *absence* or *reduction* of political restrictions on land reform implementation.

5 Conclusion

In the first part of the MASIPAG analysis, I showed that – within a normative framework that builds on Rawls' "A Theory of Justice" and Sen's "Capability Approach", and that focuses on the basic capabilities of present and future peasant rice farmers, respectively - both intragenerational and intergenerational environmental justice have been attained to a higher degree in MASIPAG farming systems than in conventional farming systems. Hence, the first hypothesis that facilitation in attaining the two justices occurred in the MASIPAG farming systems could be verified from the chosen normative perspective.

The second hypothesis that facilitation can be explained by certain determinants could be largely verified. I found that specific properties of the determinants *quantity and quality of ecosystem services*, *substitutability of ecosystem services*, *ecological efficiency* and *institutions* can explain facilitation in the MASIPAG farming systems: Enhanced provision of regulating ecosystem services and on-farm diversity, "re-substitution" of artificial fertilizers and pesticides by the free and more effective regulating ecosystem services, broad adoption of organic farming methods that enhance ecological efficiency, a seed collection of traditional rice varieties as a managed community asset and institutional structures fostering farmer empowerment have (probably) promoted both intragenerational and intergenerational environmental justice. The determinants *population development* and *political restrictions*

[12] As there is only a poor land information system existing in the Philippines, controlling evasion and monitoring land ownership faces serious problems (Ballesteros and dela Cruz 2006: 17).

cannot explain why facilitation occurred in the MASIPAG farming systems as the properties of these two determinants were not different for MASIPAG and conventional farming systems.

Based on the determinant analysis, I suppose that facilitation between the two justices in the MASIPAG farming systems is limited. Once the network has fully realized its institutional, technological and social innovations at the household and community level, environmental justice cannot be further enhanced in the MASIPAG systems. To further increase intra- and intergenerational environmental justice at that point, the MASIPAG network would need to successfully strive against political restrictions on land reform implementation.[13]

Generally, the specific determinants have proved to be fruitful categories to reveal crucial causes of facilitation between intragenerational and intergenerational environmental justice in the MASIPAG case study. Further research must still clarify whether this explanation attempt possesses general validity, and how the determinants interact to produce facilitation.

What do the specific MASIPAG results imply for environmental justice in Philippine agriculture and beyond? If the MASIPAG way of farming and living could be disseminated to a greater share of the Philippine rural population, environmental justice would further sprout bottom-up, and the MASIPAG farmers could probably increase their political influence on agrarian reform implementation. The existence and success of MASIPAG is essentially based on the high farmer involvement in the organization. Therefore, the MASIPAG approach as a whole cannot be established in other regions using a top-down approach. But the core factors of facilitation between intragenerational and intergenerational environmental justice, as identified with the determinant analysis, can be valuable hints for already existing or evolving farmer networks in other regions. The analysis of the MASIPAG network strongly supports the following conclusion drawn in the IAASTD-report[14]: “Developments are needed that build trust and that value farmer knowledge, agricultural and natural biodiversity; (…) local seed systems and common pool resource management regimes” (IAASTD 2009: 5).

6 Acknowledgements

I wish to thank Stefan Baumgärtner, Joachim Fünfgelt, Klara Helene Stumpf, the participants of the BIOECON Conference 2011 and the TEEB conference 2012 as well as two anonymous referees for critical discussion and valuable comments. Financial support from the German Federal Ministry of Education and Research (BMBF) under grants 01UN1011A/B is gratefully acknowledged.

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[13] As global climate change is a serious threat to the basic capabilities of present and future Philippine farmers (MASIPAG 2009: 103ff.), intra- and intergenerational environmental justice will also depend on the enforcement of international climate mitigation measures.

[14] IAASTD is the abbreviation for International Assessment of Agricultural Knowledge, Science and Technology for Development. The IAASTD is an intergovernmental process with a multi-stakeholder Bureau, sponsored by the FAO, GEF, UNDP, UNEP, UNESCO, the World Bank and WHO. It assesses the capacity of agricultural knowledge, science and technology on meeting development and sustainability goals.

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