LEADERSHIP IN SOCIAL DILEMMAS

Dissertation zur Erlangung des Grades eines
Doktors der Wirtschaftswissenschaft

eingereicht an der Fakultät für Wirtschaftswissenschaften
der Universität Regensburg

vorgelegt von:
Michael Jonathan Eichenseer

Berichterstatter: Prof. Dr. Wolfgang Buchholz und Prof. Dr. Andreas Roider

Tag der Disputation: 22.11.2019

LEADERSHIP IN SOCIAL DILEMMAS

MICHAEL JONATHAN EICHENSEER

Dissertation – July 2019

Michael Jonathan Eichenseer: *Leadership in Social Dilemmas,* Dissertation, July 2019

"It is good to have an end to journey toward;
but it is the journey that matters, in the end."
Ursula K. Le Guin (1969/2000, p.220)

ACKNOWLEDGEMENTS

Writing a dissertation is like a journey. To me it was not only a challenging, but also an exciting and inspiring time. I would like to express my gratitude to those who accompanied me along this way and to those who were knowledgeable guides.

I still remember the beginning in 4th floor of Kiel University. I guess this travel would have never started without the encouragement of you, Professor Seidl. Thank you for convincing me to take this venture!

In a similar vein, this thesis would not have been possible without the support and guidance of my supervisor Professor Buchholz. I was lucky to have an excellent instructor. Thank you Wolfgang for successful cooperation, inspiring talks and discussions, for encouraging me to present joint and own work at national and international conferences and workshops, for patience and advice and also for giving this thesis its leading idea. I very much appreciate the time you have spent. In addition, I would like to thank the German Federal Ministry of Education and Research for funding some part of our joint research within the project ECCUITY in their grant program "Ökonomie des Klimawandels".

Likewise, I would like to thank my co-supervisor Professor Roider who established an infrastructure in experimental and behavioral economics at the University of Regensburg. I have benefited substantially from your comments on experimental designs and paper drafts as well as from the cooperation networks you have initiated. In particular I have benefited from being affiliated to the international doctoral program Evidence-Based Economics.

Thanks also goes to Professor Schmidt. Thank you Ulli, for joint work on experiments, inspiring discussions and two research visits to Kiel.

Moreover, I would like to thank my colleagues and roommates during my time in ivory tower, in particular Lisa (D.), Jochen, Lisa (W.), Felix, Johannes, Lars and the extended 5th floor kicker-team, my co-authors, and all the others I have in mind and forget to mention.

Of course life never consists of library and seminar alone. Therefore, I would also thank those who made life beautiful. I am grateful for excellent dining, roofgarden sessions and countless evenings at the Danube. Furthermore, I would like to thank those who accompanied me on tours, took me by boat to Finnish lumberjack pubs in the middle of nowhere, hosted me, invited me to weddings, spent festival seasons with me, were my guests and everybody who has accepted late replies when I have been busy working on this thesis. Thank you all!

Last but not least my deepest gratitude goes to my family for love and unconditional support. Without you, this would not have been possible!

CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE - THE NEED FOR LEADERSHIP IN THE PROVISION OF GLOBAL PUBLIC GOODS

By the end of the last millennial, it looked like a peaceful, cooperative new century was coming up. The United Nations were defining the millennium development goals, some philosophers were already arguing that the end of history was approaching with Western liberalism spreading over the world (Fukuyama 1989). In this spirit, the term of international or "global public goods" (Kaul, Grunberg, and Stern 1999) originated as a vogue expression including, for example, free trade, financial stability, knowledge, peace and security, disease control, but also environmental protection.

Starting from the classical definition, a public good has to fulfill the criteria of non-rivalry in consumption and non-excludability (Cornes and Sandler 1996). These criteria also apply to a certain extent to global public goods. In addition, there is oftentimes an imperative of universality. The spirit of global public goods is that they should be made available universally - that is, globally - even if the material circumstances would allow exclusion in some cases. Nevertheless, as Kaul (1999, p.14) quotes Olson (1971) "the desire for peace ... for orderly financial arrangements for multilateral trade, for the advance of basic knowledge, and for an ecologically viable planet are now virtually universal, yet these collective goods are only episodically or scantily supplied".

The problem of many collective goods on a global scale is that their provision resembles a social dilemma situation, i.e. the stakeholders' best pursuit of individual interest makes them worse off than finding solutions which maximize the common benefit instead. In a streamlined form, the provision of a public good can be represented by a Prisoner's Dilemma.

Following Buchholz and Eichenseer (2016) one could imagine a situation with two countries that share an environmental medium such as air. The countries both have the binary option to either take an abatement measure to reduce emissions and improve air quality or not. If none of them reduces emissions, there is no environmental benefit at all. If one takes costly abatement measures, the other country benefits as well. And if both countries reduce emissions, the environmental benefit increases while both have to bear costs for abatement.

Given that there is a payoff structure such that from the point of view of one country the dominant strategy is always to do nothing (regardless of whether the other country abates or not), no emissions will be reduced at all in the Nash equilibrium of the game. By contrast, the social optimum would be that both countries curb their emissions. This payoff structure resembles a Prisoner's Dilemma and expounds the problem of free-riding. In consequence, a non-cooperative, "voluntary", supply of public goods by countries that are assumed to maximize their payoffs leads to undersupply.

One approach to get out of such a dilemma would be that both countries negotiate and come to an agreement in which both commit to perform the cooperative action. Such agreements are, however, not necessarily stable (Buchholz and Eichenseer 2016). Still, this approach is reflected in the attempt to solve global problems through international conferences. In international climate policy, the Kyoto Protocol is a primary example, coming close to the approach of negotiating cooperative solutions.

Against this background, the Paris Agreement marks a milestone. While the Kyoto Protocol and the attempts following have tried to maintain a cooperative, centralized solution establishing mandatory mitigation goals, the Paris approach resembles an admission to the fact that such centralized solutions are no longer politically feasible in a post Copenhagen world[1]. Turning from a top-down to a bottom-up approach with each country defining its own nationally determined contributions (NDC), individually pre-announced greenhouse gas abatement goals, the recent Paris Agreement on Climate Change marks a watershed. So, the bottom-up approach adheres to the philosophy of "know your limits" (Bodansky 2016).

The Paris Declaration codifies a system of voluntary and differentiated shaping of climate policy. One basic idea of this approach is that a good example given by one country sets a benchmark for other countries and thereby induces a positive reaction expressed by higher abatement efforts of other countries. The intention is to unleash a dynamic process and goad each other in terms of mitigation activities. Thereby, a hope is that "leadership" might ameliorate the problem of undersupply of the global public good of climate protection. This new approach in global climate policy amplifies the need for a better understanding of the effects of leadership in social dilemma situations.

The aim of this dissertation is to further explore the role of pioneers in social dilemmas both theoretically and empirically. To this end, the thesis consists of four parts that include eight chapters followed by an outlook. The first building block, Part I, "Theoretical Considerations" encompasses three chapters that are each dedicated to a particular aspect of leadership: Chapter 1 investigates coalition building whereas Chapter 2 sheds light on technology transfers. In Chapter 3 sequential contributions to public goods and the strategic choice of technology are considered. Part II "An Empirical Example" contains a description of leadership in technological progress through subsidization policies in Chapter 4 using the example of Germany's EEG and estimates the costs of incentivizing technological progress. In the following chapters the analysis then turns to experimental economics. In Part III "A Prerequisite for Leadership", an important ingredient for successful leading-by-example, reciprocity, is considered with a brief literature review in Chapter 5 whereas the stability of reciprocal patterns within individuals is reflected experimentally in Chapter 6. The last building block, Part IV, "Leadership in Public Goods Experiments" first contains a detailed literature review on leadership in public goods experiments in Chapter 7 followed by leadership in a dynamic public goods experiment in Chapter 8. The résumé recaps and addresses the questions remaining.

---

[1] Copenhagen world refers to the failed 2009 UN Climate Change Conference in Copenhagen where an attempt was made to find a follow up agreement for the Kyoto Protocol.

Part I

THEORETICAL CONSIDERATIONS

INTRODUCTORY REMARKS TO PART I

The first part of this dissertation starts with a theoretical framework.[2] Theoretical considerations for the provision of public goods follow classical public economic theory in the tradition of economists like Wicksell (1896) and Lindahl (1919). The necessity to provide public goods as a main rationale for the role of government in a market economy is a central message of this broadly accepted theory. At the national level a state can ensure the provision of public goods whereas at the international stage of global public good provision a central authority is missing. This goes back to the idea of the Westphalian sovereignty of nation states. But meanwhile international public goods (such as transboundary pollution externalities, disease eradication or global security) have increasingly got public attention and have become a central issue of international politics (see, e.g., Sandler 2004, and Peinhardt and Sandler 2015).

Correspondingly, the attention has shifted from public goods that are allocated by a central authority to public goods which are instead provided through voluntary "private" contributions by the agents involved. Such privately provided public goods could be either conceived as public goods within a nation state that are beyond the scope of the government's focus (e.g. charities) or as international/global public goods with provision resembling that of "private" provision. In this context, a key insight has been that private provision of public goods (in the ensuing Nash equilibrium) usually does not lead to an efficient solution but rather to some "underprovision" of the public good as compared to Pareto optimal levels (see Cornes and Sandler 1996, and Bergstrom, Blume, and Varian 1986).

In order to overcome the potentially fatal underprovision of international public goods, an obvious idea seems to be to try to transfer the top-down approach being applied for public good allocation at the national level to the international sphere. In the Lindahlian tradition this means that - analogous to a taxation scheme, a fair burden sharing rule must be established according to which the country-specific contributions to the public good are determined. It therefore does not come as a surprise that initially such a route has been taken in international negotiations on climate protection, which by now is considered as the most important global public good. But experience over many rounds of the "Conferences of the Parties" since the 1990s has demonstrated some quite foreseeable flaws of this top-down approach, which has inhibited global climate cooperation at the needed scale and which, in particular, has made the Kyoto Protocol as the basic international climate agreement only little effective. So, due to the absence of a central authority with coercive power

---

[2] Part I consists of three chapters which are slightly modified versions of Buchholz and Eichenseer (2017), Buchholz, Dippl, and Eichenseer (2015) and Buchholz and Eichenseer (2019). Likewise this brief introduction is adopted from Buchholz and Eichenseer (2017), Buchholz, Dippl, and Eichenseer (2015) and Buchholz and Eichenseer (2019).

and alternative sanction mechanisms, the pervasive free-rider problem could not be solved, and the enormous difficulties in reconciling divergent notions on equitable effort-sharing have repeatedly turned up in climate negotiations.

In face of these deficiencies global climate policy has changed its course to a bottom-up approach, which recently found its expression in the "Paris Agreement on Climate Change" concluded in December 2015 (e.g., Sandler 2017a, and Chen and Zeckhauser 2018). The expectation set on this agreement is that - beyond creating more transparency the pre-announced greenhouse gas abatement measures of some countries should induce higher abatement efforts of other countries and thus trigger a dynamic process towards a more effective global climate protection. For public good theory this change of paradigm in global climate policy provides some novel challenges like the need to get a deeper understanding for the role of leadership, i.e. agents who demonstrate good intentions in the voluntary provision of public goods (see Buchholz and Sandler 2017).

Against this background, Chapter 1 deals with a special kind of leadership, i.e. leadership in coalition building. Correspondingly, the research question is how coalition formation by one group of countries influences the coalition formation decision of another group. This chapter considers a two-stage game: at stage 1 the members of two groups of countries decide in a binary game whether they should form a coalition and at stage 2 then determine their contribution to a global public good cooperatively within their respective group. After describing the Nash equilibria of public good provision at stage 2, which result either after unilateral or bilateral coalition building at stage 1, we provide some characterization of the subgame-perfect equilibria of the entire game. Especially, we show that in many situations the coalition formation game at stage 1 will be of the chicken type, but that other game structures may emerge as well. Since partial cooperation by a smaller group of countries may undermine the willingness of a larger group to form a coalition some paradoxical effects can also be observed.

Chapter 2 considers another form of leadership, i.e. the case of leadership in technological development and technology transfer. It is motivated by the enormous difficulties which impede progress in global climate policy, i.e. to ensure international cooperation and coordination on greenhouse gas mitigation and to conclude an international climate agreement with ambitious and effectively binding obligations that are stable (see, e.g., Sandler 2004; Finus and Caparrós 2001, for a detailed theoretical analysis of these problems). The hope therefore is that - following a "bottom up approach" - pioneering activities of a coalition of leading countries might help to moderate global warming and thus increase the supply of this presumably most important public good. When considering such leading activities, the focus normally is on increased abatement efforts or transfers to outsider countries. But such unilateral measures are only of limited effectiveness as the countries outside the coalition may decrease their public good contributions as a reaction to the increased contributions made by the coalition (show "crowding-out" behaviour) so that, in the case of climate change "carbon leakage" results. In Sinn's (2012b) figurative terminology these outsider countries thus are "grabbing from the collection box" which reduces the positive effect on public good supply resulting from the pioneering activities (see, e.g., Andreoni 1988; Buchholz, Haslbeck, and Sandler 1998). Even worse, it is possible that total public good supply may decrease when countries unilaterally raise their abatement efforts before they enter climate negotiations (see Hoel 1991).

Quite similarly, the strategic context of privately (non-cooperatively) provided global public goods may impede incentives for innovation. It is a well-known fact that it may harm a country if it unilaterally reduces its costs for public good provision, i.e. develops and adopts better technologies even in the extreme case of a completely costless innovation (see Buchholz and Konrad 1994; Ihori 1996). The reason for this paradoxical effect is that a country-specific increase in public good productivity (which is equivalent to reduced costs of provision) concurrently increases the public good contribution of the country considered. Consequently, other countries react by reducing their own contributions so that crowding-out takes place. Anticipating this behavior, a country may block environmentally friendly technological progress based on strategic reasons. Buchholz and Konrad 1994 show that this may even be the case if countries cooperate in the future as a technological innovation moves the disagreement point in a more unfavorable position. Thus, the strategic environment may impede unilateral technological progress. However, as improved technologies offer the scope not only to reduce abatement costs in the countries which carry out the R&D-efforts but also in countries which get access to the improved technology[3] the question is what happens if there is a costless technological spillover to other countries.

Consequently, Chapter 2 considers a manifestation of leadership, which is not based on an increase of public good contributions. Rather, this chapter shows that pioneering activities, which are based on green technological innovations by members of a coalition of countries and a successive free transfer of the improved technology to other countries may be a convenient mean of leadership in global public good provision, e.g. in mitigating climate change. In an otherwise standard model of private public good supply, the success of such a policy depends on the costs of research and development (R&D) for the coalition of innovators, the number of countries within and outside the coalition and the outreach, i.e. the intensity and scope of technological spillovers. Moreover, Chapter 2 shows in the strategic context considered that a sufficient uptake of the improved technology by countries outside the coalition may be mandatory in order to provide innovation incentives for the coalition. Consequently, transfers of green technologies to less developed countries not only seem to be an appropriate remedy under fairness aspects but may also increase the research efforts in the developed countries and thus help make greenhouse gas abatement as a whole more efficient.

---

[3] The concept of international technology diffusion is discussed in Keller (2004). In addition, possible kinds and channels of technology transfer in environmentally-friendly technologies are described in Newell (2010), Popp (2011), Glachant et al. (2013), Popp (2015) and with a focus on climate negotiations in De Coninck and Sagar (2015). Moreover, existing approaches to and possibilities of collaborative efforts for R&D in climate technologies and technology transfers to developing countries are considered in Ockwell, Sagar, and De Coninck (2015).

Subsequently, Chapter 3 considers the interplay between technological progress and leadership which is expressed by going ahead in contributing to a public good (sequential provision). This chapter is motivated by the prominent role of leadership in the scientific and public debate on global public goods, for which climate protection is the most prominent example. On the one hand, climate policy in some countries like Germany has been driven by the hope that leadership by a country or a group of countries will improve public good provision and global welfare. On the other hand, it has been shown in the framework of standard public good theory (see, e.g., Sandler 1992, pp. 57 – 58, and Varian 1994) that due to the strategic reduction of the leader's public good contribution the leader-follower (Stackelberg) game with sequential moves brings about a smaller public good supply than the game with simultaneous moves. In consequence "the tendency toward underprovision is even more marked at the equilibrium of the sequential process than at the Nash-Cournot equilibrium" (Cornes and Sandler 1996, p. 331). But also, in a cooperative scenario (see, e.g., Chen and Zeckhauser 2018), in which a bargaining solution is attained, leadership may be detrimental to public good supply (see Hoel 1991 and Buchholz and Konrad 1994).

There have been a lot of attempts to support the position of leadership optimists (see Edenhofer et al. 2015, and Schwerhoff 2016, for overviews), e.g. by taking into account that leadership may resolve uncertainties about the costs and benefits of public goods (see Hermalin 1998, and Brandt 2004) or may cause positive technological externalities which automatically reduce contribution costs in other countries (see Stranlund 1996 or Buchholz, Dippl, and Eichenseer 2015). The interaction between technology spillovers and information transmission through signalling may even foster the positive effects of leadership (Mideksa 2016). Moreover, leadership proves to be successful when it facilitates communication (see Barbieri 2012) or by integrating features of behavioural economics when the agents involved have other-regarding preferences or expectations of reciprocity (see Buchholz and Sandler 2017).

Chapter 3 shows that the result of standard public good theory that the total amount of greenhouse gas mitigation (or public good supply in general) will be lower in a leader-follower (Stackelberg) game than in a simultaneous Nash game needs no longer be true when the leading country has the option to employ a technology by which it can reduce its abatement costs and thus improve the productivity of its contribution technology. In this case both countries are also better off in the Stackelberg game than in the Nash game. The general result is illustrated by an example with Cobb-Douglas preferences and, finally, an empirical application to global climate policy is briefly discussed. Summing up, Chapter 3 adds a further argument to support the belief that leadership can have a positive effect both on the level of public good supply and on the utilities of the countries involved.

1

LEADERSHIP IN COALITION BUILDING[4]

1.1 INTRODUCTION

For public good theory the change of paradigm in global climate policy towards a bottom-up approach provides some novel challenges as, e.g., the need of a deeper understanding of the role which the demonstration of good intentions by pioneers can play for the voluntary provision of public goods (see Buchholz and Sandler 2017). This chapter will deal with a special one among these issues, i.e. how coalition formation by one group of countries influences the coalition formation decision of another group. It crucially depends on this incentive effect whether it can be expected that cooperation within one group stimulates cooperation by another group, which is clearly relevant for assessing the prospects of success of the bottom-up approach. In particular, we will explore in a two-stage game how the size of the two potential coalitions affect their decision in favor of partial cooperation within their group. We thus determine the Nash equilibria at the first coalition formation stage of the entire two-stage game, whose second stage is given by a standard model of voluntary public good provision as in Cornes and Sandler (1996). The mirror image of coalition formation is strategic decentralization as considered by Eckert (2003), Buchholz, Haupt, and Peters (2013) and Foucart and Wan (2018) who treat similar questions but apply a more special framework. The method which is applied for our analysis will be the Aggregative Game Approach (AGA) which facilitated the theoretical analysis of public good provision substantially (see Cornes and Hartley 2007, and with specific application to issues in environmental economics Cornes 2016).

The chapter will be organized as follows: After presenting the theoretical framework in Section 2, Sections 3 and 4 describe which Nash equilibria will arise at stage 2, when either one group or both groups have decided to cooperate at stage 1. In Section 5 we then analyze a group's decision to form a coalition given that the members of the other group either act in isolation or are cooperating. In this context, we will - unlike Buchholz, Haslbeck, and Sandler (1998) - not consider utility effects of small variations of a coalition's public good contribution but instead assume unmitigated utility maximization of a coalition as collective Nash reaction to the public good contributions of the other group (as in Buchholz, Cornes, and Rübbelke 2014 and Vicary 2018). Therefore, corner solutions in which one of the group does not make any public good contribution at all, are of particular importance in the context of this chapter. Based on this we explore in Section 6 the properties of the Nash equilibria at the coalition formation stage in which the groups anticipate the outcome at the second contribution stage, thus characterizing the subgame-perfect equilibria for the entire two-stage game. In Section 6 we also

---

[4] This chapter is a slightly modified version of Buchholz and Eichenseer (2017).

briefly consider a version of the game in which one of the two groups acts as the first mover at the coalition formation stage. These results are illustrated by specific examples with Cobb-Douglas preferences in Section 7. Section 8 concludes.

1.2 THE FRAMEWORK

There are two groups of otherwise identical countries K and M of size $k \geq 2$ and $m \geq 2$, respectively. Each country i is characterized by its initial private good endowment w and its utility function $u(x_i, G)$, where x_i denotes agent i's level of private consumption and G indicates public good supply. Each utility function is assumed to have the standard properties, i.e., it is twice continuously differentiable, quasi-concave, and strictly monotone increasing in both variables. Moreover, both goods are assumed to be non-inferior.

The main ingredient of the AGA, which in the following is used to characterize equilibria, are *(income) expansion paths*, which are well-known from standard household theory. For any marginal rate of substitution $mrs = \rho$ between the private and the public good the associated expansion path is given by $e(G, \rho)$, which is a well-defined and strictly monotone increasing (and differentiable) function of G. In x_i-G-space, such an expansion path connects all points (x_i, G) at which country i's indifference curves have slope $-\rho$ so that $\rho = \frac{\partial u/\partial x_i}{\partial u/\partial G}(x_i, G)$ holds. In order to avoid the tedious treatment of sub-cases, we assume $e(0, \rho) = 0$ and $\lim\limits_{G \to \infty} e(G, \rho) = \infty$, which, e.g., results when preferences are of the Cobb-Douglas type.

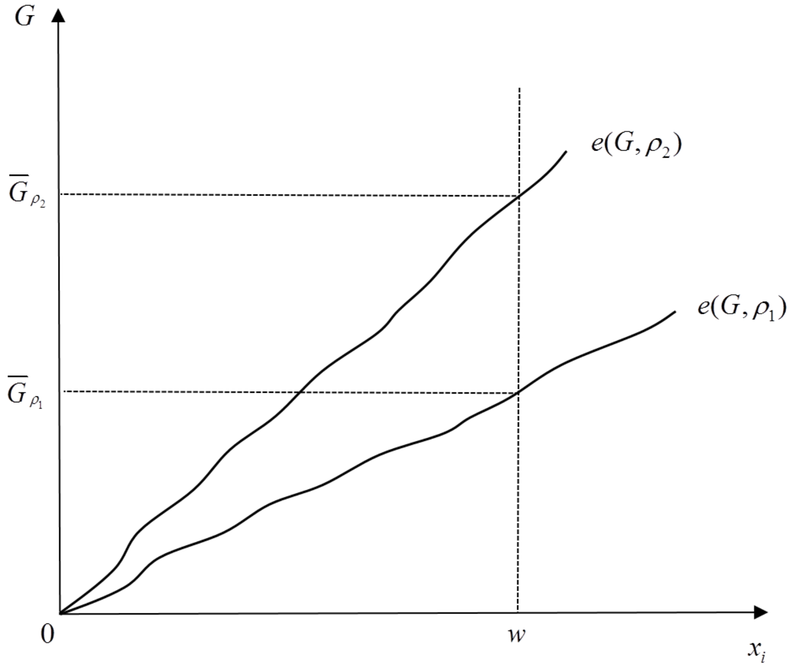


Figure 1.1: Expansion paths

As in Andreoni (1988) and Andreoni and McGuire (1993) let $\bar{G}_\rho$ be that level of public good supply for which the condition $e(\bar{G}_\rho, \alpha) = w$ is fulfilled. Convexity of indifference curves implies $e(G, \rho_2) < e(G, \rho_1)$ if $\rho_2 > \rho_1$ and thus $\bar{G}_{\rho_2} > \bar{G}_{\rho_1}$ (see Figure 1.1).

The public good is produced by a summation technology. We assume that all countries have the same marginal rate of transformation between the private and the public good, which is normalized to one. If a country i's public good contribution is $g_i = w - x_i \geq 0$ aggregate public good supply then becomes $G = \sum\limits_{i=1}^{n} g_i$ where $n := k + m$. An allocation $(x_1, ..., x_n, G)$ thus is feasible if and only if:

$$G + \sum_{i=1}^{n} x_i = nw \tag{1}$$

holds.

Public good supply in the standard Nash equilibrium $E^N(n)$, in which all n countries act non-cooperatively, is denoted by $G^N(n)$, which is given by the condition

$$G^N(n) + ne(G^N(n), 1) = nw. \tag{2}$$

The characterization of the Nash equilibrium as provided by (2) is based on the feasibility constraint (1) and on the fact that a country, which actively contributes to the public good, only is in an equilibrium position if its marginal rate of substitution coincides with the marginal rate of transformation $mrt = 1$, i.e. if its position is on the expansion path $e(G, 1)$. Since expansion paths are upward sloping, it directly follows from (2) that $G^N(n) < \bar{G}_1$.

The Nash equilibrium $E^N(n)$ only depends on the total number $n = k + m$ of countries, and it is symmetric and interior, i.e. each country makes a strictly positive contribution to the public good. In $E^N(n)$ each country's private consumption is $x^N(n) = e(G^N(n), 1)$, so that a country's utility in the standard Nash equilibrium is $u^N(n) = u(e(G^N(n), 1), G^N(n))$.

In the Cobb-Douglas case with the utility function $u(x_i, G) = x_i^\alpha G$, which will be used as an illustration throughout the chapter, we have $e(G, 1) = \alpha G$ so that condition (2) gives $G^N(n) = \frac{nw}{1+n\alpha}$ and thus $x^N(n) = \frac{n\alpha w}{1+n\alpha}$ and $u^N(n) = \alpha^\alpha \left(\frac{nw}{1+n\alpha}\right)^{1+\alpha}$.

In the following we consider, besides the Nash equilibrium $E^N(n)$, three other equilibria $E^{AK}(k, m)$, $E^{AM}(k, m)$ and $E^B(k, m)$, which result when either the countries in group K (AK-scenario) or in group M (AM-scenario) alone or the countries in both groups K and M (B-scenario) are forming a coalition and cooperatively determine their public good contributions within their group. For $L = K, M$ public good supply in $E^{AL}(k, m)$ will be denoted by $G^{AL}(k, m)$ and private consumption of a country in group K by $x_K^{AL}(k, m)$ and of a country in group M by $x_M^{AL}(k, m)$. In $E^B(k, m)$ the respective quantities are $G^B(k, m)$, $x_K^B(k, m)$ and $x_M^B(k, m)$.

As will be shown in the next sections, the equilibria $E^A(k, m)$ and $E^B(k, m)$ may be standalone allocations in which only one of the two groups K or M makes a positive contribution to the public good. Generally, for group

$L = K, M$ of countries with size $l = k, m$ public good supply $G^S(l)$ in the standalone allocation $E^S(l)$ is characterized by the condition

$$G^S(l) + le(G^S(l), l) = lw. \tag{3}$$

Condition (3) follows from the maximization of utility $u(w - g_L, lg_L)$ of a member of L, i.e. under the assumption of equal burden-sharing among the countries in L when they cooperatively determine their public good contribution. The allocation $E^S(l)$ thus is the symmetric Lindahl solution for group L. In $E^S(l)$ private consumption of a member of group L is $x^S(l) = e(G^S(l), l)$ and $G^S(l) < \bar{G}_l$ holds (see Figure 1.2).

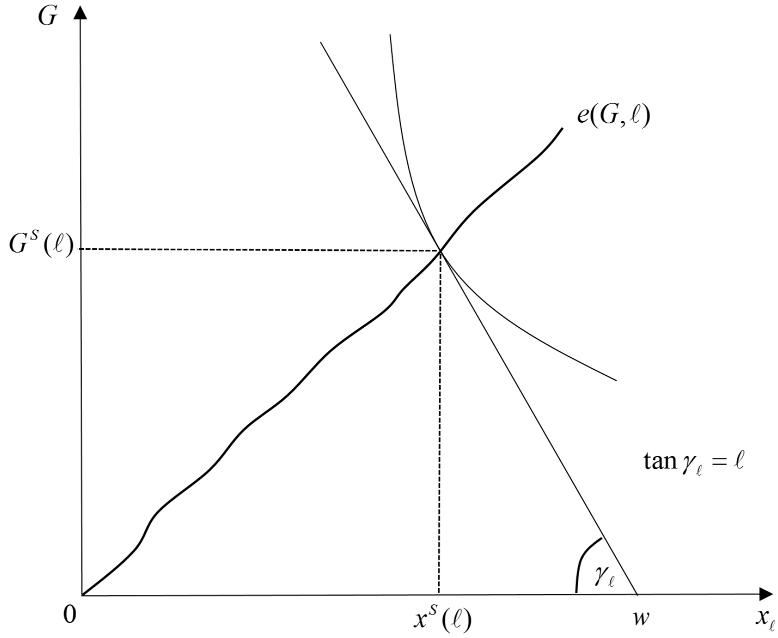


Figure 1.2: Lindahl equilibrium positions

In $E^S(l)$ a member of group L has utility $u^S(l) = u(x^S(l), G^S(l))$, while utility of a free-rider F, which does not contribute to the public good and thus has private consumption $x_F^S(l) = w$, is $u_F^S(l) = u(w, G^S(l))$. Non-inferiority of the public good implies that $G^S(l)$ is increasing in group size l. In the Cobb-Douglas case with utility function $u(x_i, G) = x_i^\alpha G$ we especially have $G^S(l) = \frac{lw}{1+\alpha}$, $x^S(l) = \frac{\alpha w}{1+\alpha}$, $u^S(l) = l\alpha^\alpha \left(\frac{w}{1+\alpha}\right)^{1+\alpha}$ and $u_F^S(l) = \frac{lw^{1+\alpha}}{1+\alpha}$.

How the two equilibria based on one-sided and both-sided partial cooperation, respectively, look like and how they depend on group sizes k and m will now be explored in detail.

1.3 UNILATERAL COOPERATION

In the AK-scenario group K jointly determines the public good contributions g_K^{AK} of each of its members collectively playing Nash against group M , whose members still choose their contributions g_M^{AK} non-cooperatively as in the standard Nash equilibrium. An interior Nash equilibrium $E^{AK}(k, m)$, in which both the countries in group K and group M make positive contributions to the public good, can be characterized with the help of the AGA in a straightforward way. For that purpose let a public good supply level $G_I^{AK}(k,m)$ be given by the condition

$$G_I^{AK}(k,m) + ke(G_I^{AK}(k,m),k) + me(G_I^{AK}(k,m),1) = (k+m)w. \tag{4}$$

Existence and uniqueness of $G_I^{AK}(k,m)$ follows from continuity and monotonicity of the expansion paths. Based on (4) we get a first characterization of $E^{AK}(k,m)$.

Proposition 1. *If $E^{AK}(k,m)$ is interior we have $G^{AK}(k,m) = G_I^{AK}(k,m) < \bar{G}_1$, $x_K^{KA}(k,m) = e(G_I^{AK}(k,m),k) < w$ and $x_M^{AK}(k,m) = e(G_I^{AK}(k,m),1) < w$.*

Proof. On the one hand, if group K - again under the assumption of symmetric burden-sharing - determines its joint Nash reaction kg_K to the aggregate public good contributions mg_M of group M, it maximizes utility of each member $u(w - g_K, kg_K + mg_M)$. This in particular means that in case of cooperation every country in K faces $mrt = k$ as its individual marginal rate of transformation between the private and the public good. If the solution of this optimization leads to a positive public good contribution each country in K attains a position where $mrs = mrt = k$ holds, i.e. a position on the expansion path $e(G,k)$. On the other hand, the position of the countries in group M is still on the income expansion path $e(G,1)$ when their public good contribution is positive. In combination with the feasibility constraint (1) this shows that an interior $E^{AK}(k,m)$ is characterized by condition (4). Interiority implies that $e(G_I^{AK}(k,m),k) < e(G_I^{AK}(k,m),1) < w$ and thus $G_I^{AK}(k,m) < \bar{G}_1$. □

The equilibrium $E^{AK}(k,m)$, however, need not be interior. The solution may also be a corner equilibrium, in which either only the group K or the group M actively contribute to the public good. We first show that the latter case can be excluded, which is in contrast to the scenario in which the coalition acts as a Stackelberg leader (Buchholz, Cornes, and Rübbelke 2014).

Proposition 2. *A corner equilibrium $E^{AK}(k,m)$, in which only the outsider group M contributes to the public good, can never occur.*

Proof. If only the members of group M made a positive contribution, public good supply would become $G^N(m)$, which in analogy to condition (2) is defined by the condition $G^N(m) + me(G^N(m),1) = mw$. Since $G^N(m) < \bar{G}_1 < \bar{G}_k$, non-inferiority would imply that the *mrs* of the members of K at $(w, G^N(m))$ is smaller than k, so that being confronted with $G^N(m)$ - coalition K would have an incentive to contribute to the public good. This, however, is not compatible with an equilibrium outcome. □

The other type of a corner solution is the symmetric standalone equilibrium $E^S(k)$ of coalition K. The following result provides criteria by which it can be determined whether the interior solution or the standalone allocation $E^S(k)$ emerges as the equilibrium outcome of the contribution game.

Proposition 3. *$E^{AK}(k,m)$ is interior if $G_I^{AK}(k,m) < \bar{G}_1$ or, equivalently, if $G^S(k) < \bar{G}_1$. Otherwise, $E^{AK}(k,m)$ is the corner solution $E^S(k)$.*

Proof.

(i) As a first step we show that the two conditions for interiority are equivalent: Assume $G^S(k) < \bar{G}_1$. Since in this case $e(G^S(k), 1) < w$, it follows from $G^S(k) + ke(G^S(k), k) = kw$ that

$$G^S(k) + ke(G^S(k), k) + me(G^S(k), 1) < (k+m)w. \tag{5}$$

But as $G + ke(G, k)$ is increasing in G and $e(\bar{G}_1, 1) = w$ we have

$$\bar{G}_1 + ke(\bar{G}_1, k) + me(\bar{G}_1, 1) > (k+m)w. \tag{6}$$

This implies that public good supply $G_I^{AK}(k, m)$, which satisfies (4), must lie in the interval $(G^S(k), \bar{G}_1)$ and thus, in particular, is smaller than $\bar{G}_1$. Conversely, if $G_I^{AK}(k, m) < \bar{G}_1$ it is shown by a similar argument that $G^S(k) < G_I^{AK}(k, m)$ holds.

(ii) Let $G_I^{AK}(k, m) < \bar{G}_1$. Then $e(G_I^{AK}(k, m), k) < w$ and $e(G_I^{AK}(k, m), 1) < w$, and the countries in K and M are in an equilibrium position when they make the strictly positive public good contributions $g_{IK}^{AK} = w - e(G_I^{AK}(k, m), k)$ and $g_{IM}^{AK} = w - e(G_I^{AK}(k, m), 1)$, respectively. This shows that the allocation as defined by condition (4) is a Nash equilibrium $E^{AK}(k, m)$. It is the only one since the interior solution is unique, and group K's standalone allocation can be excluded: From part (i) of the proof we know that $G_I^{AK}(k, m) < \bar{G}_1$ implies $G^S(k) < \bar{G}_1$. Then the countries in M would have an incentive to contribute to the public good when being confronted with $G^S(k)$ so that coalition K's standalone allocation cannot be an equilibrium.

(iii) Assume that the conditions stated in the Proposition are not fulfilled, i.e. especially that $G^S(k) \geq \bar{G}_1$ holds. Given $G^S(k)$ the countries in group M then have no incentive to contribute to the public good since in their complete free-rider position $(w, G^S(k))$ their *mrs* is larger than their marginal rate of transformation $mrt = 1$. Therefore, K's standalone allocation $E^S(k)$ is a $E^{AK}(k, m)$, and it is the only one since an interior solution is excluded by Proposition 1 as $G_I^{AK}(k, m) \geq \bar{G}_1$ in this case.

□

It is a direct consequence of Proposition 3 that $E^{AK}(k, m)$ always exists and is unique. We now show how the fulfillment of the criteria described by Proposition 3 depends on the size of the two groups K and M.

Proposition 4. *There is a coalition size* $\bar{k}_A \geq 2$ *so that, independent of the size of the outsider group* m, $E^{AK}(k, m)$ *is coalition* K*'s standalone allocation* $E^S(k)$ *if and only if* $k \geq \bar{k}_A$.

Proof. Let $\bar{k}_A = \min_{k \geq 2} \{k \in : G^S(k) \geq \bar{G}_1\}$. Existence of $\bar{k}_A$ is ensured as there clearly exists some k for which the budget line $G = -kx_i + kw$ cuts the indifference curve passing through $(w, \bar{G}_1)$ so that $G^S(k) > \bar{G}_1$ definitely holds for such k.

The threshold level $\bar{k}_A$ defined in this way is independent of m as $\bar{G}_1$ is independent of m. Following Proposition 3, $\bar{k}_A$ has the required properties. Neglecting that $\bar{k}_A$ has to be a natural number it can be determined as in Figure 1.3. $\square$

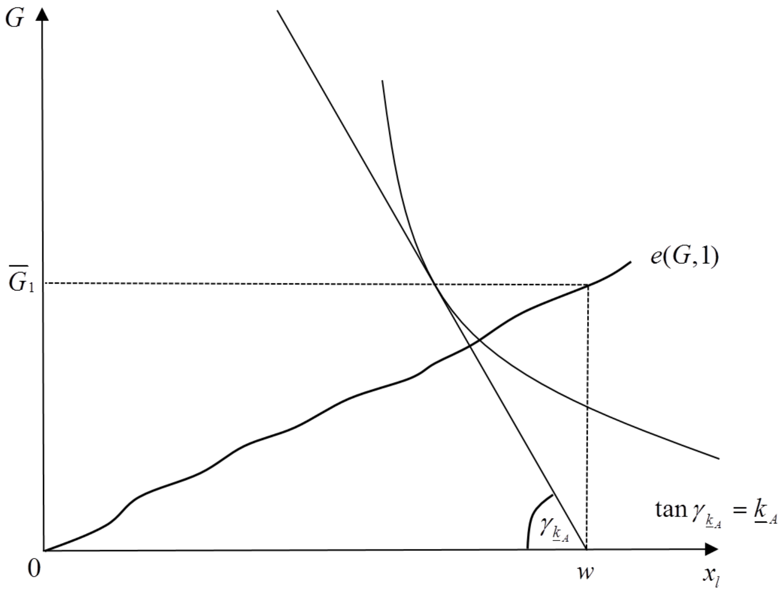


Figure 1.3: Threshold $\bar{k}_A$

When all agents have the Cobb-Douglas utility function $u(x_i, G) = x_i^{\alpha} G$ we have $e(G, \rho) = \frac{\alpha}{\rho} G$ for some given $\rho > 0$ so that $\bar{G}_1 = \frac{w}{\alpha}$. As $G^S(k) = \frac{kw}{1+\alpha}$ the construction in the proof of Proposition 4 yields $\bar{k}_A = \min\limits_{k \geq 2} \{k \in \mathbb{N} : k \geq \frac{1+\alpha}{\alpha}\}$. For $\alpha \geq 1$, we thus get $\bar{k}_A = 2$ so that an interior equilibrium never occurs in this case. But if $\alpha < 1$ is sufficiently close to zero, interior Nash equilibria may emerge for arbitrarily large coalitions since $\lim\limits_{\alpha \to 0} \frac{1+\alpha}{\alpha} = \infty$.

The equilibrium $E^{AM}(k, m)$, which results when only group M cooperates, is obtained from the considerations above by interchanging the roles between K and M. As seen by Proposition 4, it completely depends on the size of group M, which type of equilibrium arises in this case: If $m < \bar{m}_A := \bar{k}_A$ there is an interior solution, in which public good supply G^{AM} is G_I^{AM} given by the condition

$$G_I^{AM} + ke(G_I^{AM}, 1) + me(G_I^{AM}, m) = (k+m)w. \tag{7}$$

If, however, $m \geq \bar{m}_A$, the equilibrium outcome $E^{AM}(k, m)$ is the standalone equilibrium of group M, which implies $G^{AM} = G^S(m)$. The positions attained by the members of group K clearly are $(x_K^{AM}, G^{AM}) = (e(G_I^{AM}, 1), G_I^{AM})$ if $m < \bar{m}_A$ and $(x_K^{AM}, G^{AM}) = (w, G^S(m))$ if $m \geq \bar{m}_A$.

1.4 BILATERAL COOPERATION

In the second scenario both groups K and M internally cooperate when determining public good contributions of their members g_K^B and g_M^B , but play non-cooperatively against each other. Again, the AGA can be applied to characterize the interior equilibria of this game with two-sided partial cooperation. For that purpose let an allocation $E_I^B(k,m)$ with public good supply $G_I^B(k,m)$ be given by the equation

$$G_I^B(k,m) + ke(G_I^B(k,m),k) + me(G_I^B(k,m),m) = (k+m)w. \tag{8}$$

Existence and uniqueness of $G_I^B(k,m)$ again follows from the properties of expansion paths. In complete analogy to Proposition 1 we obtain the following result:

Proposition 5. *If $E^B(k,m)$ is interior we have $G^B(k,m) = G_I^B(k,m) < \min\left\{\bar{G}_k, \bar{G}_m\right\}$, $x_K^B(k,m) = e(G_I^B(k,m),k) < w$ and $x_M^B(k,m) = e(G_I^{AK}(k,m),m) < w$.*

Utilities are of the members of group K and the members of group M then are denoted by $u_I^{BK}(k,m)$ and $u_I^{BM}(k,m)$, respectively. In contrast to the case of unilateral cooperation it now becomes possible that the outcome is the standalone equilibrium of each group either.

Proposition 6. *$E^B(k,m)$ is interior if $G_I^B(k,m) < \min\left\{\bar{G}_k, \bar{G}_m\right\}$ or, equivalently, if $G^S(k) < \bar{G}_m$ and $G^S(m) < \bar{G}_k$. If, instead, $G^S(m) \geq \bar{G}_k$, $E^B(k,m)$ is the corner solution $E^S(m)$, and if $G^S(k) \geq \bar{G}_m$, $E^B(k,m)$ is the corner solution $E^S(k)$.*

Proof.

(i) It is shown in an analogous way as in the proof of Proposition 3 that the two conditions for interiority are equivalent and that $E^B(k,m) = E_I^B(k,m)$ in this case.

(ii) Let $G^S(k) \geq \bar{G}_m$. Given $G^S(k)$ the countries in M then have no incentive to make a collective contribution to the public good since at $(w, G^S(k))$ their *mrs* is larger than their *mrt* $= m$, so that $E^S(k)$ is an equilibrium. It is the only one since, on the one hand, an interior solution is excluded by (i). On the other hand, the standalone allocation of group M is not possible as $G^S(m) < \bar{G}_m \leq G^S(k) < \bar{G}_k$. But $G^S(m) < \bar{G}_k$ implies that the countries in K would have an incentive to contribute when they are confronted with public good supply $G^S(m)$. The case $G^S(m) \geq \bar{G}_k$ is treated in the same way.

□

Existence of and uniqueness of $E^B(k,m)$ follows from Proposition 6 as its three cases cover all possible situation and are mutually exclusive since $G^S(k) \geq \bar{G}_m$ implies $G^S(m) < \bar{G}_k$. We now show how the fulfillment of the criteria described by Proposition 6 depends on the size of the two groups K and M.

Proposition 7. *For any $m \geq 2$ there exist threshold levels $\underline{k}_B(m)$ and $\bar{k}_B(m)$, for which $\bar{k}_B(m) > m > \underline{k}_B(m) \geq 0$ holds and which are both increasing in m, so that*

(i) $E^B(k,m) = E^S(m)$ *if* $k \leq \underline{k}_B(m)$.

(ii) $E^B(k,m) = E^B_I(k,m)$ *if* $\underline{k}_B(m) < k < \bar{k}_B(m)$.

(iii) $E^B(k,m) = E^S(k)$ *if* $k \geq \bar{k}_B(m)$.

Furthermore, $\lim\limits_{m\to\infty} \underline{k}_B(m) = \lim\limits_{m\to 0} \bar{k}_B(m) = \infty$.

Proof.
Let $\underline{k}_B(m) = \max\left\{k \in \mathbb{N} : \bar{G}_k \leq G^S(m)\right\}$ and $\bar{k}_B(m) = \min\left\{k \in \mathbb{N} : G^S(k) \geq \bar{G}_m\right\}$. The assertions in (i), (ii) and (iii) then are a direct consequence of Proposition 6. Monotonicity of $\underline{k}_B(m)$ and $\bar{k}_B(m)$follows as $\bar{G}_m$ and $G^S(m)$are monotone increasing in m. That any given m lies in the interiority range follows since

$$\bar{G}_m + 2e(\bar{G}_m, m) = \bar{G}_m + 2mw > 2mw \tag{9}$$

so that for $k = m$ the equation (8) has a solution $G^B_I(m,m) < \bar{G}_m$. To show $\lim\limits_{m\to\infty} \underline{k}_B(m) = \infty$ we prove that $G^S(m)$ cannot be bounded above. Otherwise, if there were an upper bound $\bar{G}^S < \infty$ of $G^S(m)$, we would get a contradiction by choosing some m for which the budget line with slope m starting at $(w, 0)$ cuts the indifference curve passing through $(w, \bar{G}^S)$. □

The set of k, for which according to (i) a standalone equilibrium of group M results, may be empty. The sets of k as defined by (ii) and (iii) in Proposition 7, however, are non-empty for all $m \geq 2$. For (ii) this follows by letting $k = m$ and for (iii) through an argument as in the proof of Proposition 4. In the Cobb-Douglas case with the utility function $u(x_i, G) = x_i^\alpha G$ we especially have $\bar{G}_k = \frac{k}{\alpha}w$, $\bar{G}_m = \frac{mw}{\alpha}$, $G^S(k) = \frac{kw}{1+\alpha}$ and $G^S(m) = \frac{mw}{1+\alpha}$. Real-numbered threshold levels $\underline{k}_B(m)$ and $\bar{k}_B(m)$ then are defined by $\bar{G}_{\underline{k}_B(m)} = \frac{\underline{k}_B(m)w}{\alpha} = \frac{mw}{1+\alpha} = G^S(m)$ and $G^S(\bar{k}_B(m)) = \frac{\bar{k}_B(m)w}{1+\alpha} = \frac{mw}{\alpha} = \bar{G}_m$, respectively, which gives

$$\underline{k}_B(m) = \frac{\alpha}{1+\alpha}m \qquad \textit{and} \qquad \bar{k}_B(m) = \frac{1+\alpha}{\alpha}m. \tag{10}$$

The both equations in (10) also show that $-$ given some α $-$ an increase of group size m enlarges the sets of k, leading to a standalone equilibrium of group M and an interior equilibrium, while it reduces the set of k, leading to a standalone equilibrium of group K. Moreover, an increasing preference for the private good α makes both types of standalone equilibria more likely and an interior solution more unlikely.

If $\underline{k}_B(m) < k < \bar{k}_B(m)$ a straightforward application of condition (8) to the Cobb-Douglas case gives $G^B_I(k,m) = \frac{(k+m)w}{1+2\alpha}$ for public good supply and $x^{BK}_I(k,m) = e(G^B_I, k) = \frac{\alpha(k+m)w}{k(1+2\alpha)}$ and $x^{BM}_I(k,m) = e(G^B_I, m) = \frac{\alpha(k+m)w}{m(1+2\alpha)}$ for private consumption of the countries in K and M, respectively.

1.5 INCENTIVES FOR COALITION FORMATION

We now explore whether in a two-stage game the group K has an incentive to form a coalition at stage 1 given that the members of group M either have formed a coalition or not. Therefore we have to compare utility of the countries in K between the allocations $E^N(k,m)$ and $E^{AK}(k,m)$ on the one hand and between allocations $E^B(k,m)$ and $E^{AM}(k,m)$ on the other. Albeit for different reasons in both cases group K will have a weaker (stronger) incentive for partial cooperation when it is small (large) while group M is large (small).

1.5.1 *The Optimal Coalition Formation Decision of Group K when Group M does not Cooperate*

According to Proposition 2 we have to distinguish between the cases, in which $E^{AK}(k,m)$ is an interior solution or $E^{AK}(k,m)$ is the standalone allocation of group K, i.e. if according to Proposition 4 either $k < \bar{k}_A$ or $k \geq \bar{k}_A$.

For the treatment of the first case $k < \bar{k}_A$ let for any $\xi \in [0,k]$ public good supply $\tilde{G}_I^{AK}(\xi,m)$be given by

$$\tilde{G}_I^{AK}(\xi,m) + ke(\tilde{G}_I^{AK}(\xi,m),\xi) + me(\tilde{G}_I^{AK}(\xi,m),1) = (k+m)w. \tag{11}$$

We obtain $G^N(k+m) = \tilde{G}_I^{AK}(1,m)$ and $G_I^{AK}(k,m) = \tilde{G}_I^{AK}(k,m)$ as special cases. The function $\tilde{u}_I^{AK}(\xi)$ indicates utility a member of K attains at some $\xi \in [1,k]$, where private consumption is $\tilde{x}_I^{AK}(\xi,m) = e(\tilde{G}_I^{AK}(\xi,m),\xi)$. Omitting arguments, using e_1^K and e_2^K as abbreviations for the two partial derivatives of the expansion path $e(G,\rho)$ at $G = \tilde{G}_I^{AK}(\xi,m)$ and $\rho = \xi$ and e_1^M for the first partial derivative of the expansion path $e(G,1)$ at $G = G_I^{AK}(\xi,1)$, and observing that $\xi = \frac{u_1(x_I^{AK},G_I^{AK})}{u_2(x_I^{AK},G_I^{AK})}$ we get, similarly as on p.629 in Boadway and Hayashi (1999),

$$\frac{\partial \tilde{u}_I^{AK}}{\partial \xi} = u_2((\xi e_1^K + 1)\frac{\partial \tilde{G}_I^{AK}}{\partial \xi} + \xi e_2^K). \tag{12}$$

Total differentiation of (11) gives

$$\frac{\partial \tilde{G}_I^{AK}}{\partial \xi} = \frac{-ke_2^K}{1 + ke_1^K + me_1^M}. \tag{13}$$

Combining (12) and (13) and having in mind that the normality assumption implies $e_1^K > 0$, $e_1^M > 0$ (so that the denominator of (13) is positive) and $e_2^K < 0$ yields

$$\frac{\partial \tilde{u}_I^{AK}}{\partial \xi} < 0 \quad \text{if and only if} \quad k < \xi(1 + e_1^M) > 0. \tag{14}$$

If the slope of the expansion path w.r.t. G is bounded from below by $\underline{e}_1$, condition (14) leads to the following result:

Proposition 8. *If group M does not cooperate, group K does not benefit from forming a coalition if*

$$k < \min\left\{\bar{k}_A, 1 + m\underline{e}_1\right\}. \tag{15}$$

Proof. Condition (15) implies that (14) is fulfilled for all $\xi \in [0, k]$ so that $\tilde{u}_I^{AK}(\xi)$ is decreasing for all $\xi \in [1, k]$, which yields $u_K^{AK}(k+m) = \tilde{u}_I^{AK}(k) < \tilde{u}_I^{AK}(1) = u^N(k+m)$. ☐

For the treatment of the second case where $k \geq \bar{k}_A$ we first define

$$k_A^* = \min_{k \geq 2}\left\{k \in \mathbb{N} : u^S(k) \geq u(w, \bar{G}_1)\right\}. \tag{16}$$

In a x_i-G-diagram the threshold level k_A^* is obtained as the minimum value of group size k for which the budget line with slope k cuts the indifference curve passing through the point $(w, \bar{G}_1)$. Neglecting again that k_A^* has to be an integer, it is characterized by the tangent to this indifference curve passing through the point $(w, 0)$ (see Figure 1.4). Clearly, k_A^* exists and $k_A^* > \bar{k}_A$.

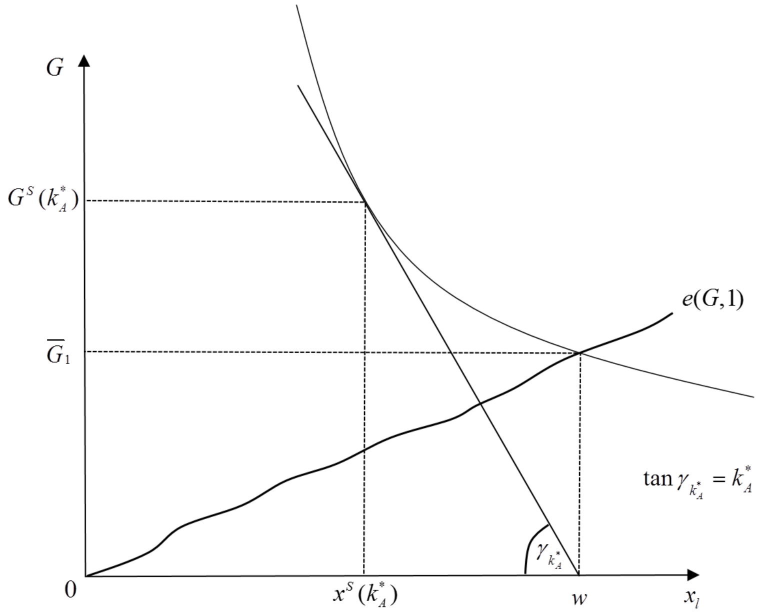


Figure 1.4: Threshold k_A^*

For any integer $m \geq 2$ we furthermore define

$$k_A^*(m) = \min_{k \geq 2}\left\{k \in \mathbb{N} : u^S(k) > u^N(k+m)\right\}. \tag{17}$$

Since $x^N(k+m) < w$ and $G^N(k+m) < \bar{G}_1$ and thus $u^S(k_A^*) > u^N(k+m)$ for all k and m, $k_A^*(m)$ exists and $k_A^*(m) \leq k_A^*$ holds for all $m \geq 2$. Based on (17) conditions can be provided, which ensures that coalition formation is the optimal reaction of group K.

Proposition 9. *If group M does not cooperate, the members of group K will benefit from forming a coalition if*

$$k \geq \overset{\frown}{k}_A(m) := \max\left\{\bar{k}_A, k^*_A(m)\right\} \tag{18}$$

For any $k \geq k^*_A$ holds coalition formation is profitable for group K even independent of the size m of group M.

Proof. The result directly follows from the definitions of $\bar{k}_A$, $k^*_A(m)$and k^*_A . ☐

Both Proposition 8 and 9 confirm that coalition building is fostered, when group K is large and the outsider group M is small.

1.5.2 *The Optimal Coalition Formation Decision of Group K when Group M Cooperates*

To explore whether group K has an incentive to cooperate, when group M does we have to compare utility of its members in the allocations $E^{AM}(k, m)$ and $E^B(k, m)$. To simplify the exposition we concentrate on the situation where the standalone solution of group M emerges as Nash equilibrium at the contribution stage when group K does not cooperate, i.e. $E^{AM}(k, m) = E^S(m)$ and $m \geq \bar{m}_A$, and the members of K have utility $u^S_F(m)$ when they do not cooperate. First of all, it is straightforward to provide a condition which ensures that group K prefers non-cooperation in this case.

Proposition 10. *If group M cooperates and $m \geq \bar{m}_A$ group K does not benefit from forming a coalition if $k < \underline{k}_B(m)$.*

Proof. It follows from Proposition 7 that a cooperating group K does not want to make a positive contribution to the public good if $k < \underline{k}_B(m)$. Thus $E^B(k, m) = E^{AM}(k, m)$ so that coalition formation would not make a change. ☐

When $\underline{k}_B(m) < k < \bar{k}_B(m)$ and hence $E^B(k, m)$ is interior, cooperation K may also not pay for the members of group K. So one can expect that cooperation will reduce utility of the countries in K below their utility in the standalone equilibrium of group M if group size k lies only slightly above the lower interiority threshold $\underline{k}_B(m)$. To show this let for a continuous variable $\xi \geq \underline{k}_B(m)$ public good supply $G^B_I(\xi, m)$ be defined by

$$G^B_I(\xi, m) + \xi e(G^B_I(\xi, m), \xi) + me(G^B_I(\xi, m), m) = (\xi + m)w. \tag{19}$$

If $u^{BK}_I(\xi, m)$ denotes utility, which a member of coalition K then attains at ξ, we get the following result where $\underline{\xi}_B(m)$ is given by $G_{\underline{\xi}_B} = G^S(m)$.

Proposition 11. *There is some threshold $\underline{\chi}$ so that for all $\xi \in \left[\underline{\xi}_B(m), \underline{\chi}\right]$ utility $u^{BK}_I(\xi, m)$ is falling in ξ.*

Proof. See the Appendix A. ☐

A straightforward implication of Proposition 11 is that under some additional conditions cooperation of group K will not pay for its members whenever the equilibrium at the contribution stage is interior. To show this first define for any $m \geq 2$

$$k_B^*(m) := \min_{k \geq 2} \left\{ k \in \mathbb{N} : u^S(k) \geq u_F^S(m) \right\} \tag{20}$$

This definition means that for all $k \geq k_B^*(m)$ utility of a country in K is higher in K's standalone solution than it would be as a free-rider in M's standalone solution (see Figure 1.5). Since $u^S(m) < u_F^S(m)$ and $u^S(k)$ is increasing in k we have $k_B^*(m) > m$. As $u_F^S(m)$ is increasing in m, $k_B^*(m)$ is non-decreasing. We then have the following result:

Proposition 12. *Assume $m \geq \bar{m}_A$, that $u_I^{BK}(\xi, m)$ is a convex function of ξ and that $k_B^*(m) > \bar{k}_B(m)$. For all k with $\underline{k}_B(m) < k < \bar{k}_B(m)$ then group K does not benefit from forming a coalition when group M cooperates.*

Proof. As $u^S(k)$ is increasing in k and $k_B^*(m) > \bar{k}_B(m)$ is assumed it follows that $u_I^{BK}(\bar{\bar{\xi}}_B(m), m) = u^S(\bar{\bar{\xi}}_B(m)) < u^S(\bar{k}_B(m)) \leq u_F^S(m)$ where $\bar{\bar{\xi}}_B(m)$ is defined by $\bar{G}_{\bar{\bar{\xi}}_B(m)} = \bar{G}_m$. According to Proposition 11 utility $u_I^{BK}(\xi, m)$, which a country in K attains in an interior solution, is falling on an interval $\left[\underline{k}_B(m), \underline{\chi}\right]$. As the convexity assumption implies that the function $u_I^{BK}(\xi, m)$ can at most have one minimum in $\left[\underline{k}_B(m), \bar{k}_B(m)\right]$ and since $u_I^{BK}(\underline{k}_B(m), m) = u_F^S(m)$, we have $u_I^{BK}(k, m) < u_F^S(m)$ for all k with $\underline{k}_B(m) < k < \bar{k}_B(m)$. □

Taken together Proposition 10 and 12 imply, that in the situation underlying Proposition 12, non-cooperation is group K's best reply to cooperation of group M for all $k \leq \bar{k}_B(m)$. As in the case, where group M does not cooperate, coalition building, however, becomes profitable if group K is sufficiently large.

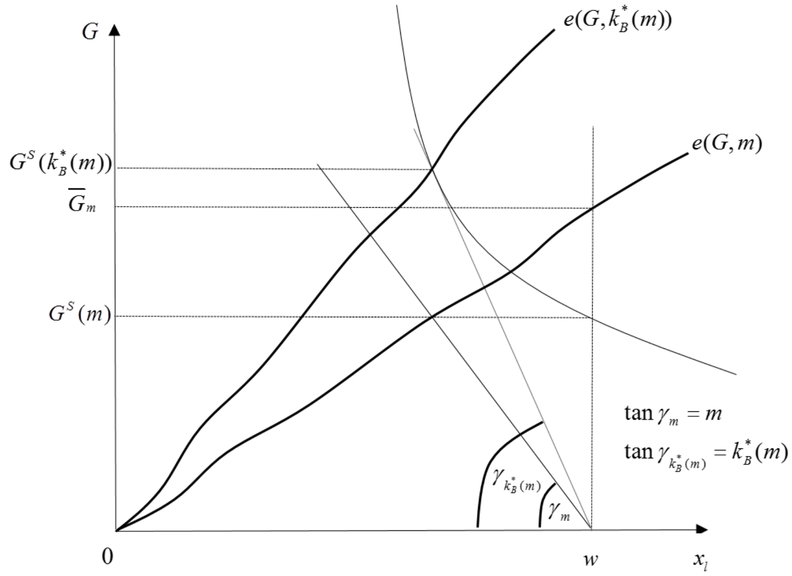


Figure 1.5: Threshold k_B^*

Based on $k_B^*(m)$ as defined by (20) we can provide a sufficient condition for coalition building by group K when M has formed a coalition.

Proposition 13. *If group M cooperates group K benefits from forming a coalition if*

$$k > \overset{\frown}{k}_B(m) := \max\left\{\bar{k}_B(m), k_B^*(m)\right\} > m. \tag{21}$$

$\overset{\frown}{k}_B(m)$ is non-decreasing in m and $\lim\limits_{m\to\infty} \overset{\frown}{k}_B(m) = \infty$.

Proof. The assertions directly follow from the definitions and the monotonicity of $\bar{k}_B(m)$and $k_B^*(m)$. That $\lim\limits_{m\to\infty} \overset{\frown}{k}_B(m) = \infty$ is a consequence of Proposition 7, i.e. of $\lim\limits_{m\to\infty} \bar{k}_B(m) = \infty$. □

Proposition 13 shows that the incentives for group K to form a coalition are larger if the group M is small. However, it has to be emphasized that – unlike the case where group M does not cooperate – it is not possible that a group K of some given size k always wants to cooperate irrespective of the size of M.

Proposition 14. *For any $k \geq 2$ there exists a $\tilde{m}(k)$ so that a group K of size k does not benefit from forming a coalition if the size of the cooperating group M is $m \geq \tilde{m}(k)$.*

Proof. The assertion again directly follows from Proposition 10 since $\lim\limits_{m\to\infty} \underline{k}_B(m) = \infty$ as stated in Proposition 7. □

1.5.3 *A Comparison of the Optimal Reactions*

The results of the previous subsections show that, concerning group K's coalition formation decision, some similarities but also some substantial differences between the two cases considered above exist.

On the one hand, there is a common tendency that cooperation is not profitable for group K if it is small and that it becomes always profitable if it is big enough - irrespective of whether the other group M acts as a coalition or not. But on the other hand, coalition formation of group K is much more likely if the other group M does not cooperate, which is reflected by some of the results formulated above: If the members of M choose their public good contributions non-cooperatively any group K whose size exceeds some minimum level wants to form a coalition independent of how large group M is (see Proposition 9). When M, however, cooperates such a lower bound does not exist. Rather, for any k we can find a sufficiently large group m so that group K has no incentive to form a coalition (see Proposition 14). Moreover, the minimum coalition size beyond which cooperation is definitely in the interest of the countries in group K is higher when group M cooperates than when it does not. This result is stated by the following Proposition.

Proposition 15. *Assume $m > \bar{m}_A$. For the threshold levels defined in (18) and (21), which provide sufficient conditions for coalition formation of group K, $\overset{\frown}{k}_B(m) > \overset{\frown}{k}_A(m)$ holds.*

Proof. On the one hand, $m \geq 2$ implies $\bar{G}_m > \bar{G}_1$ and thus $\bar{k}_B(m) > \bar{k}_A$. On the other hand, $m > \bar{m}_A$ gives $G^S(m) > \bar{G}_1$ so that $u(w, \bar{G}_1) < u(w, G^S(m)) = u_F^S(m)$. Comparing (16) and (20) then shows $k_B^*(m) > k_A^*$. Taken together, we obtain $\overset{\frown}{k}_B(m) = \max\left\{\bar{k}_B(m), k_B^*(m)\right\} > \overset{\frown}{k}_A(m) = \max\left\{\bar{k}_A, k_A^*(m)\right\}$. □

1.6 NASH EQUILIBRIA AT THE COALITION FORMATION STAGE: SOME GENERAL CONDITIONS

Changing roles and taking the reactions of group M also into account now allows us to derive some general results concerning the type of the Nash equilibria that emerges at the first coalition formation stage of the entire two-stage game. So Proposition 9 has shown that, if the size of a group is large enough, it will always react by cooperating when the other group does not cooperate, i.e. $N_M \rightarrow C_K$ and $N_K \rightarrow C_M$. Concerning the reaction when the other group cooperates, our general results suggest that the members of a small group prefer to stand alone when the other group is large, i.e. $C_M \rightarrow N_K$ or $C_K \rightarrow N_M$. To formulate conditions for a unique Nash equilibrium in this case consider the function $\overset{\frown}{m}_B(k)$, which is defined by (21) through interchanging k and m, and then its inverse $\breve{k}_B(m)$, which in an m-k-diagram is obtained by mirroring $\overset{\frown}{k}_B(m)$ on the 45^0-line. As $\overset{\frown}{m}_B(k) > k$ for all k we get $\breve{k}_B(m) < m$. Furthermore, let $\underset{\smile B}{k}(m) := \min\left\{\underline{k}_B(m), \breve{k}_B(m)\right\} < m$.

Proposition 16. *If $k, m > k_A^*$ and $k < \underset{\smile B}{k}(m) < m$ there is a unique Nash equilibrium (N_K, C_M) at the coalition formation stage in which the larger group M is willing to form a coalition while the smaller group K is not. At the second stage group M's standalone equilibrium $E^S(m)$ results.*

Proof. As noted above we have $N_K \rightarrow C_M$ as $m \geq m_A^* = k_A^*$. But given $k < \underline{k}_B(m)$ Proposition 10 says that $C_M \rightarrow N_K$ so that (N_K, C_M) is a Nash equilibrium. It is the only one since it follows from Proposition 13 and the construction of $\underset{\smile B}{k}(m)$ that for all (m, k) with $k < \underset{\smile B}{k}(m)$ group M wants to cooperate when group K does, i.e. $C_K \rightarrow C_M$. Under the conditions underlying the Proposition group K clearly must be smaller than group M as $\underset{\smile B}{k}(m) < m$. The assertion concerning the second stage follows from Proposition 4 since $k_A^* > \bar{k}_A$. □

To put it in another way: In the situation as given in Proposition 16 the payoff structures of both groups are different: While group K has payoffs as in a chicken game those of group M are as in a harmony game. This constellation gives a unique Nash equilibrium at the coalition formation stage.

If, in contrast to the situation described in Proposition 16, the sizes of both groups do not diverge too much, each group clearly will show the same reaction when the other group has built a coalition, i.e. it will either choose non-cooperation or cooperation. Assume again that groups are large enough so that non-cooperation of one group is responded by cooperation of the other. If the best reaction to cooperation is non-cooperation then a chicken game with two asymmetric Nash equilibria emerges. Under the same assumptions as made in Proposition 12 such an outcome may result when the Nash equilibrium at second stage is interior.

Proposition 17. *Let $k, m > k_A^*$ and assume that $u_I^{BK}(\xi, m)$ is a convex function of ξ and that $k_B^*(m) > \bar{k}_B(m)$. Then for all (k, m) with $\underline{k}_B(m) < k < \bar{k}_B(m)$ there are two Nash equilibria (C_K, N_M) and (N_K, C_M). At the second stage then either the standalone equilibrium $E^S(k)$ of group K or the standalone equilibrium $E^S(m)$ of group M result.*

Proof. Concerning the first stage, $k, m > k_A^*$ yields the reactions $N_K \to C_M$ and $N_M \to C_K$. From Proposition 12 we have $C_M \to N_K$ for all k with $\underline{k}_B(m) < k < \bar{k}_B(m)$. By reversing roles and observing symmetry we also obtain $C_K \to N_M$. Concerning the second stage, the assertion again follows from Proposition 4. ☐

As always in the case of a chicken game a unique solution emerges when we assume that one of the two groups, say group M, either commits to cooperation or to non-cooperation. Regarding public good supply we then have the following result:

Proposition 18. *Under the same assumptions as in Proposition 17 and given any combination (k, m) with $m < k < \bar{k}_B(m)$ public good supply will be higher when group M commits to non-cooperation than when it commits to cooperation.*

Proof. It follows from Proposition 17 that (N_K, C_M) with public good supply $G^S(m)$ results when group M commits to cooperation. When group M instead commits to non-cooperation group K forms a coalition and public good supply becomes $G^S(k)$. Since $k < m$ we then have $G^S(k) < G^S(m)$. ☐

Proposition 18 shows that a cooperation of a relatively small coalition may motivate the members of a much larger group to choose the standalone strategy and to become free-riders. In this case the presence of the smaller group M leads to a public good supply which is lower than in the situation in which M were absent. Non-cooperation of the smaller group M instead creates an incentive for the larger group K to build a coalition and then to provide the public good at a higher level, so that in this sense less goodwill by group M is advantageous for public good provision. The difference between the public good supply levels in the two cases considered in Proposition 18 may even become quite large which is shown through an example in the subsequent section.

The result stated in Proposition 18 resembles some well-known paradoxical effects that may occur in the context of climate policy: Leading behavior by a group of countries aiming at improving global environmental quality (e.g. through unilateral increases of abatement efforts as in Hoel (1991), or to carbon taxes with a rapid increase of tax rates as in Sinn 2012b) can have the counterintuitive effect that in the end environmental quality deteriorates. In this chapter, we have seen that such an adverse outcome may also arise from coalition formation decisions by groups of countries.

Looking at the sequential version of the chicken game (see also Foucart and Wan 2018), the outcome as usual depends on which of the two groups is the first mover.

Proposition 19. *Under the assumptions of Proposition 17 and Proposition 18 the outcome always is unilateral cooperation* (C_K, N_M) *with public good supply* $G^S(k)$ *when the smaller group M moves first. When the larger group K is the first mover, unilateral cooperation* (N_K, C_M) *with public good supply* $G^S(m)$ *results.*

Proof. If group M moves first it follows from Proposition 16 that $E^S(m)$ results at the second stage when it forms a coalition and $E^S(k)$ when it does not. In the first case utility of a member of M is $u^S(m)$ and in the second case it is $u^S_F(k)$. As $m < k$ and thus $G^S(m) < G^S(k)$ we have $u^S(m) = u(w - \frac{G^S(m)}{m}, G^S(m)) < u(k, G^S(k)) = u^S_F(k)$, so that group M is better off by not cooperating. The second part of the assertion follows from Proposition 20 since $k < k^*_B(m)$ implies $u^S_F(m) > u^S(k)$. □

As $G^S(m) < G^S(k)$ then, in the situation underlying Proposition 19, equilibrium public good supply is smaller when the larger group K moves first. This result is surprising, since the intuition might suggest the opposite outcome.

The assumptions made in Proposition 17, which lead to a chicken game, do not hold in any case. Hence, it is also possible that with fairly equal group sizes the best reply to cooperation will be cooperation, which leads to a harmony game with the unique Nash equilibrium (C_K, C_M). But in other rather special cases a prisoner dilemma game with the unique Nash equilibrium (N_K, N_M) or an assurance game with the two Nash equilibria (N_K, N_M) or (C_K, C_M) may result too. In the next section, where Cobb-Douglas preferences are assumed, we present examples for all these possible outcomes.

1.7 NASH EQUILIBRIA AT THE COALITION FORMATION STAGE: A COBB-DOUGLAS EXAMPLE

Let again each country's utility function be $u(x_i, G) = x_i^\alpha G$. To simplify the exposition, we normalize the initial endowment of each country to $w = 1$. We also no longer make a distinction between natural numbers k and the continuous variable ξ.

Firstly, we assume $\alpha \geq 1$ so that $\bar{k}_A = \frac{1+\alpha}{\alpha} \leq 2$. According to Proposition 4 then unilateral cooperation of group K leads to this group's standalone solution $E^S(k)$ at the contribution stage, where utility of a country in K is

$$u^S_K(k) = \frac{k\alpha^\alpha}{(1+\alpha)^{1+\alpha}}. \tag{22}$$

When both groups do not cooperate each country's utility in the standard Nash equilibrium is

$$u^N(k+m) = \alpha^\alpha \left(\frac{k+m}{1+\alpha(k+m)} \right)^{1+\alpha}. \tag{23}$$

To determine $k^*(m)$ and thus the optimal cooperation decision of group K we would have to compare the utility levels given by (22) and (23), which however, does not allow for a closed-form solution. But it is possible to give an explicit solution for the threshold level k_A^* which is defined by the condition

$$u^S(k_A^*) = \frac{k_A^* \alpha^\alpha}{(1+\alpha)^{1+\alpha}} = \frac{1}{\alpha} = u(w, \bar{G}_1) \tag{24}$$

Thus

$$k_A^* = \left(\frac{1+\alpha}{\alpha} \right)^{1+\alpha}. \tag{25}$$

k_A^* is decreasing in α and converges to the Euler number e when α goes to infinity. If $\alpha \geq 1$ we thus have $k_A^* \leq 4$ so that in this case only groups K for all $k \geq 4$ coalition formation is the best response of group K when the other group M does not cooperate. In the following we will concentrate on this case. If the other group Minstead has formed a coalition Proposition 10 shows that group K's best reaction is non-cooperation if $k \leq \underline{k}_B(m) = \frac{\alpha}{1+\alpha} m$.

To infer group K's coalition formation decision when $\underline{k}_B(m) < k < \bar{k}_B(m)$ and an interior equilibrium emerges at the second stage we have to consider

$$u_I^{BK}(k,m) = \left(\frac{\alpha}{k} \right)^\alpha \left(\frac{k+m}{1+2\alpha} \right)^{1+\alpha} \tag{26}$$

which is convex in k as further calculations show. From

$$u^S(k_B^*(m)) = \frac{k_B^*(m)}{\alpha} \left(\frac{\alpha}{1+\alpha} \right)^{1+\alpha} = \frac{m}{1+\alpha} = u_F^S(m) \tag{27}$$

we get

$$k_B^*(m) = \left(\frac{1+\alpha}{\alpha} \right)^\alpha m \tag{28}$$

so that for $\alpha > 1$ we have $k_B^*(m) > \bar{k}_B(m) = \frac{1+\alpha}{\alpha} m$. Proposition 12 thus provides that then K's optimal reaction to cooperation of M is non-cooperation also when $\underline{k}_B(m) < k < \bar{k}_B(m)$. For $\alpha = 1$ direct calculations provide the same result. Non-cooperation also is the best response of K to cooperation of group M if $k > \bar{k}_B(m)$ but $k < k_B^*(m)$ while group K will choose cooperation as soon as $k \geq k_B^*(m)$. Note that the set $\left\{ k \in \mathbb{N} : \bar{k}_B(m) < k < k_B^*(m) \right\}$ may be empty, especially if α is not far above 1 and m is small.

Based on these results on optimal reactions at the coalition formation stage we now provide a complete description of the Nash equilibria at the coalition formation stage for the special case $\alpha = 1$. We then have $\bar{k}_A = 2$, $k_A^* = 4$, $\underline{k}_B(m) = \frac{1}{2}m$ and $\bar{k}_B(m) = k_B^*(m) = 2m$, which allows us to determine the Nash equilibria for the utmost part of all combinations of group sizes k and m: If $k, m \geq 4$ and $k < \frac{1}{2}m$ it follows from Proposition 16 that (N_K, C_M) is the unique Nash equilibrium at the coalition formation stage since $\overset{\frown}{m}_B(k) = \bar{m}_B(k) = m_B^*(k) = 2k$ and thus $\underset{\smile B}{k}(m) = \frac{1}{2}m = \underline{k}_B(m)$. Analogously, (C_K, N_M) is the unique Nash equilibrium if $k > 2m$. If, however, $\frac{1}{2}m \leq k \leq 2m$ holds, Proposition 17 shows that a chicken game with the two Nash equilibria (N_K, C_M) and (C_K, N_M) emerges at the coalition formation stage.

The case $k = 2, 3$ has to be treated separately: If then $m \geq 4$ the unique Nash equilibrium at the coalition formation stage is (N_K, C_M) and if $m = 2, 3$ and if $k \geq 4$ it is (C_K, N_M). We thus obtain the partitioning of the k-m-space as depicted in Figure 1.6.

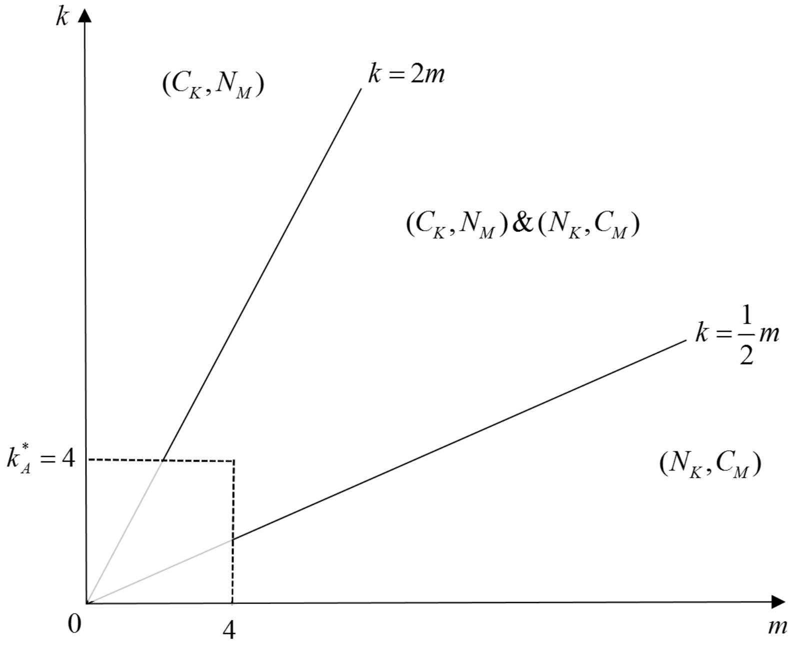


Figure 1.6: The regions of subgame-perfect equilibria

For the remaining combinations (2,2), (2,3), (3,2) and (3,3) inside the box of Figure 1.6 we infer that for (2,3) the unique Nash equilibrium is (N_K, C_M) and for (3,2) it is (C_K, N_M). At (3,3) there are the two Nash equilibria (N_K, C_M) and (C_K, N_M). In the case (2,2) it is the dominant strategy of each group not to build a coalition so that there is a prisoners' dilemma at the coalition formation stage with (N_K, N_M) as the only Nash equilibrium.

For an illustration of Proposition 18 let $k = 2m - 1$. Then $k < \bar{k}_B(m) = 2m$ so that equilibrium public good supply is $G^S(m) = \frac{m}{2}$ when the smaller group M commits to cooperation. But public good supply would become $G^S(2m-1) = m - \frac{1}{2}$ when group M commits to non-cooperation. Hence, if group M forms a coalition this almost halves public good supply as compared to situation if it is not willing or unable to do so. If in the same situation coalition formation is a sequential game, in which the larger group K moves first, then also (N_K, C_M) with the lower public good supply $G^S(m)$ results. This illustrates Proposition 19.

For other Cobb-Douglas preferences also other game types at the coalition formation stage may occur. Let, e.g., $\alpha = \frac{1}{2}$ and $k = m \geq 3$. Then (C_K, C_M) is a Nash equilibrium at the first coalition-formation stage. If, in addition, $k > k^*_A = 6$ coalition-building becomes the dominant strategy for both countries so that there is a harmony game, in which bilateral cooperation (C_K, C_M) is the unique Nash equilibrium. Finally, if $k = m = 3$ an assurance game results, which has the two symmetric Nash equilibria (N_K, N_M) and (C_K, C_M).

1.8 CONCLUSIONS

The results derived in this chapter pour some cold water on the optimistic expectation, which is connected with the bottom-up-approach in climate policy. Rather, partial cooperation by one group of countries may make it less likely that the members of the other group are willing to build their own coalition, particularly if the cooperating coalition is large. But, more surprisingly, even relatively large groups might prefer to become free-riders in the standalone allocation brought about by a much smaller group. This causes the danger that the level of public good supply in the subgame-perfect equilibrium is lower if a smaller group is present than it would be if the larger group were alone. This undesired effect on the level of global public good provision occurs in many of our scenarios if the smaller group commits to coalition formation or if in a leader-follower version of the coalition formation game the larger group is in the first mover position. The adverse effect, however, is avoided if the smaller group demonstrates unwillingness to form a coalition or if it has high costs in producing the public good. Hence, another paradoxical effect in global public good provision arises: Green technological progress, which enables the small coalition to make an effective contribution to the public good, may in the end reduce public good supply and thus aggravate the underprovision problem.

This additional feature has not been considered in this chapter. For the sake of simplicity, it has rather been assumed that production costs for the public good are exogenously given and identical for all countries. Moreover, there have only been two potential coalitions whose members have the same endowments and preferences. In further research, one might drop this assumption and allow for a greater number of heterogeneous groups whose members can differ w.r.t. their public good productivity, their income levels and their preferences.

2

LEADERSHIP IN TECHNOLOGICAL DEVELOPMENT AND TECHNOLOGY TRANSFER[5]

2.1 INTRODUCTION

This chapter considers a type of pioneering activity which is not based on an increase of public good contributions. Leading behavior rather manifests in investments to improve green technologies (such as renewable energies or energy efficiency measures) which help reduce abatement costs and thus make the production of the global public good less costly and in subsequent technology transfer.

It is well-known (see Buchholz and Konrad 1994; Ihori 1996) that it may harm a country in the context of voluntary public good provision if it unilaterally reduces its cost for public good provision even in the extreme case in which the innovation is completely costless. The paradoxical effect described in Buchholz and Konrad (1994) is based on the fact that a country-specific increase in public good productivity (which is equivalent to reduced costs of provision) concurrently increases the public good contribution of the country considered. As a consequence, other countries react by reducing their own contributions so that crowding-out takes place. Anticipating this behavior, countries may block environmentally friendly technological progress on the basis of strategic reasons.

In this chapter we extend this analysis of the strategic choice of abatement technology in consequence leads to a more optimistic pattern: If a country or a coalition of countries is – as some kind of substitute for monetary transfers - able to make the fruits of its innovation available to other countries free of charge (which decreases the other countries' costs of producing the public good) this will not only be beneficial for these countries but also for the pioneering coalition itself. This technology transfer in turn makes the coalition more prepared to engage in green R&D-activities.

The analysis in this chapter will be carried out in the standard framework of voluntary public good provision (as exposed by Bergstrom, Blume, and Varian 1986; Cornes and Sandler 1996). But unlike these traditional contributions to the theory of public goods, we will make use of the more recent Aggregative Game Approach (see Cornes and Hartley 2007 and Cornes (2016)). The application of this approach facilitates the analysis of Nash equilibria in games of public good provision considerably which are quite complex in the scenario considered in this chapter.

---

[5] This chapter is a modified version of Buchholz, Dippl, and Eichenseer (2015). A version of Buchholz, Dippl, and Eichenseer (2015) with a strong focus on climate finance also appeared as Buchholz, Dippl, and Eichenseer (2017).

The remainder of this chapter is organized as follows: Section 2 presents the framework of the public good model for the analysis. Subsequently, Section 3 describes the interdependencies between three different kinds of countries: a coalition K of pioneers that carry out the technological innovation, a group M that adopts it, i.e. receives a technological spillover and the remaining group L of countries that stick to the old technology. Comparative statics, i.e. the change in the total level of public good provision through the technological innovation of the pioneering countries are discussed in Section 4, whereas Section 5 focuses on the pioneers' change in utility, i.e. the incentives to make the technological improvement. Section 6 then considers the utility of countries in M and L which are outside the coalition. A Cobb-Douglas example is provided in Section 7. Section 8 concludes.

2.2 THE FRAMEWORK

Let there be n countries $i = 1, ..., n$, which all have the same initial endowment w of the private good and the same utility function $u(x_i, G)$ where x_i denotes private consumption of country i and G is public good supply. Especially in the context of climate change G can be interpreted as the amount of greenhouse gases totally avoided. The utility function is assumed to have the standard properties, i.e. it is twice partially differentiable with the first partial derivatives $u_1(x_1, G) > 0$ and $u_2(x_i, G) > 0$ and quasi-concave. Moreover, we suppose that the private and the public good both are strictly non-inferior, which means for a given marginal rate of transformation between the two goods that demand for both goods is increasing if endowments grow bigger.

The crucial element for our analysis is that the countries may differ in their productivities for generating the public good which are represented by the country-specific marginal rates of transformation mrt_i between the private and the public good a_i: These productivities indicate how many units of the public good country i can produce if it spends one unit of the private good for public good provision. The reciprocal value $c_i = \frac{1}{a_i}$ then indicates how many units of the public good country i has to give up in order to get one additional unit of the private good. In the case of environmental public goods c_i thus represents the marginal abatement costs of country i.

Under these assumptions a feasible allocation $(x_1, ..., x_n, G)$ has to satisfy the aggregate budget constraint

$$G = \sum_{i=1}^{n} a_i(w - x_i) \tag{1}$$

or, equivalently,

$$G + \sum_{i=1}^{n} a_i x_i = \sum_{i=1}^{n} a_i w. \tag{2}$$

To describe the Nash equilibrium of voluntary public good provision in this setting by means of the Aggregative Game Approach, i.e. a country's equilibrium position let $e(G, \alpha_i)$ be country i's (income) expansion when α_i

denotes the marginal rate of substitution mrs_i between the private and the public good. As non-inferiority of both goods is assumed these expansion paths are well-defined and strictly monotone increasing in G. Along an expansion path $e(G, \alpha_i)$ the indifference curves of a country all have the same slope $-\alpha_i = -\tan \rho_i$. As an additional assumption regarding preferences we assume that $e(o, \alpha_i) = 0$ and $\lim\limits_{G \to \infty} e(G, \alpha_i) = \infty$, which makes sure that public good demand of a country is strictly above zero for positive initial endowments and that there is no upper bound for public good demand given that the endowment is approaching infinity.

The essential point for the characterization of Nash equilibria now is that a country, which makes a strictly positive public good contribution, is in an individual equilibrium position only if its mrs_i coincides with its mrt_i, i.e. $\alpha_i = a_i$ holds. Otherwise, country i could attain a higher utility level either by slightly increasing (if $\alpha_i > a_i$ or by slightly decreasing (if $\alpha_i < a_i$) its public good contribution. This, however, means that in an interior Nash equilibrium $(\hat{x}_1, ..., \hat{x}_n, \hat{G})$ with positive public good contributions of all countries, country i's position $(\hat{x}_i, \hat{G})$ has to lie on the expansion path $e(G, a_i)$ such that $\hat{x}_i = e(\hat{G}, a_i)$.

As a benchmark for our analysis we consider the case in which the productivity parameters a_i are fixed and no country undertakes efforts to improve public good productivity. Then no R&D-costs have to be taken into account, and the budget constraint (1) for an interior Nash equilibrium becomes

$$\hat{G} = \sum_{i=1}^{n} a_i(w - e(\hat{G}, a_i)) \tag{3}$$

Given our assumptions the function $\Phi(G) := \sum\limits_{i=1}^{n} a_i(w - e(G, a_i))$, whose value at $\hat{G}$ appears on the right hand side of eq. (3), is strictly monotone increasing and continuous and, given our assumptions on expansion paths, has $\Phi(0) = \sum\limits_{i=1}^{n} a_i w$ and $\lim\limits_{G \to \infty} \Phi(G) = -\infty$. Hence, by the intermediate value theorem there exists exactly one level of public good supply $\hat{G}$, which fulfills condition (3). If $e(\hat{G}, a_i) < w_i$ holds for each country $i = 1, ..., n$, the Nash equilibrium is interior with public good supply $\hat{G}$ and private consumption levels $\hat{x}_i = e(\hat{G}, a_i)$. In this Nash equilibrium country $i = 1, ..., n$ spends $\hat{z}_i = w_i - \hat{x}_i$ on the public good thus inducing an increase of public good supply by $\hat{g}_i = a_i \hat{z}_i$.

2.3 TECHNOLOGICAL INTERDEPENDENCIES

We start from a situation in which all countries have the same productivity parameter a_0. Public good supply $\hat{G}(a_0)$ in the Nash equilibrium - which is clearly interior in this initial state of full symmetry and without any R&D-costs - then is given by

$$\hat{G}(a_0) = na_0(w - e(\hat{G}(a_0), a_0)) \tag{4}$$

Now the possibility arises that a subgroup of countries undertakes some R&D-efforts aimed at improving "green" technologies (such as better insulation of houses, renewable energies, smart grids and new methods for power storage) through which the reduction of carbon emissions becomes cheaper or, in other words, the productivity of the global public good climate protection is increased. Through intended or unintended technological spillovers other countries may also benefit from these productivity enhancing effects even if they do not incur any of the costs associated with developing these ecologically friendly technologies.

For a precise description of this scenario we divide the whole group of countries into three subgroups K, L and M whose members play a two-stage game.

2.3.1 *Subgroup K Consisting of k Countries*

The members of subgroup k form a technological coalition, which is willing to play a pioneering role in climate policy by collectively promoting green innovations. In the framework of our model this means that at the first stage of the game coalition K is able to choose an improved production technology for the public good which exhibits a higher public good productivity a than the original technology. Choosing some $a > a_0$, however, is not costless but results in R&D-costs of $c_k(a)$ for each country in coalition K. This cost function is assumed to be differentiable in a and has $c_k(a_0) = 0$. If, as in the case of basic research, R&D-costs can be divided equally among the members of the coalition $c_k(a)$ will - for any $a > 0$ - fall when k increases. However, if technological progress is based on activities, which have to be carried out in each country of the coalition at an equal scale (e.g. local learning-by-doing), then $c_k(a)$ will not be affected by the size of the coalition.

While the coalition cooperates at the innovation stage, the coalition members still act independently in the second stage of the game in which the coalition members decide on their contributions to the public good. This assumption reflects the notion that in climate policy cooperation on abatement levels is harder to achieve than technological cooperation.

2.3.2 *Subgroup L Consisting of l Countries*

The members of subgroup L do not have a share in the spillover: They stick to the original technology with the productivity parameter a_0 irrespective of the technological choice made by coalition K. This inability to make use of the better environmental technologies may arise from specific physical or meteorological conditions. E.g. countries in the tropical zones obviously do not benefit from improved efficiency in the heating of buildings, and countries like Canada with fewer sunshine hours than Florida cannot gain much from the development of solar technology. But it is also possible that in developing countries the capacities for adopting the improved technologies are lacking. In contrast to the physical limitations these obstacles can be removed, e.g. through education and the formation of human capital.

2.3.3 *Subgroup M Consisting of m Countries*

For subgroup M there is a technological spillover from the technological innovations provided by coalition K so that they become more productive in generating the public good - but possibly to a different degree than the coalition members. The differentiable function $b(a)$ describes which productivity parameter results in each country in M when the productivity parameter chosen in coalition K is a. This function measuring the intensity of the spillover effect is monotone increasing in a with $b(a_0) = a_0$. The normal case will be $b'(a) \leq 1$, which means that the countries in M benefit not more from the innovation than the countries in K. Nevertheless, situations are conceivable in which $b'(a) > 1$ holds such that the productivity increase for subgroup M is even larger than in K. An example for this might be solar energy when in the countries of subgroup M solar radiation is stronger than in the countries of subgroup K.

2.3.4 *Description of the Nash Equilibrium in the Initial State*

Like the countries in coalition K the countries in the outsider subgroups L and M also determine their public good contributions non-cooperatively at the second stage of the game. It is straightforward now by applying the Aggregative Game Approach to describe the interior Nash equilibrium which results when coalition K has chosen some productivity parameter $a \geq a_0$ as we know that in the Nash equilibrium:

- the position of all countries in K is on the expansion path $e(G, a)$.
- the position of all countries in L is on the expansion path $e(G, a_0)$.
- the position of all countries in M is on the expansion path $e(G, b(a))$.

Based on condition (3) public good supply $\hat{G}(a)$ in the Nash equilibrium if coalition K has chosen the productivity parameter a is characterized by the following equation:

$$\hat{G}(a) = ka(w - e(\hat{G}(a), a) - c_k(a)) + la_0(w - e(\hat{G}(a), a_0)) \\ + mb(a)(w - e(\hat{G}(a), b(a))) \quad (5)$$

Private consumption of the countries in subgroups K, L and M thus is $\hat{x}_k(a) = e(\hat{G}(a), a)$, $\hat{x}_L(a) = e(\hat{G}(a), a_0)$ and $\hat{x}_M(a) = e(\hat{G}(a), b(a))$, respectively. Note that eq. (5) takes into consideration that the members of group K do not spend the whole residual between income and private consumption for public good provision because they have to spend $c_k(a) > 0$ for R&D-efforts when choosing some $a > a_0$.

Since the initial Nash equilibrium is interior it follows from a standard continuity argument that the Nash equilibrium will stay interior when the productivity parameter a chosen by coalition K is sufficiently close to a_0. The subsequent analysis only considers these cases.

2.4 THE CHANGE IN PG SUPPLY THROUGH TECHNOLOGICAL PROGRESS

Let the partial derivative of any expansion path $e(G, \alpha)$ w.r.t. public good supply G be denoted by $e_1(G, \alpha)$ which describes how private consumption changes if one moves along an expansion path. Analogously, $e_2(G, \alpha)$ is the partial derivative of the expansion path w.r.t. the marginal rate of substitution α. This derivative indicates the change of private consumption, which results when - for a given level of public good supply - the move is to another expansion path corresponding to a higher marginal rate of substitution. From the non-inferiority assumption on preferences we have $e_1(G, \alpha) > 0$ and $e_2(G, \alpha) < 0$.

To calculate the effect on public good supply $\hat{G}'(a) = \frac{\partial \hat{G}}{\partial a}$, which is driven by a marginal change of its productivity parameter by coalition K we first consider the total differential of eq. (5) at some arbitrary a for which interiority holds which yields

$$\begin{aligned}\hat{G}(a) &= k(w - e(\hat{G}(a), a) - c_k(a)) \\ &\quad - ka(e_1(\hat{G}(a), a)\hat{G}'(a) + e_2(\hat{G}(a), a) + c'_k(a)) - la_0 e_1(\hat{G}(a), a_0)\hat{G}'(a) \\ &\quad + mb'(a)(w - e(\hat{G}(a), b(a))) - mb(a)(e_1(\hat{G}(a), b(a))\hat{G}'(a) \\ &\qquad + e_2(\hat{G}(a), b(a))b'(a)). \quad (6)\end{aligned}$$

We now apply eq. (6) to infer the effects on public good supply, which result from a marginal change of a starting from $a_0 = b(a_0)$. Without loss of generality we can assume $a_0 = 1$ and, to simplify notation, we use ab,breviations as follows: $\hat{G}' = \hat{G}'(1)$ $\hat{z} = w - e(\hat{G}(1), 1)$, $\kappa_k = c'_k(1)$, $\beta = b'(1)$, $\gamma_1 = e_1(\hat{G}(1), 1)$ and $\gamma_2 = e_2(\hat{G}(1), 1)$. Since $c_k(1) = 0$ by assumption condition (6) then turns into

$$\hat{G}' = k(\hat{z} - \gamma_1 \hat{G}' - \gamma_2 - \kappa_k) - l\gamma_1 \hat{G}' + m(\beta \hat{z} - \gamma_1 \hat{G}' - \gamma_2 \beta) \quad (7)$$

Solving (7) for $\hat{G}'$ and observing $k + l + m = n$ gives the following result.

Proposition 1. *If coalition K marginally increases its productivity parameter a starting from the symmetric Nash equilibrium with* $a_0 = 1$ *then public good supply changes by*

$$\hat{G}' = \frac{(k + m\beta)(\hat{z} - \gamma_2) - k\kappa_k}{1 + n\gamma_1}. \quad (8)$$

Public good supply hence increases if and only if

$$k\kappa_k < (k + m\beta)(\hat{z} - \gamma_2). \quad (9)$$

Since $\gamma_2 < 0$, condition (9) directly shows that – for a given distribution over the three subgroups – an increase in public good supply always results if the aggregate marginal costs for the technological improvement $k\kappa_k$ are not too high. A high spillover parameter β and a high public good contribution

$\hat{z}$ in the original Nash equilibrium are also favorable for an increase of public good supply as both help to make the increase of public good productivity more effective.

If, however, the R&D-costs are sufficiently high, so that $k\kappa_k > (k + m\beta)(\hat{z} - \gamma_2)$ holds, public good supply is reduced by the innovation. The reason for this adverse effect is that due to the costly R&D-efforts coalition K's resources available for public good provision are eaten up while at the same time the spillover effect is too weak, either because only few countries are positively affected or the intensity of the spillover is small.

In addition, we can infer from conditions (8) and (9) how for a fixed total number of countries n the size of the different subgroups affects the change of public good supply. In this context we first note that $\hat{z}$, γ_1 and γ_2 refer to the original fully symmetric Nash equilibrium and thus do not depend on k, l and m as long as the total number of countries $n = k + l + m$ is fixed.

Proposition 2. *Assume that $\hat{G}'$ is positive. Then $\hat{G}'$ is the larger :*

- *the larger the coalition K is when aggregate marginal costs $k\kappa_k$ of the technological improvement are not rising in k.*
- *the larger the group M is.*
- *the smaller $\gamma_1 > 0$ and the larger $-\gamma_2 > 0$ are.*

In a Nash equilibrium public good supply normally is too low as compared to Pareto optimal levels (see Buchholz and Peters 2001, for a treatment especially of exceptions). Against this background, Proposition 2 says that this "underprovision" is mitigated both through a spatial expansion of the technological spillover, i.e. an increase of m, and an increase of its intensity β. The same positive effect on public good supply occurs if the coalition K is enlarged given that $\beta \leq 1$ and $k\kappa_k$ is decreasing in k.

As a next step, we examine the incentives that coalition K has for making a green innovation through which its public good productivity is increased.

2.5 THE INCENTIVES FOR COALITION K TO MAKE THE TECHNOLOGICAL IMPROVEMENT

Given some productivity parameter a, utility of a member of coalition K is $\hat{u}_k = u(e(\hat{G}(a), a), \hat{G}(a))$ in the Nash equilibrium as $e(\hat{G}(a), a) = \hat{x}_k(a)$ is its private consumption. A marginal variation of a changes this utility by

$$\hat{u}_k{}'(a) = u_1(\hat{x}_k(a), \hat{G}(a))(e_1(\hat{G}(a), a)\hat{G}'(a) + e_2(\hat{G}(a))) + u_2(\hat{x}_k(a), \hat{G}(a))\hat{G}'(a). \tag{10}$$

Without loss of generality we can assume that at the original Nash equilibrium for $a_0 = 1$ we have $\hat{u}_1(\hat{x}_k(1), \hat{G}(1)) = \hat{u}_2(\hat{x}_k(1), \hat{G}(1)) = 1$. With the abbreviations as introduced before and additionally letting $\hat{u}'_k = \hat{u}'_k(1)$ eq. (10) then is reduced to

$$\hat{u}'_k = (1 + \gamma_1)\hat{G}' + \gamma_2. \tag{11}$$

Based on eq. (11), a precise condition for an increase of utility for countries in the coalition K is provided by the next result. In its first part, this Proposition is a direct consequence of eq. (11) and in its second part it follows from plugging $\hat{G}'$ as given by eq. (8) into eq. (11).

Proposition 3. *Starting from the Nash equilibrium with* $a_0 = 1$ *the members of coalition K benefit from an increase of their public good productivity if and only if*

$$\hat{G}' > \frac{-\gamma_2}{1+\gamma_1} > 0 \tag{12}$$

holds or, equivalently, if and only if

$$k\kappa_k < (k + m\beta)(\hat{z} - \gamma_2) + \gamma_2 \frac{1+n\gamma_1}{1+\gamma_1}. \tag{13}$$

As $\gamma_1 > 0$ and $\gamma_2 < 0$, it follows from condition (12) that a higher public good supply is a necessary but not a sufficient condition for an increase of a coalition member's utility: The coalition members only benefit from their R&D-efforts when the increase in public good supply is strong enough. Only if conditions (12) and (13) are satisfied the countries in K are willing to form a technological coalition in the first place.

The factors which determine the right hand side of inequality (13) are similar to those characterizing the change of public good supply: An enlargement both of the coalition K and of the group M are favorable for an increase of utility for the members of K. Concerning the incentives for innovation in K this in particular shows how important it is to ensure a broad dissemination of the improved technologies. Giving patents for green technological innovations to other countries away free of charge thus may be a clever strategic move for coalition K - and enhances the prospects that a R&D-coalition is forming at all.

Concerning the second term on the right-hand side of (13) we note that $\frac{1+n\gamma_1}{1+\gamma_1}$ is increasing in γ_1. Hence, a utility increase for countries in coalition K is more likely if γ_1 is small. The effect of γ_2, however, is ambiguous.[6]

2.6 UTILITY EFFECTS FOR THE COUNTRIES OUTSIDE THE COALITION

We now examine how utility of the countries in the groups L and M is changed by the innovative activities of coalition K.

Differentiating utility $\hat{u}_L(a) = u(\hat{x}_L(a), \hat{G}(a)) = u(e(\hat{G}(a), a_0), \hat{G}(a))$ of a country in L and utility $\hat{u}_M(a) = u(\hat{x}_M(a), \hat{G}(a)) = u(e(\hat{G}(a), b(a)), \hat{G}(a))$ of a country in group M w.r.t. the productivity parameter a yields

$$u'_L(a) = u_1(\hat{x}_L(a), \hat{G}(a)) e_1(\hat{G}(a), a_0) \hat{G}'(a) + u_2(\hat{x}_L(a), \hat{G}(a)) \hat{G}'(a) \tag{14}$$

---

[6] In this analysis it is assumed that the coalition size is exogenous. The question of the internal stability of the coalition when coalition size is endogenous is addressed in Buchholz, Dippl, and Eichenseer (2017).

$$
\begin{aligned}
u'_M(a) = u_1(\hat{x}_M(a), \hat{G}(a))(e_1(\hat{G}(a), b(a))\hat{G}'(a) \\
+ e_2(\hat{G}(a), b(a))b'(a)) + u_2(\hat{x}_M(a), \hat{G}(a))\hat{G}'(a). \quad (15)
\end{aligned}
$$

Assuming again $a_0 = 1$ and $u_1(\hat{x}(1), \hat{G}(1)) = u_2(\hat{x}(1), \hat{G}(1)) = 1$ and abbreviating $\hat{u}'_L = \hat{u}'_L(1)$ and $\hat{u'}_M = \hat{u'}_M(1)$ a marginal change of productivity at the initial Nash equilibrium thus results in utility changes as follows:

$$\hat{u}'_L = (1 + \gamma_1)\hat{G}' \quad (16)$$

$$\hat{u}'_M = (1 + \gamma_1)\hat{G}' + \beta\gamma_2. \quad (17)$$

Comparing the utility changes for the three groups K, L and M as described by eq. (11), (16) and (17) leads to the following result:

Proposition 4. *If coalition K marginally increases its public good productivity starting from the Nash equilibrium with $a_0 = 1$, the countries in K benefit least while countries in the group L benefit most, i.e. $\hat{u}'_k \leq \hat{u}'_M \leq \hat{u}'_L$.*

The interpretation of Proposition 4 is as follows: Through the change of public good productivity in coalition K utility of countries in each subgroup is equally affected by $(1 + \gamma_1)\hat{G}'$, which is positive if public good supply increases. For countries in K there is, however, a negative partial effect on utility which is expressed by $\gamma_2 < 0$ and which reflects the increased willingness to pay for the public good when productivity improves. The same effect affects group M but to a lesser degree if the spillover is incomplete, i.e. $\beta < 1$. If, however, $\beta = 1$ the utility change is the same for group K and group M even though only the members of the coalition K initially bear the cost of the green innovation. This means that, due to equilibrium repercussions, R&D-costs can be shifted to other countries. This indirect redistribution effect is, in a certain sense, similar to the famous Warr neutrality in voluntary public good provision (see Warr 1983, and e.g. Cornes and Sandler 1996), which in particular implies that in an interior Nash equilibrium an increase of income in some country will increase utility not only in that specific country but in all countries.

The negative effect, which arises from the change of the willingness to pay for the public good implied by the technological improvement, is completely absent for countries in group L whose technology is unaffected by the innovation. Therefore, the members of this group benefit most. This, however, creates an incentive problem because countries in group K attain a higher utility level if they do not adopt the better technology for public good provision. This strategic effect, however, is avoided if the technological spillover occurs automatically, which e.g. is the case if firms in coalition K are the dominant producers of energy technology and thus can set environmentally friendly standards worldwide (see, e.g., Barrett 2003). For the countries in group M co-benefits from climate friendly technology may also arise which, on the one hand, may be caused by improved possibilities of abating locally damaging pollutants like particulate matter from power plants (see, e.g., Finus and Rübbelke 2013) and, on the other hand, by the prospect of initiating a sustainable growth process implied by the transition to a low-carbon economy (see Stern 2015). In paves the way for the adoption of green technologies. In the sense of "issue linkage" the coalition may also introduce separate incentive mechanisms like additional financial aid as a carrot or a stick like trade restrictions as envisaged by Nordhaus (2015) to ensure broad dissemination of its green innovation.

Moreover, the countries outside the coalition K may notice that their unwillingness to apply the new technology can undermine the willingness of coalition K to make the R&D-efforts and to form a technological coalition. To prevent this undesirable outcome the outsiders may also form a separate coalition in which they commit themselves to adopt the improved technology.

2.7 A COBB-DOUGLAS EXAMPLE

We now specifically assume that $w = 1$ and that all countries have the Cobb-Douglas utility function $u(x_i, G) = x_i^{\rho} G$. For some marginal rate of substitution α the expansion path is given by $e(G, \alpha) = \frac{\rho}{\alpha} G$ which gives $e_1(G, \alpha) = \frac{\rho}{\alpha}$ and $e_2(G, \alpha) = -\frac{\rho}{\alpha^2} G$. According to eq. (4), the symmetric Nash equilibrium at $a_0 = 1$ is given by the public good supply level $\hat{G}(1) = \frac{n}{n\rho+1}$, the private good consumption levels $\hat{x}(1) = \frac{n\rho}{n\rho+1}$ and country-specific public good contributions $\hat{z}(1) = \frac{1}{n\rho+1}$. Since $\gamma_1 = \rho$ and $\gamma_2 = -\frac{n\rho}{n\rho+1}$ we get

$$\hat{G}' = \frac{k + m\beta - k\kappa_k}{n\rho + 1} \tag{18}$$

$$\hat{u}'_k = \frac{(\rho + 1)(k + m\beta - k\kappa_k) - n\rho}{n\rho + 1} \tag{19}$$

$$\hat{u}'_L = \frac{(\rho + 1)(k + m\beta - k\kappa_k)}{n\rho + 1} \tag{20}$$

$$\hat{u}'_M = \frac{(\rho + 1)(k + m\beta - k\kappa_k) - n\rho\beta}{n\rho + 1} \tag{21}$$

We now especially look at eq. (19) and consider the extreme case when there is only a single pioneering country, i.e. $k = 1$. The innovation is profitable for this country if its R&D-costs are below a certain threshold level, i.e.

$$\kappa_1 < 1 + m\beta - \frac{n\rho}{\rho + 1} \tag{22}$$

Now let either $m = 0$ or $\beta = 0$ so that there are no technological spillovers. Then, even if the innovation is completely costless, the potentially pioneering country has no incentive to increase its public good productivity if $1 - \frac{n\rho}{\rho+1} < 0$ or, equivalently, $n > \frac{\rho+1}{\rho}$, which is always the case if the total number of countries is sufficiently large. A single country then would even have an incentive to choose a technology with higher abatement costs, which is the paradoxical effect described by Buchholz and Konrad (1994). Such a strategy would induce higher contributions of the other countries such that free-riding could take place on behalf of the single country that can choose the technology parameter endogenously. But if in contrast there is a technological spillover the innovation will be profitable for the country if the technological spillover extends to sufficiently many countries, i.e. if

$$m > \frac{(n-1)\rho - 1}{(\rho+1)\beta} \tag{23}$$

Some values for m which satisfy condition (23) exist if the right hand side of this inequality is smaller than $n - 1$, i.e. if the spillover is sufficiently strong such that

$$\beta > \underline{\beta} := \frac{1}{n-1}\left(\frac{n\rho}{\rho+1} - 1\right) \tag{24}$$

holds. In the case of a perfect spillover ($\beta = 1$) condition (24) is always fulfilled. The example thus clearly illustrates how a single country's incentive to innovate depends on the number of followers and the strength of the spillover effect. For a further specification consider the case where $n = 10$ and $\rho = 1$. Then without a spillover a costless marginal increase of public good productivity does not pay for a single country. But if there is a spillover with $\beta = 1$, which benefits at least five other countries, condition (24) implies that the innovation becomes worthwhile for the country which undertakes it. Moreover, the lower threshold for the productivity parameter which follows from condition (24) is $\underline{\beta} = \frac{4}{9}$.

2.8 CONCLUSION

In this chapter we have shown how the provision of a global public good such as climate protection may be improved through unilateral action of a group of countries which collectively carry out a green technological innovation that lowers the costs of providing the global public good, i.e. the costs of greenhouse gas abatement. The success of such a specific form of leading behavior is not only more likely if the cooperating coalition is large but also if there is a steep rise of public good productivity in as many other countries as possible, i.e. if the technological spillover effect is strong both at the intensive and at the extensive margin. Consequently, the basic message of this chapter is that it is not only favorable for the climate but also for the coalition if these follower countries get free access to the improved technology and thus receive some indirect donation from the coalition.

In other words, it especially pays off for the group of pioneers to transform the club good of technological innovations which could be protected for example by intellectual property laws into a public good. However, the recipient countries benefit less from the innovation than the complete outsiders that stick to the old high-cost technology. This creates an incentive problem for technology adoption so that it may become necessary to complement the unilateral R&D-policy by additional mechanisms to ensure a far-reaching diffusion of newly developed green technologies.

A discussion of appropriate strategies lies outside the scope of this theoretical chapter. An example for pioneering efforts in this regard is considered in Chapter 4.

3

LEADERSHIP AND THE STRATEGIC CHOICE OF TECHNOLOGY[7]

3.1 INTRODUCTION

This chapter adds a further argument to support the belief that leadership can have a positive effect both on the level of public good supply and on the utilities of the countries involved. The mechanism, which underlies these positive effects of leadership, completely works within the standard framework of public good theory (see Bergstrom, Blume, and Varian 1986 and Cornes and Sandler 1996). In particular, it does without assuming specific preferences or asymmetric information but sticks in a scenario without uncertainty and asymmetric information to the conventional modest assumption of purely strategic leadership, i.e. that "governments are ... the narrow payoff-maximizers postulated in models as those of Hoel (1991) and Varian (1994)" (Schwerhoff 2016, p. 200). At the same time, the analysis takes an empirically relevant element of leadership behavior in climate policy into account, i.e. climate friendly technological progress through which greenhouse gas mitigation is made less expensive. Against this background, the main point of our analysis is that, by acting as the leader in the Stackelberg game, a country has a higher incentive to utilize a cost-saving "green" technology than in the Nash game, in which strategic considerations may prevent countries from applying an improved contribution technology (see Buchholz and Konrad 1994 and Ihori 1996). The positive effect on public good supply that is caused by the improved technology then may be so strong that it overcompensates the negative crowding-out effect that occurs in the usual leader-follower scenario, which even leads to a Pareto improvement.

The structure of the chapter will be as follows: In Section 2 we describe an otherwise standard two-stage model of voluntary public good provision with two countries L and F in which at stage 1 one of the two countries, country L has the possibility to switch to a new contribution technology, which improves its productivity in public good provision. At stage 2 voluntary public good provision then takes place either in a Nash game or a Stackelberg game. Section 3 first of all provides a condition implying that country L does not want to take the opportunity of technological improvement in the Nash game but adheres to the original less productive contribution technology. If country L instead is the leader in a Stackelberg game of public good provision it always has an incentive to apply a productivity-enhancing technology. Section 3 concludes with a description of the subgame-perfect equilibria in the Nash and in the Stackelberg case. In Section 4, we then provide a general condition, which ensures that public good supply in the subgame-perfect equilibrium of the Stackelberg game with the new improved technology in country exceeds

---

[7] This chapter is a slightly modified version of Buchholz and Eichenseer (2019).

public good supply in the subgame-perfect equilibrium of the Nash game with the old less productive technology. In that case, leadership also makes both countries better off so that the sequential game structure is preferred by both countries over the simultaneous one. In Section 5 our general results are illustrated through a Cobb-Douglas example. Section 6 concludes by giving some brief hints at empirical applications of our theoretical results.

3.2 THE FRAMEWORK

We assume that there are two countries L and F, which have the same utility function $u(x_i, G)$, where x_i is private consumption of country $i = L, F$ and G is public good supply. This utility function has the standard properties, i.e. it is twice continuously differentiable and strictly monotone increasing in both variables and quasi-concave. The first partial derivatives of $u(x_i, G)$ w.r.t. x_i and G are denoted by u_1 and u_2, respectively. Moreover, it is assumed that both the private and the public good are non-inferior. This implies that the (income) expansion paths $e(G, \rho)$, which connect all points in the $x_i - G$-diagram where the marginal rate of substitution *mrs* between the private and the public good is equal to some given $\rho > 0$ are well-defined and strictly monotone increasing in G.

The public good is produced by a summation technology, i.e. $G = g_L + g_F$, where g_L and g_F are country L's and country F's public good contributions. The contribution productivities of both countries, which are their marginal rates of transformation *mrt* between private consumption and the public good, are assumed to be constant and equal to $a_0 = 1$ in the initial state. But while country F's contribution productivity will stay at $a_0 = 1$, country L may - through a binary choice at a stage before the public good provision game starts - turn over to a technology with a higher productivity parameter $a > 1$. The costs of public good provision then fall to $\frac{1}{a}$ for country L, which in the context of climate change means the transition to an improved greenhouse gas abatement technology with lower abatement costs. For the sake of simplification we assume that this technological improvement does not require any investment costs. Empirical studies (see, e.g., Stern, Pezzey, and Lambie 2012) have shown that considerable differences between abatement costs exist across countries: In countries like China with high carbon emission intensity and still unexhausted abatement options, costs of available abatement technologies are lower than in the old industrialized countries. Moreover, in the long run countries will encounter very different possibilities for applying more cost-efficient abatement technologies. For example, extreme variations in solar radiation and wind forces as well as in the availability of space for building renewable plants make the deployment of renewable energy more or less rewarding in different countries.[8]

If the initial endowment ("income") of country L is denoted by w_L and that of country F by w_F, an allocation (x_1, x_2, G) is feasible for some given $a \geq 1$ (and no resources are wasted) if and only if $az_L + z_F = G$, where $z_i = w_i -$

---

[8] A description of various types of abatement costs and their regional differences is provided by the IPCC (2015, p. 457).

$x_i \geq 0$ denotes that part of income country $i = L, F$ spends on public good provision. This feasibility constraint is obviously equivalent to $ax_L + x_F + G = aw_L + w_F$, which includes the original case where both countries have the contribution productivity $a = a_0 = 1$.

In an interior Nash equilibrium NE, where both countries make strictly positive contributions to the public good, the *mrs* of both countries must coincide with their respective *mrt*, which implies that, given some contribution productivity $a \geq 1$ of country L, country L's position lies on the expansion path $e(G, a)$ and that of country F on the expansion path $e(G, 1)$. Combining this with the feasibility constraint gives the following condition for public good supply $G^N(a)$ in an interior NE for any $a \geq 1$:

$$ae(G^N(a), a) + e(G^N(a), 1) + G^N(a) = aw_L + w_F. \tag{1}$$

Existence and uniqueness of the NE follow from normality of the public good and, given equal preferences of both countries, interiority of the NE is ensured when incomes of the both countries do not diverge too much (see, e.g., Cornes and Hartley 2007).

Private consumption of country L in the interior NE for some given contribution productivity $a \geq 1$ is $x_L^N(a) = e(G^N(a), a) < w_L$ and that of country F is $x_F^N(a) = e(G^N(a), 1) < w_F$. Country L's public good expenditures then are $z_L^N(a) = w_L - x_L^N(a)$, which yields L's public good contribution $g_L^N(a) = az_L^N(a)$. For country F we have $g_F^N(a) = z_F^N(a) = w_F - x_F^N(a)$. The utility levels of both countries in the NE are denoted by $u_L^N(a) = u(x_L^N(a), G^N(a))$ and $u_F^N(a) = u(x_F^N(a), G^N(a))$, respectively. Upper bounds for public good supply in an interior NE are given by $\bar{G}_L(a)$, which is defined by $e(\bar{G}_L(a), a) = w_L$, and $\bar{G}_F(1)$, which is defined by $e(\bar{G}_F(1), 1) = w_F$.[9]

In the same situation the Stackelberg equilibrium SE for some given contribution productivity $a \geq 1$ results from maximizing utility of the leading country L, i.e. $\max_{z_L} u(w_L - z_L, az_L + z_{RF}(az_L))$ where $z_{RF}(az_L) = z_{RF}(g_L)$ denotes country F's reaction function as given by $\max_{z_F} u(w_F - z_F, g_L + z_F)$. If $z_{RF}(g_L) > 0$ country F consequently is in a position where its marginal rate of substitution between the private and the public good is $a_0 = 1$. Concerning the slope $z'_{RF}(g_L) = \frac{\partial z_{RF}}{\partial g_L}$ of country F's reaction path, the normality assumption yields $0 \geq z'_{RF}(g_L) > -1$, i.e. an additional public good contribution by country L is partially crowded out by country F (see, e.g., Cornes and Sandler 1996, p. 152).

The optimal level $z_L^S(a)$ of country L's public good expenditures in an interior SE, then is characterized by the f.o.c.

$$mrs(w_L - z_L^S(a), G^S(a)) = \frac{u_1(w_L - z_L^S(a), G^S(a))}{u_2(w_L - z_L^S(a), G^S(a))} = a(1 + z'_{RF}(az_L^S(a))), \tag{2}$$

where $G^S(a) = az_L^S(a) + z_{RF}(az_L^S(a))$ is total public good supply in the SE. Private consumption of country L in the SE for some given a is denoted by $x_L^S(a) = w_L - z_L^S(a)$. Private consumption of country F is $x_F^S(a)$,

---

[9] See, e.g., Andreoni (1988). These threshold levels coincide with the "dropout levels" for voluntary public good contributions as described in Cornes and Hartley (2007).

which equals $e(G^S(a),1)$ in the interior case. Utility levels in the SE then are $u_L^S(a) = u(x_L^S(a), G^S(a))$ and $u_F^S(a) = u(x_F^S(a), G^S(a))$. In Figure 3.1 we depict the entire possibility curve

$$G_P(z_L, a) = az_L + z_{RF}(az_L) \tag{3}$$

along which country L as the Stackelberg leader moves, when it varies its public good expenditure $z_L \geq 0$. In order to simplify the exposition, we assume that this possibility curve is concave. If $z_L = 0$, country L's position is $Q = (w_L, G_F^A)$ when G_F^A is country F's standalone solution resulting from $\max_G u(w_F - G, G)$. If $0 < z_L < \bar{z}_L(a) := \frac{\bar{G}_F(1)}{a}$ country L is in the interior part of its possibility curve where country F makes a positive public good contribution $z_{RF}(az_L)$. If, however, $z_L \geq \bar{z}_L(a)$ country F stops contributing to the public good and country L is in its standalone position, i.e. $z_{RF}(az_L) = 0$ thus $G_P(z_L, a) = az_L$ holds (see Buchholz, Konrad, and Lommerud 1997). In Figure 3.1 the two segments of $G_P(z_L, a)$ meet at the point $P(a) = (w_L - \frac{\bar{G}_F(1)}{a}, \bar{G}_F(1))$.

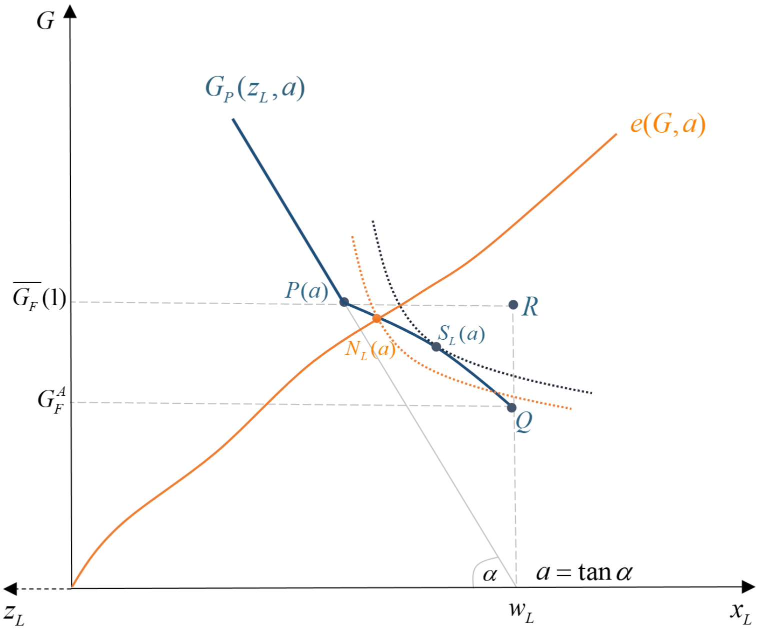


Figure 3.1: The leading country L's possibility curve

In Figure 3.1 country L's position $S_L(a)$ in an interior SE is obtained as the point of tangency between the interior part of $G_P(z_L, a)$ and an indifference curve of country L. For high levels of a the point of tangency will instead lie on the linear segment of $G_P(z_L, a)$, where the SE is country L's standalone solution with public good supply $G_L^A(a)$. This outcome arises if the contribution productivity a is large enough so that the budget line given by $G = a(w_L - x_L)$ cuts the indifference curve through point $R = (w_L, \bar{G}_F(1))$. However, for a equal or close to one it may happen that the leader's $mrt = a(1 + z'_{RF}(0))$ at $z_L = 0$ is so small that it lies below $mrs(w_L, G_F^A)$. In this case the SE is country F's standalone solution.

It is also possible to depict in Figure 3.1 country L's position $N_L(a) = (x_L^N(a), G^N(a))$ in the NE for some given a. We obtain $N_L(a)$ as the point of intersection between the expansion path $e(G, a)$ and the possibility curve $G_P(z_L, a)$ when the NE is interior (and country F is in a position where its *mrs* is equal to one) or L's standalone solution. As $z'_{RF}(az_L) < 0$ and thus

$$\frac{\partial G_P}{\partial z_L}(z_L, a) = a(1 + z'_{RF}(az_L)) < a \tag{4}$$

holds in the interiority zone of $G_P(z_L, a)$, the indifference curve at $N_L(a)$, whose slope is $-a$, is steeper than the possibility curve at $N_L(a)$. Given the same contribution productivity a, public good supply in the SE hence is lower than in the NE, i.e. $G^S(a) < G^N(a)$ (see also Cornes and Sandler 1996, p. 331).

3.3 INCENTIVES FOR TECHNOLOGICAL IMPROVEMENTS IN THE NASH AND IN THE STACKELBERG GAME

In the Nash case, we first of all examine whether at the original NE (with identical contribution productivities $a_0 = 1$ and identical consumption levels $x^N(1) = x_L^N(1) = x_F^N(1) = e(G^N(1), 1)$ in both countries) country L will benefit or not by marginally increasing its contribution productivity. Differentiating country L's utility $u(w_L - z_L^N(a), G^N(a))$ w.r.t. to a and observing $u_1(x^N(1), G^N(1)) = u_2(x^N(1), G^N(1))$ in the original NE for $a = 1$ (which follows from the NE equilibrium condition $mrs = \frac{u_1(x^N(1),G^N(1))}{u_2(x^N(1),G^N(1))} = 1 = mrt$) immediately shows that country L loses if and only if

$$\frac{\partial z_L^N}{\partial a} > \frac{\partial G^N}{\partial a} \tag{5}$$

holds at $a_0 = 1$. To specify criterion (5) further let $\hat{e}_1$ and $\hat{e}_2$ denote the partial derivatives of the expansion path $e(G, \rho)$ w.r.t. G and ρ at the countries' original position $(x^N(1), G^N(1))$, respectively. Normality implies $\hat{e}_1 > 0$ and $\hat{e}_2 < 0$. Differentiating $z_L^N(a) = w_L - x_L^N(a) = w_L - e(G^N(a), a))$ w.r.t. a at $a_0 = 1$ gives

$$\frac{\partial z_L^N}{\partial a} = -(\hat{e}_1 \frac{\partial G^N}{\partial a} + \hat{e}_2) \tag{6}$$

while differentiating condition (1) w.r.t. a also at $a_0 = 1$ yields

$$\frac{\partial G^N}{\partial a} = \frac{z_L^N(1) - \hat{e}_2}{1 + 2\hat{e}_1} > 0. \tag{7}$$

Based on this we obtain the following result, which provides some extension of Buchholz and Konrad (1994), Ihori (1996) and Hattori (2005).

Proposition 1. *If*

$$w_L < x^N(1) - \frac{\hat{e}_1 \hat{e}_2}{1 + \hat{e}_1} \tag{8}$$

there exists a critical level $\bar{a} > 1$ for the contribution productivity at which $u_L^N(\bar{a}) = u_L^N(1)$ holds. For $a \in [1, \bar{a}]$, country L will not benefit from choosing the contribution productivity a and moving to the corresponding new NE.

Proof. The existence of a threshold $\bar{a}$ with the required properties follows assumption (8) by combining (5), (6) and (7) and then applying the intermediate value theorem. This is possible since the leader's utility $u_L^N(a)$ is a continuous function of a, whose value definitely exceeds $u_L^N(1)$ if a is so large that in Figure 3.1 the point $P(a)$ lies right to country L's position $N_L(1)$ in the original NE, so that $N_L(a)$ is located on a higher indifference curve than $N_L(1)$. □

If condition (8) is not fulfilled we set $\bar{a} = 1$, which indicates that country L would increase its utility in the Nash game by choosing a contribution productivity $a > 1$. To avoid the tedious treatment of special cases we assume that country L's utility $u_L^N(a)$ in a NE is hump-shaped if $\bar{a} > 1$ and increasing if $\bar{a} = 1$. Then threshold $\bar{a}$ is uniquely determined.

Proposition 1 in particular shows that a negative incentive for technological progress becomes more likely if income of country L is relatively small. This is intuitively plausible since in this case country L's expenditure for the public good in the original NE is relatively small so that it cannot benefit much from falling costs of its original contribution while it suffers from its increased willingness to contribute to the public good as induced by the technological improvement.

As (because of $\hat{e}_1 > 0$ and $\hat{e}_2 < 0$) we have $x^N(1) - \frac{\hat{e}_1\hat{e}_2}{1+\hat{e}_1} > x^N(1)$, it is – irrespective of the underlying preferences in both countries – always possible to meet condition (8) through a redistribution of income from country L to country F that brings country L's income close enough to $x^N(1)$. Such a transfer will not change public good supply and private consumption in the NE as long as $w_L > x^N(1)$ and $w_F > x^N(1)$ holds. This reflects Warr's neutrality result (see, e.g., Cornes and Sandler 1996, pp. 164-165) but also is an immediate consequence of the characterization of the NE as provided by condition (1). Moreover, it can be shown that an income redistribution from country L to country F increases the level of the threshold $\bar{a}$.

Concerning the leading country L's incentives for a technological improvement in the Stackelberg case, we observe that an increase of the contribution productivity (from an initial a to some $\tilde{a} > a$) leads to an outward shift of L's possibility curve (see Figure 3.2).

For the linear segment of $G_P(z_L, a)$ this is obvious. For its interior part it is shown by taking the derivative of $G_P(z_L, a)$ w.r.t. a, which gives

$$\frac{\partial G_P}{\partial a}(z_L, a) = z_L(1 + z'_{RF}(az_L)) > 0 \tag{9}$$

for any given z_L, where the inequality holds since $z'_{RF}(g_L) > -1$. The point $P(a)$ where both segments meet is parallelly shifted when the contribution productivity increases since $\bar{z}_L(a) = \frac{\bar{G}_F(1)}{a}$ is decreasing in a. This change of the possibility curve directly provides a generalization of a result that Hattori and Yamada (2018) have obtained for the Cobb-Douglas case.

Proposition 2. *If country L is the leader in the Stackelberg game it will never lose when it chooses a higher contribution productivity. It becomes better off when it actively contributes to the public good after the technological change.*

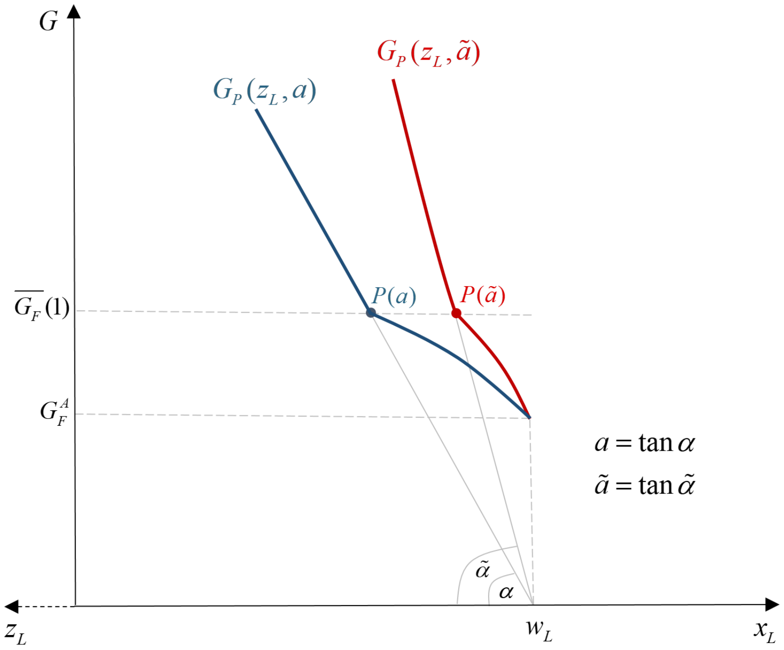


Figure 3.2: The change of the Stackelberg leader's possibility curve

The simple intuition behind Proposition 2 is that country L as a Stackelberg leader can get the same own public good contribution (and thus the same reaction by country F and, consequently, the same total public good supply) with lower public good expenses after an increase of its contribution productivity (see Hattori and Yamada 2018). Note that country L does not benefit from the outward shift of its possibility curve only if the SE remains the standalone allocation of country F.

Based on Proposition 1 and Proposition 2 we can now describe the subgame-perfect equilibria of the entire two-stage game, where a_N^* and a_S^* denote country L's technology choices in the subgame-perfect equilibrium in the Nash and in the Stackelberg scenario, respectively.

Proposition 3. *Assume that at stage 1 country L has the binary choice between the original contribution productivity* $a_0 = 1$ *and some higher* $a > 1$. *If there is a Nash contribution game at the second stage, the subgame-perfect contribution productivity is* $a_N^* = 1$ *if* $a \leq \bar{a}$ *and* $a_N^* = a$ *if* $a > \bar{a}$. *In the Stackelberg case the subgame-perfect contribution productivity always is* $a_S^* = a$. [10]

In the following section, we compare the levels of public good supply in the subgame-perfect equilibria in the Nash case and in the Stackelberg case, i.e. $G^N(a_N^*)$ with $G^S(a_S^*)$.

---

[10] As a special case of Proposition 3 we have for any if condition (8) is not fulfilled and thus holds.

3.4 INCREASING PUBLIC GOOD SUPPLY THROUGH LEADERSHIP: A GENERAL CONDITION

As a first step, we infer the effect which results when, starting from an interior SE, country L's contribution productivity rises from any $a \geq 1$ to some $\tilde{a} > a$. For a moment, we assume that country L adapts to that productivity increase by reducing its expenditure for the public good to $\tilde{z}_L = \frac{g_L^S(a)}{\tilde{a}}$. This keeps L's public good contribution and thus the reaction of country F constant so that total public good supply $G^S(a)$ also does not change. In Figure 3.3 the position of country L then moves parallely to the right.

On the one hand, normality implies that in country L's new position $\tilde{S}_L$ the *mrs* between the private and the public good is lower than in the original position $S_L(a)$, i.e. that the indifference becomes flatter. On the other hand it follows from (4) that

$$\frac{\partial G_P}{\partial z_L}(\tilde{z}_L, \tilde{a}) = \tilde{a}(1 + z'_{RF}(g_L^S(a))) > a(1 + z'_{RF}(g_L^S(a))) = \frac{\partial G_P}{\partial z_L}(z_L^S(a), a), \quad (10)$$

so that in $\tilde{S}_L$ the possibility curve $G_P(z_L, \tilde{a})$ is steeper than the original possibility curve $G_P(z_L, a)$ in $S_L(a)$. Therefore, all points on the concave possibility curve $G_P(z_L, \tilde{a})$ right to $\tilde{S}_L$ lie below the indifference curve passing through $\tilde{S}_L$, which implies that country L must move to the left in order attain a higher utility than in $\tilde{S}_L$. Consequently, we have the following result (which is completely obvious when the SE is country L's standalone solution):

Proposition 4. *An increase of the leading country L's contribution productivity yields a higher public good supply in the SE when the SE for a either is interior or the standalone solution of country L.*

As a second step we show that the original NE, where both countries have the same contribution productivity $a_0 = 1$, can be partially mimicked as an SE for an appropriately chosen productivity parameter $\hat{a}$ of country L. As in the demonstration of Proposition 4 we adjust, for any $a > 1$, country L's public good expenditure to

$$\widehat{z}_L(a) = \frac{g_L^N(1)}{a} = \frac{1}{a}(w_L - x^N(1)) \quad (11)$$

so that country L's private consumption becomes $\widehat{x}_L(a) = w_L - \widehat{z}_L(a)$, which is increasing in a, while public good supply remains constant at $G^N(1)$.

The desired productivity parameter $\hat{a}$ then is determined by the following condition, which ensures that the f.o.c. (2), which characterizes an interior SE, is fulfilled for country L's public good expenses $\widehat{z}_L(\hat{a})$ and public good supply $G^N(1)$, i.e. $z_L^S(\hat{a}) = \widehat{z}_L(\hat{a})$ and $G^S(\hat{a}) = G^N(1)$:

$$mrs(w_L - \widehat{z}_L(\hat{a}), G^N(1)) = \hat{a}(1 + z'_{RF}(\hat{a}\widehat{z}(\hat{a}))) = \hat{a}(1 + z'_{RF}(g_L^N(1))) \quad (12)$$

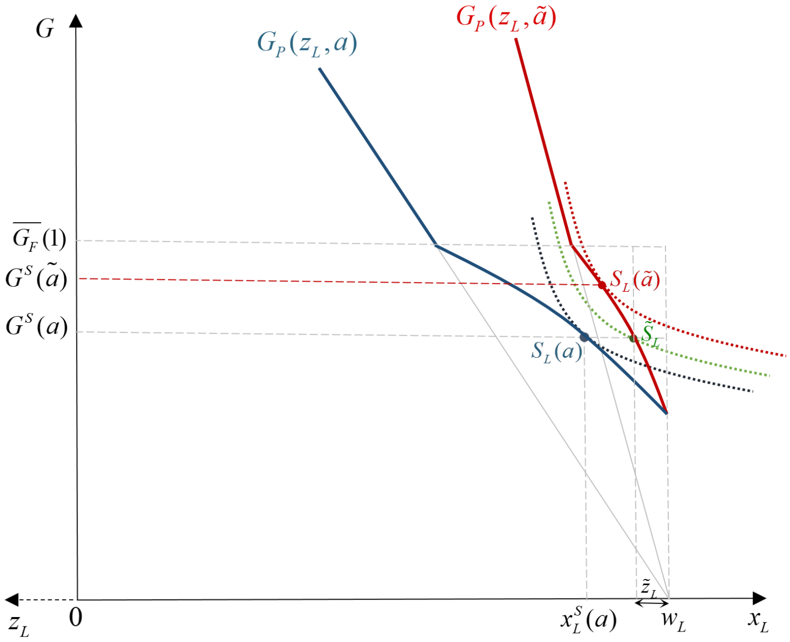


Figure 3.3: The change of the Stackelberg equilibrium through an increase of the contribution productivity

It remains to be shown that a contribution productivity $\hat{a}$ which satisfies condition (12) actually exists: Starting at $a = 1$ we have

$$mrs(\widehat{x}_L(1), G^N(1)) = mrs(x^N(1), G^N(1)) = 1 > 1 + z'_{RF}(g_L^N(1)) \qquad (13)$$

as $z'_{RF}(g_L^N(1)) < 0$. Hence, at $a = 1$ the left-hand side of (12) exceeds the right-hand side of (12). Since, moreover, $z'_{RF}(g_L^N(1)) > -1$ the linear function $a(1 + z'_{RF}(g_L^N(1))$ is increasing in a with $\lim_{a \to \infty} a(1 + z'_{RF}(g_L^N(1))) = \infty$. But at the same time normality implies that $mrs(\widehat{x}_L(a), G^N(1))$ is a decreasing function of $\widehat{x}_L(a)$ and thus of a, which converges to $mrs(w_L, G^N(1)) < \infty$ if a goes to infinity. Hence, in (12) the right-hand side will exceed the left-hand side if the productivity parameter gets large enough. Therefore, the intermediate value theorem provides the existence of a unique productivity parameter $\hat{a}$ with equality of both sides in (12). Based on this we get the following result:

Proposition 5. *Assume that the original NE, where both countries have the same contribution productivity $a_0 = 1$, is interior. If the threshold $\hat{a}$ is defined as above then $G^S(a) > G^N(1)$ holds for all $a > \hat{a}$. Moreover,* $\min\{u_L^S(a), u_F^S(a)\} > u^N(1)$, *i.e. the SE for any $a > \hat{a}$ is Pareto superior to the NE for $a_0 = 1$.*

Proof. The result on the change of public good supply is a direct consequence of Proposition 4 since $G^S(\hat{a}) = G^N(1)$ if an interior SE results for $\hat{a}$. Concerning the change of utilities, first note that in the SE for $\hat{a}$ utility of country L is higher than in the original NE as it attains the same public good supply $G^N(1)$ with a lower expenditure for the public good and thus with a higher level of private consumption. Utility of country F, however, is the same as in the original NE if $a = \hat{a}$. For any $a > \hat{a}$ country L then will improve further in the SE because as a Stackelberg leader it could have $G^N(1)$ with an even lower expenditure for the public good than in the SE for $\hat{a}$. But also country F becomes better off: As Proposition 4 implies that $G^S(a) > G^S(\hat{a}) = G^N(1)$ country F in an interior SE is moving outwards on the expansion path $e(G, 1)$ and increases its utility when L's contribution productivity rises from $\hat{a}$ to some $a > \hat{a}$. When, however, for $a > \hat{a}$ large enough the SE is country L's standalone allocation with public good supply $G_L^A(a)$, we observe that $G_L^A(a) > \bar{G}_F(1) > G^N(1)$. Hence, as $x^N(1) < w_F$ we get $u(w_F, G_L^A(a)) > u(x_F^N(1), G^N(1))$, i.e. also in such a corner SE country F's utility will exceed its utility in the original NE. □

Comparing Proposition 1 and Proposition 5 indicates that, on the one hand, a negative incentive for a technological improvement in the Nash game results for a low level of the contribution productivity a while, on the other hand, a higher public good supply in the SE than in the original NE is implied by a high level of a. Both requirements can only be satisfied simultaneously if the regions of a, that are defined by Proposition 1 and Proposition 5, respectively, overlap, i.e. if the alternative contribution productivity $a > 1$ is small enough to prevent the choice of a by country L in the Nash case but at the same time a is large enough to yield a higher public good supply in the SE for a than in the original NE for $a_0 = 1$. The possibility for such a double advantage of leadership is described by the following Proposition, which is the central result of this chapter.

Proposition 6. *Assume that the original NE with productivity $a_0 = 1$ in both countries is interior and that at stage 1 country L has the choice between the original contribution productivity $a_0 = 1$ and some higher contribution productivity $a > 1$. If $\hat{a} < \bar{a}$ and $a \in (\hat{a}, \bar{a})$ then in the subgame-perfect equilibrium of the Stackelberg case both public good supply and the utilities of the two countries are strictly larger than in the subgame-perfect equilibrium of the Nash case.*

Proof. Proposition 3 implies $a_N^* = 1$ as $a < \bar{a}$. Since $a_S^* = a > \hat{a}$ Proposition 5 then yields $G^S(a_S^*) = G^S(a) > G^N(1) = G^N(a_N^*)$ as well as the assertion on Pareto superiority of the SE for a over the NE for $a_0 = 1$. □

In Proposition 6 as in the whole analysis until now, it has been assumed that only the leading country L has the option to apply a more productive contribution technology. If this assumption is abandoned and also country F is able to switch to some contribution productivity $b > 1$, the outcome may change considerably depending on the size of b. Consider the most important situation where $\hat{a} < \bar{a}$ and $a \in (\hat{a}, \bar{a})$. Then it follows from a continuity argument that the results of Proposition 6 (ii) and (iii) still hold given that country F's alternative contribution productivity b stays close to one, since in this case the relevant equilibria do not differ too much from those for $b = 1$. For higher levels of b, however, public good supply in the subgame-perfect equilibrium of the Nash case may become higher than in the subgame-perfect equilibrium of the Stackelberg case due to country F's application of the improved abatement technology. Finally, if b is large enough so that country F

definitely chooses the improved technology, both the NE and the SE at the second stage of the game are the standalone solution of country F so that public good supply becomes the same in both subgame-perfect equilibria. The different outcomes that may result when also the follower can choose an improved technology will be illustrated in the next section by a numerical example. If, in still another setting, there are (as in Stranlund 1996 and Buchholz, Dippl, and Eichenseer 2015) automatic technological spillovers from the innovating country L to the other country F better incentives for technological improvement result for country L in the Nash scenario, which makes $\bar{a} = 1$ more and thus $\hat{a} < \bar{a}$ less likely. Since technological diffusion usually needs some time, this effect will be stronger over a longer time horizon. Notwithstanding that, meteorological conditions will permanently limit the use of renewables as efficient greenhouse gas abatement technologies, which can make the contribution productivities a and b different also in the long run.

Based on Proposition 6 we can, in addition, also consider a scenario with endogenous timing [11] where - at a stage 0 before the two-stage game underlying our analysis starts - the two countries have to decide whether they want to act as leader or as follower. If we assume (as in Hamilton and Slutsky 1990, or Hattori and Kitamura 2013) that the Nash game results when both countries simultaneously either choose to be leader or follower then, in the case $\hat{a} < \bar{a}$, the distribution of roles with country L as the leader and country F as the follower becomes a subgame-perfect equilibrium of this three-stage game: According to Proposition 6 each country (as well as the other one) would become worse off in the ensuing Nash equilibrium when it deviates and changes its role. The endogenous timing model thus may also be useful to explain why the possibility for a technological improvement in one country can make it the leader in the contribution game.

It is, however, not obvious from the beginning that the condition $\hat{a} < \bar{a}$, which implies advantageous leadership both w.r.t the level of public good supply and the utility of both countries, can really be satisfied. Therefore we have to provide an example, in which $\hat{a} < \bar{a}$ actually holds. This will be done in the next section by assuming Cobb-Douglas preferences.

3.5 A COBB-DOUGLAS EXAMPLE

Let both countries have the same symmetric Cobb-Douglas utility function $u(x_i, G) = x_i G$ for $i = L, F$. The marginal rate of substitution at (x_i, G) is $mrs(x_i, G) = \frac{G}{x_i}$ so that the expansion paths for some given marginal rate of substitution is $e(G, \rho) = \frac{G}{\rho}$. For the partial derivatives we thus have $e_1(G, \rho) = \frac{1}{\rho}$ and $e_2(G, \rho) = -\frac{G}{\rho^2}$. For a given contribution productivity a of country L it follows from condition (1) that the levels of the public good, private consumption and the utilities of both countries that result in an interior NE are given by Table 3.1 where the abbreviation $W(a) := aw_L + w_F$ is used.

---

[11] In models in which two countries strategically choose their emission taxes Bárcena-Ruiz (2006) and Hattori and Kitamura (2013) have addressed the endogenous timing issue in the context of international environmental policy.

$G^N(a)$	$x_L^N(a)$	$x_F^N(a)$	$u_L^N(a)$	$u_F^N(a)$
$\frac{W(a)}{3}$	$\frac{W(a)}{3a}$	$\frac{W(a)}{3}$	$\frac{W(a)^2}{9a}$	$\frac{W(a)^2}{9}$

Table 3.1: The interior NE

The interiority conditions $x_L^N(a) < w_L$ and $x_F^N(a) < w_F$ for the NE are satisfied if

$$\frac{1}{2}a < q < 2a, \tag{14}$$

where $q = \frac{w_F}{w_L}$. Given $q > 1$ the threshold level $\bar{a}(q)$ as defined by Proposition 1 then is calculated from $u_L^N(\bar{a}(q)) = u_L^N(1)$. By using the fourth column of Table 3.1 we obtain

$$\bar{a}(q) = q^2. \tag{15}$$

Concerning the Stackelberg game, maximizing country F's utility $(w_F - z_F)(g_L + z_F)$ for a given g_L yields country F's reaction function $z_{RF}(g_L) = \frac{1}{2}(w_F - g_L)$ in its interior zone. Hence, country L as a Stackelberg leader maximizes $\frac{1}{2}(w_L - z_L)(w_F + az_L)$, which gives $z_L^S(a) = \frac{aw_L - w_F}{2a}$ as country L's public good optimal expenses in an interior SE. A complete description of the interior SE is provided by Table 3.2.

$G^S(a)$	$x_L^S(a)$	$x_F^S(a)$	$u_L^S(a)$	$u_F^S(a)$
$\frac{W(a)}{4}$	$\frac{W(a)}{2a}$	$\frac{W(a)}{4}$	$\frac{W(a)^2}{8a}$	$\frac{W(a)^2}{16}$

Table 3.2: The interior SE

An interior solution with $z_L^S(a) > 0$ is obtained if and only if $q < a$. The threshold level $\hat{a} = \hat{a}(q)$ as defined by Proposition 5 is obtained by applying conditions (11) and (12), i.e. by solving the equation $mrs(\widehat{x}_L(\hat{a}(q)), G^N(1)) = \frac{\hat{a}(q)G^N(1)}{(\hat{a}(q)-1)w_L + x_L^N(1))} = \hat{a}(q) \cdot \frac{1}{2} = \hat{a}(q)(1 + z'_{RF})$ for $\hat{a}(q)$.

By inserting the values of Table 3.2 gives

$$\hat{a}(q) = \frac{1}{3}(4 + q). \tag{16}$$

Comparing (15) and (16) gives that $\bar{a}(q) > \hat{a}(q)$ if $3q^2 - q - 4 > 0$. Determining the zeros of this quadratic function yields

$$\bar{a}(q) > \hat{a}(q) \Leftrightarrow q > \frac{4}{3}. \tag{17}$$

In summary, it follows from condition (14), (15), (16) and (17) that any combination (q, a)

$$q \in \left(\frac{4}{3}, 2\right) \qquad \text{and} \qquad a \in \left(\frac{1}{3}(4+q), q^2\right) \tag{18}$$

leads to a higher public good supply and higher utility levels in the subgame-perfect SE than in the subgame perfect NE. In this context note that the upper bound condition (17) is stronger than (14) if $q < 2$. The "advantageous leadership range", i.e. the set of (q, a)-combinations, which satisfies the condition (18), is visualized in Figure 3.4.

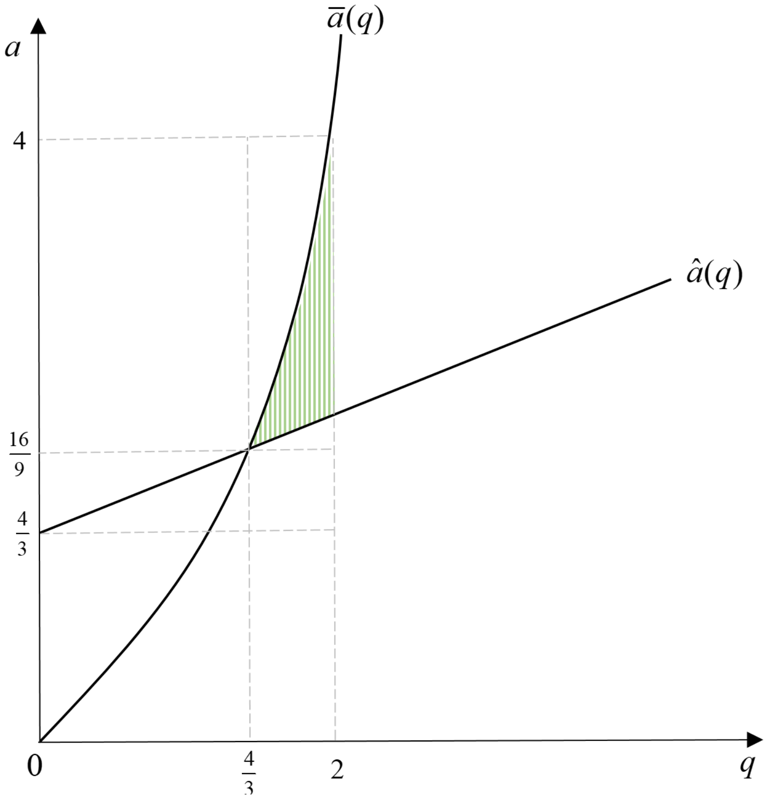


Figure 3.4: The advantageous leadership range

A specific numerical example for advantageous leadership, e.g., is provided by $w_L = 2$ and $w_F = 3$, i.e. $q = \frac{3}{2}$, and $a = 2$. By using the formulas calculated above, $u_L^N(2) = \frac{49}{18} = 2.72 < 2.78 = u_L^N(1)$ results. This confirms that country L does not want to adopt the improved technology in the Nash case. In the Stackelberg case, where country L chooses the better technology, total public good supply is $G^S(2) = \frac{7}{4} = 1,75 > 1,67 = G^N(1)$ and utilities of both countries are $u_L^S(2) = u_F^S(2) = \frac{49}{16} = 3,06 > 2,78 = u_L^N(1) = u_F^N(1)$. This confirms that a Pareto improvement over the initial NE is attained.

Now we look at the same example, but now we assume that also country F has the opportunity to switch to a higher contribution productivity $b > 1$. Then a subgame-perfect equilibrium in the Nash case always is $(a_N^*, b_N^*) = (1, b)$ while in the Stackelberg case it is $(a_S^*, b_S^*) = (2, 1)$ if $b \in [1, 1.36]$ and

$(a_S^*, b_S^*) = (2, b)$ if $b > 1.36 = \frac{49}{36}$. Concerning public good supply in the two subgame-perfect equilibria we have (with adapted notation) $G^N(1, b) = \frac{2+3b}{3} < \frac{7}{4} = 1.75 = G^S(2, 1)$ if $b \in (1, \frac{13}{12}) = (1, 1.08)$, i.e. the essentially same result as in Proposition 6 (ii) holds in this case in which b is relatively small. If, however, $b \in (1.08, 1.36)$ the ranking of public good supply is reversed, i.e. $G^N(1, b) > G^S(2, 1)$ holds so that the advantage of leadership by country L w.r.t. the level of public good supply vanishes. (Note that for $b < \frac{4}{3} = 1.33$ the NE is interior with public good supply $G^N(1, b) = \frac{2+3b}{3}$ while for $b \in [1.33, 1.36]$ it is the standalone solution of country F, i.e. $G^N(1, b) = G_F^A(b) = b\frac{w_F}{2} = b\frac{3}{2}$.) For $b > 1.36$ country F applies the improved technology with the contribution productivity b in the Nash as well as in the Stackelberg case and the corresponding standalone solution for country F results in both scenarios. As the incentive for country F's technology choice in the Stackelberg case are changing at $b = \frac{49}{36} = 1.36$ public good jumps there from 1.75 to $G_F^A\left(\frac{49}{36}\right) = \frac{49}{36} \cdot \frac{3}{2} = 2.04$.

3.6 CONCLUSION

In public good theory, it appears to be a common belief that leadership will aggravate the underprovision problem, which is a typical feature of non-cooperative public good provision and which also is of empirical relevance with regard to global climate policy. Without leaving the standard framework of public good theory, this assertion, however, needs no longer be true if the leading country can choose the technology, by which it generates its public good contribution and, more specifically, by which it carries out abatement measures. Rather, leadership may remove the obstacle, which could prevent the application of a cost-saving abatement technology in the Nash game, and by application of this improved contribution technology, public good supply may become larger and utility of both countries may increase in the leader-follower game so that a double advantage of leadership arises (see Proposition 6). Moreover, this effect becomes more likely if the poorer country acts as a leader since the incentives to adopt the improved technology in the Nash case are particularly weak in this case (see Proposition 1 and the Cobb-Douglas example). The possible Pareto improvement through leadership in the presence of a technological improvement may also provide an explanation as to why a country may become a leader in the contribution game at all (see the considerations following Proposition 6).

In real-world global climate policy China seems to have adopted a leadership position in the process following the Paris Agreement. Statements by high-ranking Chinese representatives are indicative of such a change of attitude.[12] Concerning China's leadership, a central role is attributed to the development and application of cost-saving abatement technologies. China's "leadership had identified low-carbon technologies as the technologies of the

---

[12] So the general secretary of China's Communist Party, Xi Jiniping, has declared at the 19th National Party Congress in October 2017 that China has "taken a driving seat in international cooperation to respond climate change". For a critical assessment of the recent trends in China's clean-air policy see The Economist.

future ..." (Hilton 2016). In particular, China is intensifying the development and application of low-carbon technologies as wind and solar power and e-mobility. This chapter has shown by the central Proposition 6 that in the strategic context of global climate policy such leadership - by triggering environmentally friendly technological progress - may not only lead to more overall climate protection but can also be in the interest of all countries involved. Against the background of our results it does not come as a surprise that these positive effects of leadership occur when it is a - compared to the OECD countries - still relatively poor country that acts as the leader.

Part II

AN EMPIRICAL EXAMPLE

INTRODUCTORY REMARKS TO PART II[13]

Part II considers an empirical example of leadership in climate policy. At the Global Climate Action Summit at San Francisco in September 2018, Nobel laureate and climate activist Al Gore emphasized that humankind has the tools it needs to solve the climate crisis. In particular he referred to the "relief that is literally heaven sent" from sun and wind with the cheapness of these sources of electricity not only making them competitive but even more favorable than conventional technologies in many parts of the world.

Even though the largest part of renewable energy is literally falling from the sky, this does not apply to the technology development that is requisite to make use of it. In fact, developing the technological innovations that make it possible to use renewable energies at a competitive level requires much effort.

Leadership by countries does not only materialize in achieving mitigation efforts but also in promoting green technological progress. This has already happened in the past with tremendous consequences: In the case of photovoltaics an unprecedented cost reduction of 99.4% between 1976 and 2014 has been the result of policy measures taken by a group of nations that alternated in taking the leadership in capacity additions and research and development (Trancik et al. 2015). These technological developments could indeed prove to be a major game changer for global climate policy, as they offer the perspective of negative abatement costs in the near future.

In the same vein, the Paris Agreement (United Nations 2016) emphasized that innovation is crucial for an effective global response to climate change, which constitutes a strong mandate for technological development and transfer (Minas 2016). In the Paris Agreement there is a close link between the Climate Convention's Technology Mechanism (TM) and "climate finance", i.e. the Green Climate Fund (GCF) and the Global Environmental Facility (GEF).

In face of this relationship, financing technological progress in green technologies is part of an individual country's contributions in the fight against climate change. Traditionally (in the Kyoto world), individual countries' public good contributions only consisted of emission reductions. In the Paris Agreement a broader approach is applied, by which Nationally Determined Contributions (NDCs) are considered as indicators of the countries' climate policy efforts. In the NDCs of 137 parties the word "technology" (NDC Partnership 2018) appears, and a great deal of these submissions (especially from developing countries) refer to their own efforts in the field of technology and, moreover, express the desire for technological support as a prerequisite for more ambitious mitigation efforts.

---

[13] Part II (including these introductory remarks) is a slightly modified version of Buchholz, Dippl, and Eichenseer (2019).

Consequently, Chapter 4 considers an empirical example of leadership in climate-friendly technological progress: Germany's feed-in tariff for solar energy. By creating reliable demand it constitutes technological leadership. Based on global learning curves, we argue that the enormous reduction of prices for photovoltaic modules is due to such demand side interventions and related international technology diffusion and policy transfer, especially to China. In addition, we calculate the costs of incentivizing this technological progress for the German case (through the EEG).

4

SUBSIDIZING RENEWABLES AS PART OF TAKING LEADERSHIP IN INTERNATIONAL CLIMATE POLICY: THE GERMAN CASE[14]

4.1 INTRODUCTION

The aim of this chapter is to provide some quantitative assessment of a country's indirect contribution to climate protection via the promotion of green technologies. In particular, we show how subsidies such as Germany's feed-in tariff for solar energy have helped create a market for climate-friendly technology and thereby constitute a contribution and a manifestation of climate leadership in a broader sense.[15] Based on global learning curves, an enormous reduction of prices for photovoltaic modules can to a large degree be attributed to these demand side interventions such as Germany's "Renewable Energy Law" ("Erneuerbare Energien Gesetz" EEG) and the subsequent technology diffusion enabling other countries to reduce greenhouse gas emissions more cheaply. Using the example of the German feed-in tariff for solar power, we aim at calculating in monetary terms the scale of these contributions related to technological development of solar energy. Hence this chapter does not discuss the fiercely disputed question whether the implementation and subsidization of renewables through the German EEG has been efficient. Instead, it focuses on the costs associated with taking on a leadership role in the deployment of renewable energies. Or, in other words, the chapter does not deal with static but with dynamic efficiency of the subsidization of renewables in Germany (Del Río 2012).

The remainder of this chapter will be organized as follows: In Section 2, we describe the global learning process that has occurred in the field of photovoltaics making reference to the concept of "learning curves". In Section 3, we consider the German EEG and the learning by doing associated with it. In particular, we quantify the cost burden of the subsidization of solar energy through the EEG that has mainly been borne by the German electricity consumers so far. Section 4 concludes by discussing possible consequences that may result with regard to the assessment of climate policy if promotion of green technology is explicitly considered as a component of a country's contribution to the fight against global warming.

---

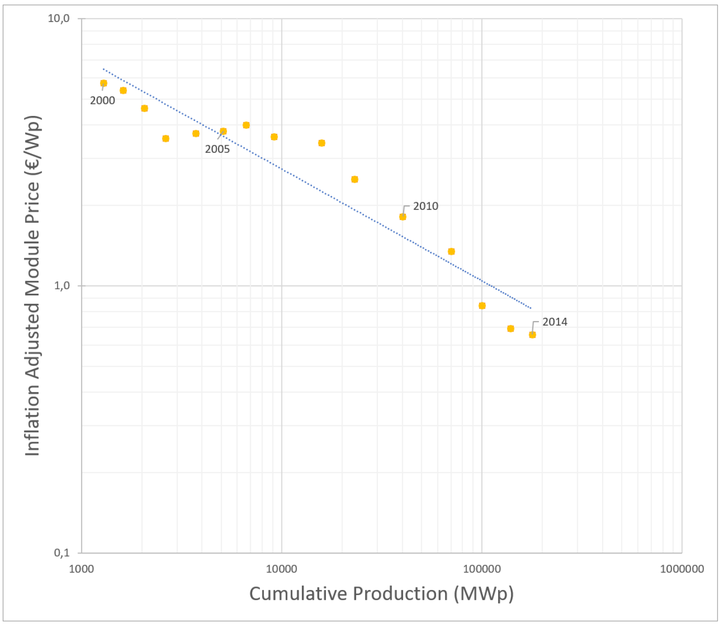
[14] This chapter is a slightly modified version of Buchholz, Dippl, and Eichenseer (2019).

[15] How leadership in the development and application of green technologies is perceived by energy policy experts as one of the targets of the German Energy Transition ("Energiewende") has been empirically investigated in a survey by Joas et al. (2016).

4.2 LEARNING CURVES AND TECHNOLOGICAL PROGRESS IN PHOTOVOLTAIC

To show how market formation policies achieve technological progress we need to understand how technological development generally comes about. Two approaches can be distinguished: The first approach is referred to as “learning by searching” or simply “R&D”. It is prevalent in an early stage of technological development and is characterized by financing or subsidizing research activities through private firms and the government. The second concept relates to the deployment of technology at a later stage paving the way to commercial maturity. It is best known as ”learning by doing”. Technological progress achieved through learning by doing is commonly analyzed by making use of so-called learning curves (first described by Wright (1936)).

Arrow (1962) highlights that technological progress is the result of an ongoing extensive learning process. His claim is that we can attribute learning to experience. Traditional learning curves (see Yelle 1979 for a review) focus on the relationship between cumulative output and working hours (as a proxy for production cost). The learning curves used to describe technological progress in the photovoltaic sector generally relate the cumulative output to module price/kWp where the module price is a proxy for production costs (e.g. Neij 1997; Harmon 2000; Van der Zwaan and Rabl 2003; De La Tour, Glachant, and Ménière 2013; Rubin et al. 2015).



Based on data from Mayer et al. (2015), EPIA (2014) and Solar Power Europe (2016). The dashed line represents a linear trend.

Figure 4.1: Learning curve for PV modules

Learning Curves represent a ”fit of a power function to the measured points” (Wene 2000). We can describe the curve by:

$$C(X) = C_1 X^{-b} \qquad (1)$$

where $C(X)$ refers to the cost of producing the xth unit of output for a specific cumulative output X (which explicitly includes the xth unit) (Wene 2000).

The constant C_1 gives the costs associated with one unit of cumulative output ($X = 1$) and the parameter b is dubbed the learning index. The learning index helps determine the "learning rate" which refers to the reduction in costs (of producing one unit) when cumulative output is doubled ($X_2 = 2X_1$):

$$LR = \frac{C(X_1) - C(X_2)}{C(X_1)} = 1 - 2^{-b} \tag{2}$$

De La Tour, Glachant, and Ménière (2013) consider several studies on learning curves for photovoltaic modules in a meta-analysis and calculate an average learning rate of 20.9%. This means that for each doubling of cumulative output, module costs (or prices) per kWp decrease by 20.9% . Rubin et al. (2015) who calculate an average learning rate of 22% obtain similar results.

Despite the criticism by several authors (e.g. Nemet 2006; Jamasb and Köhler 2008; Rubin et al. 2015) on (log-linear) learning curves, they remain the standard instrument in assessing technological development and future prospects of photovoltaic (in the following PV) technology. As a consequence of this learning process solar power is getting more and more competitive and will soon be the cheapest form of electricity in many parts of the world (Mayer et al. 2015), especially in the developing countries, where solar radiation is generally significantly higher than in Germany. Latest estimates by Frauenhofer ISE (Burger et al. 2018) suggest an average learning rate of 24% for the last 36 years for all commercially available PV technologies.[16] Figure 4.1 depicts the relationship between cumulative capacity produced and module prices (inflation adjusted with 2014 as base year) between 2000 and 2014.

Learning by doing for marketable goods and devices requires their wide use and application, which often can only be achieved by pushing them in the market or even by creating a market for them. In the case of solar power, this has happened through market-formation policies of a pioneering group of industrialized countries (Trancik et al. 2015). Trade and the ensuing untargeted diffusion of technology have led to a global learning effect[17] in the course of which there has also been a transfer of knowledge and technology which has paved the way for the creation of production capacities around the world, especially in China. Chinese companies mainly procured production skills for photovoltaic production by international trade in manufacturing equipment and Chinese returnees (De La Tour, Glachant, and Ménière 2011).

So, with the help of technology transfer, process innovation, talent mobilization and scaling strategies as well as interaction with the global innovation system and global market formation policy (Zhang and Gallagher 2016), China's PV industry witnessed a formidable takeoff from 4% share of global

---

[16] Likewise, one can use learning curves to predict technological development in inverters, another key component of PV systems. Historical data indicates learning rates of about 18.9 % (Mayer et al. 2015) in this case.

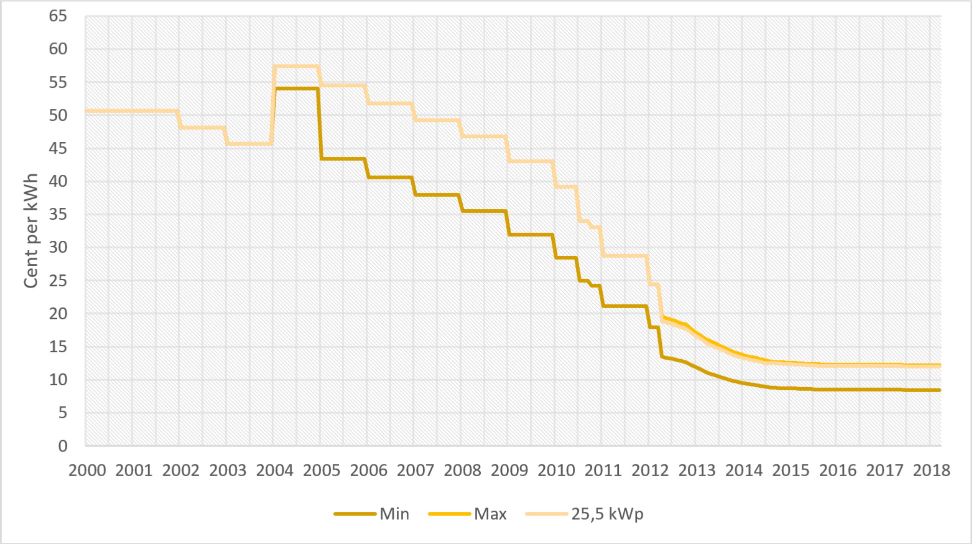
[17] Similarly, inverters reflect global learning effects while there are local learning effects for example in the installation of the system.

cell production in 2004 to 71.4% in 2012 (Puttaswamy and Ali 2017). During the 2000s a large share of China's production in PV cells and modules was exported with only about 5% sold to domestic consumers (Liu and Goldstein 2013). Only in the aftermath of the global economic crisis of 2008, China fostered its domestic demand for photovoltaic installations (Puttaswamy and Ali 2017). By 2015, China surpassed Germany as the lead market for PV deployment (IEA PVPS 2016). This clearly shows that market formation policies have created incentives for the diffusion of PV (production) technologies, especially for China, which consequently again "greatly drove down the cost of solar panels" (Gallagher 2013, p.33).

4.3 GERMANY'S CONTRIBUTION THROUGH THE EEG TO GLOBAL LEARNING BY DOING

4.3.1 *The EEG and Learning by Doing*

Germany's EEG as introduced in 2000 is a classic example of a market formation policy. It requires network operators to feed-in electricity from renewable sources into the grid. This tariff is a 20-year, technology-specific, guaranteed payment for a plant operator's electricity generation. Feed-in tariffs decrease in regular intervals (Figure 4.2) to exert cost pressure on energy generators and technology manufacturers. The decrease (called "degression") applies to new plants.



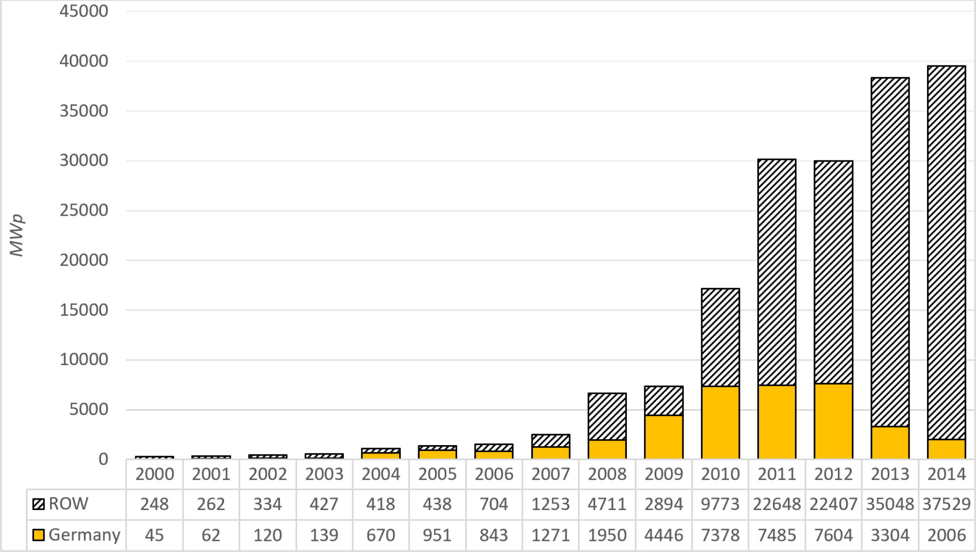
Based on data from Netztransparenz (2018b) and own calculations.

Figure 4.2: (Fixed)Feed-in tariffs in Germany by installation date

In its original version in 2000 the aim of the EEG was to facilitate a sustainable development of energy supply, particularly for the sake of protecting our climate and the environment, while in the amendment of 2004, the social democratic-ecological coalition government (1998-2005) emphasized the objective to "promote the further development of technologies for the generation of electricity from renewable energy sources" in article 1 EEG (Bundesgesetzblatt I, 2004, p.1918). Thus, the EEG entails an emission reduction component as well as a technology development component on which we will focus in this chapter. In this context, we will restrict our analysis to energy generated from PV because solar energy only accounts for 19.21% of predicted German energy generation from regenerative sources covered by the EEG but makes up for 34.06% of predicted EEG expenses in 2018 (Netztransparenz 2017). Furthermore, in the public debate it is arguably the most controversial source of energy supported by the EEG as Germany, being located between the 47th and 55th parallel, is not exactly known for its long hours of sunshine.

After having described the main features of the EEG, we assess the impact that Germany's subsidization of PV and the related creating of a market has had on technological progress through learning by doing and thus on cost reduction in the PV sector.

To this end, we depict in Figure 4.3 both the total capacity of PV annual new installations and Germany's share of it, which is described by the yellow bar. Obviously, the German share has been considerably high throughout the whole period (22% share of all new installations between 2000 and 2014) and especially between the years 2004 to 2007 (57%) as well as in 2009 and 2010 (48%).

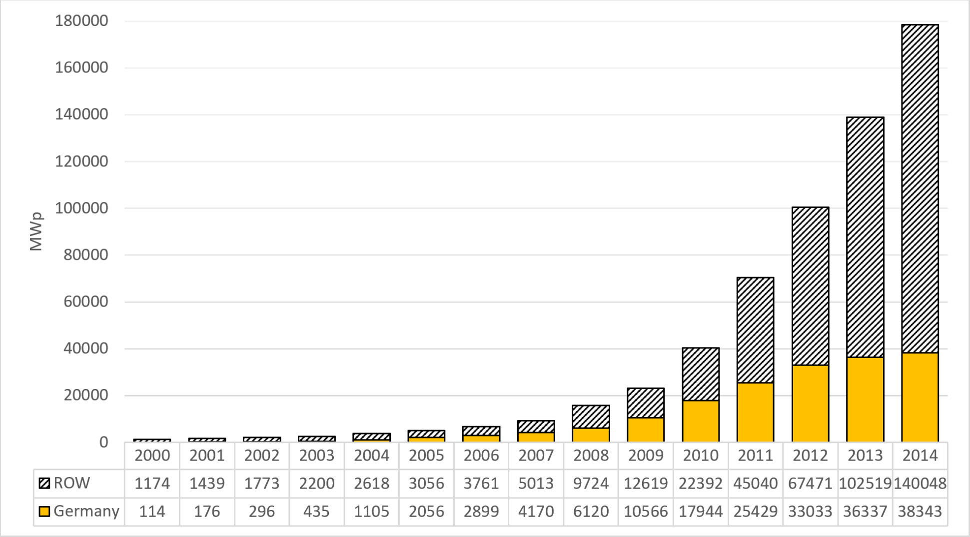


	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
▨ ROW	248	262	334	427	418	438	704	1253	4711	2894	9773	22648	22407	35048	37529
🟨 Germany	45	62	120	139	670	951	843	1271	1950	4446	7378	7485	7604	3304	2006

Based on data from BMWi (2016), Solar Power Europe (2016), and EPIA (2014).

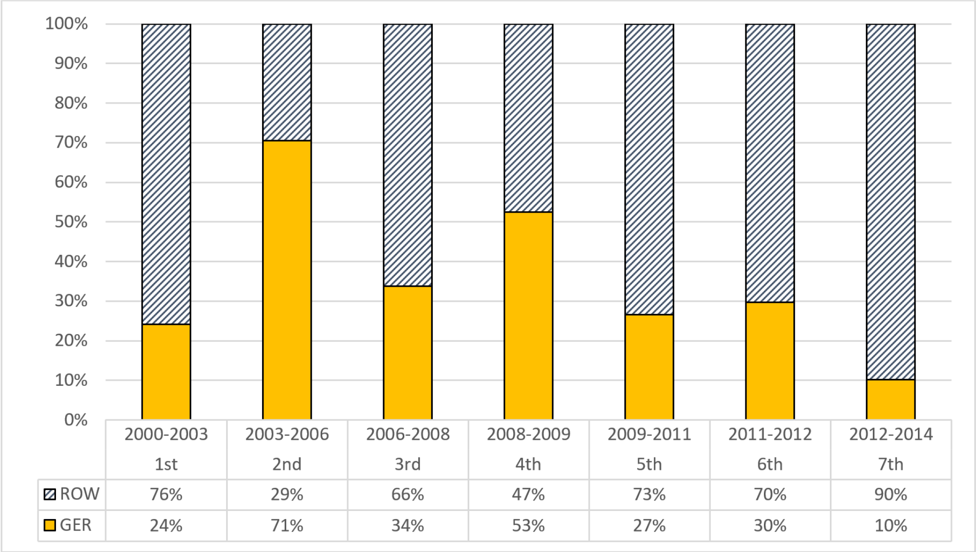
Figure 4.3: New installations

Figure 4.4 reflects this pattern by depicting the German share not of annual, but of cumulative installed capacity (again in yellow). Since 2004, Germany has taken the leading role with regard to cumulative installed capacity and constituted the lead market for PV deployment. The relative share of Germany in cumulative capacity reached a peak in 2009. By 2014 worldwide cumulative capacity was about 140 times larger than in 2000, whereas cumulative capacity in Germany had expanded by a factor of 336.



Based on data from BMWi (2016), Solar Power Europe (2016), and EPIA (2014).

Figure 4.4: Cumulative capacity



Own calculations based on data from BMWi (2016), Solar Power Europe (2016), and EPIA (2014).

Figure 4.5: German share of doublings

However, what really matters for learning by doing is the share in each doubling, as this is what the average 24% cost reduction in module prices (Burger et al. 2018) refers to. Figure 4.5 depicts the German share in doublings of cumulative capacity since 2000. On average Germany has had a share of about 35% in each doubling of cumulative capacity. Thus, it can be concluded that Germany - by taking on a pioneering role and providing a stable and reliable market for PV modules - has contributed to driving PV down the learning curve and thus achieving technological progress. This corresponds to the observation by Trancik et al. (2015) that Germany with its policy of subsidizing renewables has been the primary driver for PV from 2004–2012 (based on new installations).

4.3.2 *Costs Related to Technological Progress*

As a next step we want to get an idea of the magnitude of the costs that have arisen for Germany by taking on this pioneering role through promoting the application of PV. To this end, we compare the net value of subsidies for all PV-installations that were connected to the grid by the end of 2014 with the net value of subsidies that hypothetical new entrants in late 2014 would have paid (keeping the amount of electricity produced equal). The idea underlying our thought experiment is to determine the additional costs that PV-subsidization has caused for German energy consumers. These subsidies made Germany a forerunner in PV-application and thus helped induce cost-reducing learning-by-doing effects at a global scale.

Or, to put it differently, these "excess costs" represent the hypothetical costs savings Germany could have obtained if it had begun to start building up its PV-capacity only in late 2014. As a reward for waiting this – also quite hypothetically – would have made it possible to benefit from the price reductions having occurred until then (which in turn would have had to be financed by other countries) while the long-run effect on Germany's aggregate CO_2-emission and hence on the global climate would essentially be the same. The difference between these hypothetical costs of subsidizing solar energy and the real costs will be interpreted as Germany's contribution to the technological progress in the PV-industry.

In order to gain a better understanding of our thought experiment it may be important to note that the two cost values that we are going to compare clearly do not reflect the total costs that arise for Germany due to the substitution of fossil fuels through solar energy: The "system costs" of renewables are higher than the "levelized costs of electricity" (LCOE) per MWh generated by PV, which are covered by the level of the feed-in tariffs (see, e.g., Stram 2016, and Pariente-David 2016). In addition, there are network expansion costs and costs systemically associated with accommodating the volatile supply of energy from renewable sources into the grid. Not only do transmission networks have to be adapted and extended to cope with a higher share of solar energy but also – due to the intermittency of the most important renewables – reserve and storing capacities must be made available to ensure a sufficiently steady supply of electricity also when the sun doesn't shine (see, e.g., Joskow 2011). These "hidden costs" of renewables are hard to quantify but may be relatively high – and unavoidable if the economic and social losses of reduced supply security are to be prevented (see Röpke 2013).

As important as the system costs are for an overall cost-benefit analysis of the EEG it cannot be expected that they differ greatly between our scenarios. It can instead be reasonably assumed that whether PV-plants are built a few years earlier or later will not have a high impact on the total system costs. Therefore, system costs do not seem to be of much relevance for our results.

For our calculations we choose the year 2014 as the reference point since the major cost reductions have been realized by the end of 2014 (see Figure 4.2). We then determine the difference between the costs of subsidization for solar energy that actually occurred under the EEG to those incurred by hypothetical new entrants making instalments only in late 2014 with the reduced costs of PV at that time. To calculate these "excess costs" we apply two different methods. The first method is cohort based whereas the second one is year specific.

4.3.2.1 *The Cohort Based Approach*

A key parameter of this approach is the feed-in tariff for each cohort. As the feed-in tariff are staggered by size of an installation this parameter must be based on assumptions about the average size of an installation in Germany for which we assume a value of 25.5 kWp [18] Subsequently, we compute the feed-in tariff for this average installation. In December 2014, the first ten kWp are valued at 12.59 Cent and the remaining 15.6 kWp at 12.25 Cents resulting in a feed-tariff of $FI_{2014}^{\varnothing PV} = 12.38$ Cent per kWh. This figure also represents an estimate of 2014 costs associated with generating one kWh of PV energy using an average sized installation. It can further be interpreted as the costs of incentivizing one kWh of PV energy at the end of the year 2014. [19]

We now compare the feed-in remuneration that each of the 14 cohorts $t = 2000, \ldots, 2013$ of installation will receive during the funding period of 20 years with the costs that a cohort of the same size would generate over 20 years if it applied the improved 2014 technology and thus was compensated by $FI_{2014}^{\varnothing PV}$. Formula 3 sums up the excess costs for the cohorts from t=2000 up to t=2013 as a rough estimate without discounting:

$$\sum_{t=2000}^{2013} \left[20 FI_t^{\varnothing PV} P Z_t - 20 FI_{2014}^{\varnothing PV} P Z_t \right] \tag{3}$$

In this formula $FI_t^{\varnothing PV}$ indicates the feed-in tariff of the average installation in year t, and Z_t is the total capacity of cohort t measured in MWp. The parameter P represents a productivity parameter that indicates the number of kwh generated from one MWp within one year [20] Figure 4.6 provides a graphical representation of the cost burdens associated with the individual cohorts. Table 4.1 shows how the numerical quantities that are appearing in formula (4) have developed between 2000 and 2013.

---

[18] This is achieved by dividing the cumulative installed capacity by the number of registered installations (1.5 Mio- BSW Solar 2015) at the end of 2014. We obtain an average size of 25.562 kWp per Installation. For our calculations we use a value of 25.5 kwp per Installation as an assumption.

[19] Note that this method leads to a rather pessimistic estimate of costs as larger scale installations can work with feed-in tariffs of well below 9 Cent as can be seen in Figure 4.2 and prices even below that can now be realized for large plants via tenders.

[20] P empirically determined as 849 kWh/ kWp as weighted average adjusted for global radiation using data from DWD (2018).

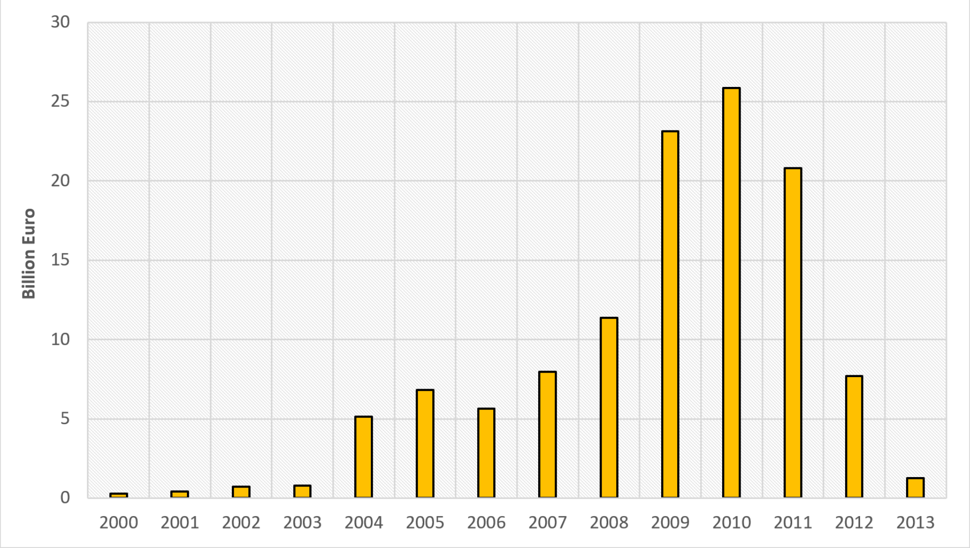


Figure 4.6: Costs of technology promotion in Euro (1st Approach)

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
$FI_t^{\varnothing PV}$	50.62	50.62	48.1	45.7	57.4	54.53	51.8
Z_t	45	62	120	139	670	951	843
P	849	849	849	849	849	849	849
$FI_{2014}^{\varnothing PV}$	12.38	12.38	12.38	12.38	12.38	12.38	12.38

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
$FI_t^{\varnothing PV}$	49.21	46.75	43.01	33.03	28.74	18.33	14.6
Z_t	1271	1950	4446	7378	7485	7604	3304
P	849	849	849	849	849	849	849
$FI_{2014}^{\varnothing PV}$	12.38	12.38	12.38	12.38	12.38	12.38	12.38

Data from BMWi (2016), Netztransparenz (2018b) and own calculations.

Table 4.1: Relevant parameters for the 1st Approach

In the case with positive discounting formula (3) turns into

$$\sum_{t=2000}^{2013}\left[PZ_t\left(FI_t^{\varnothing PV}-FI_{2014}^{\varnothing PV}\right)\sum_{k=0}^{19}\frac{1}{(1+i)^{t+k-2014}}\right] \qquad (4)$$

where 2014 serves as the point of reference. This implies that the value of all payments before 2014 is increased while payments after 2014 are devaluated. For instance, for an installation that is part of the 2012 cohort, the payments for 2012 and 2013 are compounded as 2014 is the point of reference, while the payments for the remaining funding period after 2014 (comprising the years 2015-2021) are discounted.

Using the parameters in Table 1 and applying formula (3) gives an estimate of excess costs of 117.8 billion Euro in the absence of discounting. Abstaining from discounting comes close to the current level of interest rates. If we assume positive interest rates at the level of long run (10 year) German sovereign bonds in 2014 of 1.16%[21] , formula (4) gives a slightly lower value of 112.34 billion Euro. It is these excess costs that we identify as Germany's contribution to technological progress in PV-production.

4.3.2.2 *The Year Based Approach*

The second method we apply in order to calculate the excess costs of being an early adopter is year specific. By adopting this approach we first of all compare, without discounting, the actual costs of PV subsidization in Germany incurred throughout the years 2000 to 2013 to the hypothetical costs if the same amount of PV energy were subsidized by the feed-in tariff $FI_{2014}^{\varnothing PV} = 12.38$ Cent - reflecting the state of technology in 2014.

$$\sum_{t=2000}^{2013} EXP_t^{PV} - Y_t^{PV,FI} FI_{2014}^{\varnothing PV} - Y_t^{PV,MP} (FI_{2014}^{\varnothing PV,MP} - MV_t) \tag{5}$$

In this formula EXP_t^{PV} indicates the total amount of remuneration for PV energy in year t in Euro. The amount of energy (kWh) compensated with a fixed feed-in tariff is denoted by $Y_t^{PV,FI}$ (see Table 4.3 for relevant parameters). For the years 2012 and 2013, we also consider installations that make use of the market premium model ("Marktprämie" - opportunity for direct marketing). In this case $Y_t^{PV,MP}$ is the amount of energy produced in kwh and $FI_{2014}^{\varnothing PV,MP}$ the feed-in tariff for our average installation in the market premium model where an average energy source-specific market value MV_t is subtracted.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
$Y_t^{PV,FI}$	29000000	76000000	162430000	313300000	556500000	1282300000	2220300000	3075000000	4419800000	6578000000	11682523772	19339465533	24368850191	25258694576
$Y_t^{PV,MP}$													1024521880	3525504152
EXP_t^{PV}	15000000	39000000	81710000	153670000	282650000	679110000	1176800000	1597480000	2218620000	3156520000	5089943327	7766067088	9156012309	9346043021
$FI_{2014}^{\varnothing PV}$	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38	12.38
$FI_{2014}^{\varnothing PV,MP}$													12.78	12.78
MV_t													3.29475	3.28575

Data from Netztransparenz (2018a), Netztransparenz (2018b) and own calculations.

Table 4.2: Relevant parameters for the 2nd Approach

---

[21] The use of the interest rate of government bonds is motivated by the assumption that in our hypothetical scenarios the subsidies for the entire PV-instalment in 2014 would be financed by public debt so that no risk premium of private investors (and thus no 'beta' as component of the capital asset pricing model CAPM) has been included. Apart from that, as we will see later, our numerical results are relatively robust against the choice of the discount rate. For an assessment of risk premia of investments in different types of renewables (and different countries) see Donovan and Corbishley (2016).

The difference which in our context amounts to 28.02 billion Euro serves as a proxy for the costs associated with technology promotion accrued until the end of 2013; a huge chunk of excess costs has yet to be paid. This is due to the fact that the PV installations that have been connected to the grid between 2000 and 2013 benefit from their higher subsidy rates also after 2014. The calculation of these payments, which from the perspective of the year 2014 are lying in the future, is based on the following reasoning: We assume that systems installed in 2014 and subsequent years do not generate excess costs as they receive a feed-in tariff of $FI_{2014}^{\varnothing PV}$ or even one below that. All installations that were first connected to the grid before the end of 2013 are still running between 2014 and 2019 and reimbursed by their individual high feed-in tariffs. Hence, the excess costs during those six years are equal to the excess costs in 2013. Since installations receive a guaranteed feed-in tariff only for 20 years, in 2020 the solar plants that have been installed in the year 2000 fall out of subsidization in 2020 - or, more precisely, receive their guaranteed feed-in tariff merely for a couple of days/weeks/months, depending on when exactly in 2000 they were first connected to the grid. For example, installations that were first connected to the grid at the beginning of April, 2000 receive guaranteed feed-in tariffs during the first three months of 2020. To get an estimate of the excess costs for 2020 we thus must subtract the excess costs of 2000 from the excess costs of 2013. Accordingly, the excess costs for 2021 are obtained by subtracting the excess costs of 2000 and 2001 from the excess costs of 2013. For subsequent years until 2032 the excess costs are calculated in a similar way.[22]

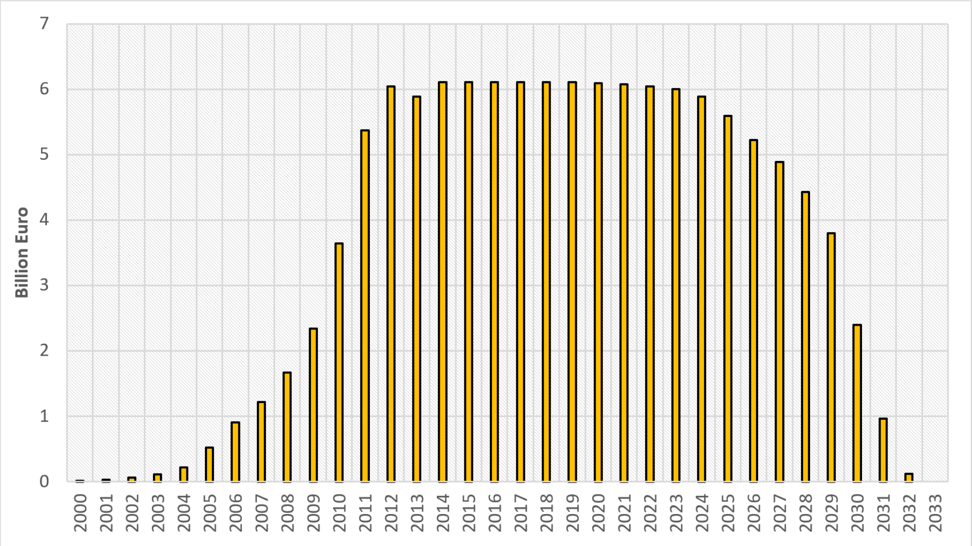


Figure 4.7: Costs of technology promotion in Euro (2nd Approach) until 2033.

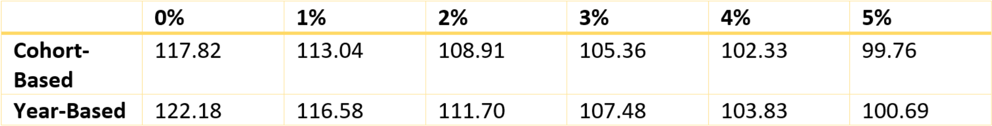
Adding up the excess costs for all years from 2001 until 2032 yields total excess costs of 122.18 billion Euro, a number quite similar to that of the cohort based approach. Figure 4.7 visualizes these costs for individual years from

---

[22] To control for the amount of sunshine, we normalize these values using global radiation data from DWD (2018).

2000 up to 2033. Applying a discounting scenario – again with the interest rate 1.16% and 2014 as the base year – yields a value of 115.75 billion Euro.

In the scenarios with discounting we have used a relatively low discount rate of about 1% , which reflects the low interest rates for German government bonds. With an increasing discount rate the values of the excess costs are decreasing but not too much as Table 3 shows.



	0%	**1%**	**2%**	**3%**	**4%**	**5%**
Cohort-Based	117.82	113.04	108.91	105.36	102.33	99.76
Year-Based	122.18	116.58	111.70	107.48	103.83	100.69

All figures in billion Euro.

Table 4.3: Excess costs for different discount rates

Even in the case of a high discount rate of 5%, which would include a high risk premium, the excess costs, i.e. the aggregate level of German indirect subsidies for solar technology improvement, do not fall far below 100 billion Euro. Hence, our numerical results prove to be relatively robust against variations of the discount rate.

4.4 CONSEQUENCES FOR THE ASSESSMENT OF CLIMATE POLICY AND CONCLUSION

The EEG, first of all, has resulted in the creation of a relatively large and secure market for photovoltaics in Germany, which enabled learning-by-doing effects and thereby - as described above - has led to significant price reductions for solar energy production. Subsequently, this has encouraged other countries to create their own production facilities in order to benefit from this market. So, the support of renewables through the EEG helped foreign companies, in particular Chinese ones, to gain strong market positions. Global competition between solar firms has increased, which also helped to bring about further cost reductions, and many countries have adopted measures for the promotion of solar energy as well, which further enlarged the market for photovoltaics considerably.[23] While this has been bad news for German solar firms and the jobs offered by them it is good news for the earth's climate (see, e.g., Pegels and Lütkenhorst 2014). Similar effects may occur in the future in the context of other green technologies such as electric cars or storage facilities for electricity.

The expenses that the promotion of green technological progress by means of the EEG and thus for the provision of the global public good knowledge about climate-friendly technologies (Stiglitz 1999) has caused for Germany are considerably large. As we have shown in this chapter by a simple thought experiment the net present value of these contributions Germany amounts

---

[23] By a theoretical argument it can be shown that the incentives for green R&D measures are improved if the improved technology is made available free of charge to other countries (see Buchholz, Dippl, and Eichenseer 2015; Foucart and Garsous 2018).

to more than 100 billion Euro. This is much more than what Germany in the past has contributed from budgetary sources to "climate finance", i.e. for financing measures both for greenhouse gas mitigation and for climate change adaptation in developing and emerging countries. Until 2014 the total amount of these expenses has been about 12.5 billion Euros and about 18.6 billion Euros until 2016 (BMU 2017, p.59). In 2015, Germany has announced that it will raise its annual contribution to climate finance – through bilateral and institutions of multilateral cooperation as the "Green Climate Fund" – to 4 billion Euros by 2020. But also with this increased contribution it will take a long time until the total level of Germany's expenses for the development of climate friendly technologies will be reached.

It is quite common in the discussion of the GCF to compare the different countries' contributions. Against this background it could be an interesting topic for future research to also quantify the other countries' contribution to the promotion of green renewable technologies – in analogy to our analysis for Germany and PV in this chapter.

The enormous improvement of solar technology and the ensuing cost reductions have far-reaching benefits for global climate policy. So, the often-expressed hope that renewable energies are able to catch up with fossil and nuclear energy has almost come true (e.g. Obama 2017). The falling costs for greenhouse gas abatement offer scope for governments to raise their climate policy targets and hence to commit to more ambitious NDCs. If, however, countries by themselves prefer renewables to their conventional counterparts the free-rider problem that plagues global collective action on climate change mitigation will lose its importance (see, e.g., Peinhardt and Sandler 2015). Given lower abatement costs the risks that relate to unilateral mitigation activities are reduced, which makes it more likely that a "ratcheting-up" process w.r.t. national climate policy as intended by the Paris Agreement targets will set in (Falkner 2016, and Schmidt and Sewerin 2017).

Improved green technologies in particular allow developing countries to leapfrog many steps that today's developed countries had to take in the past, which means that they can use low carbon technologies already at an early stage in their development process (Trancik et al. 2015, and Goldemberg and Guardabassi 2012). Then they are no longer in the inconvenient situation of having to choose between environmental protection on the one hand and economic development on the other so that "investing in climate" and "investing in growth" will become better compatible.[24] While the diffusion of climate friendly technology reduces the mitigation costs and thus the burden of poor countries, the upfront expenditures of green innovation have been taken by the developed countries. In this way, the promotion of renewables by developed countries automatically constitutes some kind of (financial) compensation for less developed countries and thus contributes to global climate justice.

The fact that technological transfers are an important component of global climate policy obviously should have consequences for the evaluation of national policies for the promotion of renewable energy and especially for the discussion on the faults and merits of the EEG. In its initial phase the EEG

---

[24] See the corresponding OECD report (2017).

- with its generous subsidization of solar over wind energy - clearly did not attain the targeted reduction of CO_2-emissions at minimum cost since the 'law of one price' is violated (see Sinn 2012b). This has become the central point of criticism of the EEG (see, e.g., Frondel et al. 2010, Sinn 2012a, or Monopolkomission 2009). This lack of cost-efficiency, which has also been reflected in different feed-in-tariffs for the various types of renewables, can be interpreted as a price that had to be paid for a successful promotion of green technology.[25] Yet only a few participants in the debate on the EEG emphasize its technology promotion effect and the related technology transfer component.[26] This interpretation, which is in line with the argument of this chapter, also supports the view that instead of surcharges on the electricity price, taxes should be used to finance the liabilities of renewables subsidization that are inherited from the first phase of the EEG. In this way, also the EEG's huge regressive distributive effects (see, e.g., Frondel, Sommer, and Vance 2015) could be alleviated.

---

[25] Cost-efficiency of CO_2-emissions has gained much importance w.r.t. the subsidization so renewables in Germany. Consequently, the EEG has been subject to a fundamental reform in 2017 through which tariff auctions (tenders) have become an important element of the subsidization mechanism. Since renewables technology had been promoted successfully until then this change only seems logical from the perspective of this chapter.

[26] Among these are the former chancellery minister Bodo Hombach (2013) and the former minister of the environment Jürgen Trittin in a TV-debate in October 2017.

Part III

A PREREQUISITE FOR LEADERSHIP

INTRODUCTORY REMARKS TO PART III

> "What appears at first blush to be a rather cosmic question more suited to a metaphysical analysis is in actuality one that is central to an ultimate understanding of the social relation we call leadership. [...] one's assumptions about whether humans are by nature social or independent, selfish or altruistic, rational or irrational, or incorrigible or capable of improvement, determines in great part one's view of leadership [...] as well as one's proposed solution to perceived challenges [...]"

Thomas Wren (2007, pp.5-6)

As pointed out by Wren's quotation the assessment of the prospects of leadership also depends on the underlying conception of man. The theoretical approaches to leadership in Part I share the assumption that governments are narrow payoff-maximizers. Correspondingly, the representative government is an agent that shares attributes with the concept of a "homo oeconomicus". In a world of these narrow payoff-maximizing agents the problem of "crowding out" is omnipresent. Increased ambition in contributions by one party are replied by a decline in others' contributions.

If one assumes, however, that humans are a social animal having "social preferences", there is scope for a positive reaction to leadership (Buchholz and Sandler 2017). One such "social preference" is reciprocity. The hope associated with "homo reciprocans" is that leadership efforts such as those described exemplarily in Part II are reciprocated by increased ambition of others. So the micro-foundations of human behavior are decisive for the success of leadership. Therefore the question at hand is whether the concept of "homo reciprocans" can be sustained.

This is of particular relevance for the global public good of climate protection. The approach of the Paris Agreement is built on the hope of reciprocal reactions to ambitious Nationally Determined Contributions (NDCs hereafter). NDCs are voluntary, non-binding commitments under international law. One basic idea of this approach is that a good example given by one country sets a benchmark for other countries and thereby induces a positive reaction expressed by higher efforts of other countries. The intention is to unleash a dynamic process of increasing ambition ("ratcheting up").

Consequently, Part III goes in search of reciprocity. Thereby it tries to come to an answer to the question of whether pioneers can expect others to follow their example by increasing their efforts - a prerequisite for successful leadership. To this end, Chapter 5 summarizes the state of knowledge in the literature on reciprocity in experimental economics and international relations. Chapter 6 subsequently investigates the stability of reciprocal patterns across two social dilemma games using an online experiment.

5

RECIPROCITY IN ECONOMICS AND INTERNATIONAL RELATIONS

5.1 INTRODUCTION

Can we expect reciprocity in global public good provision in the absence of a central governing authority? The purpose of this chapter is to explore whether there is reasonable hope that pioneering efforts may be reciprocated by others which may help solving international public goods problems such as climate change mitigation in an otherwise non-cooperative scenario. So, we are going in search of reciprocity, taking stock of the literature. The approach is a hybrid one: first we look at the micro-level of individual preferences in economics and then try to find out whether there is evidence that these results can be transferred to the level of international relations (IR hereafter). In other words, we match the ideas brought up by economists with the lessons learned in international politics. In the end, we're trying to draw a conclusion whether these findings may be applicable to the example of raising ambition in Nationally Determined Contributions (NDCs hereafter) in the context of the Paris Agreement. Accordingly, the remainder of this chapter will be as follows: Sections 2 and 3 briefly wrap up the evidence gathered by economists and IR scholars while Section 4 offers a synthesis of the findings and interprets them in the context of the NDCs followed by a conclusion.

5.2 ECONOMICS AND RECIPROCITY

5.2.1 *Background*

In economics, there is a tradition of studying reciprocal behavior. In fact, even the most fundamental market exchange is based on social cooperation, a reciprocal relationship.[27] For a long time, however, reciprocity has not been the focus of economic research. The inspiration has rather been drawn from sociology. In a seminal paper, Gouldner (1960) clarified the concept by defining reciprocity as a pattern of mutually contingent exchange of gratifications and as a moral norm that is rooted in folk belief and relates to the stability of social systems. Subsequently, economists referred reciprocity to a broad range of economic outcomes like gift exchange in labor markets (Akerlof 1982), em-

---

[27] Adam Smith describes this in the following way: "in a nation of hunters, if any one has a talent for making bows and arrows better than his neighbor he will at first make presents of them, and in return get presents of their game. By continuing this practice he will live better than before and will have no occasion to provide for himself, as the surplus of his own labor does it more effectually"(Smith, 1976, p.220 as cited by Ashraf, Camerer, and Loewenstein (2005, pp.137-138)). This line of argumentation justifies the emergence of market exchange even in primitive societies in the absence of a state that could intervene.

ployee theft (Giacalone and Greenberg 1997), informal insurance (Coate and Ravallion 1993) and public goods supply (Sugden 1984).

But the topic really has become important with the spread of experimental economics. Simple games have provided valuable insights. In the ultimatum game (Güth, Schmittberger, and Schwarze 1982), responders reject low offers (less than 20 % of the surplus) with a large probability (Fehr and Schmidt 2006). This indicates negative reciprocity as small payments are penalized with the rejection of the offer under the sacrifice of own material interests. By contrast, gift-exchange games (Fehr et al. 1998) and trust games (Berg, Dickhaut, and McCabe 1995) indicate positive reciprocity. In the latter, many first movers send money which seems to trigger positive reactions by second movers that give money back. The amount sent and the amount sent back are frequently correlated both at the individual and the aggregated level. In addition, these simple one-shot interactions already show that there is a relatively large proportion (between 40 and 60 %) of people who exhibit reciprocal behavior (Fehr and Gächter 2000).

5.2.2 *Experimental Evidence on Reciprocity in the Sequential Prisoner's Dilemma*

A convenient way to assess reciprocal behavior is to use the sequential prisoner's dilemma. In this sequential version of the Prisoner's Dilemma game players move one after the other. Correspondingly, the second player has the means of reciprocally responding to the first player's action. Clark and Sefton (2001) show that a substantial fraction of second movers make use of this opportunity. About 90% of the experimental subjects respond with defection to the first mover's defection whereas 58% use the cooperative action if the first mover cooperated. Clark and Sefton (2001) consider this as evidence for reciprocity, since the first mover's choice is the key variable in predicting second mover behavior. Cooperation, however, decreases with repetition of the game and the extent of reciprocity diminishes with rising monetary costs of cooperation. Miettinen et al. (2017) make use of the strategy method to determine the reaction on cooperation as well as defection for every individual. This allows to classify discrete behavioral types (see also Kosfeld 2019). The largest group of players (47%) consists of free-riders or unconditional defectors who always choose defection followed by conditional cooperators who form the second largest group (38%). These players behave exactly reciprocal to first-mover behavior. In addition, there are altruists who cooperate unconditionally and missmatchers who always counteract the first mover with 9% and 6% respectively. This shows that a substantial fraction of subjects can be classified as conditional cooperators in the sequential prisoner's dilemma.

5.2.3 *Experimental Evidence on Reciprocity and Public Good Supply*

5.2.3.1 *The Basic Setup*

The workhouse model to study cooperation in experimental public goods games is the voluntary contribution mechanism (VCM) in a linear version.

Given that there are N players, the payoff of player i in a one-shot game (or per period in a repeated game) with initial endowment y_i is given by: $\pi_i = y_i - g_i + \alpha \sum_{j=1}^{N} g_j$ where g denotes individual contributions and α the marginal per capita return (MPCR) of the public good. The MPCR is set in a way ($\alpha < 1$) that zero contributions are individually rational and full contributions generate the largest aggregated payoffs ($N\alpha > 1$). Consequently, for a parameter range of α that fulfills $1 > \alpha > \frac{1}{N}$, we obtain a social dilemma situation.

From the beginning, a common result of public goods games has been that the corner solution theoretically predicted for the usual parameterization does not emerge. Contributions significantly exceed zero with about 40-60% of the endowment on average (Ledyard 1995). At the same time, there is a declining pattern of contributions in finitely repeated one-shot interactions whereas a "restart" increases cooperation levels again. In repeated games, there is usually a sharp decline of contribution at the end of play (last period) referred to a last round effect.

5.2.3.2 *Conditional Cooperation*

The beginning of the concept of conditional cooperation is most likely Croson (1996) who compares individual contributions to those of others in a group (and own expectations thereof). She reports that there is a strong positive correlation to both, others' contributions and to the beliefs about others' contributions. This indicates positive reciprocity and is contrary to a standard crowding-out hypothesis. Subjects increase their contributions if others do so or they expect others to do so.

Subsequently, the term conditional cooperation (CC) has emerged in the late 1990s. This refers to the assumption that some subjects mirror the behavior of others: they cooperate if others do so while they do not if others don't cooperate. Sonnemans, Schram, and Offerman (1999) and Keser and Van Winden (2000) gained insights by comparing partner and stranger conditions. Sonnemans, Schram, and Offerman (1999) used a partner design with a component of a perfect stranger matching: one player was exchanged by another after a given number of periods while the remaining group composition is unchanged. Given subjects' beliefs, they conclude that group members contribute the more the more they expect others to contribute. This gives rise to the assumption that it may be rational for selfish players to act strategically and contribute much to encourage others to contribute more (to obtain a positive reaction). Indicators thereof are that the magnitude of contributions depends on the number of periods remaining with the same group composition (future looking behavior) and that subjects who will leave a group contribute less than subjects who will stay. In a similar vein Keser and Van Winden (2000), who find significantly larger contributions in a partner matching compared to a stranger matching, interpret their results as evidence for conditional cooperation, characterized by future-oriented (future relationship) as well as reactive behavior (average behavior of the others). For the former, they report evidence in the form of higher initial contributions, while they read a subject's reaction

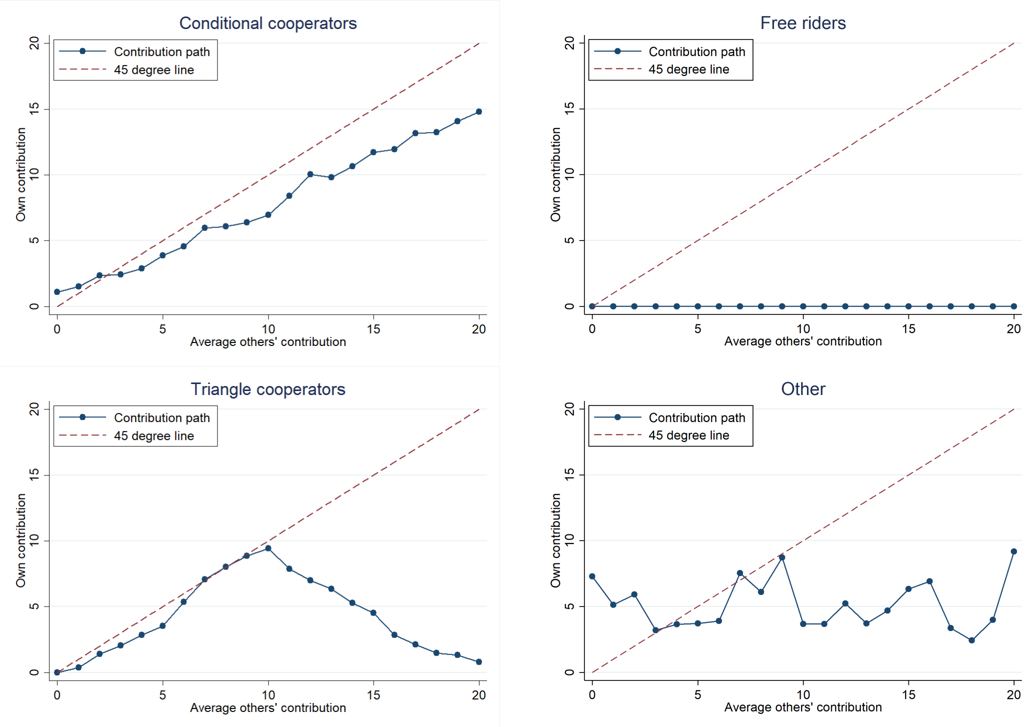


Figure 5.1: Contribution paths for different behavioral types in Fischbacher, Gächter, and Fehr (2001)

to a deviation from average contributions (adjustment towards the average) as sign of the latter.

A major methodical innovation was introduced by Fischbacher, Gächter, and Fehr (2001).[28] They use a four player one-shot public goods game to classify a subject's cooperation type using the strategy method. Subjects state an unconditional contribution as well as a vector of conditional contributions contingent on the average contribution of the three other players. This allows to derive a reaction function for a subject's contribution conditional on the other subjects' average contribution. Accordingly, it is possible to classify subjects into four different categories according to their reaction function. A conditional cooperator is someone who matches the others' contributions to a large degree (see Figure 5.1). Free riders are subjects that always give zero. Triangle cooperators start by matching contributions up to a certain point where their reaction function starts being negatively sloped. A last category captures the remaining subjects (including unconditional cooperators)[29]. In Fischbacher, Gächter, and Fehr (2001) the fraction of conditional cooperators is about half of the subjects, while one third can be classified as free-riders.[30]

Conditional cooperation is a cross-culturally robust phenomenon with a varying fraction of conditional cooperators (Kocher et al. 2008; Herrmann and

---

[28] A comparison of conditional cooperation patterns in the Prisoner's Dilemma and the Public Goods Game is given in Chapter 6 (Eichenseer and Moser 2019a).

[29] Refinements of the classification method are proposed by Fallucchi, Luccasen, and Turocy (2018) and Thöni and Volk (2018).

[30] There is an on-going discussion whether conditional cooperation is related to confusion (see e.g. Burton-Chellew, El Mouden, and West 2016; Goeschl and Lohse 2018).

Thöni 2009) that can be observed from early on (Hett et al. 2018). The classification based on Fischbacher, Gächter, and Fehr (2001) actually has a good predictive power for repeated interactions. Fischbacher and Gächter (2010) show that elicited conditional cooperation (strategy method) and expectations predict behavior in a repeated public goods game. In addition, the number of subjects classified as conditional cooperators within a group positively and significantly increases group contributions (De Oliveira, Croson, and Eckel 2015).

However, mapping most subjects' contributions relative to the average contribution of the remaining subjects reveals that their contributions are below the 45 degree line when using the strategy method (e.g. Fischbacher, Gächter, and Fehr 2001; Fischbacher and Gächter 2010). Subjects try to "cheap ride" in a repeated PG experiment which is referred to as "selfish-biased conditional cooperation" which means that contributions increase not fully proportionally in others' contributions (Neugebauer et al. 2009). Moreover, when individual contributions instead of an average of others' contributions are revealed, more subjects align to a low contribution rather than to a good example of high contributons (Hartig, Irlenbusch, and Kölle 2015).

5.2.3.3 *Punishment*

A channel to allow subjects to behave in a negative reciprocal way is to allow them to punish those who acted unfriendly. A simple alteration of the public goods game is to introduce costly, decentralized, punishment of other players, such that "homo reciprocans has the opportunity to discipline those subjects who are selfish or insufficiently motivated by positive reciprocity"(Fehr and Gächter 1998, pp.855-856). Subjects can punish others at the expense of own earnings such that simple payoff maximization would yield that no-one punishes (at least in a single interaction). However, Fehr and Gachter (2000) find that punishment occurs both in situations where subjects interact repeatedly with each other (partner matching) and in situations where subjects are randomly rematched after each interaction (stranger matching). In both conditions, the threat of decentralized punishment by other subjects induces very high contribution levels and the groups succeed in maintaining them. By contrast, the within subject design allows to state that the same subjects reduce their contributions steadily in the absence of punishment to almost full defection in the last period. Generally, the punishment (negative reciprocity) is the larger, the larger a subject's contribution deviates from the group's average.

From an evolutionary perspective, a small fraction of people who punish free-riding could induce selfish types to cooperate (Gintis et al. 2003). Thus, do we see that the introduction of the possibility of punishment unequivocally leads to an improvement in the amount of public good? Unfortunately, this cannot be generally affirmed. The experiments by Herrmann, Thöni, and Gächter (2008) reveal that an amelioration is present in places like Boston, Nottingham, Copenhagen and Bonn whereas it does not seem to work in places like Samara, Athens, Istanbul and Riyadh. This can be attributed to the different degrees of antisocial punishment, i.e. punishing people who contribute above average to the public good. In addition, Herrmann, Thöni, and Gächter

(2008) are able to show that there is a positive correlation between antisocial punishment and perceptions of the importance of norms of civic cooperation and the rule of law.

Recently, Kirchkamp and Mill (2018) have investigated the impact of punishment power on conditional cooperation - both for the role of having the power to punish and for being under the threat of being punished. As both punishment and conditional cooperation are variants of reciprocal behavior, they can possibly be regarded as substitutes and it could be possible that the amount of conditional cooperation decreases as subjects have the power to punish. However, this is not the case. If individuals have the possibility of punishing others, they show a pattern of more conditional cooperation. The threat of being punished on the other hand has opposite effects. Regarding the extensive margin, the number of free-riders increases and conversely the intensive margin of conditional cooperation increases, i.e. the remaining conditional cooperators react stronger to an increase in others' contributions. In total, the effect of the threat of punishment on conditional cooperation is positive. In a similar vein, Weber, Weisel, and Gächter (2018) explore the relation between positive and negative reciprocity in a strategy method setting. They find that subjects that are classified as free-riders when using the method of Fischbacher, Gächter, and Fehr (2001) cooperate only when punishment is possible whereas conditional cooperators also cooperate in the absence of punishment. They find no evidence that disposition towards positive (conditional cooperation) and negative (punishment) reciprocity are correlated which means that there are no remarkable differences in the punishment activity of conditional cooperators and free-riders such that dispositional free riders "do not free ride on punishment of others" (Weber, Weisel, and Gächter 2018, p.6).

5.2.4 *Moral Wiggle Room, Image Concerns and Social Norms*

There is the question whether individuals are actually intrinsically motivated to behave reciprocally. The argument of the moral wiggle room signifies that if there is in a given situation a plausible excuse for behaving less generous or fair which prevents a condemnation by others or oneself, this changes the amount of social preferences observed. For example, people reduce the amount of pro-social behavior if there is a chance that their decision was randomly replaced by a computer.

A number of studies have found that the amount shared in a dictator game declines significantly if there is a good situation-specific excuse that allows to canvas the relationship between own actions and resulting outcomes for others (see e.g. Dana, Weber, and Kuang 2007). In addition, the amount given in dictator games varies depending on whether there is an audience,[31] which leads to the hypothesis of Andreoni and Bernheim (2009) that many people find it important to be considered as fair by others. This is underlined by the

---

[31] In public goods provision, observability increases contributions in one-shot games (Rege and Telle 2004) but not in repeated interactions in which the opposite holds (Noussair and Tucker 2007). With regard to punishment, observability promotes moral punishment (Kurzban, DeScioli, and O'Brien 2007).

results of Lazear, Malmendier, and Weber (2012) who are able to show that a significant amount of people are sorting out situations in which it is possible for them to share, in this case a dictator game. This indicates that they share reluctantly.

Correspondingly, the question is to what extent these arguments are also valid in reciprocal settings. If one first looks upon the argument of the moral wiggle room, the evidence at hand from trust games is inconclusive. Van der Weele et al. (2014) consider second mover behavior in trust games. The authors show that the introduction of an apology for not behaving reciprocally does not have an impact on second mover behavior. By contrast Matthey and Regner (2015) and Regner (2018) find that also reciprocal behavior is influenced by the moral wiggle room. Malmendier, Velde, and Weber (2014) give evidence for sorting out of conditions of positive reciprocity in a double dictator game experiment albeit to a lesser extent than in a classical dictator game. It can therefore not be ruled out that reciprocal behavior is not only caused by internal motives such as a preference for fairness or generosity but also by motives such as self-signaling (which are depending on the decision situation) and also external motives such as social approval or disapproval (which refer to image concerns). As well, social norms and rules have an impact on reciprocity. There is evidence that people who follow rules in general ('rule followers') have a higher propensity to behave reciprocally in the trust game (Kimbrough and Vostroknutov 2016).

5.2.5 *Models of Reciprocity*

Up to this point, we have more or less agnostically pursued the question of evidence for reciprocity in experimental economics. If one approaches the question of how the mechanisms involved can be presented theoretically, there is at least a distinction to make between models that assume a preference for outcome-based fairness and models that account for intentions of the decision makers. The earliest and maybe most prominent one of the intention-based models is the model by Rabin (1993) that builds upon psychological game theory. In a two player setting its basic assumption is that players would sacrifice own material well-being to reward kind intentions and punish unkind intentions. Accordingly, players form beliefs about the other player's actions and hold beliefs on the other player's beliefs about own actions. To measure kindness, Rabin (1993) sets up a function f_i that measures kindness of player i towards j and f_j' as perceived fairness of j towards i. Kind actions are described by a positive value of the kindness function whereas negative values are indications of treating the other player badly. Utility of player i is then given by the additive separable function: $U_i = x_i + f_j'(1 + f_i)$. This model has been further developed and many variants exist, for example for sequential games in Dufwenberg and Kirchsteiger (2004) who incorporate updating of beliefs. In addition, there are a number of outcome-based models like inequity aversion by Fehr and Schmidt (1999) or the Equity, Reciprocity and Competition model of Bolton and Ockenfels (2000) that can rationalize reciprocal behavior though they remain silent on the decision-makers' intentions. Some models like Charness and Rabin (2002) and Falk and Fischbacher (2006, for extensive form games) combine intentions and distributional concerns. Furthermore, there are models in which the kindness towards another player depends on the other player's type (Levine 1998) or the own emotional state (Cox, Friedman, and Gjerstad 2007). In addition, a relatively new line of literature asks whether people have some kind of norm-dependent utility such that they receive utility following societal norms like the norm of reciprocity (e.g. Kimbrough and Vostroknutov 2016). This focus on norms certainly also forges a link back to early models of reciprocity like Sugden (1984).

He formulates a model based on a "reciprocity principle" in which people in a public goods game feel a moral obligation to either follow an adapted version of a Kantian "categorical imperative" (choose a contribution level that they would prefer that every member of the group makes) or (if others contribute less) stick to at least to the minimum contribution of the group. Consequently, an individual maximizes utility subject to a "moral constraint" that includes an obligation for reciprocal behavior.[32]

5.3 RECIPROCITY IN INTERNATIONAL RELATIONS

5.3.1 *Reciprocity in International Relations Theory*

After this brief review of the development on reciprocity in the field of economics, we now turn to examine the extent to which reciprocity is inherent in IR. There are two schools of thought in political science that allow to bridge the gap to the findings of behavioral economics. A direct linkage is the work of Elinor Ostrom who promoted the integration of elements of behavioral economics like reciprocity into economically minded rational choice theory (Ostrom 1998). Likewise, theorists like Axelrod described reciprocity as a mean of achieving cooperation among egoists by formalizing the argument through an iterated Prisoner's Dilemma (Axelrod 1981).

A further, possibly less obvious starting point is the liberal school of institutionalism. In a seminal paper, Robert Keohane (1986) has described the immanent meaning of reciprocity for liberalist institutionalism as follows. The starting point is the often prevailing motive of anarchy in international relations theory in conjunction with the question of why this does not result in a "war of all against all" in a Hobbesian sense. Rather, his overall diagnosis is limited cooperation in an environment that is characterized by sovereignty of individual countries on the one hand and the lack of centralized enforcement mechanisms on the other hand. A major point of his reasoning is that this cooperation can be traced back (also referring to Axelrod (1981)) in large parts to reciprocity which represents an appropriate remedy - probably the most effective one - in achieving cooperation among egoists (Keohane 2005). Keohane (1986) distinguishes two different kinds of reciprocity also in order to avoid the term getting ambiguous. The first kind of reciprocity "diffuse reciprocity"

---

[32] In contrast to later approaches like the work by John Roemer, the model of Sugden (1984) relies on Nash optimization. In addition, it entails a component (the minimum contribution) that prevents exploitation of Kantian behavior.

is something that happens in the sphere of individual actors. This form of reciprocity is characterized by the fact that it is not always clear whether it is an exchange of equivalent values and moreover the sequence of the exchange is less obvious. It can probably be best described as a kind of conformity to standards of behavior or norms that are generally accepted. By contrast, "specific reciprocity" refers to the contingent exchange of equivalent items in a pre-specified sequence. Consequently, it is a much more formalized kind of reciprocity. For diffuse reciprocity Keohane (1986) makes it very clear that a sense of obligation is a necessary precondition with the actors involved to make it work.

If preconditions like powerful common interests, a shadow of the future (the fear of future retaliation) or international regimes are met, there is a chance of transferring diffuse reciprocity into specific reciprocity. Concurrently, successful specific reciprocity may create trust (see also Rathbun 2011, on trust and diffuse reciprocity)[33] and lead to diffuse reciprocity in other domains. Specific and diffuse reciprocity therefore mutually interrelate. Prosperous institutions thus are rooted on both grounds as "the successful functioning of institutions depends heavily on the operation of reciprocity, both specific and diffuse" (Keohane and Martin 1995). Likewise, membership in international organizations promotes cooperation as it reinforces and institutionalizes reciprocity. Thereby regimes that incorportate reciprocity delegitimize defection (Axelrod and Keohane 1985).

5.3.2 *Social Preferences, Norms and Values of the Electorate*

Besides the somewhat "rationalized" form of reciprocity described at the beginning of this section, there is a discussion in IR research of whether there is a more intrinsic form of reciprocity and, on a more general level, the question of as to what degree norms and ethics are an important ingredient of foreign policy attitudes. In doing so, scholars make reference to the findings of behavioral economics and social psychology and the evidence on departures from pure selfishness. At the same time, this branch of IR research reproaches its sharpest critics from the realist school, who oftentimes treat states as if they were black boxes solely governed by the "national interest", that even their constructs are not free of norms, morals and cultural influences which constitute the micro-foundations of the national interest (Kertzer et al. 2014). Moreover, attitudes of elites to domestic and foreign policy are related such that the term national interest is conceived differently depending on the decision maker's position on the political spectrum (Rathbun 2007).

As Kertzer et al. (2014) points out, the debate about to what extent social preferences and norm orientations in the electorate do and shall carry over to foreign policy has been hold for a long time between realists and liberals. On part of the realists, scholars like Morgenthau complain about an intoxication from moral abstractions stating that moral principles could not be applied to

---

[33] Rathbun (2011) points out that generalized trust can be regarded as kind of anarchic social capital which facilitates diffuse reciprocity and alleviates the fear of free-riding and opportunism which allows decision makers to commit to multilateralism and international institutions.

states while others like Mearsheimer point out that decision makers would not be influenced by them. Liberals on the contrary state that the electorate would be capable of a thoughtful opinion on international affairs.

The norm of reciprocity is sometimes a mean of justifying political decisions such as the Byrd-Hagel resolution in the US Senate that hindered a ratification of the Kyoto Protocol in 1997. The question arises, however, as to what extent reciprocal behavior in the population in economic experiments also relates to public foreign policy attitudes and attitudes towards international environmental treaties in particular. Bechtel and Scheve (2013) use survey evidence from France, Germany, the United Kingdom, and the United States to link conditional cooperation in a strategy method public goods game to public support for different kinds of climate agreements. They find that conditional cooperators are more sensitive to the number of participants in the agreement and the share of emissions covered by the agreement, i.e. their support increases more powerful if more countries are involved. Bechtel and Scheve (2013, p.13763) consider this finding supportive of the view that " the sensitivity of public support to design features reflects underlying norms of reciprocity". Tingley and Tomz (2014) conduct a survey on Amazon Mechanical Turk among United States citizens to explore the willingness to act reciprocally. They find that most US citizens have an attitude of positive reciprocity when other countries cut their emissions i.e. respond positively while they would not advocate to increase emissions if others did.[34] In addition, there seems to be public support for a reciprocal response based on trade sanctions or blaming and shaming in reaction to an increase in emissions by another country (especially when the polluters violate a treaty).

5.3.3 *Empirical Examples and Evidence for Reciprocity*

But is there evidence for reciprocal behavior between nations? For bilateral interactions, Frank et al. (2018) use a Goldstein time series on ICEWS event data on cooperation and non-cooperation between countries. They come to the conclusion that for a considerable number of pairs of bilateral interactions reciprocal patterns can be detected which they interpret as evidence for reciprocity to be a widespread mechanism in international relations. Reciprocal reactions are also present in (military) conflict situations and were observed for example in superpower relations between the United States and the Soviet Union (Goldstein 1991), the Bosnia Conflict (Goldstein and Pevehouse 1997), the Middle East (Goldstein et al. 2001) and between India and Pakistan (Rajmaira 1997). For international trade, reciprocal behavior has been widely described by Keohane (1986) and further empirical descriptions for US trade relations in the GATT system have been documented by Rhodes (1989). More-

---

[34] Similarly, Beiser-McGrath and Bernauer (2019, p.248) argue that in their experimental setting "information on other countries failing to reduce their emissions does not undermine support for how international agreements are designed" However, there is possibly a difference to policymakers as a sample of high-level policy elites in the US showed that policymakers become less willing to join international (trade) agreements as the expectation of defection increases. In addition, policymakers are averse to making false promises even if there is no enforcement device (Hafner-Burton, LeVeck, and Victor 2017).

over, reciprocal norms for international trade have been institutionalized in the GATT and the WTO (Bagwell and Staiger 1999). Governments use a quasi-matching scheme for concessions in tariff reductions and more formally, reciprocal principles are applicable to renegotiation and tariff increases. Dluhosch and Horgos (2013) furthermore empirically show that tit-for-tat diplomacy in the WTO dispute settlement mechanism has a positive impact on trade openness.

Reciprocity is also a main mechanism in the domain of international law. Simma (2008) describes how reciprocity is involved in the law making process and the emergence of customary international law. The claims put by states that initiate the process of law-making depend on the expectation of the acceptance of claims by other states in a similar position. In addition, expectations of reciprocity may bring about mutual restraint and encourage self-limitation of the actors involved. Furthermore, Simma (2008) argues that reciprocity was governing every international agreement especially with regard to the reservations, termination and suspension of multilateral treaties and the observance of law. Parisi and Ghei (2003, p.107) describe by citing article 21 of the Vienna Convention of 1969 that this convention establishes that any reservation that has been set up with respect to another party changes "those provisions to the same extent for that other party in its relations with the reserving State" which can be conceived as a reciprocity constraint that closely resembles specific reciprocity. Parisi and Ghei (2003) interpret this article as effectively removing all incentive for unilateral defection. Reciprocal principles, moreover, apply for example to the mutual recognition and enforcement of judgments, the granting of copyright to foreign authors in the Bern Convention and the accepting of the compulsory jurisdiction of the International Court of justice.

Since the 19th century diplomatic privileges and immunity have been granted on the basis of reciprocity which is also rooted in the Vienna Convention of 1961 (Hestermeyer 2009). Even the expulsion of diplomats is commonly based on the reciprocity principle. As well, travel visas are negotiated on the basis of reciprocity. Czaika, Haas, and Villares-Varela (2018) analyze a panel dataset (DEMEG VISA) on bilateral visa restrictions and find that visa reciprocity is a very stable pattern (a lower degree of visa reciprocity may be an indicator of power asymmetries). Also international agreements oftentimes explicitly refer to the principle of reciprocity. This, for example, was the case in the negotiation of the Basic Principles Agreement between Nixon and Brezhnev in 1972 (Keohane 1986). In addition arms control during the cold war resembles a specific form of reciprocity (Bernauer 2013).

Reciprocity may also explain the adherence to international law even in times of war. Morrow (2007) analyzes a dataset on state conduct in the 20th century. He finds that noncompliance is almost always mutual, stating that when one side was not complying the other was responding in kind. In addition, joint ratification of laws is amplyfing a reciprocal response of democratic actors giving rise to the assumption that enforcement of agreements on conduct in times of war is achieved through reciprocity.[35] While in the former example one can speak of specific reciprocity, diffuse reciprocity is immanent to many multilateral settings. In many instances, governments can do each other a favor and create favor banks, i.e. they are kind in the hope that others return the favor when needed. Mikulaschek (2018) for example shows that EU member states with a temporal UN security council membership receive higher fractions of the EU budget which the authors attribute to an exchange with the promotion of security interests. Another example for diffuse reciprocity is development aid and voting behavior in the United Nations General Assembly. Rather than a vote buying tit-for-tat strategy (specific reciprocity), the evidence speaks more in favor of strategic loyalty and diffuse reciprocity (Brazys et al. 2017).

In climate policy, high hopes have been put on reciprocity recently. A central point of reference to the Paris Agreement has been that parties should submit plans for Nationally Determined Contributions (NDCs). These are voluntary, non-binding commitments under international law. Even though comparability has not always been given, it represents an effort to ensure transparency about expected contributions. These contribution plans comprise a framework of five-year cycles [36]that follow the idea of "pledge and review": countries first communicate or update their NDC which is followed by an aggregated information synthesis that feeds global stockages that inform on the progress made.[37] Based on this information, countries can decide upon new NDCs and a new cycle starts. There is hope of establishing something that can be described as "soft reciprocity" where leadership efforts are reciprocated by increased ambition of others (Falkner 2016). From this point of view, NDCs are institutional arrangements that could make reciprocal behavior more likely. The next section will elaborate whether this hope of reciprocal reactions that trigger a "ratcheting up" of ambition seems reasonable.

5.4 AN APPLICATION TO NDCS IN CLIMATE POLICY

5.4.1 *Reciprocity and Motivations*

When one tries to apply the evidence both from the field of (behavioral) economics and research on IR to the application of NDCs in climate policy one may state at first that a broad body of research documents reciprocal behavior. Simple economic experiments quite strikingly show the human motiva-

---

[35] Such reciprocal considerations are also present in the electorate. In a survey experiment Chu (2019) examines the attitude of US residents to the treatment of prisoners of war and the interplay with information on obligations under international humanitarian law. The results suggest that preferences are shaped by the behavior of the conflicting party which leads to reciprocal preferences (especially among those who believe that humane treatment of prisoners was a legal obligation).

[36] Although the Paris Agreement does not include a settlement whether to use five or ten years cycles the provision exists that the governing body shall consider common time frames (Müller and Ngwadla 2016).

[37] These global stockages on the one hand, reviews whether the pledges have been kept "backward-looking track" and on the other hand projects the level of aggregated contributions "forward-looking track" (Müller and Ngwadla 2016).

tion to act in a reciprocal or conditionally cooperative manner. Given that in a simplified form, the climate change problem can be represented by a Prisoner's Dilemma (Keohane and Oppenheimer 2016) the evidence suggests that a large fraction of people would choose cooperation as a response to cooperation if the game was played sequentially (Clark and Sefton 2001; Miettinen et al. 2017). A similar pattern holds for the representation through a public goods game (see Fischbacher, Gächter, and Fehr 2001, for example).

Regarding the mechanisms that motivate reciprocal behavior, the explanation of outcome based social preferences as a ground for reciprocal behavior may be well tied to a lab context where different actions commonly result in a departure from equal payoffs. In international climate policy the states involved, however, differ in so many relevant dimensions of comparison (not only their GDP) from the outset such that there are well reasoned doubts whether inequality aversion provides a central motivation for reciprocal behavior. The idea of intention-based reciprocity, on the other hand, seems plausible. This means that friendly behavior of the counterpart is encountered by a friendly reaction and vice-versa for hostile behavior. Similarly, the idea that there exists a norm of reciprocity that people follow seems quite reasonable. In particular, if all actors consider the topic or public good to be important and feel a sense of obligation to address the issue, it is quite likely that they feel a requirement to follow the norm of reciprocity. This also forges a bridge to the literature in political science, that uses this sense of obligation as a precondition for diffuse reciprocity.

5.4.2 *Specific or Diffuse Reciprocity?*

Using the framework by Keohane (1986) and following the division into diffuse and specific reciprocity, one has to realize that specific reciprocity in the domain of carbon dioxide mitigation through the pledge and review process seems quite unlikely. Lamp (2018) argues that already the UNFCCC principle of common but differentiated responsibility can at best be regarded as a form of diffuse reciprocity as it creates a moral obligation for all participants to make contributions to the common goal of climate change mitigation. Likewise, the Paris agreement's pledge and review mechanism is characterized by diffuse reciprocity (and a lack of specific reciprocity). The commitments made in the NDCs are often written in a vague tone and a strict enforcement institution is simply not present such that Lamp (2018) argues that the concept could be described as a very diffuse notion of reciprocity. This in a certain sense may resemble the nature of the underlying problem. Unlike, for example in controlling the depletion of the ozone layer through the Montreal Protocol, the problem is more complex and a prescription of certain substances (such as banning CO_2) conditional on a ban in other countries as well, such that behavior is reduced to a quasi binary decision, is quite unlikely. So this very clear-cut form of reciprocity which is inherent in international law and which one can observe in many domains of international policy as for example the prohibition of weapons of war, provisions on the treatment of prisoners of war, the submission to international jurisdiction, international trade or visa regulations probably cannot be applied here.

5.4.3 *Positive Reciprocity*

Accordingly, the hopes are based on diffuse reciprocity within the scope of the pledge and review process. When pursuing the question whether it is likely that this process results in diffuse reciprocity we have to reason about the motivations of countries to act reciprocally. Subsequently, we need to clarify how reciprocity can be expressed. i.e. describe the scope of action before we discuss factors that might facilitate or impede diffuse reciprocity. Following Keohane's sense of obligation it is first of all important that the countries involved consider climate policy to be an urgent issue. At this point, the involvement of civil society is a crucial element. Public pressure to follow (or not fall behind) the example of countries that set a good example may be useful in achieving positive reciprocity. Regarding intrinsic reciprocity, there are no signs that political decision makers act fundamentally less positive reciprocal as compared to students in the lab as discussed previously. Also from a strategic perspective it seems reasonable to be of good intentions and act in a positive reciprocal manner. Countries interact on many different levels and are often dependent on the goodwill of others and a crowding out of others' contributions can lead to reputational losses. Or, as Keohane and Oppenheimer (2016, p.274) put it "Proceeding by small steps to build confidence and generate patterns of reciprocity is not a timid, second-best strategy. Instead, it is essential, because in world politics authority is divided, national preferences vary and there is pervasive suspicion that states seek self-interested gains at the expense of others."

As a result, there is at least some scope for positive reciprocity. A strength of the pledge and review approach is the flexibility such that the mechanism for ratcheting up[38] the NDCs allows for a dynamic response to others' changes in successive rounds (Lamp 2018). However, an important prerequisite for positive reciprocity to work is that transparency about others' contributions prevails and that they are verifiable such that for pledge and review to be successful a highly effective review mechanism is needed (Keohane and Victor 2016). This allows to check whether pledges of other parties were credibly implemented. To date, there are doubts whether the current structure is adequate for a timely analysis and review (Jacoby, Chen, and Flannery 2017).

In addition, a problem of a more general nature is that the contributions may relate to a multiplicity of dimensions like greenhouse gas mitigation, technology transfers, adaptation aid or joint projects with developing countries. Hence contributions are difficult to compare and it is difficult to set them off against each other. Some contributions are not listed either and one cannot expect positive reciprocity for contributions no one knows of.

---

[38] The Paris Agreement demands countries to go beyond previous NDCs up to their highest possible level of ambition.

5.4.4 *Negative Reciprocity*

Another question relates to the scope for negative diffuse reciprocity if others do not live up to their promises. One possibility would be to cut own contributions in this case. For many decision-makers in western democracies this option does not sound very promising as the response of public opinion would be quite devastating. Survey evidence of Tingley and Tomz (2014) show that even US citizens would not argue for an increase in emissions in this case. In addition, this collective punishment would also affect countries that are still contributing. Increasing own emissions would "undermine the entire effort of collective goods provision" (Bernauer 2013, p.429). Alternatives would be to apply a direct punishment. Such punishment could for example comprise ostracizing those countries from global club goods such as international trade. Such sanctions do not only impose costs to the punished country but also impose costs for the punisher which creates a second order public good problem. From experimental economics we know that many humans would be willing to bear monetary costs in order to punish those that didn't act cooperatively. However, there is a substantial threat of damaging these club goods and initiating a downward spiral of negative reciprocity. Such a downward spiral would also be stimulated by the fact that other countries would be undiscerning to this issue-linking and react by countervailing measures themselves in a tit-for-tat manner. And analogously to the literature in experimental economics, antisocial punishment is not unlikely to occur.

A remaining option consists in a naming and shaming approach, to expose those states publicly that do not adhere to their promises or do not cooperate at all thereby punishing them by damaging their reputation. Being stigmatized as a non-cooperating country "could hurt the state with respect to issues in which it has clear interests"(Keohane and Victor 2016, p.273). The pledge and review system could thereby be conceived as an instrument to put moral pressure on the actors involved. Applying the argument of the moral wiggle room, however, sophisticated players could anticipate this and find a plausible excuse not to enter or leave the pledge and review process of the Paris Agreement.

5.5 CONCLUSION AND OUTLOOK

Concluding, we can speak of a broad range of instances of reciprocal behavior and theories on reciprocity in both economics and international relations research. In economics, simple games like the Prisoner's Dilemma and the Public Goods Game provided valuable insights on positive and negative reciprocity. The evidence is large enough so that one can speak of a "homo reciprocans" that shows behavioral patterns that can be described as conditional cooperation. The next chapter will provide us with an experiment that investigates how stable this behavioral type is across games. Regarding international relations, both theoretical approaches as well as empirical examples and empirical evidence demonstrate the relevance of reciprocal behavior.

Regarding the application to climate policy and NDCs, we can state that there is scope for positive reciprocity while negative reciprocity may be considered problematic. But is an upward trend feasible? Basically, as previously described, there is reason to assume that countries may react positively to the efforts of others. Whereas for many governments it is not so easy to increase their own emissions as a reaction to others failing to meet their promises. In addition, climate summits offer much scope for restarts of cooperation such that downward trends could be mitigated. Problematic for reciprocal reactions is on the one hand that the contributions may relate to a multiplicity of dimensions and on the other hand that some contributions are not listed in the NDCs and consequently cannot be replied.

On a meta level, however, the more important question is whether relying on diffuse reciprocity is the ultimate end in this endeavor. Finally, the Paris Agreement is an ongoing process (Keohane and Oppenheimer 2016). Maybe there is a way of implementing elements of specific reciprocity such as the proposal (see Cramton, Ockenfels, and Tirole 2017, for example) of (national) taxes on greenhouse gases in combination with border tax adjustments that apply to imports from those countries that do not implement a tax on greenhouse gases themselves .

6

CONDITIONAL COOPERATION: TYPE STABILITY ACROSS GAMES[39]

6.1 INTRODUCTION

Regarding reciprocity as a prerequisite for successful leadership, the previous chapter pointed out the contribution of behavioral economics to establish the behavioral relevance of another type beyond the purely payoff-maximizing "homo oeconomicus", named "homo reciprocans", who represents a large fraction of the population.[40]

If a researcher needs to determine behavioral types of subjects in the lab, there are essentially two methods available to him. On the one hand, he can use the method introduced by Fischbacher, Gächter, and Fehr (2001) which relies on a conditional contribution vector elicited by the strategy method in a one-shot public goods game (*FGF* hereafter).[41] This method is typically based on a set of 22 questions.[42] On the other hand, a simple sequential prisoner's dilemma (*SPD* hereafter), for which only three questions are sufficient, can be used for type classification as well (Miettinen et al. 2017; Kosfeld 2019; Eichenseer and Moser 2019b). For a researcher, the question arises whether using the simpler method is sufficient for type classification as it may save time and reduce cognitive load for the participants. To the best of our knowledge, there exists no systematic comparison of classification congruence between these two procedures.

Consequently, the aim of this chapter is to assess the stability of classifications across games thereby contributing to the literature on the within subject stability of cooperation preferences (Blanco, Engelmann, and Normann 2011; Volk, Thöni, and Ruigrok 2012). To this end, we compare the types assigned by *SPD* to those assigned by *FGF* in its latest refinements (Fallucchi, Luccasen, and Turocy 2018; Thöni and Volk 2018). The remainder of this chapter will be as follows: Section 2 describes the experimental design and procedures. Section 3 presents and discusses our results. Section 4 provides as short summary and concludes.

---

[39] This chapter is a slightly modified version of Eichenseer and Moser (2019a).

[40] See also, for example, Fehr and Gächter (2000), Dohmen et al. (2009), and Kosfeld (2019).

[41] This method is by now the most commonly used one and, for example, labeled as "P-Experiment" in Fischbacher and Gächter (2010).

[42] As a second-mover, subjects are typically asked to specify their contribution conditional on the other players' average contribution for integers in the interval $[0, 20]$. This results in 21 questions plus an unconditional contribution question for the role as first-mover.

6.2 DESIGN AND PROCEDURES

6.2.1 *Protocol*

The experiment was programmed in LimeSurvey and conducted on Amazon Mechanical Turk (MTurk henceforth) in December 2018 using a sample of MTurk experienced US residents. In total, 232 participants took part in the experiment earning $2.85 on average with an average completion time of approximately 13 minutes. About half of the subjects (120) played *SPD* first, while the other half (112) was doing the *FGF* task first. Subsequently, the participants completed a short questionnaire on age, gender, and education. Instructions for the experiment can be found in Appendix B.

6.2.2 *Sequential Prisoner's Dilemma (SPD)*

In the *SPD* we have two players, indexed by $i = 1, 2$. Each player can choose between actions *SEND* (S) and *KEEP* (K). Choices are elicited by using the strategy method such that Player 2 can condition his choice on the action of Player 1. Figure 8.1 depicts the structure of the game in extensive form including the resulting final payoffs in POINTS (worth $0.05 each). The social optimum is reached when Player 1 chooses *S* and Player 2 responds with action *S* as well. However, maximizing their own payoffs means that Player 2 will choose action *K* at both decision nodes and Player 1, who anticipates this behavior, chooses *K* at the beginning. This is the unique subgame-perfect equilibrium of this game. Hence, the decision situation resembles a sequential prisoner's dilemma.

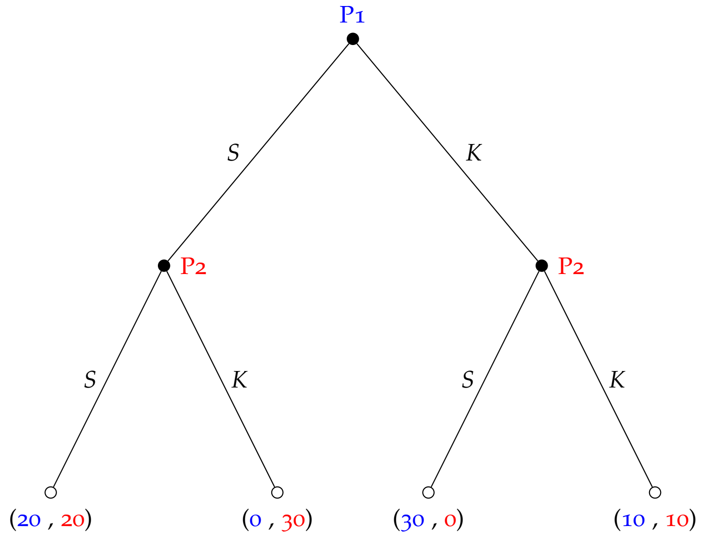


Figure 6.1: Payoff structure of the sequential prisoner's dilemma

All subjects state decisions for both being Player 1 and 2 (strategy method). They are randomly allocated to one of these roles at the end of the experiment and paid accordingly. The set of strategies, X_i, in this game for Player 2 is given by $X_i = \{SS, KK, SK, KS\}$.[43] Based on the participants' conditional second mover's choices, we can classify subjects as *altruists* (unconditional cooperators), *conditional cooperators* (cooperate only if the first-mover cooperates), *free-riders* (never cooperate), and *mismatchers* (counteract the other player) as depicted in Table 6.1.

Cooperation type	***Strategy***
Conditional cooperator (CC)	$(SEND, KEEP)$
Selfish (SF)	$(KEEP, KEEP)$
Altruist (AL)	$(SEND, SEND)$
Mismatcher (MM)	$(KEEP, SEND)$

Table 6.1: Cooperation types in *SPD*

6.2.3 *Sequential Public Goods Game (FGF)*

For the conditional contributions task in *FGF*, we used an adapted version of the procedure of Fischbacher, Gächter, and Fehr (2001). Four players, indexed by $i = 1, 2, 3, 4$, play a sequential public goods game in which one player makes his contribution after observing the other three players' rounded average contribution when they were moving simultaneously beforehand. The resulting payoff of player i with initial endowment $y_i = 20$ POINTS is given by:

$$\pi_i = y_i - g_i + \alpha \sum_{j=1}^{4} g_j$$

where $g_i \in [0, 20]$ denotes individual contributions and $\alpha = 0.4$ is the marginal per capita return (MPCR) of the public good. Choices are elicited by using the strategy method such that every player i makes a choice both for being one of the three first-movers (*unconditional contribution*) and being a second-mover (*contribution table*). As a second-mover, subjects condition their contribution g_i on the average contribution (rounded to the next integer) of the first-movers which results in a conditional contribution path. Subjects are randomly assigned roles of first- and second-movers at the end of the experiment. For the type classification, only the *contribution table* of a subject is considered. The classification of Fischbacher, Gächter, and Fehr (2001) results in four types: a *conditional cooperator* whose contributions increase with other players' contributions, a *selfish type* who never cooperates, a *triangle cooperator* with hump-shaped contributions, and the *remaining subjects* who do not fit either one of the classifications.

---

[43] The first action is played when Player 1 chooses *SEND* and the second action is played when Player 1 chooses *KEEP*.

Recently, there have been two proposals to refine the classification based on Fischbacher, Gächter, and Fehr (2001): (i) the method of Thöni and Volk (2018), which is based on the Pearson correlation coefficient and (ii) the method of Fallucchi, Luccasen, and Turocy (2018), which is based on hierarchical clustering. We will describe the behavioral types resulting from both refinements in Section 6.3.2. They have in common that they entail a behavioral type whose description comes close to the altruist in *SPD*: the unconditional cooperator (UC) in Thöni and Volk (2018) and the unconditional high type (UHC) in Fallucchi, Luccasen, and Turocy (2018).

6.3 RESULTS

6.3.1 *Contribution Paths in FGF by SPD Type*

As a first step in our data analysis, we provide a visual inspection to see whether there is a systematic relationship between behavioral types in *SPD* and contribution paths in *FGF* which follow from the subjects' conditional contributions. Figure 6.2 depicts contribution paths in *FGF* by *SPD* type.[44]

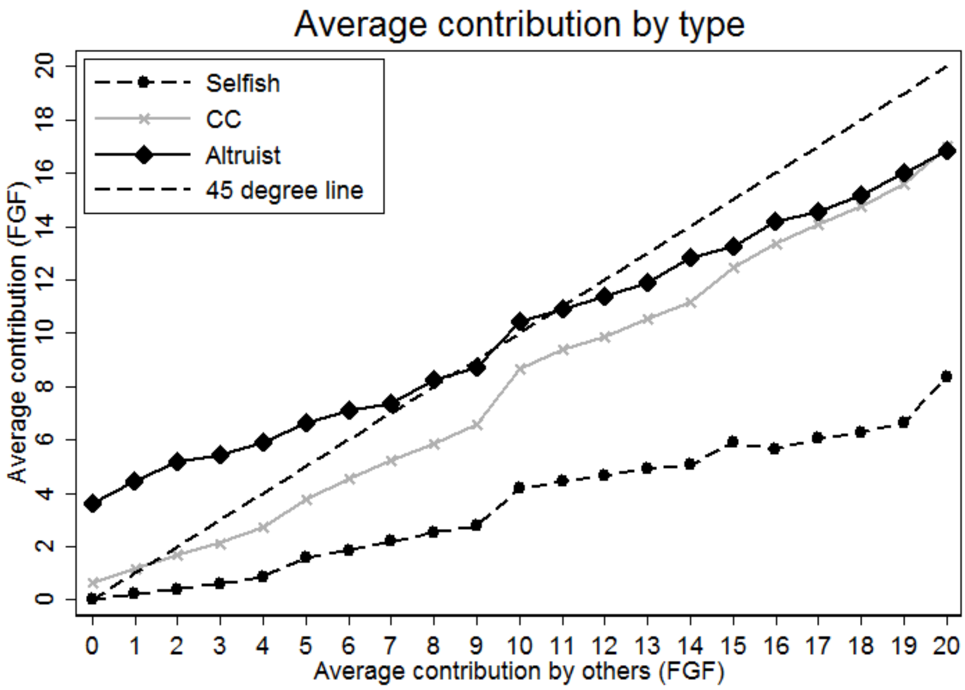


Figure 6.2: Contribution paths by *SPD* classification in *FGF*

There are considerable differences between types. Compared to subjects classified as "selfish" in *SPD*, contributions of "conditional cooperators" (CC) have a decisively steeper slope in the contributions of others, i.e., they match others' contributions to a larger degree. In addition, subjects classified as "altruist" in

---

[44] We excluded the mismatcher type in this graph, since it is a rare empirical phenomenon (9 of 232 subjects) whose behavior is difficult to interpret.

SPD have the highest intercept which reflects that they give most when others give nothing. In line with expectations, "selfish" types have, on average, the lowest conditional contributions for every level of average contributions of others.

	Contribution			
	OLS(1)	OLS(2)	Tobit(1)	Tobit(2)
Conditional cooperator	4.573^{***}	0.174	7.688^{***}	3.394^{***}
	(0.499)	(0.350)	(1.003)	(1.021)
Altruist	6.426^{***}	3.781	10.299^{***}	8.432^{**}
	(1.798)	(2.410)	(2.796)	(3.639)
Mismatcher	3.545^{***}	2.339^{*}	6.970^{***}	7.415^{***}
	(0.999)	(1.278)	(1.455)	(2.142)
Avg. contr. of others (ACO)	0.665^{***}	0.394^{***}	0.970^{***}	0.720^{***}
	(0.028)	(0.045)	(0.034)	(0.061)
Conditional cooperator X ACO		0.440^{***}		0.387^{***}
		(0.055)		(0.074)
Altruist X ACO		0.265^{*}		0.148
		(0.142)		(0.182)
Mismatcher X ACO		0.121		-0.075
		(0.144)		(0.188)
Constant	-3.071^{***}	-0.358^{**}	-10.007^{***}	-7.115^{***}
	(0.359)	(0.170)	(1.017)	(0.933)
Observations	4872	4872	4872	4872
Subjects	232	232	232	232
R^2	0.483	0.518		
Pseudo R^2			0.114	0.118

Note: Cluster-robust standard errors (on the subject-level) are in parentheses. Tobit regressions account for 1,646 left-censored and 346 right-censored observations. ACO abbreviates "average contributions of others". The 'selfish' type serves as a reference category.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6.2: Regression Table - Contribution paths

In Table 6.2, we examine whether this visual interpretation can be supported statistically. Columns OLS(1) and Tobit(1) assume a common slope of all types in the *average contribution of others* (ACO) - and only different intercepts - whereas OLS(2) and Tobit(2) take different slopes for different *SPD* types into account. The Tobit regressions consider observations censored at 0 and 20. Both regressions OLS(2) and Tobit(2) indicate that conditional cooperators show a significantly larger reaction to others' contributions compared to the reference category of selfish types. This corresponds to the graphical findings reported in Figure 6.2. Moreover, the coefficient of the intercept - the unconditional contribution - is largest for the altruist type and significantly different from the reference category of selfish types in the regressions OLS(1), Tobit(1), and Tobit(2).

6.3.2 *Relationship between Classification Methods*

We now investigate the relationship between the discrete behavioral types classified by *SPD* and *FGF* in the refinements of Thöni and Volk (2018) and Fallucchi, Luccasen, and Turocy (2018). The refinement of Thöni and Volk (2018) of *FGF* (*FGF-**T*** hereafter) resembles a theory-driven approach and is based on the Pearson correlation coefficient. It distinguishes the five behavioral types depicted in Table 6.3.

Type	***Behavior***
Free-rider (FR)	Zero contributions.
Conditional cooperator (CC)	Monotonically increasing pattern in others' contributions.
Unconditional cooperator (UC)	Constant contributions irrespective of what others do.
Triangle cooperator (TC)	"Hump-shaped" contributions.
Other	Undefined contribution pattern.

Table 6.3: Cooperation types in Thöni and Volk (2018)

In our sample, we can categorize 184 out of 232 subjects (79.3%) as conditional cooperators (CC) using the *FGF-**T*** refinement.[45] Conditional cooperators also constitute the largest group in *SPD* with a share of 57.8%. The second largest group are selfish types that account for 33.6% of all subjects in *SPD* and 13.8% in *FGF-**T***. In both games, these two categories cover the vast majority of subjects. Table 6.4 reports the number and percentage of subjects falling into each possible combination of the two methods in a contingency table.

Behavioral type FGF − T

		FR	*CC*	*UC*	*TR*	*Other*	*Total*
Behavioral type SPD	*Selfish*	**27** **(11.64%)**	**44** **(18.97%)**	1 (0.43%)	5 (2.16%)	1 (0.43%)	78 (33.62%)
	CC	**4** **(1.72%)**	**125** **(53.88%)**	2 (0.86%)	2 (0.86%)	1 (0.43%)	134 (57.76%)
	Altruist	1 (0.43%)	8 (3.45%)	2 (0.86%)	0 (0.00%)	0 (0.00%)	11 (4.74%)
	Mismatcher	0 (0.00%)	7 (3.02%)	2 (0.86%)	0 (0.00%)	0 (0.00%)	9 (3.88%)
	Total	32 (13.79%)	184 (79.31%)	7 (3.02%)	7 (3.02%)	2 (0.86%)	232 (100.00%)

Table 6.4: Types in *SPD* and *FGF* (Refinement of Thöni and Volk 2018)

---

[45] This is close to the 80.6% CC share reported in the US sample of Kocher et al. (2008).

Comparing the classification of *SPD* and *FGF-**T***, we see that slightly more than half of all subjects (125 of 232) are classified as CC according to both methods, while 11.6% are classified as selfish types in both games (27 of 232). Overall, only around 13.8% of the subjects (32 of 232) are classified in a category different from selfish or CC according to at least one of the methods. The results of a χ^2-test suggests that the characteristics of both methods are not independent ($p < 0.001$). Hence, we can reject the null-hypothesis that there is no relationship between the two classification methods.

Conditional relative frequencies allow us to get a better picture of the type stability across games. About 93.3% of the subjects who are classified as CC in *SPD*, are also classified as CC according to *FGF-**T***. However, individuals classified as "selfish" in *SPD*, are classified as "selfish" according to *FGF-**T*** only in around 34.6% of the cases. This indicates that *SPD* performs well in identifying subjects who have a consistent pattern of conditional cooperation across games, while this does not hold for selfish types.

Conversely, starting from *FGF*, subjects classified as CC according to *FGF-**T***, are in around 67.9% of the cases also CC in *SPD*, and those who are classified as "selfish" according to *FGF-**T*** are in around 84.4% of the cases also "selfish" in *SPD*. This means that *FGF* is better suited to identify types who are classified as "selfish" in both games compared to *SPD*.

Type	***Behavior***
Own maximizers (OWN)	Zero contributions.
Strong conditional cooperators (SCC)	Match others' contributions exactly.
Weak conditional cooperators (WCC)	Increasing contributions, less than one-for-one.
Unconditional high contributors (UCH)	Contribute fully irrespective of what others do.
Other	Undefined contribution pattern.

Table 6.5: Cooperation types in Fallucchi, Luccasen, and Turocy (2018)

These findings are robust when changing to the refinement of Fallucchi, Luccasen, and Turocy (2018), which is based on hierarchical clustering and resembles a data-driven approach (*FGF-**F*** hereafter). The *FGF-**F*** categorization splits the CC category and distinguishes between weak conditional cooperators (WCC) and strong conditional cooperators (SCC). The type classification of *FGF-**F*** is depicted in Table 6.5. In our experimental sample, there has not been a distinct cluster of "Other" types and, hence, we only consider four behavioral types.

Table 6.6 presents the contingency table of types. Again, a χ^2-test shows that the type classifications are not independent ($p < 0.001$), indicating a significant relationship between the two methods. If we look at the conditional relative frequencies, we see that conditional on being classified as CC type in *SPD*, the relative frequency is 88.8% to be classified as either WCC or SCC according to *FGF-**F***. By contrast, a subject classified as selfish in *SPD* is only selfish in 39.7% of the cases according to *FGF-**F***.

		Behavioral type FGF − F				
		OWN	*WCC*	*SCC*	*UCH*	*Total*
Behavioral type SPD	*Selfish*	**31** **(13.86%)**	**37** **(15.95%)**	**10** **(4.31%)**	0 (0.00%)	78 (33.62%)
	CC	**11** **(4.74%)**	**45** **(19.40%)**	**74** **(31.90%)**	4 (1.72%)	134 (57.76%)
	Altruist	1 (0.43%)	2 (0.86%)	6 (2.59%)	2 (0.86%)	11 (4.74%)
	Mismatcher	0 (0.00%)	6 (2.59%)	3 (1.29%)	0 (0.00%)	9 (3.88%)
	Total	43 (18.53%)	90 (38.79%)	93 (40.09%)	6 (2.59%)	232 (100.00%)

Table 6.6: Types in *SPD* and *FGF* (Refinement of Fallucchi, Luccasen, and Turocy 2018)

Starting from *FGF*-***F***, a subject sorted in the group of selfish types according to *FGF*-***F***, is also selfish in *SPD* in 72.1% of the cases. By contrast, the relative frequency of being CC in *SPD* is only 65.0% when being classified as either WCC and SCC according to *FGF*-***F***. When distinguishing between WCC and SCC, we observe that in the group of those who are classified as WCC according to *FGF*-***F***, only 50% are also classified as CC in *SPD*, whereas in the group of those who are classified as SCC, almost 80% are classified as CC in *SPD*. Thus, the distinction between WCC and SCC predicts the relative frequency of being CC in *SPD* quite well. Likewise, the relative frequency of being selfish in *SPD* is highest for OWN maximizers, followed by WCC and SCC types.

Figures 6.3 and 6.4 illustrate the respective intersections between *SPD* and *FGF* - for CC and selfish types - graphically by using Venn diagrams. The solid circles represent the respective sets of CC and selfish types according to *SPD*, while the dashed circles represent these types according to the *FGF* classification. The intersection of both circles illustrates the set of subjects who are of the same type according to both methods. In Figure 6.4 (*left*), the WCC and SCC types are pooled as conditional cooperators.

The fact that the overlap between selfish types in *SPD* and *FGF* is quite small leaves room for further research. One hypothesis would be that the *FGF* method underestimates the share of selfish types. Confused types, who do not understand the rules of the game completely, may act as if they were cooperative types in *FGF* (see Detemple, Kosfeld, and Kröll 2019). Assuming that the *SPD* imposes fewer cognitive load on subjects would allow for the hypothesis that the share of confused types is lower in this game and, consequently, the share of selfish types should be higher in *SPD* compared to the *FGF* method. This might explain why many of the selfish types in *SPD* behave cooperatively in *FGF*.

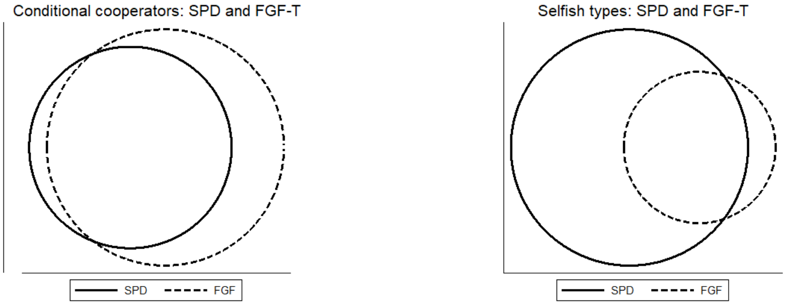


Figure 6.3: Venn diagrams of SPD and FGF-T (Refinement of Thöni and Volk 2018)

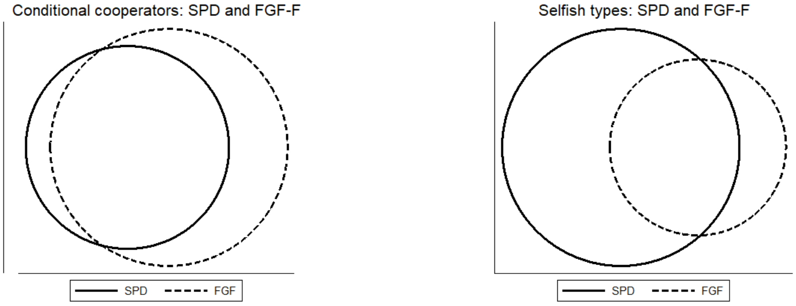


Figure 6.4: Venn diagrams of SPD and FGF-F (Refinement of Fallucchi, Luccasen, and Turocy 2018)

6.4 SUMMARY AND CONCLUSION

We provided an online experiment, in which we investigated the consistency of two methods for classifying different cooperation types. With regard to discrete behavioral types, our results indicate that *SPD* performs very well in identifying subjects with a stable pattern of conditional cooperation. Given that a subject is of CC type in *SPD*, the probability is 93.3% to be classified as CC as well according to *FGF-**T*** (refinement of Thöni and Volk 2018) and 88.8% according to *FGF-**F*** (refinement of Fallucchi, Luccasen, and Turocy 2018), respectively. We further observe that the distinction between WCC and SCC is helpful for identifying CC types in *SPD* more precisely, since the likelihood for being "selfish" in *SPD* is considerably higher for WCC types compared to SCC types. Considering contribution paths in *FGF*, subjects classified as conditional cooperators in *SPD* match others' contributions to a significantly larger degree compared to selfish types. This is captured in the significantly larger slope of their conditional cooperation path.

On this basis, we can conclude that if a researcher's objective is is to identify those subjects in a group who are, with a high probability, conditional cooperators in both games, the simple method of the *SPD* is well suited for this task. If, on the other hand, the focus is on identifying selfish types, we cannot offer a clear conclusion. We observe many "selfish" subjects in *SPD* who show cooperative behavioral patterns in *FGF*. However, based on the hypothesis that there is a larger share of confused types in *FGF*, who act as if they were CC types, the simpler game (*SPD*) is not necessarily a weak tool for identifying selfish types, but may be more accurate in measuring the true fraction of selfish types in the population (see Detemple, Kosfeld, and Kröll 2019).

Part IV

LEADERSHIP IN PUBLIC GOODS EXPERIMENTS

INTRODUCTORY REMARKS TO PART IV

The preceding Part III has raised expectations that we may indeed see a positive reaction to pioneering activities. In particular, Chapter 5 has described that there is evidence for reciprocal behavior in experimental economics as well as in international relations. Chapter 6 has then demonstrated that this preference for reciprocity expressed through conditional cooperation is quite stable within subjects across social dilemma games. Consequently, an important prerequisite for successful leadership seems to be present.

The question is whether we might expect that there are leaders that precede by setting a good example. In addition the interplay between leaders and followers may be decisive in whether there is ultimately an improvement through leadership. These questions are addressed in part IV. Chapter 7 offers a literature review that aims at exploring main results of leading-by-example in public goods experiments. Based on a systematic literature analysis, I examine whether leadership increases contributions to a public good and outline factors that foster or impede leadership success. To understand how leadership becomes effective, followers' reactions as well as leadership behavior are examined in more detail. Besides public goods games that shed light on free-riding behavior, also coordination games will be considered. Finally, I briefly discuss the external validity in the context of global public goods.

Subsequently,[46] Chapter 8 considers a situation where leadership might be very important. In the experimental dynamic public goods game considered subjects can reinvest their profits from cooperation. They start with an endowment of 2 Euro and could end up with around 34 Eur in the case of full cooperation. Such a situation might resemble for example research and development joint-ventures which generate either cost reductions or larger profits. Such technological cooperation is a cornerstone of growth in developed countries. In a similar vein, much hope rests on technological development in international climate policy. Jointly developed improved green technologies offer the scope to reduce the cost burden borne to mitigate climate change. Chapter 8 explores how leadership expressed through leading-by-example affects such a dynamic public goods game. The findings suggest that leadership has a positive impact on final wealth of the groups as well as on reducing inequality within groups as measured by the Gini index.

---

[46] Chapter eight including this summary is based on Eichenseer and Moser (2019b).

7

LEADING-BY-EXAMPLE IN PUBLIC GOODS GAMES: WHAT DO WE KNOW?

7.1 INTRODUCTION

> "We must lead the world, by deed and by example."
> Barack Obama (2007, p.4)

About a year before winning the pre-election campaign against Hillary Clinton, Barack Obama made a point for visionary leadership to cope with global problems like transnational terrorism, failed states and climate change (Obama 2007). In particular, he stressed that leading does not mean solving the problems on one's own, but rather setting a good example. Likewise, many consider leadership as an important factor that might ameliorate the problem of free-riding and coordination failures (Arce M. 2001). Correspondingly, desires for and expectations of leadership are high when it comes to mutual global challenges like managing global migration flows, financial market stability, peacekeeping or the preservation of international organizations and institutions.

Consequently, there is a long tradition of studying leaders and leadership[47] in the humanities that can be traced back to ancient political philosophers like Plato (Wren 2007). Extensive literature on leaders and leadership has developed in political science, sociology, psychology and management (see Ahlquist and Levi 2011; Bass and Riggio 2006; Hartley 2012; Stogdill 1974; Van Vugt and De Cremer 1999; Zehnder, Herz, and Bonardi 2017, for reviews). In economics, a renewed focus has been laid on leadership starting with Varian (1994) and Hermalin (1998) and especially in environmental economics the question of leadership in mitigating climate change is an important one (see Schwerhoff 2016, for a review). Quite recently, also a significant body of research worth of review has developed in experimental economics that focuses on the effects of leadership in social dilemma situations starting with Moxnes and Van der Heijden (2003), Güth et al. (2007) and Levati, Sutter, and Van der Heijden (2007). This is of particular importance, since most of the literature on leadership is largely based on theoretical considerations and case studies.

The aim of this survey is to collect, categorize and evaluate the evolved literature in experimental economics and present a selection of results systematically. The emphasis will be laid on the workhorse model to study such social dilemmas: the linear public goods game in the laboratory. The remainder of this chapter is organized as follows: Section 2 presents the methodology, structures the topics in the literature and distills the main research questions

---

[47] To separate the terms, a simple and straightforward definition of a leader as being someone with followers was given by Hermalin (1998) whereas leadership can be described as an influence relation between leaders and followers to approach group or societal objectives (Wren 2007).

which are considered in the sections following. Section 7 concludes with a discussion of the external validity of the findings and a conclusion.

7.2 METHODOLOGY AND TOPICS IN THE LITERATURE

7.2.1 *Search Strategies*

In order to cover the experimental literature on the topic, a targeted search of the existing literature has been used. Based on the work found, main topics and research questions are identified. A first search was conducted in February 2017 on Repec/IDEAS by using combinations of the keywords {sequential; leadership} + {social dilemma; public goods; contribution} + {experiment}. This first search yielded 337 potential results. After removing obvious duplicates, I checked whether the study considers an experimental public goods or closely related game. An initial assessment thereof was made based on reading the abstract. In addition, I chose to restrict the literature to the experimental economics literature. Over the past decades, common standards for conducting economic experiments have been established such that one can expect that they follow a comparable protocol. This means, for example, that the experiments are incentivized. Experimental economics literature in specific means, that the paper has been published in an economic journal or at least one of the authors has a background in economics.

After applying these criteria and controlling for obvious duplicates, the first search encompassed 61 studies. This Repec search served as a basis for the literature database. Searches on google scholar and a targeted evaluation of the quoted literature helped to track and broaden the literature. Additionally, I used Mendeley suggestions and a keyword alert on google scholar to check for new papers. An additional check for literature were the references in Ahlquist and Levi (2011) and Schwerhoff (2016).

7.2.2 *Topics in the Literature and Research Questions*

Given the corpus of literature identified, it is remarkable that most experimental economic work conceives leadership as leading-by example. Accordingly, the focus will be placed on this aspect of leadership in this review. In addition, the voluntary contribution mechanism and other linear public goods games with summation technology represent a majority of the studies. In consequence, this survey will also be based on linear public goods games in large parts. Other public goods games in the lab and field experiments will be considered in Section 6. As far as leading-by-example is regarded, three main research questions can be established that cover most of the studies:

Is leadership effective? (RQ1)

The first building block is the question whether leadership is effective at all in bringing contribution levels closer to the social optimum (RQ1).[48] It has

---

[48] RQ1: Section 3 for linear public goods games with summation technology & section 6 for other public goods games.

become common practice in the literature to model leadership by modifying the timing of contributions away from a simultaneous game in which everybody contributes at the same time towards sequential play in which followers can observe the actions or contributions of leaders. In its plain version, this setting offers the opportunity of leading-by-example. Related to this issue are factors that might moderate or foster the effectiveness of leadership such as endogenous and exogenous leadership, formal power of the leader, leading by words, uncertainty and conditional commitments.

How do followers react to leadership? (RQ2)

If one considers leadership as an influence relation between leaders and followers, the two remaining questions of research will be the behavior of followers and leaders and their mutual influence. The starting point and second building block is the behavior of followers (RQ2; section 4). It encompasses the reaction (curve) of followers, the reaction to different kinds of leadership, and to which degree a leader has influence on the beliefs of followers.

What do we know about leader behavior and motivations? (RQ3)

Likewise studies that may help getting further insights in leader behavior are subsumed in the third building block (RQ3; section 5) which in particular involves the question of who is a good leader (type), the motivation and self-selection of leaders and the interaction with monetary incentives and costs).

To answer RQ1, i.e. to measure leadership effectiveness, we need to distinguish between different technologies of aggregation. A technology of aggregation describes how individual contributions are aggregated to the total amount of public good provided (Sandler 2015). Depending on which technology of aggregation is employed, agents face a problem of coordination or a problem of free-riding or both. The first and most common contribution technology considered is the summation technology. In this case the total amount of public good corresponds to the sum of individual contributions which is referred to as a classical problem of free-riding. This is discussed for linear public goods games in Section 3. In Section 6, leadership in weakest-link public goods games, threshold public goods games and summation technology public goods games that offer predicted interior Nash equilibria will be examined.

7.3 LEADERSHIP EFFECTIVENESS IN THE LINEAR PUBLIC GOODS GAME WITH SUMMATION TECHNOLOGY

7.3.1 *Leading by Example and Strategic Incentives*

The Voluntary Contribution Mechanism

Given a summation technology, the most prevalent experimental setup is the voluntary contribution mechanism (VCM, hereafter) in a linear version. In a game with N players, the payoff of player i in a one-shot game (or per period in a repeated game) with initial endowment y_i is given by:

$$\pi_i = y_i - g_i + \alpha \sum_{j=1}^{N} g_j \tag{1}$$

where g_i denotes individual contributions and α the marginal per capita return (MPCR) of the public good. The MPCR is set in a way $(\alpha < 1)$ that zero contributions are individually rational and full contributions generate the largest aggregated payoffs $(N\alpha > 1)$. Consequently, for a parameter range of α that fulfills $1 > \alpha > \frac{1}{N}$, we obtain a social dilemma situation with the corner solution of zero contributions being the unique Nash equilibrium.

A simple and elegant solution to test a plain version of leading by example is to give subjects the opportunity of leading by modifying the structure of the game. One player is selected to be a first mover and the others contribute subsequently after observing the first mover's decision which renders the possibility of giving a salient example for the first mover. The most basic implementation is to select a person at random to move first.

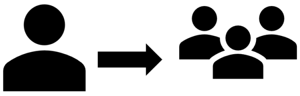


Figure 7.1: A sequential game with one leader

In the case of a linear public good game with the usual parameters used in the lab and assuming only purely payoff maximizing players, a simple backwards induction argument yields that the zero contribution prediction, a corner solution, would not change through this implementation of leadership.

However, the pattern will change if we assume that a fraction of the population shows reciprocal behavior (i.e. $g_j\ (g_i)$ increasing in g_i). For the first mover equation (1) can be rewritten as:

$$\pi_i = y_i - (1-\alpha)g_i + \alpha \sum_{\substack{j=1 \\ j \neq i}}^{N-1} g_j(g_i). \tag{2}$$

Taking the first derivative w.r.t. g_i gives:

$$\frac{\partial \pi_i}{\partial g_i} = \alpha\,(1 + \sum_{\substack{j=1 \\ j \neq i}}^{N-1} \frac{\partial g_j}{\partial g_i}) - 1. \tag{3}$$

Thus, assuming a strategic leader like Cartwright and Lovett (2014) , we obtain the corner solution of full investment (i.e. $\frac{\partial \pi_i}{\partial g_i} > 0$) by the first mover if:

$$\sum_{\substack{j=1 \\ j \neq i}}^{N-1} \frac{\partial g_j}{\partial g_i} > \frac{1-\alpha}{\alpha}. \tag{4}$$

In case of a two player game and an MPCR of $\alpha = 0.75$, this yields $\frac{\partial g_j}{\partial g_i} > \frac{1}{3}$ when we assume a similar reaction of all followers while for a four player game and the usual MPCR of $\alpha = 0.4$, the average $\frac{\partial g_j}{\partial g_i}$ has to be larger than $\frac{1}{2}$. This simple sketch for a one-shot game shows that a sufficient reciprocal response of followers (or an expectation thereof) gives incentives for first-movers to invest - even if they have no preference for reciprocity themselves i.e. stick to the standard assumptions. On behalf of the followers that act reciprocally, one may assume that their investment increases if the first mover sets an example by choosing an exemplary contribution relative to the simultaneous game where they can only form expectations.

As the linear public goods game with a summation technology is the standard public goods model in the laboratory, there are several studies that test whether sequential play yields an improvement compared to simultaneous play.

7.3.2 *Exogenous Leadership*

Exogenous leadership means that a player is determined by chance or by the experimenter to move first. Regarding efficiency (total contributions), the results of exogenous leadership are mixed at first sight. Significant positive effects are reported by Moxnes and Van der Heijden (2003),[49] Güth et al. (2007), Levati, Sutter, and Van der Heijden (2007), Pogrebna et al. (2011), Dannenberg (2015) and McCannon (2018), insignificant effects by Haigner and Wakolbinger (2010), Gächter and Renner (2018), Sahin, Eckel, and Komai (2015) and Gürerk, Lauer, and Scheuermann (2018) while Rivas and Sutter (2011) report a significant negative effect of sequential play. This has evoked the motivation to compute an overall effect size by using a plain meta-analysis.

Studies must meet the following inclusion criteria to be considered in the meta-analysis: (a) there must be at least one exogenous sequential treatment in which one leader first chooses his contribution and there must be a control treatment in which all players contribute simultaneously. In addition (b), the game needs to be a linear public goods game with summation technology and complete information. Moreover (c), the game needs to be a lab experiment.

From the compilation of literature attained by the searches described in Section 2.1, 11 studies meet these criteria. I mailed a data request to all authors of those studies in Juli 2017 and a reminder in August 2017. Many of the authors responded immediately and I sent a final request to the remaining authors in 2018. After dropping studies from the list for which no data could

---

[49] Moxnes and Van der Heijden (2003) consider a public bad experiment which is closely related to the VCM. In addition, they restrict the choice set of the first-mover. To take account of this, only second-mover decisions and investments in the non-damaging good will be considered here.

be obtained,[50] this left a total of 9 studies considered.[51] The analysis was conducted using metan (Bradburn, Deeks, and Altman 1999).

To account for a small sample size, an adjusted uniform effect size measure has been used. Hedges adjusted g is calculated (Bradburn, Deeks, and Altman 1999, p.12) as:

$$g = \frac{\bar{x}_T - \bar{x}_C}{\sigma}\left(1 - \frac{3}{4(n_T + n_C) - 9}\right) \tag{5}$$

where $\bar{x}_T$ and $\bar{x}_C$ denote means and n_T and n_C the number of subjects in treatment (T) and control (C). The pooled standard deviation of the two groups σ is given by:

$$\sigma = \sqrt{\frac{(n_T - 1)\sigma_T^2 + (n_C - 1)\sigma_C^2}{(n_T + n_C - 1)}} \tag{6}$$

where σ_T and σ_C indicate standard deviations in treatment and control, respectively.

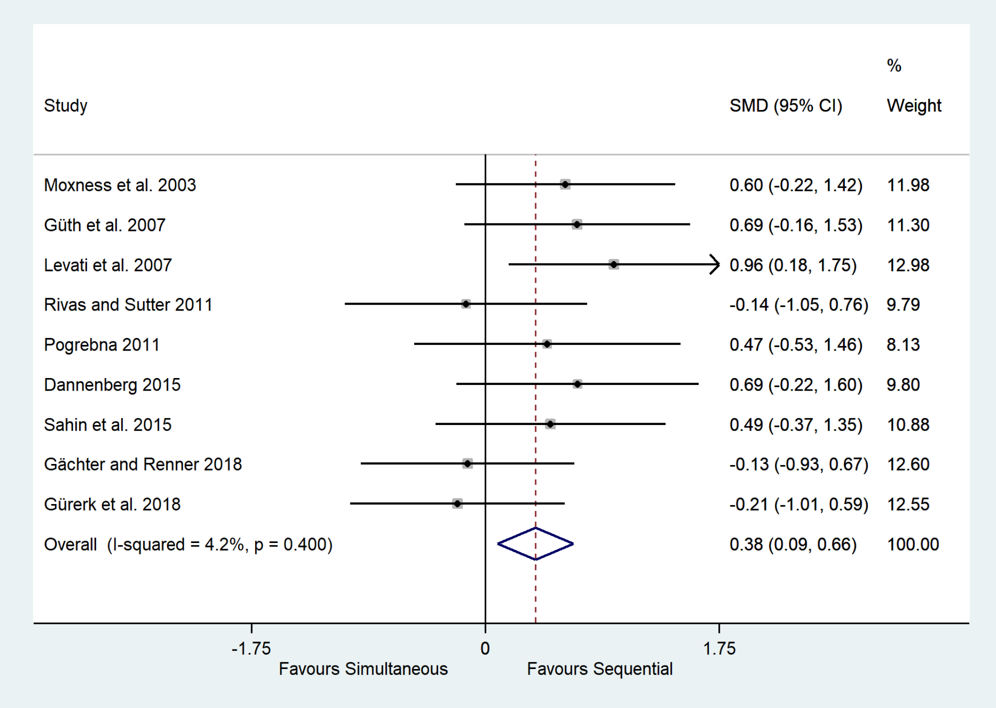


Figure 7.2: Forest plot for exogenous leadership

---

[50] No data could be obtained for Haigner and Wakolbinger (2010) and McCannon (2018).

[51] These studies include: Moxnes and Van der Heijden (2003), Güth et al. (2007), Levati, Sutter, and Van der Heijden (2007), Pogrebna et al. (2011), Rivas and Sutter (2011), Dannenberg (2015), Sahin, Eckel, and Komai (2015), Gächter and Renner (2018) and Gürerk, Lauer, and Scheuermann (2018).

If we compile the collected evidence in a common effects meta-analysis (a forest plot is depicted in Figure 7.2),[52] we see that the overall effect of exogenous leadership is positive with a standardized mean difference of 0.377. A test of the null hypothesis of no leadership effect ($D = 0$) can be rejected at the 1% level ($z = 2.60$, $p = 0.009$) thus indicating a significant treatment effect for exogenous leadership. A I^2 value of 4.2% indicates that heterogeneity between studies of exogenous leadership is rather low. Both Egger's test and Begg's test are insignificant thus rendering no indications of a publication bias.[53]

So we can already state that the synopsis of all studies suggests that exogenous leadership leads to an improvement in the laboratory experiments considered. In the next step we augment the analysis by additional factors that might either foster or moderate the effect of leading-by-example.

7.3.3 *Voluntary Leadership*

One of these factors is voluntary (endogenous) leadership: the question is whether it makes a difference whether a person decides by oneself to be a leader (endogenous leadership) or whether the leader is exogenously determined by the experimenter. Compared to no leadership at all, higher contributions in endogenous leadership are reported by Haigner and Wakolbinger (2010) (significant), Rivas and Sutter (2011) (significant), Dannenberg (2015) (significant) and Cappelen et al. (2016) such that the evidence so far supports the claim that a voluntary leader improves contributions compared to having no leader at all. Comparing exogenous and endogenous leadership, group contributions are higher when leadership is voluntary (endogenous) which is reflected in the studies of Haigner and Wakolbinger (2010), Rivas and Sutter (2011) (significant) and Dannenberg (2015).

7.3.4 *Formal Authority*

Another modification of the simple framework considered is formal authority of the leader. In this case, the leader can underpin the contribution norm he created as a first mover by punishing players that do not follow the norm or (depending on the experiment considered) reward others that follow the norm. Formal authority is considered in the literature by the power to exclude (ostracize) players from the public goods game (Güth et al. 2007; Levati, Sutter, and Van der Heijden 2007), monetary punishment by the leader (Gürerk, Lauer, and Scheuermann 2018) and the possibility of the leader to reward (Sutter and Rivas 2014; Gürerk, Lauer, and Scheuermann 2018).

---

[52] As Rivas and Sutter (2011) use data from Güth et al. (2007) for the control treatment, the method of splitting the control treatment (see Chapter 16.5.4 of Higgins and Green 2011, for an overview on possible approaches) has been used to mitigate the unit of analysis problem. As a robustness check, results from the alternative method of pooling groups are reported in Appendix C.

[53] As the sample size is small with nine observations we can, however, not conclude that there is no publication bias as the tests may be under-powered.

Correspondingly, the question is whether leadership is more effective if it is accompanied by formal authority. At first the answer seems to be very clear, formal authority improves efficiency compared to a leader without sanctioning devices. Contributions are substantially higher when leaders have exclusion power (ostracism) compared to not having it (Güth et al. 2007; Levati, Sutter, and Van der Heijden 2007). These treatments with strong leadership (ostracism) have shown that backing up a leader's (good) example with the punishment option of excluding another group member promotes cooperation. In the same vein, monetary punishment increases contributions (Gürerk, Lauer, and Scheuermann 2018) compared to sequential play without a punishment option.

When comparing a reward option of the leader to exclusion or punishment ("the carrot or the stick"), it is apparent that the reward option is less effective compared to exclusion (Sutter and Rivas 2014)[54] and punishment (Gürerk, Irlenbusch, and Rockenbach 2009). Having the choice between reward and punishment, a change from the former (rewards) to the latter (negative incentives) results in an enduring increase in contributions as Gürerk, Irlenbusch, and Rockenbach (2009) point out. A similar pattern emerges in the study of Sutter and Rivas (2014) showing that leaders with an option to reward followers are less effective than leaders with a sanctioning device through exclusion.

Obviously, reward and punishment often work in increasing cooperation (see, for example, Fehr and Gachter 2000 and Andreoni, Harbaugh, and Vesterlund 2003). The question is whether there is a particular effect of centralized punishment, i.e. a situation in which only the leader has the option to punish. Gürerk, Lauer, and Scheuermann (2018) suggests that this is not the case. A leader equipped with reward or punishment power does not yield an improvement compared to the effects of rewards or punishments without a leader in increasing contributions[55].

7.3.5 *Additional Factors*

Words vs Actions

Moreover, in addition to leading by example via actions, leadership can also take the shape of leading by words, i.e. non-binding commitments which are considered by Pogrebna et al. (2011) and Dannenberg (2015). Regarding the question, whether announcements (words) are equally effective in increasing contributions as actions, there is contradicting evidence. Pogrebna et al. (2011) find that non-binding announcements and binding commitments are equally effective. In contrast, the experimental results of Dannenberg (2015) show that leading by example is much more effective than leading by words (both for exogenous and endogenous leadership).

---

[54] In Rivas and Sutter (2008) data from Güth et al. (2007) is used for the comparison with exclusion.

[55] In this comparison every subject has the option to punish in sequential play whereas only the leader can punish in the leadership treatment.

Rotating Leadership and Voting

What would happen if there was a change of the leader every round? Güth et al. (2007) consider exogenous leaders that either remain in their position for all rounds played or that are randomly re-determined in every round. They find that there are no significant differences between those two modes of play.

And what happens if subjects elect the leader or vote whether the institution of leadership should sustain after they have played the game for several rounds? This question is explored by the experiments of Güth et al. (2007), Levati, Sutter, and Van der Heijden (2007) and Sutter and Rivas (2014). In Güth et al. (2007) every team member can vote either who shall be the leader (rotating leadership treatments) or whether to have a leader at all (fixed leadership treatments) after having played the game for 16 rounds. Leadership is only implemented if a leader is elected unanimously. Güth et al. (2007) can show that having a leader triggers contributions and that especially those subjects are more likely to be elected that contributed a large amount to the public good.[56] Levati, Sutter, and Van der Heijden (2007) also find that there will be higher contributions if a leader is appointed. However, Levati, Sutter, and Van der Heijden (2007) find no significant relation between an individual's contributions beforehand and the probability of being elected to be the leader. Sutter and Rivas (2014) observe that groups were more successful in appointing a leader if they had been more cooperative beforehand.

Leadership and Information

A source of leadership in addition to moving first and giving an example may also be that a leader has an information advantage. Hermalin (1998) points out that followers may believe that a leader has superior information on the options to choose. Thus leadership can also be considered as information transmission from a leader to followers.[57] At the same time, Hermalin theoretically shows that the leader can also use this information strategically. In this vein, Potters, Sefton, and Vesterlund (2007) have explored the question of leaders' influence when there is uncertainty about the value of cooperation. In an environment in which the leader has private information about the returns from contributing, leading-by-example increases contributions and earnings. As suggested, the simple mechanism behind is that the leader can signal important information to the followers. Another source of uncertainty is that there may be imperfect or no knowledge about individual capabilities and benefits. Levati, Sutter, and Van der Heijden (2007) study an environment with different endowments of the agents. Here, the presence of a leader increases average contributions in case of full information about endowment

---

[56] If groups failed to appoint a leader potential leaders themselves oftentimes prevented their election because they were not willing to carry the "burden of leadership" (Güth et al. 2007, p.1035) in the treatments without formal authority of the leaders.

[57] Vesterlund (2003) shows theoretically that sequential donations yield an improvement if there is imperfect knowledge about the quality of a charity.

asymmetries. However, leadership is almost ineffective if participants do not know the distribution of endowments[58].

Alternative Move Structures

In addition to the sequential game with one leader depicted in Figure 7.1, there are other possible move orderings. Cartwright, Lovett, and Stepanova (2017) consider a game in which a leader is preceded by a first follower as depicted in Figure 7.3. Compared to the game with one leader, average contributions are significantly larger at the 10 % level. The same holds true when the first-follower game is compared to a fully sequential game.

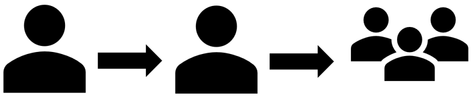


Figure 7.3: A sequential game with one leader and a first-follower

In a fully sequential game, players move one after the other (Figure 7.4). Figuières, Masclet, and Willinger (2012) compare simultaneous play to such a fully sequential game and their results indicate in groups of four that a fully sequential game yields significantly (10 % level) higher contributions compared to a simultaneous game. However, this only holds true if there is information on the contributions of those prior in the sequence. Thus, sequentiality alone does not increase contributions but observability of all others' prior contributions does.

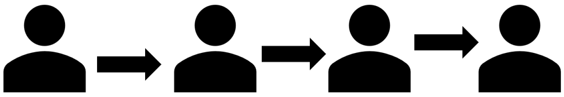


Figure 7.4: A fully sequential game

Haigner and Wakolbinger (2010) and Sutter and Rivas (2014) also consider a treatment in which one subject contributes after three others have already chosen their contribution publicly. One may interpret such a setting either as having three leaders or as having one leader that contributes last (Figure 7.5). Compared to simultaneous play, there are no significant differences in average contributions.

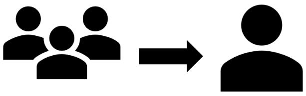


Figure 7.5: A sequential game with three leaders

---

[58] Sutter (2016) offers a more detailed discussion on leadership and uncertainty.

Closely related to the alternative move structures is the setting of Helland, Hovi, and Sælen (2018) who start the game with one exogenously chosen leader (see Figure 7.1) which serves as the control treatment. They modify it by giving the first mover the opportunity of contributing in a third stage after the three followers (see Figure 7.6) which they refer to as "implicit conditionality". In two accompanying treatments the leader makes either a binding or a non-binding pledge in stage one about his contribution in stage three having the opportunity of conditioning it on the followers' contributions.[59] Analyzing the data in the online appendix of Helland, Hovi, and Sælen (2018) suggests that leading with conditional commitments (either implicit, non-binding or binding pledge) offers no significant enhancement in average contributions compared to a plain version of leading by example (as depicted in Figure 7.1) given that all agents have the same initial endowments and returns to the public good.

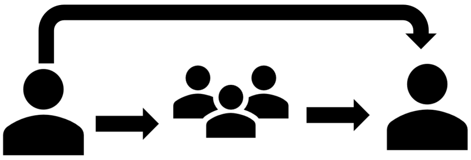


Figure 7.6: A sequential treatment with one leader that can contribute first and last

Group Size

With regard to the generalization of the results, it is worth knowing whether the findings obtained in relatively small experimental groups also hold true in the context of larger groups. Unfortunately, this issue is barely addressed in the area of linear public goods games with leadership. In a fully sequential setting, Figuières, Masclet, and Willinger (2012) only detect small insignificant differences in average contributions when varying the group size from four to eight players. Generally, there is a declining pattern of contributions in the sequence ("fading reciprocity" and "vanishing leadership"). Nevertheless there is a smaller decline in larger groups thus rendering almost the same average contribution. In the smaller groups of four players, however, average contributions are significantly larger than in simultaneous play (10% level), while there is no significant difference for larger groups of eight players. In a closely related game, the investment game, Komai and Grossman (2009) investigate the effectiveness of one player taking a leadership position and increasing the number of players from three to nine. The experimental results obtained suggest that group size decreases the effectiveness of leading by example in free-riding problems. This may be due to the incentives of leaders and followers. A leader becomes more pivotal with an increase in group size while a follower becomes more marginal, giving rise to free-riding incentives.

---

[59] Together with heterogeneity in returns to the public good (α_i) and the initial endowment (y_i) this renders a 3X3 factorial design with Helland, Hovi, and Sælen (2018) having nine treatments plus one control.

Accordingly, followers in the nine player game more often don't follow the leader's example compared to the three player game. However, as the experiment does not include a treatment without leadership, it remains an open question whether leadership improves cooperation in larger groups if there is one leader moving ahead. Even though, the evidence obtained by Komai and Grossman (2009) suggests that leadership may be more ineffective in larger groups.

7.4 FOLLOWER BEHAVIOR

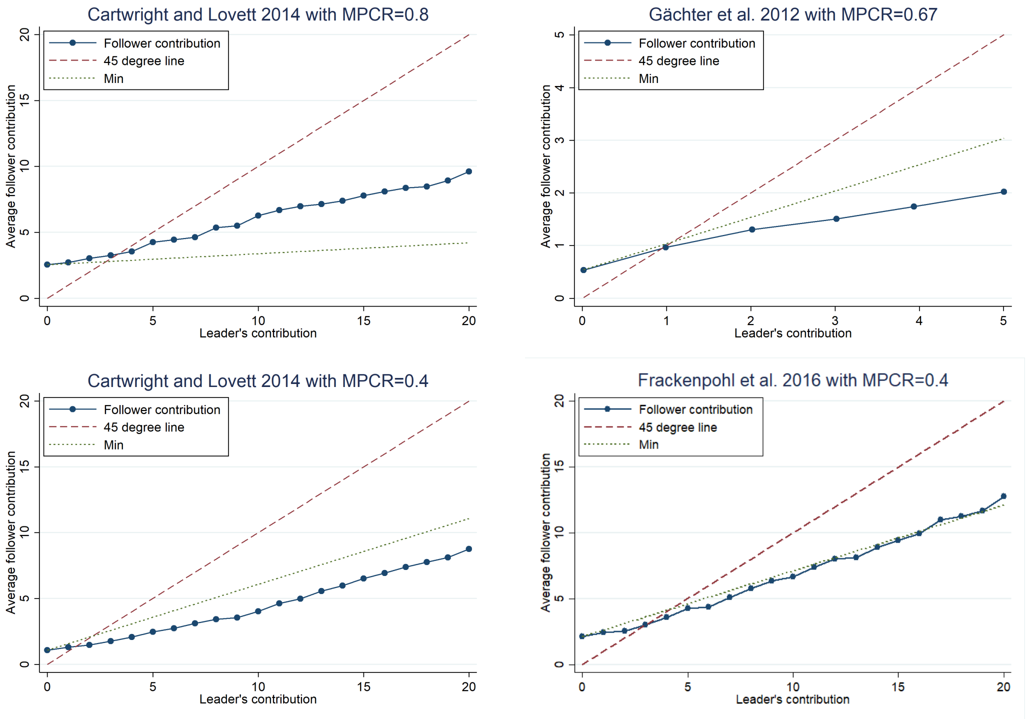
7.4.1 *Eliciting Follower Behavior by the Strategy Method*

In the following we try to refine the analysis. While the previous section has turned to the question whether and under what circumstances leadership can increase cooperation within a group and thus lead to an improvement in individuals' welfare, we now seek to further examine the effect of leadership. In this section, the focus is primarily on the followers' reaction. How do followers react to a leader's contribution? Section 5 finds answers for the question what makes leaders successful and how they recruit themselves.

A first straightforward approach to examine follower behavior is to apply the strategy method. Experimental subjects are requested to state their contribution conditional on a given hypothetical contribution level of the leader. This procedure is continued for the whole set of actions available to the leader. The scheme is incentive compatible as the hypothetical decision is actually implemented given the leader's realized decision. The procedure is similar to Fischbacher, Gächter, and Fehr (2001) with the difference that there is one leader (Figure 7.1) instead of three in Fischbacher, Gächter, and Fehr (2001) as depicted in Figure 7.5. Thereby followers face uncertainty about other followers' contributions which are unknown to them in a game with four players.

A major benefit of the strategy method is that the follower's whole contribution path is revealed. By contrast in a usual one shot interaction only the reaction to a single leader contribution is disclosed. Likewise, the leader is more salient with the strategy method as he has the followers' unrivaled attention. In the repeated game, the other followers' contributions of the previous period otherwise also provide a reference point that players may align themselves with.

Figure 7.7 describes the average contribution paths of followers as determined by the strategy method for different constellations. In the studies of Cartwright and Lovett (2014) and Frackenpohl, Hillenbrand, and Kube (2016) a game with four players and a MPCR of 0.4 and 0.8 are considered whereas Gächter et al. (2012) examine a game with two players and an MPCR of 0.67. The red dashed 45°-line indicates a perfect matching of the leader's contributions. If the followers' average contribution path lies below this line, this indicates that they contribute less than leaders and vice versa. In all four cases presented, it is evident that follower contributions are for the most part distinctly below that line. Hence, they contribute less than the leaders. Moreover, the followers' revealed reciprocity is not always sufficient to make a leader with a positive contribution better off compared to the case where he contributes zero. This is indicated by the green dashed line (”Min”). The slope of this line refers to equation (4) and the intercept is given by the conditional contribution of follower(s)’ when the leader gives zero. If the average contribution path of followers lies above this line, the leader fares better when he contributes an amount larger than zero and accordingly vice versa for the case that the followers’ contribution path lies below the green dashed line.


Cartwright and Lovett 2014 with MPCR=0.8

Gächter et al. 2012 with MPCR=0.67

Cartwright and Lovett 2014 with MPCR=0.4

Frackenpohl et al. 2016 with MPCR=0.4

Figure 7.7: Followers’ average contribution paths (strategy method)

In the studied examples, the latter is the case for Gächter et al. (2012) and Cartwright and Lovett (2014) with an MPCR of 0.4, whereas it pays for the leader to contribute fully in Cartwright and Lovett (2014) with an MPCR of 0.8. In Frackenpohl, Hillenbrand, and Kube (2016) the followers match the green dashed line almost perfectly thus providing an incentive for the leader to invest his whole endowment in the public good.

Regarding second movers’ motivation to act reciprocally, Teyssier (2012) shows that subjects who are sufficiently advantageous-inequity averse have a higher probability of being a perfect conditional cooperator i.e. contribute the same as the leader.

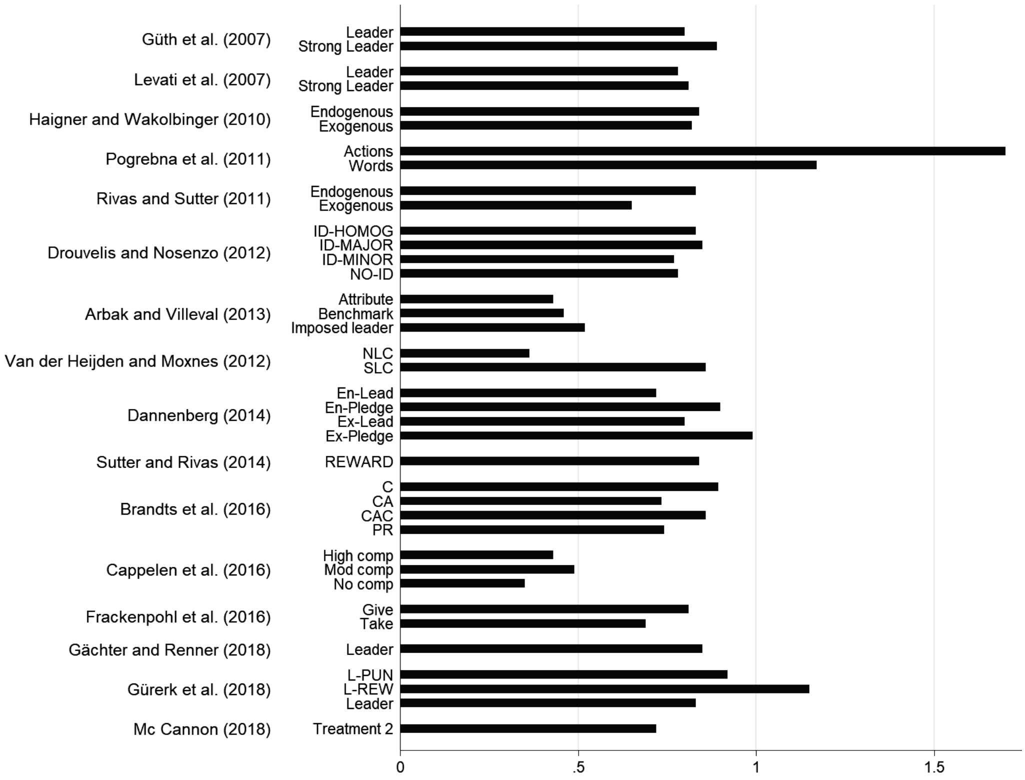
7.4.2 *Contribution Ratios in the Repeated Game*

The observation made with the strategy method that leaders contribute more to the public good than followers is also reflected in the repeated game. In most cases considered, there are significantly larger contributions of leaders (e.g. Rivas and Sutter (2011) and Gächter and Renner (2018)). This picture solidifies considerably if we consult more studies. This is illustrated in Figure 7.8. For this purpose a contribution ratio (CR) is defined as

$$CR = \frac{g_F}{g_L} \tag{7}$$

where g_F and g_L state the average contributions of followers and leaders.

Only very sporadically followers contribute more than leaders (Pogrebna et al. 2011 and one treatment in Gürerk, Lauer, and Scheuermann 2018). In the majority of cases, however, the leaders' average contributions are considerably higher compared to the followers.



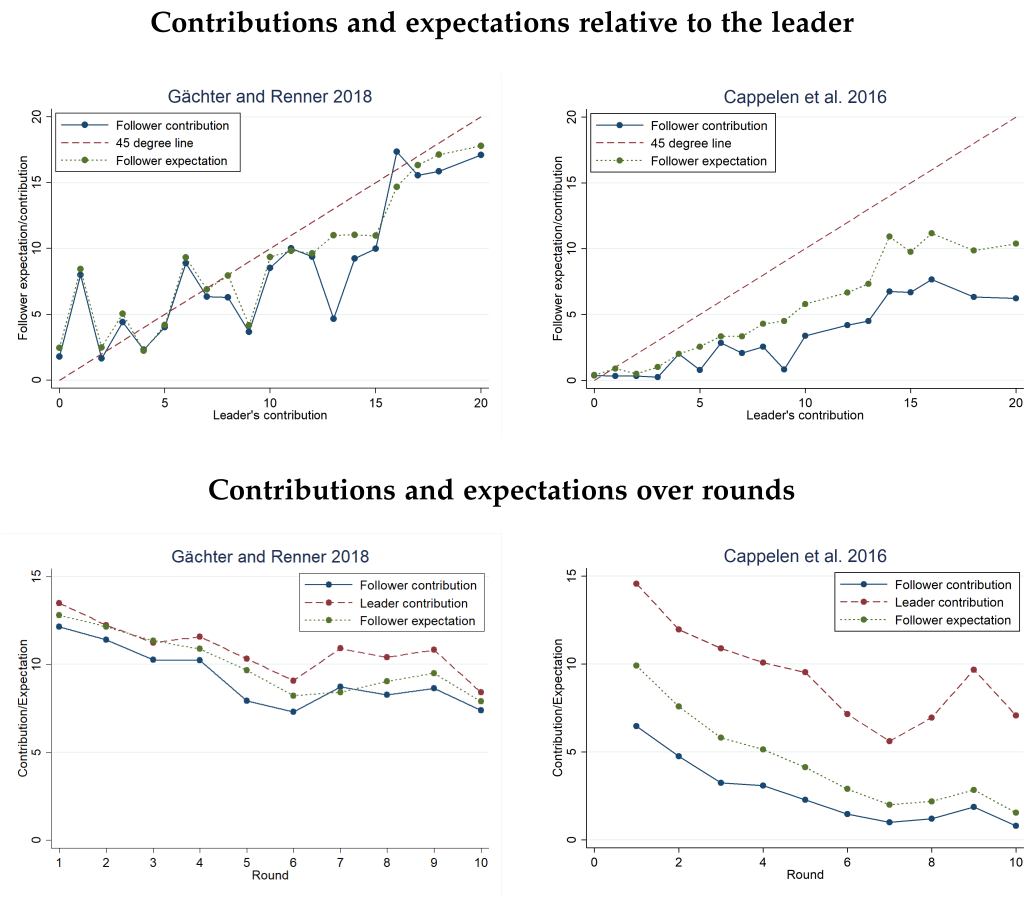
Note: For the public bad experiment of Van der Heijden and Moxnes (2013), investments in the non damaging good are considered. For Güth et al. (2007), Levati, Sutter, and Van der Heijden (2007) and Sutter and Rivas (2014) only periods that do not include a voting procedure (periods 1-16) are considered.

Figure 7.8: Contribution ratios

7.4.3 *Reciprocity in the Repeated Game and Followers' Beliefs*

As the strategy method has already indicated, followers react positively to the leader's contribution with an increase in their contributions. This is also reflected in the repeated game. Overall, there is a high positive correlation between leaders' and followers' contributions (e.g. Güth et al. (2007) and (Figuières, Masclet, and Willinger 2012)). Moreover, changes in the leader's contribution level have a huge impact on followers' behavior. Regression coefficients that state the marginal increase of a follower's contribution if the leader increases his contribution by one unit suggest that a variation in the leader's contribution actually does not translate in a 1:1 variation of followers' contributions, although there is certainly a huge impact on the contribution decisions (e.g. regression coefficients of 0.73 in Arbak and Villeval (2013), 0.40 in Dannenberg (2015) and 0.55 in Préget, Nguyen-Van, and Willinger (2016)).[60]

In a game with more than two players, reciprocal consideration may not only be a reaction to the leader's actions, but also to the other followers. In round 1 of a repeated public goods game a subject can only form beliefs about the contributions of other followers. The more the game progresses the more a subject can also condition reciprocity on other followers' past contributions. Consequently, it is interesting to see whether the pattern of imperfect conditional cooperation observed in section 7.4.1 is also transferable to repeated games.



Only leadership treatments are considered, in Cappelen et al. 2016 leadership without compensation.

Figure 7.9: Follower expectations (beliefs) and contributions and leader contributions

Two studies have a measure of followers' beliefs: Gächter and Renner (2018) ask subjects what they think all others would on average contribute and Cappelen et al. (2016) ask followers about their belief on other followers' aver-

---

[60] Frackenpohl, Hillenbrand, and Kube (2016) show that the reaction is different in a "take" compared to a "give" frame. In the "take" frame followers contribute 0.38 tokens for a marginal increase of one token by the leader, whereas it is on average about 0.54 tokens in the "give" frame.

age contribution. The studies differ as in Gächter and Renner (2018) leaders are randomly selected (exogenous leadership) and groups remain the same in the course of the experiment whereas Cappelen et al. (2016) use random re-matching after each round and endogenous leadership. Using data from all rounds of the game and mapping average followers' contributions to a leader's contribution, we can see in the upper half of Figure 7.9 that in both studies follower contributions are in most cases below the red dashed line of equal contributions of a leader and the followers. Typically, followers' beliefs rise in leader contributions. For this reason Gächter and Renner (2018) call the leader "belief manager". Also Cappelen et al. (2016) state that followers' beliefs about others' contributions are strongly correlated with the leader's contribution. Moreover, the dotted green line of follower expectations is typically in between, especially in Cappelen et al. (2016) on the right hand side of Figure 7.9. If one looks at this graph in the upper right corner, one could hypothesize that followers expect other players' imperfect conditional cooperation relative to a leader's contribution. They react to this by being imperfectly conditionally cooperative relative to their expectation. The mechanism may be the same as in level-k thinking. Looking at the contributions in the course of the game in the lower half, we recognize as well that followers' expectations are below leaders' contributions but above their own contributions on average.

Regarding a leader's influence in a fixed group over the course of a game Gächter and Renner (2018) state that especially in early stages of the game, the leader has a major impact on the expectations of experimental subjects. Leaders shape the followers' original beliefs and contributions. In the further course of the game, however, the followers place more emphasis on other followers' past behavior than on the leader's current action. So the leader tends to lose his importance at least to a certain extent.

7.5 LEADER BEHAVIOR

7.5.1 *Do Leaders Fare Well?*

Regarding the leader, the question at hand is how they fare in terms of material payoffs. Leaders usually fare worse than followers as we have seen in Figure 7.8 (contribution ratio). In the majority of cases, they contribute more to the public good and consequently receive lower absolute payoffs. Gächter and Renner (2018, p.330) call it the "leader curse".[61] The experimental results of Chapter 8 in a dynamic public goods game indicate that - despite this fact - leaders are not worse off compared to the average participant in a simultaneous treatment. Thus the simultaneous game without a leader provides a second noteworthy comparison.

---

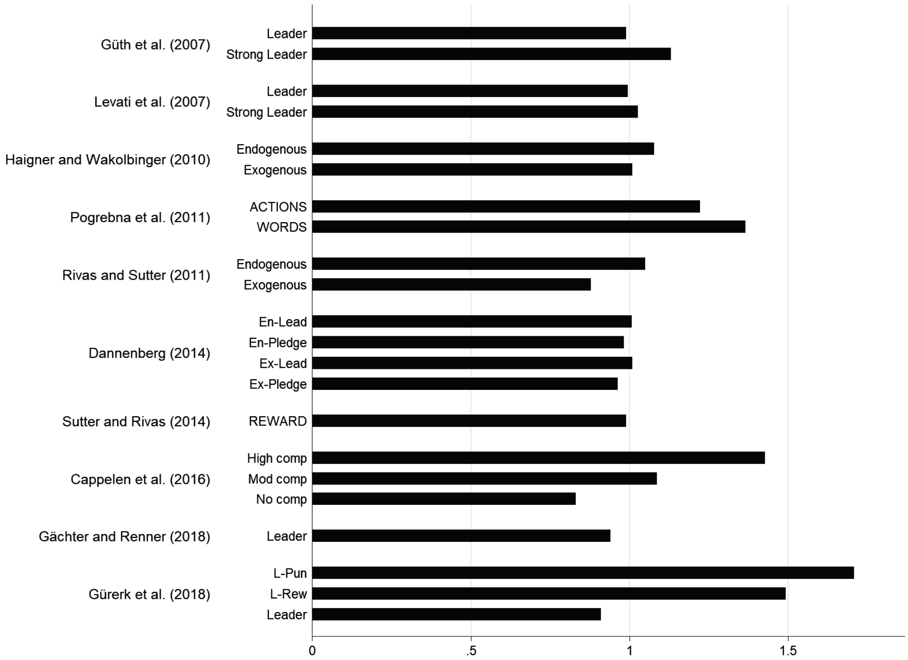
[61] This empirical phenomenon also emergence theoretically in the presence of reciprocal preferences as illustrated by a short theoretical example in Appendix E.

Accordingly, the corresponding question is how the leader's payoffs generally relate to those of the average player in a simultaneous public goods game. For this purpose, we define payoffs relative to simultaneous (PRS) as:

$$PRS = \frac{\pi_L}{\pi_S} \tag{8}$$

where π_L and π_S denote leaders' average payoffs in the sequential treatment and average payoffs of individuals in the simultaneous treatment respectively.

Figure 7.10 contains this measure for several studies. It turns out that leaders' payoffs are in general quite comparable to those of an average player in a simultaneous treatment. However, having the choice between leading and not leading, a subject would in most cases be better off choosing to be a follower as Figure 7.8 revealed. Consequently, one has to ask what motivation people have to take this role in voluntary (endogenous) leadership.



Note: Average leader payoffs are always compared to an average player in the simultaneous treatment (without punishment/reward and without self-selection into the simultaneous treatment). For Güth et al. (2007), Levati, Sutter, and Van der Heijden (2007) and Sutter and Rivas (2014) only periods that do not include a voting procedure (periods 1-16) are considered.

Figure 7.10: Leader payoffs relative to simultaneous

7.5.2 *Willingness and Motivation to Be a Leader*

When given the alternative between leading and not leading, only few subjects volunteer to be the leader: about a quarter choose to lead when facing the binary option to lead by example or not to lead (Haigner and Wakolbinger 2010; Arbak and Villeval 2013; Cappelen et al. 2016). Given the additional option to lead by words, only 13 Percent choose to lead by example and 43

Percent want to lead by words (Dannenberg 2015). Given that leading by example is costly, the question is what motivates those at all who agree to do it?

Arbak and Villeval (2013) attribute this to three possible motivations: Individuals may assume that they are better off compared to situations without leadership such that there are personal gains based on a positive reaction of the followers. This is indicated by the fact that leadership behavior is conditional on the perceived responsiveness of the followers. In the first stage of the experiment of Arbak and Villeval (2013) subjects can give donations to a charity in some treatments. If the charitable donations are public information and leaders see that they are matched with less charitable participants, leaders reduce their contributions in the public goods game (2nd stage of the experiment). Hence leaders reduce their contribution because low charitable giving in stage one may serve as a signal that followers are less responsive or less generous which could be interpreted as a sign of strategic leadership. Another motivation could be altruistic, i.e. voluntary leadership at personal cost. The experiment of Arbak and Villeval (2013) shows that there is a strong positive correlation between charitable behavior and the probability of deciding to lead. In addition, frequent leaders contribute substantially more than others which is driven mainly by men as females contribute almost the same amounts in both roles (leader/follower). Related to this is a third source of motivation - maintaining a positive self-image. Arbak and Villeval (2013) interpret leading as a signal for social rank. Clues are that male subjects are more likely to apply for leadership in general and revise contributions sharply if not selected.

In addition, the behavioral type of a player is also crucial in the decision whether or not to lead by example. Préget, Nguyen-Van, and Willinger (2016) show that the probability to lead by example is significantly increased if someone is a conditional cooperator. Moreover, the experiment of Cappelen et al. (2016) shows that a material compensation for being a leader increases the willingness to be a first mover significantly from 23% without compensation to 63.4% with "moderate compensation" to 94.4% with "high compensation". This goes hand in hand with a steep increase in the share of free-riders that would volunteer to be a leader.

7.5.3 *Leader Contributions*

What determines the size of a leader's contribution? As Gächter et al. (2012) point out, a high contribution of the leader may signal that he is cooperatively inclined but on the other hand also might be a strategic decision (as shown in equation (4)) expecting followers to be reciprocal enough such that the leader contribution is a good investment.

One shot public goods games using the strategy method offer first insights. Gächter et al. (2012) show that those subjects who are more reciprocal[62] as followers contribute more as leaders, even after controlling for optimism. Nevertheless, as leaders' beliefs on followers' contributions are highly correlated with their own second mover decision, part of their contribution may steam from a false consensus effect. In the same vein, Teyssier (2012) finds that there is a significant positive correlation between leaders' contribution and their belief about followers' contributions. Moreover, the less risk averse leaders are, the more they contribute.[63]

In repeated games, an often observed pattern is that voluntary (endogenous) leaders contribute more in absolute terms than imposed ones (see e.g. Dannenberg 2015; Rivas and Sutter 2011; Haigner and Wakolbinger 2010). In addition, Van der Heijden and Moxnes (2013) show in a public bads game that the costs of leading also matter for a leader's contribution. If leaders have no costs of acting socially they set "better" examples, i.e. invest less in a public bad, but are also much less influential.[64] In a similar vein, Cappelen et al. (2016) study compensation for leaders. They find that a high compensation decreases leader contributions compared to no compensation or a moderate compensation. This reflects a "social crowding out effect" as selfish types are attracted to be leaders. An approach that studies quite the opposite is Centorrino and Concina (2013). They auction the leadership position and find that subjects indeed bid positively (around $\frac{2}{3}$ of the subjects) to compete for the role of a leader despite having no monetary incentives. The higher the bid, the higher the first contribution to the public good. This could indicate that high bids are chosen by those who are the more cooperative leaders. This experimental result is quite surprising given that usually only a quarter of the subjects choose to be leaders when it is costless. To sum up, the results of Cappelen et al. (2016) and Centorrino and Concina (2013) indicate that the costs or benefits of leading induce a self-selection of cooperative or selfish types in this position.

7.6 LEADERSHIP EFFECTIVENESS IN OTHER PUBLIC GOODS GAMES

7.6.1 *Summation Technology Public Goods Games with Interior Equilibrium*

The considerations so far have focused on the linear public goods game with summation technology and predicted corner solutions. Nevertheless, many theoretical considerations are based on settings in which the payoffs or the utility and costs are arranged in a way that interior solutions emerge as the predicted solution. An example for such an experimental public goods game

---

[62] Gächter et al. (2012) come up with a new classification criterion for conditional cooperation: a subject (follower) is denoted as a conditional cooperator if reciprocity is strong enough to induce a selfish leader to invest parts (weak conditional cooperator) or all of the endowment (strong conditional cooperator).

[63] Gächter et al. (2012) find no significant correlation between risk-aversion and leader contributions, however, compared to Teyssier (2012) they have no incentivized measure of risk-aversion.

[64] Van der Heijden and Moxnes (2013) observe that followers react more strongly to leaders who have higher costs such that average investments in the public good remain unchanged.

is Bracha, Menietti, and Vesterlund (2011) who introduce a convex and piecewise linear cost function which results in the prediction of an interior equilibrium. In their two player setting, average contributions are larger in sequential play compared to simultaneous play. Bracha, Menietti, and Vesterlund (2011) explain this result by reciprocity considerations (treatments without fixed costs).

In the theoretical literature, a first mover advantage is discussed for interior solutions, i.e. in such a setting leaders have no incentive to proceed by large contributions because of crowding out of followers. They rather stick to committing to low initial contributions thereby realizing a first-mover advantage. Under these circumstances, the theoretical literature predicts that the amount of public good provided is smaller under simultaneous play than under sequential play. This results in a comparison between a Cournot-Nash equilibrium and a Stackelberg equilibrium. Varian (1994) and Cornes and Sandler (1996) both show that given preferences with standard properties the amount of public good provided in an interior Stackelberg equilibrium (sequential game) is lower than in a Cournot-Nash equilibrium (simultaneous game).[65]

Gächter et al. (2010) allow for a first-mover advantage. They modify the linear public goods game discussed in equation (1) by introducing decreasing marginal returns from the shared account (public good). In addition, there is heterogeneity in the returns from the public good between the two players in the game. They examine two different parameterizations: one in which a first-mover advantage is theoretically predicted (i.e. the first-mover could commit to zero contributions in the sequential game) and one with the general prediction of a standalone allocation in which only the player with the high returns contributes. In both settings, a sequential protocol with either the agent with the high or the one with the low returns moving first is compared to a simultaneous protocol. In general, considering both settings, there seems to be no first-mover advantage even when it is predicted. On the contrary, the player with the higher returns from the public good as first mover has a tendency to fare worse compared to being the second mover or being in the simultaneous game. Second movers seem to oppose unfair outcomes even if this means foregoing monetary payoffs. Comparing total contributions under sequential and simultaneous play there are no significant differences except for the case when the player with the highest returns moves first. In this case, contributions are significantly lower in sequential play compared to a simultaneous play.

Consequently, as a first mover advantage does not really materialize it is unclear whether such an ordering really emerges, especially the one in which the player with the high returns from the public good moves first. Nosenzo and Sefton (2011) give an answer to this question. Allowing subjects to endogenously choose their contribution stage they find that subjects avoid the setting in which the agent with a high return of the public good moves first

---

[65] However, if followers either have social preferences (e.g. inequity aversion), act reciprocally or the leader's contributions changes the follower's beliefs, one can assume a positive response to leadership (upward sloping response curves) as shown by Buchholz and Sandler (2017). Hence even leaders with standard preferences would have some incentive to proceed by setting a good example.

(and can commit to a low contribution). The largest fraction of subjects prefers to contribute in the second stage even though the theoretical prediction would be for both players to opt for contributing first.

7.6.2 *Weakest Link Public Goods Games*

A weakest link game is a variant of a public goods game in which the minimum contribution of the players involved determines the total amount of public good available to all. It resembles a collective action problem as players have to coordinate. At the same time, no free-riding incentives emerge as free-riding would bring provision levels to zero (Sandler 2015). Examples for weakest-link aggregation can be found in disease control or financial stability (Kaul et al. 2003).

Weber, Camerer, and Knez (2004) compare a weakest link public goods game in which three players move one after the other (fully sequential) with information about contributions of those prior in the sequence to one in which players contribute simultaneously. Minimum choices in the weakest-link public goods game are significantly higher in the fully sequential treatment (see Figure 7.5) compared to the sequential treatment giving rise to increased efficiency under sequential play.

In a more classical leader follower relation, Cartwright, Gillet, and Van Vugt (2013) study the effect of one player going ahead in groups of four. The leader is either selected at random (exogenous leadership) or a volunteer (endogenous leadership) such that there are two leadership treatments. The results indicate that there is no statistically significant difference between the two, such that moving from exogenous to endogenous leadership seems to have little effect. Comparing treatments with leadership to a simultaneous treatment of equal sized groups of four shows that groups in the leadership treatments do better in coordination. Minimum contributions are larger and subjects earn more indicating an increase in efficiency. In addition, coordination levels improve over time (dynamic improvement).[66] Cartwright, Gillet, and Van Vugt (2013) observe a positive reaction of followers when the leader proceeds with a large contribution. Choices of followers are positively correlated to those of the leader. However, there are not so many leaders that choose to contribute a lot such that leadership could unleash its full effect of improving coordination in some groups.

For a six player weakest link game, Sahin, Eckel, and Komai (2015) examine two forms of leadership, leading by example and leading by words. There is either a first mover that can choose the level of contributions which is observed by five other players that move simultaneously afterwards (commitment) or a first mover that makes suggestions (cheap talk). Compared to simultaneous play, both of them, cheap-talk or commitment, equally improve efficiency. There is no statistically significant difference in the two modes of leadership in reducing coordination failures. Raised ambition by the leaders either in the form of cheap talk or commitment has a positive impact on

---

[66] However, leadership does not yield an improvement in efficiency compared to groups of three contributing simultaneously.

the followers' contributions. Sahin, Eckel, and Komai (2015) interpret this as strong evidence for conditional cooperation.

7.6.3 *Threshold/Step Level Public Goods Games*

In a step level or threshold public goods game, a public good is only provided when a minimum level of contributions, a provision point, is met. For instance, charities may have properties of step-level public goods (Normann and Rau 2015) or threshold public goods. Erev and Rapoport (1990) consider a simple binary version of a threshold public goods game in which a minimum of three of five group members have to contribute. A simple backwards induction argument yields that a fully sequential move structure in which players move one after the other has a unique subgame perfect Nash equilibrium of provision in which earlier players contribute little or nothing compared to those later in the sequence. By contrast in a simultaneous version there are multiple equilibria including inefficient ones without provision. The empirical results of Erev and Rapoport (1990) indicate that fully sequential play is indeed more efficient in providing the public good compared to simultaneous play. However, not all subjects follow the game theoretic prediction of exploiting later movers.

Enriching the setting with treatments that include a refund if the provision point is not met, Coats, Gronberg, and Grosskopf (2009) similarly find that (fully) sequential play increases efficiency compared to simultaneous play for a given refund rule in groups of four. Within treatments of sequential play, however, a refund does not significantly increase efficiency while this is the case in simultaneous play. Related to that, Coats and Neilson (2005) also study possible motivations of first movers and state that their behavior supports beliefs in reciprocity of those later in the sequence.

Adding a second step level in some of the treatments, Normann and Rau (2015) study a two player game under simultaneous and sequential play. Once again, higher efficiency has been achieved in the sequential treatments. In addition, second movers punish low contributions by giving little themselves, acting reciprocally and thereby deviating from their best response such that exploitation by earlier movers is limited.

Summing up, moving fully sequential unequivocally increases the provision of step level public goods. However, there is still an experiment missing to test what happens if followers move simultaneously after a leader has made his decision. This question is dedicated to future research.

7.6.4 *Field Experiments*

Obviously, it is also worth knowing what happens when one goes beyond studying students' behavior in the lab. There are two experiments that probe the effectiveness of leading-by example in a lab in the field setting.

Jack and Recalde (2015) study in a rural area of Bolivia whether elected authorities have a larger impact on local public good provision when moving ahead compared to randomly selected citizens or no leadership at all. A main finding is that democratically elected local authorities are effective in moving ahead whereas randomly selected community members have little effect. Especially local authorities in a leader position give more to the public good which increases the likelihood that followers follow the example set. Controlling for individual information about the quality of the public good, Jack and Recalde (2015) state that uninformed followers are more responsive to leading by example of authorities in the community, but also informed community members are responsive to the example set. This indicates that in addition to signaling the value of the public good, local authorities also trigger a reciprocal reaction of followers.

Focusing on the effects of cultural heterogeneity between Hindu and Muslim citizens in India on public good provision, Keuschnigg and Schikora (2014) test the interaction with leading by example in an experimental public goods game in groups of four players. The results indicate that leadership does not improve the level of cooperation. On the contrary, leading-by example in culturally heterogeneous groups leads to a deterioration of the level of public good provided. Keuschnigg and Schikora (2014) attribute this to the lack of conditional cooperation and poor leadership in mixed groups. By contrast, cultural heterogeneity has no effects on simultaneous play.

7.7 external validity and conclusion

Finally, we take up the question that forges the bridge to the introduction: To what extent do economic experiments give insights that are relevant for the provision of global public goods? A basic prerequisite to pursue this question is a critical glimpse on the external validity of laboratory experiments. So, to what degree can we apply the findings from the lab to real global public good contexts?

A first point that is likely to raise concern is the question of whether experimental subjects in the lab, most of them college and university students, differ in how they make decisions compared to policy makers in international relations. The fundamental question is whether elites do exhibit very different characteristics compared to other populations (Hafner-Burton et al. 2017). To this end the literature in experimental political science is informative. Using a sample of US policy and business elites with decades of experience on average in international diplomacy or policy strategy, LeVeck et al. (2014) show that elites are not more self-interested in an ultimatum game compared to undergraduate students and by contrast are significantly more prone to reject low offers and make significantly higher initial offers. Penalizing small payments with the rejection of the offer under the sacrifice of own material interests indicates negative reciprocity. Therefore, elites do not necessarily behave less reciprocally than students. In a similar vein, Dannenberg, Sturm, and Vogt (2010) who elicit Fehr and Schmidt (1999) inequality aversion parameters for a group of subjects involved in climate negotiations, most of them employed by national governments, come to the conclusion that inequality aversion was of considerable importance for policy makers (Dannenberg, Sturm, and Vogt 2010).

A second potential point of concern is whether the structure of the games considered resembles global public goods concerns. An answer is that the aggregation technologies considered reflect those described for many global public goods. Summation technologies come into play when it does not matter who contributes, but only the total amount contributed. This is for example the case for carbon dioxide mitigation (Kaul et al. 2003) but also for UN peacekeeping operations (Sandler 2017b). Examples for weakest-link aggregation can be found in disease control or financial stability (Kaul et al. 2003). By contrast, charities may have properties of step-level public goods (Normann and Rau 2015) and decisions by the UN security council and other committees resemble a threshold public good problem. Of course, a setting in the lab always resembles to some degree triviality or artificiality of the experimental situation, but concurrently experiments help advance and aggregate knowledge and give us a more comprehensive understanding (McDermott 2002). As in a theoretical model, the aim is to uncover fundamental mechanisms at work in a simplified world.

Wrapping it up, we have seen that leading by example indeed yields an amelioration in many contexts, especially if the leader has some kind of formal authority and in settings of voluntary leadership. Followers typically employ an imperfect matching strategy as they contribute only a fraction of the leader's contribution. Thereby, they succeed in exploiting the leader to some degree as leaders contribute more and consequently receive lower payoffs. Nevertheless, leaders are important as they have a big impact on followers' beliefs, especially in the beginning. Moreover, they are on average not worse-off than the participants in a simultaneous game. Still, they earn less than followers. Consequently, only a fraction of around a quarter of all experimental subjects would opt to lead by example. We can find possible motivations to become a leader mainly in altruistic thinking and self-image concerns besides strategic considerations. Oftentimes, leaders' contributions are related to their expectation of followers' contributions and also to their risk-aversion. In public goods games with interior equilibrium, followers' reciprocity oftentimes prevents a first-mover advantage where it is theoretically predicted. In addition, leadership brings an improvement in weakest-link and threshold public goods games as well. Generally, we can state that leading-by-example crucially depends on the example set by the leader as well as conditional cooperation of the followers. Leadership can only be successful if both are present.

8

LEADERSHIP IN DYNAMIC PUBLIC GOOD PROVISION: GROWTH AND INEQUALITY[67]

8.1 INTRODUCTION

Are leaders important for the progress of societies? Jones and Olken (2005) find evidence for this claim regarding national leaders and show that they are an important determinant for economic growth. In general, economic growth in developed countries is often linked with cooperation processes such as the development and spread of new technologies and knowledge. The development of these technologies requires in many cases the joint efforts of several actors. In a similar vein, much hope rests on technological development in international climate policy. Jointly developed improved green technologies offer the scope to reduce the cost burden borne to mitigate climate change. A key question here is whether "leading-by example" (Hermalin 1998) fosters cooperation. In experimental economics, a common tool to analyze cooperation problems are static public goods games (PG games henceforth).

Most of the time, cooperation, however, is not a one-time affair. Instead, stakeholders commonly interact many times with each other and dynamic dependencies exist such that contributions in former rounds have an impact on the public good supply in the current round. An example for a dynamic dependency is an *endowment carryover* which generates scope for endogenous growth and inequality. Such an environment enables individuals to reinvest cooperation profits from the previous round into further cooperation. For example, several actors like countries or companies invest in research and development (R&D) joint-ventures which generate either cost reductions or higher profits. These cooperation gains subsequently can be reinvested in further cooperation in the next round. A similar pattern holds for public infrastructure or, in a broader context, the evolution of societies (Gächter et al. 2017).

We are interested whether *leading-by-example* yields an amelioration in public good supply considering such a dynamic environment with endowment carryover. In our setup, leading-by-example means that a group member decides first and other group members can observe his or her decision right before they make their own decision. Hence, the leader has the opportunity of preceding by setting a (good) example. We use a plain setting with a random subject being determined as a leader (exogenous leadership). The implementation that is probably most close to ours is that of Güth et al. (2007). In their fixed treatment, one of four group members is randomly selected to be the leader and remains in that position. This exogenous procedure offers a simple and clear-cut treatment.[68] We designed the dynamic dependency in a

---

[67] This chapter is a slightly modified version of Eichenseer and Moser (2019b).

[68] Furthermore, at least in a static game, there seems to be no differences with respect to contributions between a fixed and a rotating leader (see Güth et al. 2007).

way that is close to that of Gächter et al. (2017), having the following features: (i) there is no consumption until the last round, i.e., the entire wealth can be reinvested at the beginning of a new round and (ii) endogenous endowments are determined by previous contributions. As a result, this variant of a public goods game allows for both, endogenous growth and endogenous inequality.

With our experiment we contribute both to the literature on leadership in public goods experiments (see Chapter 7 for a review) and the literature on dynamic public goods games (e.g., Sadrieh and Verbon 2006; Battaglini, Nunnari, and Palfrey 2016; Rockenbach and Wolff 2017; Gächter et al. 2017). Our results indicate that a positive effect of leading-by-example is present in a dynamic setting with endowment carryover. Moreover, the presence of a leader also significantly reduces the within-group inequality. Regarding the literature on leadership in public goods games, we provide a further contribution by establishing a link between behavioral types of the leader and leadership success, which complements existing research (e.g., Gächter et al. 2012). Using a sequential prisoner's dilemma for classification (Kosfeld 2019; Eichenseer and Moser 2019a), we show that an important predictor for the success of a group is the behavioral type of the leader.

The remainder of this chapter is organized as follows. Section 2 offers a brief review of the related literature followed by Section 3 which describes the experimental design. Section 4 gives an overview on hypotheses and research questions whereas Section 5 presents and discusses the results of the experiment. Section 6 concludes the chapter.

8.2 LITERATURE REVIEW

Many classical examples of public goods have in common that they entail a dynamic dependency which can be modeled by a carryover (Cadigan et al. 2011) which is depicted in Table 8.1, e.g. they provide streams of benefits in the long run (stock-level carryover), their provision becomes more efficient with experience (marginal per capita return *(MPCR)* carryover) or cooperation benefits can be reinvested (endowment carryover). Consequently, it is important to know whether major results of static public goods also hold for dynamic variants, which are often closer to reality.

In experimental economics, an emerging literature has attempted to fill this gap in the past years. Sadrieh and Verbon (2006) analyze an environment where social output today determines production possibilities tomorrow (endowment carryover), and social output is distributed unequally. Noussair and Soo (2008) study a dynamic public goods game with a MPCR carryover: the return on contributions is a function of decisions in previous rounds. This characteristic leads to the effect that, in most cases, the usual pattern of declining contributions over time does not turn up. Cadigan et al. (2011) investigate whether subjects' behavior in a PG game with a stock level carryover comes close to the qualitative predictions of Markov Perfect Equilibria. Gächter et al. (2017) and Rockenbach and Wolff (2017) both investigate the effects of punishment in a dynamic public goods game with endowment carryover. While punishment in a static setting is usually very successful, there are

Endowment	**MPCR**	**Stock Level**
Previous outcomes affect future endowments.	"Learning-by-doing": productivity depends on the contributions in previous stages.	Durable public goods or bads.
E.g., profits from the use of public infrastructure; R&D cooperation.	E.g., better trained staff in public administration; renewable energies.	E.g., public and social capital; environmental pollution.

Table 8.1: Types of Carryover

drawbacks in a dynamic setting. Punishment results in fewer resources available for the punished ones, which could be invested in further cooperation. In consequence, it reduces the potential for future cooperation gains (Rockenbach and Wolff 2017). To sum up, it is not obvious that standard recipes to improve cooperation do really work well in a dynamic setting.

This question also holds for *leading-by-example*. To the best of our knowledge, there exists no paper in the experimental literature that explores the effect of leadership in a dynamic public goods game. Restricting our attention to experiments in which a leader is exogenously determined and does not enjoy formal power or superior information, we can summarize previous results in static public goods games as following: exogenous leadership significantly increases contributions to the public good in Moxnes and Van der Heijden (2003), Güth et al. (2007), Levati, Sutter, and Van der Heijden (2007), Pogrebna et al. (2011), Dannenberg (2015), and McCannon (2018) while insignificant effects are reported in Haigner and Wakolbinger (2010), Gächter and Renner (2018), Sahin, Eckel, and Komai (2015), and Gürerk, Lauer, and Scheuermann (2018). A significant negative effect is reported in Rivas and Sutter (2011). We can therefore state that in the majority of cases, exogenous leadership yields an improvement in public good contributions.[69]

Leaders that set a good example have a positive impact on followers. A common observation from static PG experiments is that leaders' and followers' contributions are correlated to a large degree (see, for example, Arbak and Villeval 2013). In addition, leaders also greatly shape the followers' expectations (Gächter and Renner 2018). However, the literature also shows that followers systematically contribute less than leaders (see, for example, Güth et al. 2007; Haigner and Wakolbinger 2010; Rivas and Sutter 2011; Arbak and Villeval 2013; Dannenberg 2015; Cappelen et al. 2016; Gächter and Renner 2018). As a result of "selfish-biased" conditional cooperation (Neugebauer et al. 2009), leaders are relatively worse off giving rise to a "leader's curse"

---

[69] Larger effects of leadership usually show up when it is endogenous (Rivas and Sutter 2011; Haigner and Wakolbinger 2010), when the leader is endowed with formal power (Güth et al. 2007; Levati, Sutter, and Van der Heijden 2007; Gürerk, Irlenbusch, and Rockenbach 2009; Sutter and Rivas 2014), or when the leader has an informational edge (Potters, Sefton, and Vesterlund 2005; Levati, Sutter, and Van der Heijden 2007).

(Gächter and Renner 2018). Regarding the question of who makes a good leader, Gächter et al. (2012) try to give an answer by classifying subjects in a one-shot strategy method setting. They elicit within-subject leader and (conditional) follower contributions as well as their beliefs. The main finding is that subjects that would behave conditionally cooperative as followers, give significantly more if they are leaders, even after controlling for optimism. As a result, groups perform best when led by weak or strong conditional cooperators in this strategy method setting. We are interested whether these findings are reflected in a dynamic public goods game with endowment carryover. This is a setting where cooperation really pays off: in our experiment subjects start with 2 EUR and could end up with around 34 EUR each, if all subjects cooperated fully in all rounds of the public goods game. At the same time, a leader only has the possibility of proceeding by setting a good example if followers reciprocate to a sufficiently high degree as this determines a leader's contribution capabilities in the next round.

8.3 EXPERIMENTAL DESIGN AND PROCEDURES

To this end, our experiment consists of two parts. Part I, which is a sequential prisoner's dilemma, is the same for all subjects. We use this decision task to classify subjects' cooperation types. In part II of the experiment, subjects performed a dynamic public goods game which was either played *simultaneously* without leader (*NOLEAD*) or *sequentially* with a leader who moved first (*LEAD*). We use a between-subject design, hence, subjects either participated in *NOLEAD* or in *LEAD*.

8.3.1 *Part I*

Eliciting conditional cooperation types
Before entering one of the two main treatments (*NOLEAD* or *LEAD*) we elicit conditional cooperation types of all subjects by a sequential prisoner's dilemma.[70] We matched the subjects in groups of two people and both players are endowed with 1 Euro.

First, Player 1 decides whether to send his Euro to Player 2 (choose action *S*) or keep the Euro for himself (choose action *K*). After observing his choice, Player 2 can decide, conditionally on the choice of Player 1, whether to send 1 Euro (action *S*) or keep it (action *K*). If the Euro is sent to the other player, it doubles. Therefore, a social optimum is reached when both players send their Euro. However, maximizing their own payoffs means that none of the two players send their Euro. Hence, the decision situation of part I resembles a sequential prisoner's dilemma. Figure 8.1 depicts the payoff structure of this game.

---

[70] This method is used for example by Miettinen et al. (2017) and described in further detail in Kosfeld (2019) and Eichenseer and Moser (2019a).

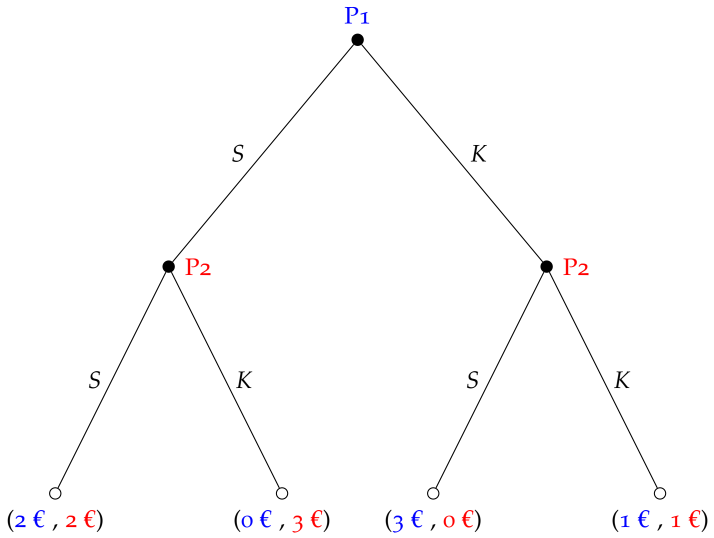


Figure 8.1: Payoff structure of the sequential prisoner's dilemma

All subjects state their decisions for being either Player 1 or 2 (strategy method). They are randomly allocated to one of these roles at the end of the experiment and paid accordingly. In addition, we asked them how many percent of participants they consider to choose the cooperative action when Player 1 cooperates/defects in order to elicit their beliefs about the other players' behavior.[71] The set of strategies, X_i, in this game for Player 2 is given by $X_i = \{SS, KK, SK, KS\}$. Based on the participants' conditional second mover's choice, we can classify subjects as *altruists* (unconditional cooperators), *conditional cooperators* (cooperate only if the first-mover cooperates), *free-riders* (never cooperate) and *mismatchers* (play the opposite of the other player) as shown by Table 8.2.[72] [73]

Cooperation type	***Behavior & Strategy***
Conditional cooperator (CC)	Cooperates only if the other player also cooperates; SK
Selfish (SF)	Never cooperates (free-rider); KK
Altruist (AL)	Always cooperates; SS
Mismatcher (MM)	Does the opposite of the other player; KS

Table 8.2: Cooperation types

---

[71] We did not incentivize this task in order to keep cognitive load at a moderate level.

[72] In our experiment, we only had one subject who we classified as *mismatcher*. Since this subject responded to cooperation with selfish behavior, we also classified him as a *selfish* type for our further analysis.

[73] A balancing table, reporting the distribution of types across treatments, can be found in Appendix D (see Table D.1).

8.3.2 *Part II*

Simultaneous treatment (*NOLEAD*)

In the main part of our experiment, subjects play a dynamic public goods game in one of two treatments (between-subject design), either *NOLEAD* or *LEAD*. The earnings of a given round serve as the endowment for the next round.

Period	1	2	3	4
Round	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

Table 8.3: Structure of periods and rounds

In both conditions, subjects are randomly assigned to groups of four people, which stay the same for one period consisting of seven rounds. After each period, subjects are randomly rematched. In total, the game is played for four periods (see Table 8.3). In round 1 of every period, each participant i, with $i \in \{1,2,3,4\}$, is endowed with $E_i^1 = 20$ Taler (exchange rate 1 Euro = 10 Taler), which he can either keep for himself in his "private account" or contribute to the public good labeled as a "group account" (g_i denotes the individual contribution to the group account). The MPCR for the group account is 0.375 which means that the group account has a return of 1.5.

Hence, the earnings at the end of round 1 are given by:

$$E_i^2 = E_i^1 - g_i^1 + \frac{1.5}{4}\sum_{j=1}^{4} g_j^1$$

which serve as the endowment in round 2. Consequently, the endowment for round t is given by:

$$E_i^t = E_i^{t-1} - g_i^{t-1} + \frac{1.5}{4}\sum_{j=1}^{4} g_j^{t-1}$$

and the final payoff of a period is given by the endowment after round 7, which is:

$$\pi_i = E_i^7 - g_i^7 + \frac{1.5}{4}\sum_{j=1}^{4} g_j^7.$$

In each round of a period, subjects simultaneously make their decisions without knowledge of other participants' contributions prior to taking their own contribution decision in *NOLEAD*. After each round, they are informed how many Taler the other group members contributed individually and about their and the others' new endowment. After finishing a period, subjects are randomly rematched to new groups of four. One of the four periods is randomly chosen for payment.

Sequential treatment (*LEAD*)
Treatment *LEAD* is similar to treatment *NOLEAD*, except that one subject is randomly allocated to the role of a leader at the beginning of a period. This participant (leader) moves first in all rounds of a period. In each round the other subjects (followers) are informed about the leader's contribution and subsequently simultaneously decide upon their own contributions. In every period a new leader is randomly selected. Everything else is identical to *NOLEAD*.

8.3.3 *Participants and Procedures*

The experimental sessions were conducted in the Regensburg Economic Science Lab (RESL) in February 2018 using zTree (Fischbacher 2007) for programming and Orsee (Greiner 2015) for recruitment. 92 participants (45 men and 47 women; mean age: 23), most of them enrolled in business administration, economics, or a related subject, took part in four experimental sessions with a minimum of 20 and a maximum of 24 subjects per session. Before entering the lab, participants were randomly assigned to a cabin with a computer. For both parts of the experiment, we provided participants with written instructions as well as a verbal summary that was read aloud (instructions are available in Appendix D). Subjects were not aware of the content of part II of the experiment before finishing part I. We paid participants in Euro in private at the end of the experiment. In total, the experiment lasted about 75 minutes and generated average earnings of about 14.12 EUR per subject (including a show-up fee of 4 EUR).[74]

8.4 HYPOTHESES AND RESEARCH QUESTIONS

8.4.1 *Wealth*

Under the assumption of selfish, payoff-maximizing players, the unique equilibrium of the simultaneous game, *NOLEAD*, is that all players contribute zero in each round (consider the online appendix of Gächter et al. 2017, for a formal proof). A simple backwards induction argument also renders zero contributions in each round as the unique equilibrium of the sequential game *LEAD* (hence, we abstain from providing a formal proof here). Therefore, zero contributions, and thus, no difference in final payoffs should emerge in both treatments assuming only selfish players.

However, in the presence of a substantial proportion of subjects whose patterns of behavior can be described as reciprocal types that exhibit conditional cooperation (Keser and Van Winden 2000; Fischbacher, Gächter, and Fehr 2001), this does not necessarily hold anymore. Ambrus and Pathak (2011) set up such a model and adopt it to a static public goods game. Their main idea is that in an environment where both selfish and reciprocal types exist, the

---

[74] In part I of the experiment, payoffs were given in EUR. For part II, we use Taler as experimental currency unit (ECU) with an exchange rate of 1 Euro = 10 Taler.

selfish types can induce reciprocal types to choose non-zero contributions. As conditional cooperators are backward-looking in determining their contributions, selfish players can influence future contributions of reciprocal players positively by contributing a large amount. The more rounds that are left, the higher the influence of these contributions. It is therefore in the interest of selfish players to contribute, especially in early rounds of a period, as this causes a positive reaction of the reciprocal players affecting the remaining rounds. In the course of a period, this incentive for selfish players diminishes, which leads to a decreasing pattern of their contributions. The intuition behind this mechanism is the assumption that selfish players maximize their material payoffs and that reciprocal players' payoffs additionally depend on a concave reciprocity function. The function itself is non-decreasing in other players' contributions and is embedded in the payoff function of a reciprocal player. This payoff function is maximal when a specific target contribution is reached - which depends on the other players' contributions and the reciprocity function. Additionally, there is the assumption of no overreciprocation, which means that one unit of contribution by any player does increase the value of the reciprocity function by not more than 1. This in turn, leads to a decreasing marginal impact of contributions over the course of the game.[75] This driving force in the model of Ambrus and Pathak (2011) is also reasonable in our dynamic setting with endowment carryover. In addition, higher contributions by selfish players have a positive impact on contribution capabilities of the reciprocal types, thus, constituting a second incentive for them to contribute in early rounds.

The sources of a possible positive impact of leadership are twofold. *First*, due to their exposition, the initial contribution of a leader offers a chance for amelioration: it gives clues for everyone else about the distribution of types and the degree of optimism the leader has over the occurrence of cooperation. Reciprocal types are no longer solely dependent on their expectations about the contributions of others, instead the leader's first contribution is setting a salient example. The leader acts as a "belief manager" (Gächter and Renner 2018). As early contributions determine later contribution capabilities, the (positive) sign that the leader can give here might have a big impact. *Second* and likewise, the leader can give a positive signal inducing conditional cooperators to reciprocate in other periods by his particular visibility. Consequently, even a selfish type has a larger incentive to contribute when selected to be the leader. This is also true for the very last round of a given period: a selfish leader has incentives to make a positive contribution in the last period, since reciprocal types may respond to his contribution. In the simultaneous game this is not the case. Selfish types should choose a contribution of zero in the last round. Taken together, this gives rise to our first hypothesis:

Hypothesis 1. *Assuming a substantial fraction of conditional cooperators, we expect non-negative contributions in both treatments. In addition, we expect that contributions in LEAD are larger than in NOLEAD, resulting in higher final earnings.*

---

[75] Consider the appendix of Ambrus and Pathak (2011) for a formal proof.

8.4.2 *Inequality*

As described in Section 8.2, followers typically contribute less than leaders. Followers adopt an imperfect matching strategy and donate systematically less compared to the leaders, displaying signs of imperfect or selfish-biased conditional cooperation. In our dynamic setting, this effect would intensify round by round, so that the leader would be impoverished relative to the followers. Compared to *NOLEAD*, larger inequality would be the result. This leads to the following hypothesis:

Hypothesis 2a. *LEAD leads to* ***higher*** *average within group inequality compared to NOLEAD.*

An alternative view would insist that due to the leader's influence (Gächter and Renner 2018), the followers may have a more homogeneous contribution pattern than subjects in *NOLEAD*. Despite the discrepancy between a leader's and his followers' contributions, this would give rise to reduced inequality compared to *NOLEAD* which consequently yields the following alternative hypothesis:

Hypothesis 2b. *LEAD leads to* ***lower*** *average within group inequality compared to NOLEAD.*

So in summary, we have two competing hypotheses. Accordingly, it is undecided to us a priori whether leadership (*LEAD*) leads to an increase or decrease in inequality within a group compared to *NOLEAD*.

8.4.3 *Leader Types*

Similar to the one-shot-game scenario of Gächter et al. (2012), we also expect cooperative types to be the better leaders with respect to average final earnings of a group. Due to a kind of "false consensus effect" and their social preferences, we expect them to make higher initial contributions. In addition, we especially expect conditional cooperators to promote cooperation by giving the group the right signals for cooperation. In the spirit of the model of Ambrus and Pathak (2011), we expect strategic leadership of selfish types with a declining pattern of their contributions.

Hypothesis 3. *Within LEAD we expect that groups work best when led by cooperatively inclined individuals.*

8.5 RESULTS

In this section we present the results of our experiment. First, we focus on the effect of leadership by comparing both treatments. This mainly involves answering the question of whether leadership has an impact on the wealth of group members and inequality within groups. For each of the two questions, we also consider the influence of the behavioral type of the leader. Furthermore, we want to know whether leadership reduces the number of individuals that are likely to find themselves in a sucker position, not benefiting from any cooperation gains. We define a criterion which we call *mutual benefit* from cooperation. We have *mutual benefit* from cooperation within a group and round as long as *all* group members *strictly* improve their earnings at the end of a round compared to the previous round, in absolute terms.[76]

In the last part of the analysis, we focus on treatment *LEAD* only, to get a deeper insight about the underlying mechanisms of successful leadership. We try to find out whether the followers' behavior is also dependent on their behavioral types, with regard to their reaction on a leader's contribution. Furthermore, it is our goal to reveal what makes leaders successful. In particular, we investigate whether we can observe the predicted pattern of decreasing relative contributions of selfish leaders, and thus strategic leadership behavior. We conclude with illustrative examples of successful and less successful leadership.

Overall, our results suggest that leadership is an important driver for the success of a group with respect to higher wealth, less inequality and more inclusive growth (mutual benefit). Especially the behavior of the leader in the first round(s) is crucial for the further course of the group. Moreover, we find that the cooperation type of the leader matters a lot: groups led by cooperatively inclined types have, on average, a significantly larger final endowment. The leader himself, however, is, on average, not better off than the participants in the simultaneous treatment *NOLEAD*. So it is mainly the followers who profit from leadership.

8.5.1 *Wealth*

Regarding the question of whether group members are better off in the end, when they are in a group with a leader, Figure 8.2 (*left*) depicts average endowments at the end of each round by treatment.

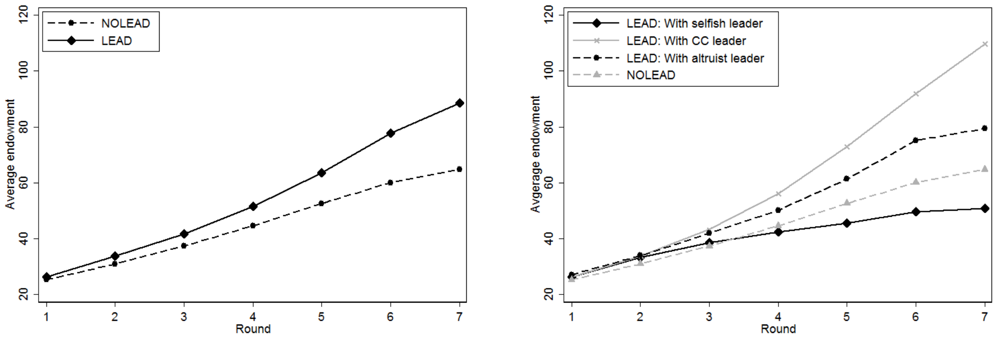


Figure 8.2: Average endowment at the end of each round

---

[76] More formally: there is *mutual benefit* at the end of round $t-1$, as long as $E_i^t > E_i^{t-1}$ holds for all $i \in \{1,2,3,4\}$. In this sense *mutual benefit* can also be seen as a stricter version of the Pareto criteria.

We find a significant treatment effect when we compare final earnings of participants at the end of round 7 (p=0.025, clustered two-sided two-sample t-test). Participants in the sequential treatment *LEAD* earn, on average, about 89 Taler compared to 65 Taler average earnings in *NOLEAD* at the end of round 7 - which is an increase of around 37%. In addition, Table 8.4 reports random-effects models, in which we estimated the treatment effect of *LEAD* on final earnings in different specifications (period controls are always included). In this regression table, we use the information from part I of the experiment, regarding the cooperation type of the leader, and we also investigated the effect of a violation of the *mutual benefit* criterion already after round 1.

	Endowment (end of round 7)		
	(1)	(2)	(3)
LEAD	23.847^{**}	-10.780	-33.224^{***}
	(10.511)	(8.342)	(6.712)
LEAD X CC leader		54.339^{***}	57.315^{***}
		(13.505)	(12.562)
LEAD X AL leader		24.365^{**}	23.365^{*}
		(11.929)	(13.159)
No mutual benefits after R1			-65.028^{***}
			(6.485)
Constant	60.439^{***}	58.545^{***}	103.191^{***}
	(8.297)	(8.406)	(8.063)
Period controls	YES	YES	YES
Observations	368	368	368
Subjects	92	92	92
R^2 overall	0.024	0.075	0.217

Note: Random effects regression with period controls. Cluster-robust standard errors (on the subject-level) are in parentheses. In columns (2) the and (3) the variable "*LEAD*" can be interpreted as *LEAD* treatment times a *selfish leader*.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8.4: Regression Table - Final endowment

It becomes apparent that the leader's cooperation type is essential (see also Figure 8.2 (*right*)). Leadership with a conditional cooperator as first-mover improves earnings a lot (more than an altruist) while a selfish leader worsens the outcome (although not significantly).[77] We will discuss this in more detail in Section 8.5.4.2. If there are no mutual benefits of cooperation in round 1, this has persistent effects on final outcomes (see column (3) of Table 8.4). The

---

[77] We used a Wald test for comparing the coefficients.

coordinating role of leadership is also reflected in the fact that the presence of a leader delays the first violation of the *mutual benefit* condition, as we will show in the further part of the analysis (see Section 8.5.3). Our results can be summarized as follows:

Observation 1. *Our findings suggest that leadership has a positive impact on final wealth. In addition, the behavioral type of the leader has a major impact. The members of groups led by a conditional cooperator are best off, on average. Furthermore, if there are no mutual benefits of cooperation in round 1, this has persistent negative effects on final outcomes.*

8.5.2 *Inequality*

A natural question in connection with a dynamic public goods game with endowment carryover is that of inequality. In our setting, inequality can endogenously arise through different contributions of the group members to the public good. According to Hypothesis 2a, leaders suffer some kind of curse. They are, so to speak, exploited by the followers. This pattern should lead to rising inequality. However, as reflected in Hypothesis 2b, previous research also states that leaders have a great influence on the followers' expectations and contributions (see, for example, Gächter and Renner 2018). Thus, if a leader has a huge impact on the followers, it can be expected that the contributions to the public good will become more even which would result in less within-group inequality. A common measurement for inequality is the Gini index that we compute for every group and round (a value of 0 refers to complete *equality*, whereas a value of 1 refers to complete *inequality*).

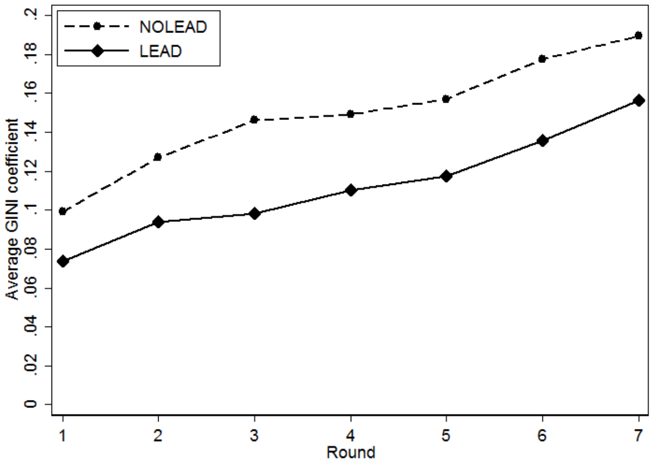


Figure 8.3: Average Gini coefficient at the end of each round by treatment

Figure 8.3 depicts the Gini index for both treatments. In addition, we use a random-effects regression where the Gini coefficient of a group is the panel variable and the rounds are the time variable (see Table 8.5).

	GINI coefficient		
	(1)	(2)	(3)
LEAD	-0.037***	0.003	0.011
	(0.013)	(0.018)	(0.018)
LEAD X CC leader		-0.058***	-0.058***
		(0.020)	(0.019)
LEAD X AL leader		-0.041	-0.040
		(0.026)	(0.026)
No mutual benefits after R1			0.028**
			(0.013)
Constant	0.099***	0.100***	0.081***
	(0.013)	(0.013)	(0.016)
Period controls	YES	YES	YES
Round controls	YES	YES	YES
Observations	644	644	644
Groups	92	92	92
R^2 overall	0.193	0.246	0.277

Note: Random effects regression with period and round controls. Cluster-robust standard errors (on the subject-level) are in parentheses. In columns (2) and (3) the variable "*LEAD*" can be interpreted as *LEAD* treatment times a *selfish leader*.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8.5: Regression Table - GINI coefficient

With respect to within group equality, we can report a significant positive treatment effect. Within group inequality is lower in *LEAD* and this effect is significant (see column (1) in Table 8.5). Again the leader's type does matter a lot. A conditional cooperator as a leader has a significant effect in reducing inequality as measured by the Gini index, while the effect for other leader types is insignificant (see column (2) in Table 8.5). We also see that groups that achieve no mutual benefit in round 1, have a significantly higher inequality. In general, we observe that inequality rises with each round in both treatments of the dynamic public goods game. We can summarize our results as follows:

Observation 2. *Leadership has a positive impact on reducing inequality within groups as measured by the Gini index. This effect is mainly driven by the conditional cooperators. If there are no mutual benefits of cooperation in round 1, this increases inequality significantly.*

8.5.3 *Mutual Benefit across Rounds*

As we have seen in the previous parts, having at least one group member that does not strictly improve his or her endowment already in round 1 has a persistent effect, resulting in lower final earnings for *all* group members.

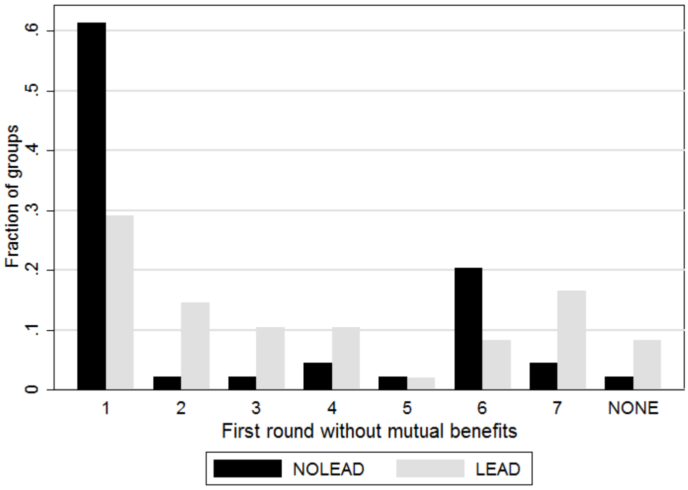


Figure 8.4: First emergence of no mutual benefit

Figure 8.4 depicts the first violation of the mutual benefit criterion by treatments. On average, at least one subject within a group does not strictly improve for the first time after 2.75 rounds in *NOLEAD*, compared to 3.75 rounds in *LEAD* (p=0.0289, two-sided two-sample t-test).

	Round of first violation of MB	
	(1)	(2)
LEAD	1.000***	0.186
	(0.351)	(0.384)
LEAD X CC leader		1.243***
		(0.388)
LEAD X AL leader		0.689*
		(0.405)
Constant	2.609***	2.571***
	(0.361)	(0.360)
Period controls	YES	YES
Observations	368	368
Subjects	92	92
R^2 overall	0.055	0.088

Note: Random effects regression with period and round controls. Cluster-robust standard errors (on the group-level) are in parentheses. In column (2) the variable "*LEAD*" can be interpreted as *LEAD* treatment times a *selfish leader*. MB is an abbreviation for mutual benefits.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8.6: Regression Table - Violation of mutual benefit

The sequential treatment delays the first violation of the mutual benefit criterion, on average, by one round. As Figure 8.4 indicates, at least one individual does not strictly improve in *NOLEAD* after the first round in more than 60% of the cases. By contrast, in *LEAD* only in about 30% of the cases the criterion for no mutual benefit is met after the first round. Moreover, in *NOLEAD*, there is a second peak in round 6, whereas in *LEAD* this second peak occurs only in round 7. This indicates that typical last round effects, driven by free-rider behavior, occur earlier in *NOLEAD* compared to *LEAD*. In Table 8.6 we can see that the sequential treatment *LEAD* has a significant effect on deferring the first appearance of a situation where at least one subject of the group has no benefits from cooperation (the dependent variable is the round in which at least one group member does not strictly improve for the first time). Controlling for the type of the leader (column (2) of Table 8.6), we find that it is the conditional cooperators that have a positive impact when selected to be leaders. Thus, we can summarize our findings as follows:

Observation 3. *Leadership can be a useful tool in preventing an early violation of the mutual benefit condition, highlighting the leader's role in coordinating others' contributions. The sequential treatment LEAD delays the first occurrence of the event, that at least one individual does not strictly improve, on average, by one round. The behavioral type of the leader is again crucial in this context.*

8.5.4 *Further Analysis of the LEAD Treatment*

In this section we want to take a closer look behind the mechanisms of effective leadership and investigate why some groups in *LEAD* are more successful than others. We begin by analyzing the followers' reactions and then proceed by looking at the leaders' behavior.

8.5.4.1 *Follower behavior*

The followers' reaction is decisive for successful leading-by-example. Only if they respond adequately, it will be ensured that leadership (i) is successful in terms of the final endowments for the group members, and additionally, (ii) that the leader does not fare worse either.

We consider the reactions to a leader's contribution both relative to a subject's own endowment and in absolute terms. Focusing on absolute contributions first, Table 8.7 (*left*) indicates that for every Taler a leader gives in a round, followers give on average 0.822 Taler to the public good. Additionally, follower type heterogeneity leads to different reactions. Although all types react positively to higher contributions of the leader, this reaction is particularly pronounced for followers that were classified as conditional cooperators and altruists, as the coefficients in Table 8.7 reveal. Selfish follower types match a Taler given by the leader by only 0.56 Taler, which is much less compared to the amount given by conditional cooperators and altruists. A similar pattern emerges for relative contributions (see Table 8.7 (*right*)).

	Contribution	
	(1)	(2)
Leader contribution (LC)	0.822***	
	(0.056)	
LC X SF type		0.560***
		(0.095)
LC X CC type		0.837***
		(0.056)
LC X AL type		0.909***
		(0.085)
Constant	1.526	1.830*
	(1.235)	(1.087)
Period controls	YES	YES
Round controls	YES	YES
Observations	1008	1008
Subjects	47	47
R^2	0.781	0.791

Note: OLS regression with period controls. Cluster-robust standard errors (on the subject-level) are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

	Relative Contribution	
	(1)	(2)
Rel. leader contribution (RLC)	0.835***	
	(0.027)	
RLC X SF type		0.639***
		(0.101)
RLC X CC type		0.853***
		(0.024)
RLC X AL type		0.869***
		(0.080)
Constant	0.021	0.033
	(0.037)	(0.036)
Period controls	YES	YES
Round controls	YES	YES
Observations	1008	1008
Subjects	47	47
R^2	0.701	0.711

Note: OLS regression with period controls. Cluster-robust standard errors (on the subject-level) are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8.7: Regression Table - Matching of leader contribution (absolute and relative)

This high rate of matching a leader's contribution further illustrates why the behavior of the leader matters a lot, since even selfish types react positively on the amount spent by the leader. Our result is summarized in Observation 4:

Observation 4. *In general, followers react positively to a leader's contribution, matching it to a large degree, both in absolute and in relative terms. The type of the follower plays a major role as selfish followers exhibit a much smaller reaction.*

8.5.4.2 *Leader behavior*

We have already pointed out that leadership is beneficial. In the next step we will go more into detail to explain the mechanisms behind successful leadership. Overall, a high early contribution by the leader in round 1 of a period has a large impact on final earnings in round 7 of the respective period.

Figure 8.5 depicts the relationship between a leader's first contributions and final wealth. We see a pattern of increasing final wealth of a group when the leader contributes much in the beginning. However, we can observe that there is a large heterogeneity between leader types for the 20 Taler bracket. There are many selfish leaders that contribute their entire endowment in the beginning. But they are less successful than conditional cooperator leaders who do the same.

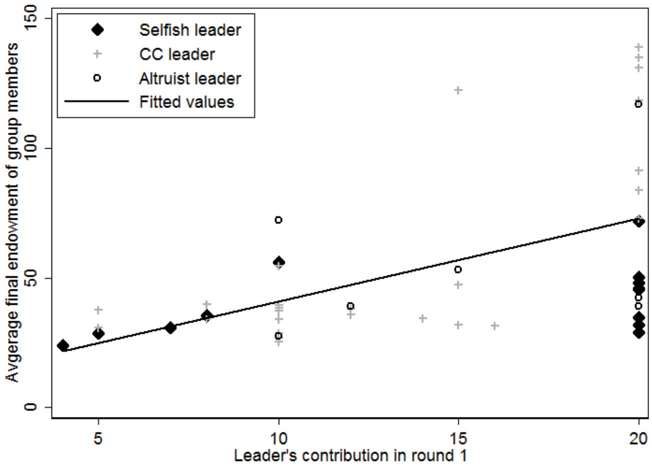


Figure 8.5: Leader's first contribution and final group earnings

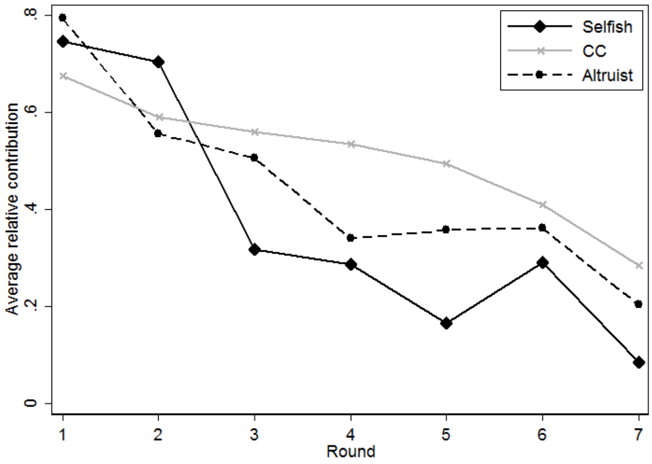


Figure 8.6: Leader's contribution pattern over rounds by type

Figure 8.6 indicates why this is the case. We see that while conditional cooperators have the lowest average initial leader contribution of all types, they are persistent in contributing. That makes CC types successful. By contrast, we discover signs of strategic leadership by selfish types. They start with relatively high contributions in the first two rounds, revising them sharply afterwards. What came to our mind was a strategy that the New York Times (Gleick 1986) described as a "tranquilizer strategy" for the repeated prisoner's dilemma: to lull the opponent for a few moves and then try to exploit him. We find evidence for this claim in our data as selfish types contribute more in the beginning when they are leaders. In round 1 of *LEAD*, 61.54% of the leaders, which we classified as "selfish", contributed their whole endowment of 20 Taler. However, only 21.74% of the selfish followers also contributed this amount. In treatment *NOLEAD* by comparison, 25.00% of the selfish types contributed 20 Taler in round 1. A behavior that can probably be explained by a false consensus effect, is the one shown by those subjects classified as altruists. When they are leaders, they start with very high relative contributions in the beginning, but display a faster decline than the CC types afterwards.

	Endowment (end of round 7)		
	(1)	(2)	(3)
Is leader	-26.540**	-25.703**	24.404
	(12.829)	(12.884)	(27.012)
Leader first contr.		7.566***	8.351***
(Leader1st)		(1.332)	(1.433)
Leader1st X Is Leader			-3.567
			(2.539)
Constant	80.073***	-15.345	-26.520*
	(11.066)	(13.489)	(15.160)
Period controls	YES	YES	YES
Observations	192	192	192
Subjects	48	48	48
R^2 overall	0.029	0.194	0.196

Note: Random effects regression with period controls. Cluster-robust standard errors (on the subject-level) are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8.8: Regression Table - Final endowment (only *LEAD*)

In columns (2) to (3) of Table 8.8 we can see that a leader's first contribution has a large effect on final wealth. Column (2) indicates that for each Taler the leader gives in round 1, the final endowment of every group member (including the leader) increases by around 7.6 Taler, on average.

In general, being the leader is not necessarily good for the own payoffs as column (1) of Table 8.8 reveals. Leaders face some kind of curse as their earnings are lower than those of other group members.

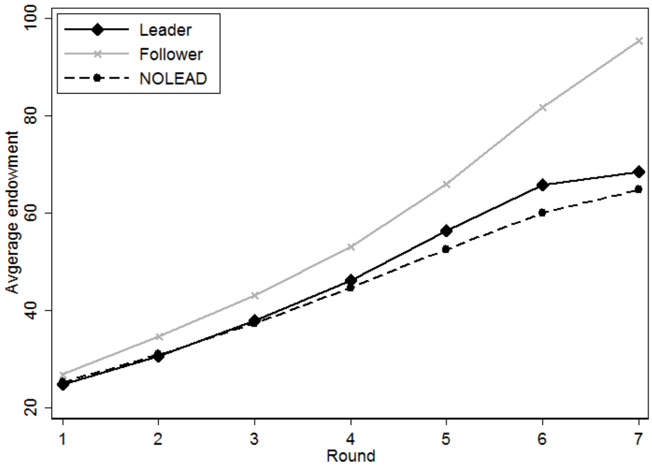


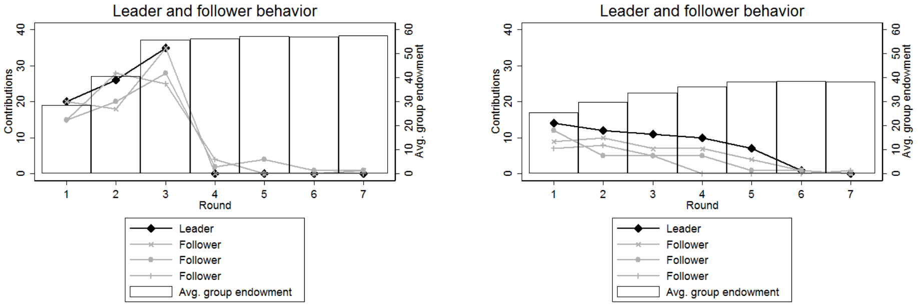
Figure 8.7: Average endowment by treatment + leader/no-leader

Figure 8.7 illustrates this circumstance graphically. However, leaders do not fare worse than average participants in *NOLEAD* in the end. This, too, is depicted in Figure 8.7. The leader himself in turn, does not lose money by contributing more in round 1, but he profits less from each Taler compared to the other group members as it can be seen by the interaction effect in column (3) of 8.8. We can thus summarize our last finding as follows:

Observation 5. *The leader type has a significant effect on final earnings of the group members. The results suggest that leaders classified as conditional cooperators are successful because they give persistently a larger fraction of their endowment over the course of a period. In addition, the first contribution of the leader yields a high return concerning final earnings. The leader is slightly better off than an average subject in NOLEAD, but not significantly.*

8.5.4.3 *Examples of good and bad leadership*

To illustrate the effect of good and bad leadership, we present some exemplary groups in this section. The black line in the graphs represents the leader contributions, while the grey lines represents the follower contributions. Figure 8.8 depicts two examples of bad leadership. In the left part we see that the leader stops contributing after three rounds, although the followers matched him before (at least partly). This results in a breakdown of cooperation and almost no further growth after round 3. In the right part we can observe a leader who started with a medium contribution in the first round. After this, the leader decreases his contribution in every subsequent round and the followers mimic this behavior, resulting in a low final average endowment.


Leader and follower behavior

Leader and follower behavior

Figure 8.8: Bad leadership

Figure 8.9 shows two examples of good leadership. In both cases the leader starts with a full contribution of 20 Taler in the beginning. In the left part we can see that the leader only deviates in the last round from full contribution. The same is true in the graph on the right part, where the leader sticks to his plan of full contribution until round 6, although one group member is a free-rider who only matches the leader partly.

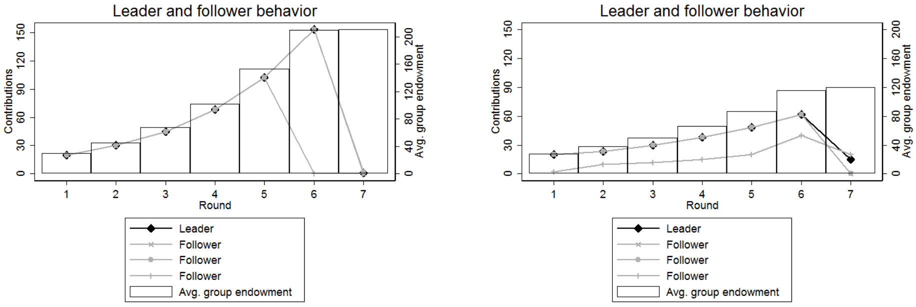


Figure 8.9: Good leadership

8.6 CONCLUSION

Is leading-by-example a suitable tool in improving cooperation in dynamic environments like research and development partnerships? In this chapter, we provided an experiment investigating the effect of leadership in a dynamic public goods game with endowment carryover and, hence, endogenous growth and inequality. The analysis of our experiment shows that leadership indeed yields an improvement: We see larger contributions and consequently higher earnings if groups have a leader. The leaders, however, benefit less. They contribute more to the group pot than the followers, but receive lower payouts. However, the average leader in *LEAD* is not worse off than an average player in *NOLEAD*. From a welfare perspective, it can thus be argued that *leading-by-example* leads to a Pareto improvement. In addition, we observe a significantly lower inequality in groups with a leader compared to *NOLEAD*. As a measurement for inequality we use the Gini Index which also refers to a utilitarian social welfare function that integrates individual inequity aversion (Schmidt and Wichardt 2018). Assuming inequity averse agents, we can thus report a further welfare improvement through leadership.

We also find that the leader's contribution in the first round has a large impact on the final results across all groups. For the groups, it pays off if the leader prefaces by setting a good example in the form of a large initial contribution. Based on a sequential prisoner's dilemma, we elicited types for conditional cooperation in part I of the experiment. Our results indicate that groups work best when led by conditional cooperators. The mechanism is quite interesting: it is apparently their perseverance in setting a good example (contributing a high proportion of their income for a long time) that makes conditional cooperator types successful. By contrast, we discover signs of strategic leadership in the selfish types, with very high contributions in the first two rounds followed by a sharp crash. In a similar vein, we see that followers that are classified as conditional cooperators match a leader's contribution to a higher degree than selfish types.

RÉSUMÉ

This thesis has set out to further explore the role of pioneers in social dilemma situations both theoretically and empirically. High expectations have been placed on leadership, in particular when dealing with global problems such as the provision of global public goods. The question is: Does leadership meet these expectations?

The theoretical Part I that sticks to the standard assumption of narrow payoff-maximizing agents has shown that it depends on the kind of leadership considered whether an amelioration of a social dilemma situation is possible. Regarding pioneering behavior in coalition building, Chapter 1 has poured some cold water on optimistic expectations. We have seen that partial cooperation of one group reduces the likelihood that others are willing to form a coalition, in particular if it is a large coalition that cooperates. Moreover, coalition building of a small group may even reduce the level of public good supply.

Another kind of pioneering behavior discussed in Chapter 2 seems more promising: the approach of technological innovation of a coalition and subsequent free transfer of the technology to other countries. While the countries within the coalition cooperate at the innovation stage, they act non-cooperatively when choosing their public good contribution (which is in contrast to Chapter 1). The prospects of such leadership are quite good: a costly innovation of the coalition may increase both the level of public good supply and the utilities of all countries involved given a sufficient scope of technological diffusion and automatic spillovers, e.g. through international trade. But there remains an incentive problem to adopt the innovation on behalf of the recipients if technological diffusion is endogenous.

In a similar vein, Chapter 3 has focused on technological innovation. In this chapter, an interesting effect materializes. Leadership expressed through the move structure, i.e. a leader-follower (Stackelberg) game instead of a simultaneous (Nash) game is usually unfavorable for the level of public good provided (Varian 1994). Chapter 3, however, has shown that this needs no longer be true when the leading country has the option to adopt a better technology. In this case, advantageous leadership is feasible where public good supply and utilities of both countries increase compared to simultaneous play.

Technology thus appears to be an interesting sphere for leadership. To get an impression how such technological leadership and technology diffusion may look like, Part II has studied the example of Germany's feed-in tariff for photovoltaic. It illustrates the magnitude of such pioneering efforts and outlines the technological progress through learning-by-doing.

Moving away from narrow payoff-maximizing agents, Part III and Part IV have pursued the questions of the existence and possible implications of reciprocity in a leader-follower relation. Both in the public discussion and theoretical literature reciprocity is regarded as a key to successful cooperation. Given that followers have reciprocal preferences (i.e. react to an increase in the leader's contribution by increasing own contributions), the argument of crowding-out looses its importance. In a leader-follower (Stackelberg) game an increase in public good supply thus seems feasible compared to the benchmark of simultaneous play (Nash-Game) given sufficiently reciprocal preferences of the followers – even in the absence of reciprocal preferences of the leader (see Buchholz and Sandler 2017).

Does that mean that reciprocity is the secret of successful leadership? This thesis provided some evidence for this assertion. As a first step, Part III pursued the question whether it seems reasonable to assume reciprocal behavior. In this regard, Chapter 5 has shown that there is indeed empirical evidence for reciprocity in the field of experimental economics as well as international relations. Moreover, reciprocal preferences are quite stable across social dilemma games as the experimental investigation in Chapter 6 has pointed out. Consequently, a basic prerequisite for successful leadership is given. Does this materialize in an amelioration in public goods supply in experimental public goods games? The answer is yes for most of the experiments portrayed in the systematic literature review in Chapter 7 but also for the dynamic public goods game in Chapter 8 of Part IV.

However, there remains an interesting aspect of leadership - the question of "Why lead?". In the classical world of narrow payoff-maximizing agents, this question is obvious: the first mover attains a first-mover advantage. In this world, the leader can commit himself to a low public good contribution while the followers will have to give more in equilibrium. This is, however, in contrast to the results in Chapter 7 and Chapter 8. What we can observe here is that a first-mover advantage is either only present in a reduced form or in many cases does not exist at all. On the contrary, in the voluntary contribution mechanism (VCM) which has a zero contribution prediction for narrow payoff maximizing agents, leaders contribute distinctly more than followers. Quite similarly, in a game with predicted interior equilibria and first-mover advantage given agents without reciprocal preferences, this first-mover advantage does not materialize. Why is this the case? This seems to be the flipside of reciprocal preferences.

Reciprocity apparently alters the balance of power in the leader-follower game. Without reciprocity, the leader is in a fortunate position and consequently contributes less than the follower(s). In anticipation of a reciprocal response of the follower(s) this game now turns. The first-mover position of the leader becomes unfavorable – some even speak of a "leader curse". The leaders contribute more than the followers, the profits from cooperation are unevenly divided among leaders and followers. It is the followers that benefit most from sequential play. Followers' reciprocity thus not only is a reliable remedy to stand one's ground in a strategically unfavorable position but it also allows to exploit the leader to a certain extent.

This impression gained from the empirical Part IV can also be illustrated by a short theoretical example in Appendix E. In this example, the leader would not contribute at all in the Stackelberg equilibrium if neither of the two players had reciprocal preferences and public good supply in consequence would be the standalone allocation of the follower. Given a sufficiently reciprocal follower in this example, however, the leader contributes more than the follower - even if he holds reciprocal preferences himself.

So, why lead? Why should one choose to be the leader? A first answer might be that the leader does not fare worse compared to simultaneous play, he only improves less. Consequently, it is better to swallow the bitter pill if no one else did. Still, the question is who should do it. Maybe, it takes some idealism to adopt this pioneering position, a sort of idealism that makes the cake bigger even though the own piece of cake may be smaller than that of the rest. The problem of leadership is ultimately not only a problem of finding reciprocal followers, it is also a problem of finding idealistic leaders willing to sacrifice relative gains for the common good.

Part V

APPENDIX

A

APPENDIX CHAPTER 1: DERIVATION OF THE THRESHOLD LEVEL IN PROPOSITION 13

Proof. It directly follows from eq. (18) in Chapter 1 that

$$\frac{\partial G_I^B}{\partial \xi} = \frac{w - e_K - \xi e_2^K}{1 + \xi e_1^K + m e_1^M} \tag{1}$$

which is positive since $e_1^K > 0$, $e_1^M > 0$, $e_2^K < 0$ and $1 - e^K$ is a member of K's private consumption which is positive in the equilibrium $E_I^B(k, m)$ by definition. Inserting (21) into

$$\frac{\partial u_I^{BK}}{\partial \xi} = \frac{\partial u(e(G_I^B, \xi), G_I^B)}{\partial \xi} = u_2((\xi e_1^K + 1)\frac{\partial G_I^B}{\partial \xi} + \xi e_2^K) \tag{2}$$

gives

$$\frac{\partial u_I^{BK}}{\partial \xi} = \frac{u_2((\xi e_1^K + 1)(w - e_K) + \xi m e_2^K e_1^M)}{1 + \xi e_1^K + m e_1^M}. \tag{3}$$

Then an upper bound $\underline{\chi} > \underline{\xi}_B(m)$ which has the properties required by Proposition 11 exist since at $\xi = \underline{\xi}_B(m)$ we have $w - e^K = 0$. Hence, because of $e_1^M > 0$ and $e_2^K < 0$, the numerator is of (30) is negative there so that continuity implies that u_I^{BK} must also be falling for all ξ close to $\underline{k}_B(m)$. □

B

APPENDIX CHAPTER 6: INSTRUCTIONS FOR THE EXPERIMENT

Basics
This online experiment will consist of **two parts**.
First, part 1 will be explained. After part 1 ends, you will receive instructions for part 2. Your decisions in part 1 do not influence your payoff in part 2 and vice versa.

In this study you will earn POINTS. **Each POINT is worth 0.05 Dollar (20 POINTS = 1 DOLLAR)**. At the end of the study you receive your amount of POINTS cashed out in Dollar.

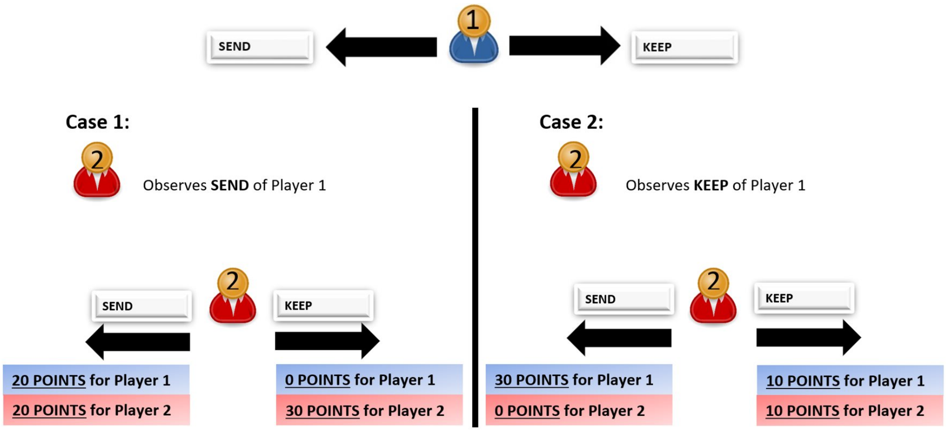
In this study, you must answer control questions to ensure that you have understood the task correctly (there are five control questions in total). Only if you answer them correctly you can complete this survey. **The control questions require some small calculations**. If you give a wrong answer to a control question, you can try **multiple times** until you find the correct solution.

Sequential Prisoner's Dilemma (SPD)
You will be matched with one other random MTurker who also participates in this study. One of you has the role of "Player 1" and the other one has the role of "Player 2". Each of you is endowed with **10 POINTS**. You have to decide whether you want to **KEEP** your 10 POINTS or whether you want to **SEND** your 10 POINTS. If the POINTS are sent, they double for the other player. The other MTurker has to make the same decision.

This game is played sequentially – i.e., the players make their decisions subsequently (this is illustrated by the graph below).

First Player 1 (BLUE) makes a decision. Player 2 (RED) observes this decision and makes a decision as well. In this study, you make a decision for both roles, Player 1 and Player 2 (follow for this purpose simply the instructions on the screens). At the end of the study, a random device determines the role of you and the other MTurker. There are two possibilities: you are Player 1 and the other MTurker is Player 2 or you are Player 2 and the other MTurker is Player 1. The combination of the decisions of you and the other MTurker determines your payoff in this game, as shown in the graph below.

Conversion rate: 20 POINTS = 1 DOLLAR.



Before starting with the actual decisions, you are asked to answer two short control questions to make sure that you have understood all rules of the game correctly.

Sequential Public Goods Game (FGF)

You will now be in a group of 4 MTurkers. Each MTurker must decide on the division of 20 POINTS. You can put these 20 POINTS in a **private account** or you can invest them fully or partially into a **project**. Any POINT that you do NOT invest into the **project**, will automatically be transferred to your **private account**.

Your income from the private account:

For each POINT you put in your private account you will earn exactly one POINT. Nobody except you earns something from your private account.

Your income from the project:

The amount of POINTS contributed to the project by ALL group members, will be increased by 60% and then equally split among all group members. This means, each group member will receive the same income from the project. Consequently, for each POINT invested in the project each group member (including yourself) receives 1.6/4 = 0.4 POINTS.

Hence, for each group member the income from the project will be determined as follows:

Income from the project = sum of contributions to the project x 0.4.

For example, if the sum of all contributions to the project is 70 POINTS, then you and all group members will get a payoff of 70 x 0.4 = 28 POINTS each from the project. If the sum of contributions is 15 POINTS, then you and all group members will get a payoff of 15 x 0.4 = 6 POINTS each from the project.

Your total income:
Your total income is the sum of your income from the **private account** and the **project**:

Income from the private account (= **20** - contribution to the project)
+
Income from the project (= 0.4 x Sum of contributions of all four players to the project)
= **TOTAL INCOME**.

Conversion rate: 20 POINTS = 1 DOLLAR.

Your decisions:
In this part of the study, each participant has to make two types of decisions. In the following we call them "**unconditional contribution**" and "**conditional table**":

With the "**unconditional contribution**" to the project you have to decide how many of your 20 POINTS you want to invest into the project. You do not know how much the other players will invest.

Your second task is to fill a "**contribution table**". For each possible average contribution of the other group members (rounded to the nearest integer), you must specify how many POINTS you want to contribute to the project. Thus, you can condition your contribution on the contribution of the other group members.

In each group a random mechanism will select **one group member**. For the randomly selected group member only the **contribution table** will be the payoff-relevant decision. For the other three group members only the **unconditional contribution** will be the payoff-relevant decision. When you make your **unconditional contribution** and when you fill out the **contribution table**, you do not know whether you will be selected by the random mechanism. Hence, you have to think carefully about both types of decisions because both can be relevant to you. The combination of the decisions of you and the other group members determines your payoff in this game.

C

APPENDIX CHAPTER 7: DIFFERENT SPECIFICATIONS FOR THE META-ANALYSIS

COMBINING GROUPS IN ORDER TO GET A SINGLE PAIRWISE COMPARISON

To combinine groups, the formulas from table 7.7a from Higgins and Green (2011) have been applied such that:

$$n_T = n_{t1} + n_{t2} \tag{1}$$

is the sample size for the collapsed comparison and $t1$ and $t2$ indicate the exogenous leadership treatments of Güth et al. (2007) and Rivas and Sutter (2011), respectively[78].

The mean of the combined group is given by:

$$\bar{x}_T = \frac{n_{t1}\bar{x}_{t1} + n_{t2}\bar{x}_{t2}}{n_{t1} + n_{t2}} \tag{2}$$

whereas we can write the collapsed standard deviation as:

$$\sigma_T = \sqrt{\frac{(n_{t1}-1)\sigma_{t1}^2 + (n_{t2}-1)\sigma_{t2}^2 + \frac{n_{t1}n_{t2}}{n_{t1}+n_{t2}}\left(\bar{x}_{t1}^2 + \bar{x}_{t2}^2 - 2\bar{x}_{t1}\bar{x}_{t2}\right)}{n_{t1}+n_{t2}-1}}. \tag{3}$$

The data for the common control treatment were adopted from Güth et al. (2007).

META-ANALYSIS USING THE COMBINING GROUPS APPROACH

If we compile the collected evidence in a common effects meta-analysis[79] (a forest plot is depicted in figure C.1), we see that the overall effect of exogenous leadership is positive with a standardized mean difference of 0.373. A test of the null hypothesis of no leadership effect ($D = 0$) can be rejected ($z = 2.58$, $p = 0.010$) thus indicating a significant treatment effect for exogenous leadership. A I^2 value of 0.0% indicates that heterogeneity between studies of exogenous leadership is very low. Both Egger's test and Begg's test are insignificant thus rendering no indications of a publication bias[80].

---

[78] The notation is otherwise similar to chapter seven.

[79] A common effects meta-analysis assumes a common effect based on studies that are quite homogeneous, i.e. identical in important characteristics. As a robustness check, also a random effect meta-analysis has been conducted using the combining groups approach. This yields no change in the overall effect size, I^2 measure or one of the test statistics reported. A forest plot for the random effects meta-analysis is depicted in figure C.2.

[80] As the sample size is small, we can, however, not conclude that there is no publication bias as the tests may be under-powered.

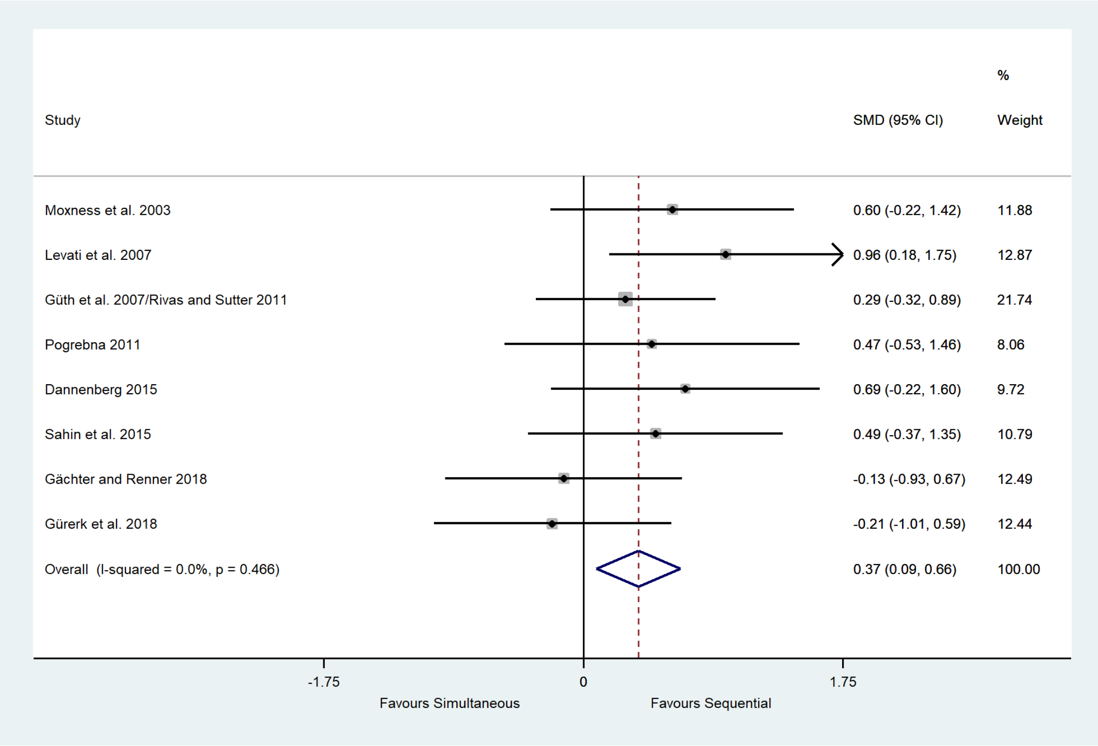


Figure C.1: Forest plot for exogenous leadership (common effects)

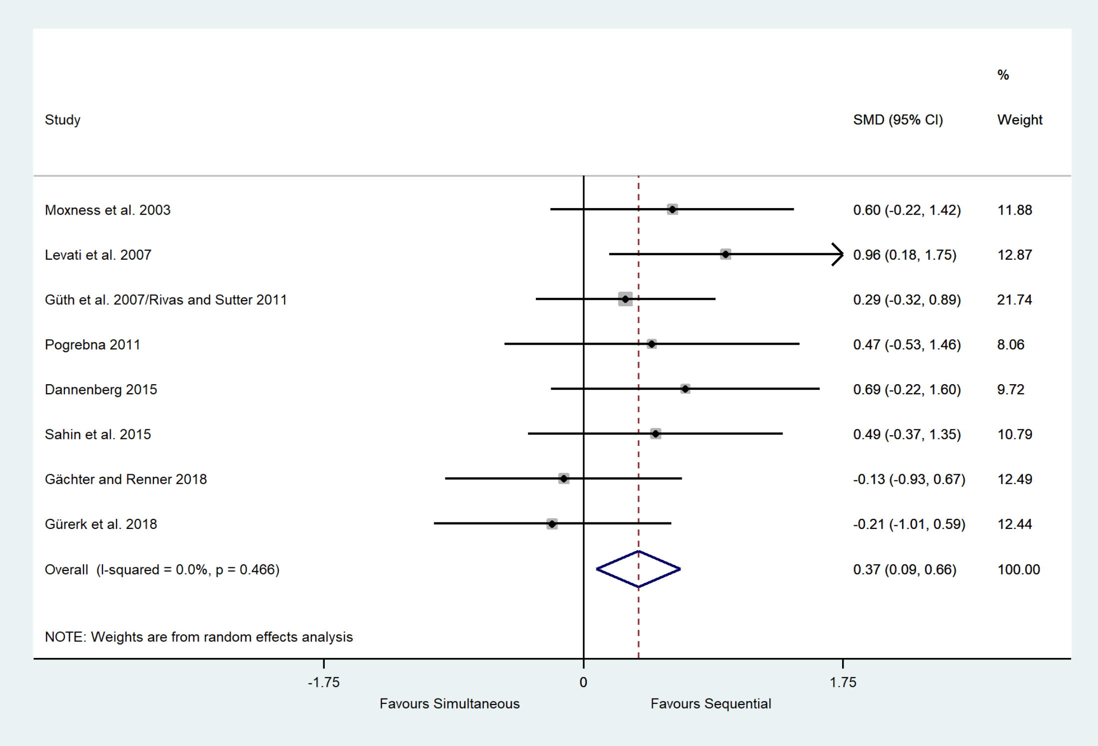


Figure C.2: Forest plot for exogenous leadership (random effects)

D

APPENDIX CHAPTER 8

D.1 BALANCING TABLE

Type	**Treatment**	
	NOLEAD	*LEAD*
Selfish	14	8
CC	26	31
Altruist	4	8
Mismatcher	0	1
Total	44	48
	Pearson $\chi^2(3) = 4.2424$; $p = 0.236$	

Table D.1: Number of different cooperation types across treatments

Instruktionen

Herzlich willkommen zu diesem wirtschaftswissenschaftlichen Experiment! Während des Experimentes haben Sie die Möglichkeit, eine Aufgabe auszuführen, welche in den nachfolgenden Instruktionen im Detail erklärt werden wird. Dabei können Sie einen nicht unerheblichen Geldbetrag gewinnen. Wie hoch Ihre Auszahlung letztendlich sein wird, hängt von Ihren Entscheidungen und den Entscheidungen der anderen Teilnehmer ab. Während des Experiments ist es Ihnen untersagt, mit den anderen Teilnehmern zu kommunizieren. Bitte lesen Sie die vorliegenden Instruktionen gründlich durch. Sollten Sie vorab oder während des Experiments noch Fragen haben, heben Sie bitte Ihre Hand und ein Experimentator wird zu Ihrem Platz kommen.

Allgemeiner Aufbau

Das Experiment besteht aus einem **Teil 1** und einem **Teil 2**. Diese beiden Teile sind unabhängig voneinander – d.h. Ihre Entscheidungen in Teil 1 haben keinen Einfluss auf den Ausgang von Teil 2 und umgekehrt. Sie bekommen zunächst Instruktionen für Teil 1. Sobald dieser Teil abgeschlossen ist, bekommen Sie Instruktionen für Teil 2. Sowohl in Teil 1 als auch in Teil 2 können Sie Geld verdienen. Ihr endgültiger Verdienst besteht aus der Summe Ihrer Verdienste aus Teil 1 und Teil 2. Zusätzlich bekommen Sie am Ende des Experiments eine Teilnahmeprämie von **4 EUR** ausbezahlt. Diese bekommen Sie in jeden Fall, unabhängig von Ihren Entscheidungen im Experiment.

Ihre endgültige Auszahlung wird sich also folgendermaßen zusammensetzen:

Gesamtauszahlung = 4 EUR + Verdienst in Teil 1 + Verdienst in Teil 2

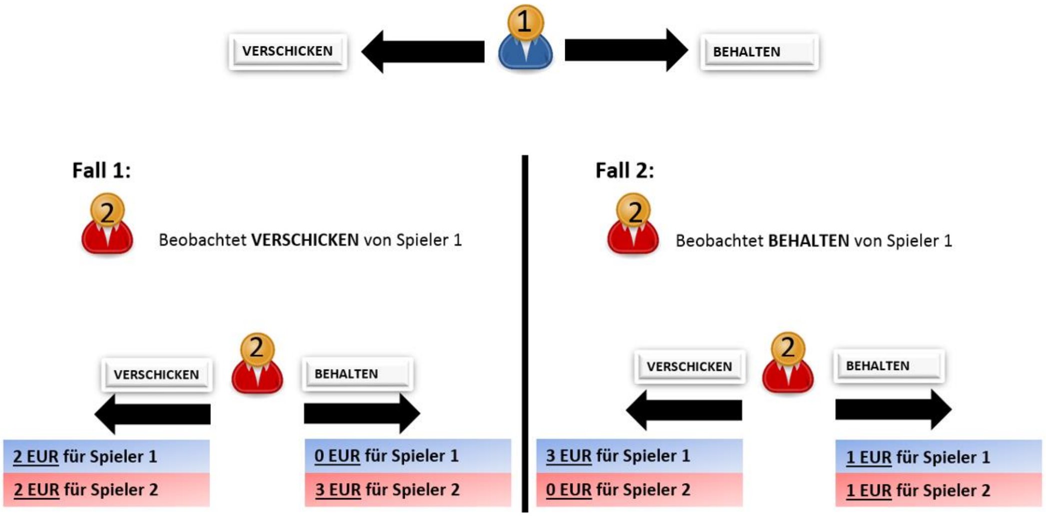
Ihre Gesamtauszahlung beträgt also in jedem Fall mindestens 4 EUR.

Teil 1

In Teil 1 werden Sie mit einem zufällig ausgewählten Experimental-Teilnehmer aus diesem Raum gruppiert, welcher Ihr Mitspieler für diesen Teil ist. Einer von Ihnen bekommt zufällig die Rolle als „Spieler 1" und der andere als „Spieler 2". Jeder von Ihnen erhält nun **1 EUR** vom Experimentator. Sie können sich nun überlegen, ob Sie diesen Euro BEHALTEN oder an Ihren Mitspieler VERSCHICKEN wollen. Wenn der Euro verschickt wird, verdoppelt er sich für Ihren Mitspieler. Ihr Mitspieler steht vor derselben Entscheidung wie Sie.

Diese Entscheidungssituation findet sequentiell statt – d.h. die Spieler treffen Ihre Entscheidungen nacheinander. Dies ist in der unten angehängten Grafik auch noch einmal dargestellt.

Zunächst trifft **Spieler 1** **(BLAU)** eine Entscheidung. **Spieler 2** **(ROT)** kann diese Entscheidung beobachten und trifft dann ebenfalls eine Entscheidung. Sie treffen im Experiment sowohl für die Rolle als Spieler 1 als auch für die Rolle als Spieler 2 eine Entscheidung. Bitte folgen Sie dazu einfach den Anweisungen auf dem Bildschirm. Am Ende des Experimentes wird ausgelost, ob Sie oder Ihr Mitspieler die Rolle des „Spieler 1“ bekommen. Der andere bekommt automatisch die Rolle des „Spieler 2“. Durch die Kombination Ihrer Entscheidungen wird dann schließlich Ihre Auszahlung gebildet, wie in der unten angehängten Grafik dargestellt. Die Auszahlung für Spieler 1 ist hier in BLAU dargestellt und die Auszahlung für Spieler 2 ist in ROT dargestellt.



Beispiel

Spieler 1 entscheidet sich für VERSCHICKEN.

Spieler 2 entscheidet sich für VERSCHICKEN wenn Spieler 1 VERSCHICKT und für BEHALTEN wenn Spieler 1 BEHÄLT.

In diesem Szenario erhalten also beide Spieler jeweils **2 EUR**.

Beispiel

Spieler 1 entscheidet sich für BEHALTEN.

Spieler 2 entscheidet sich für VERSCHICKEN wenn Spieler 1 VERSCHICKT und für VERSCHICKEN wenn Spieler 1 BEHÄLT.

In diesem Szenario erhält Spieler 1 **3 EUR** und Spieler 2 **0 EUR**.

Teil 2

Teil 2 besteht aus **4 Perioden** und jede Periode besteht ihrerseits aus **7 Runden**. Dies ist in der nachfolgenden Tabelle noch einmal verdeutlicht.

Perioden	1	2	3	4
Runden	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

In Teil 2 könne Sie Taler verdienen. Die Umrechnung beträgt dabei

10 Taler = 1 Euro

Am Ende des Experiments bekommen Sie die Ausstattung an Talern, die Sie besitzen, in EUR ausbezahlt. Für Ihre Auszahlung in Teil 2 wird eine **zufällige Periode ausgewählt**. Das heißt nur **eine der vier Perioden ist relevant für Ihre Auszahlung**. Sie wissen aber vorher nicht, welche dies ist, sondern erfahren dies erst am Ende des Experimentes.

Zu Beginn jeder Periode werden Gruppen aus jeweils **4 Teilnehmern** gebildet. Diese Gruppen sind fest für die komplette Periode – d.h. sie werden innerhalb einer Periode nicht mehr durchmischt. Jedes Gruppenmitglied wird entweder als **A**, **B**, **C** oder **D** bezeichnet. Für jede neue Periode werden Sie **zufällig einer neuen Gruppe** zugeordnet. Das heißt auch Ihre Bezeichnung (**A**, **B**, **C** oder **D**) kann sich ändern.

Die Aufgabe

Zu Beginn jeder Periode sind Sie mit **20 Talern** ausgestattet. Sie können Ihre Ausstattung an Talern in jeder Runde ganz oder teilweise in ein **Gruppenprojekt** investieren (*individueller Beitrag*). Der Teil, den Sie NICHT investieren, wandert in Ihren **Privattopf** und diesen behalten Sie für sich. Die Investitionen **aller 4 Gruppenmitglieder** wandern in einen **Gruppentopf**. Der Inhalt des Gruppentopfs wird danach **um 50 % erhöht** und unter allen Gruppenmitgliedern gleichmäßig verteilt, unabhängig davon wie viel jeder Einzelne dazu beigetragen hat.

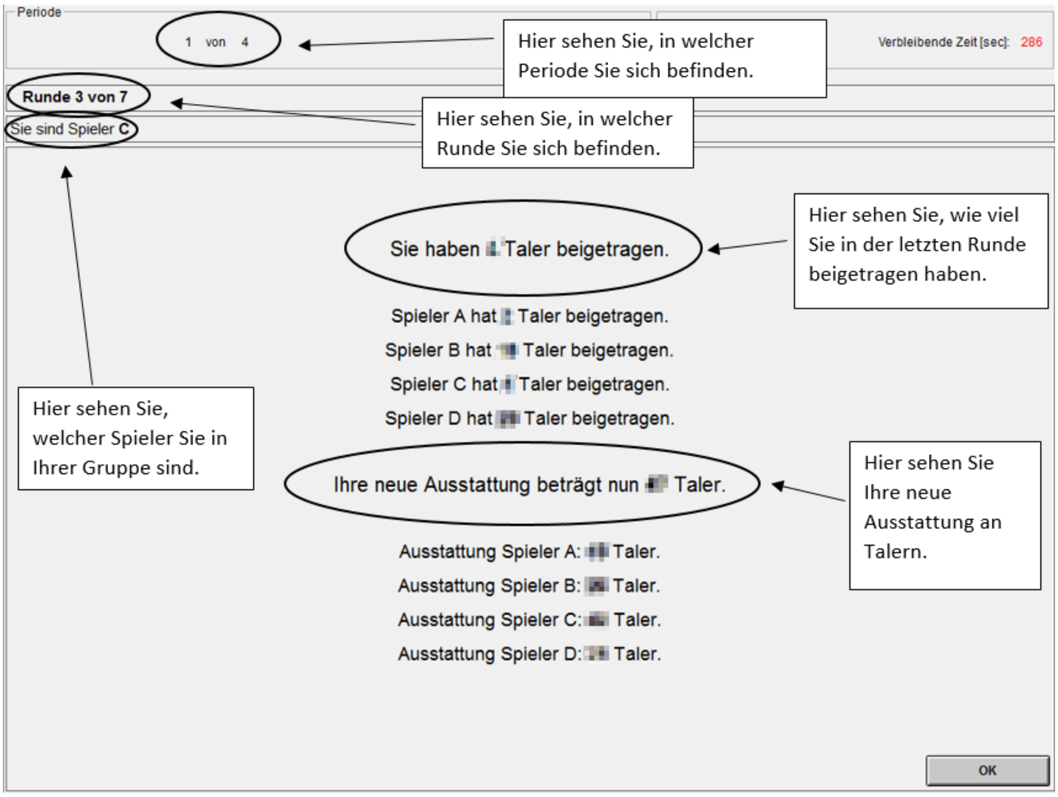
Die neue Ausstattung eines Teilnehmers am Ende einer Runde wird dann folgendermaßen berechnet:

$$\textbf{Neue Ausstattung} = \underbrace{\textbf{Alte Ausstattung} - \textbf{individueller Beitrag}}_{= \textit{Privattopf}} + \frac{\mathbf{1.5*Gruppentopf}}{\mathbf{4}}$$

Nach jeder Runde erfahren Sie Ihre neue Ausstattung. **Zusätzlich sehen Sie auch** wie viel die anderen Mitglieder in Ihrer Gruppe beigetragen haben und deren aktuelle Ausstattung (siehe *Screenshot 1*).

Alle Beträge werden immer auf ganze Taler-Beträge gerundet.

Für die weiteren Runden gilt, dass jeder Spieler einen beliebigen individuellen Beitrag zum Gruppentopf wählen kann, welcher jedoch maximal so groß sein kann wie die aktuelle Ausstattung an Talern. Im Gegensatz zu Runde 1 kann die Ausstattung an Talern in den Runden 2 – 7 kleiner oder größer als 20 sein.



Hier sehen Sie, in welcher Periode Sie sich befinden.

Hier sehen Sie, in welcher Runde Sie sich befinden.

Hier sehen Sie, welcher Spieler Sie in Ihrer Gruppe sind.

Sie haben [redacted] Taler beigetragen.

Hier sehen Sie, wie viel Sie in der letzten Runde beigetragen haben.

Spieler A hat [redacted] Taler beigetragen.
Spieler B hat [redacted] Taler beigetragen.
Spieler C hat [redacted] Taler beigetragen.
Spieler D hat [redacted] Taler beigetragen.

Ihre neue Ausstattung beträgt nun [redacted] Taler.

Hier sehen Sie Ihre neue Ausstattung an Talern.

Ausstattung Spieler A: [redacted] Taler.
Ausstattung Spieler B: [redacted] Taler.
Ausstattung Spieler C: [redacted] Taler.
Ausstattung Spieler D: [redacted] Taler.

Screenshot 1

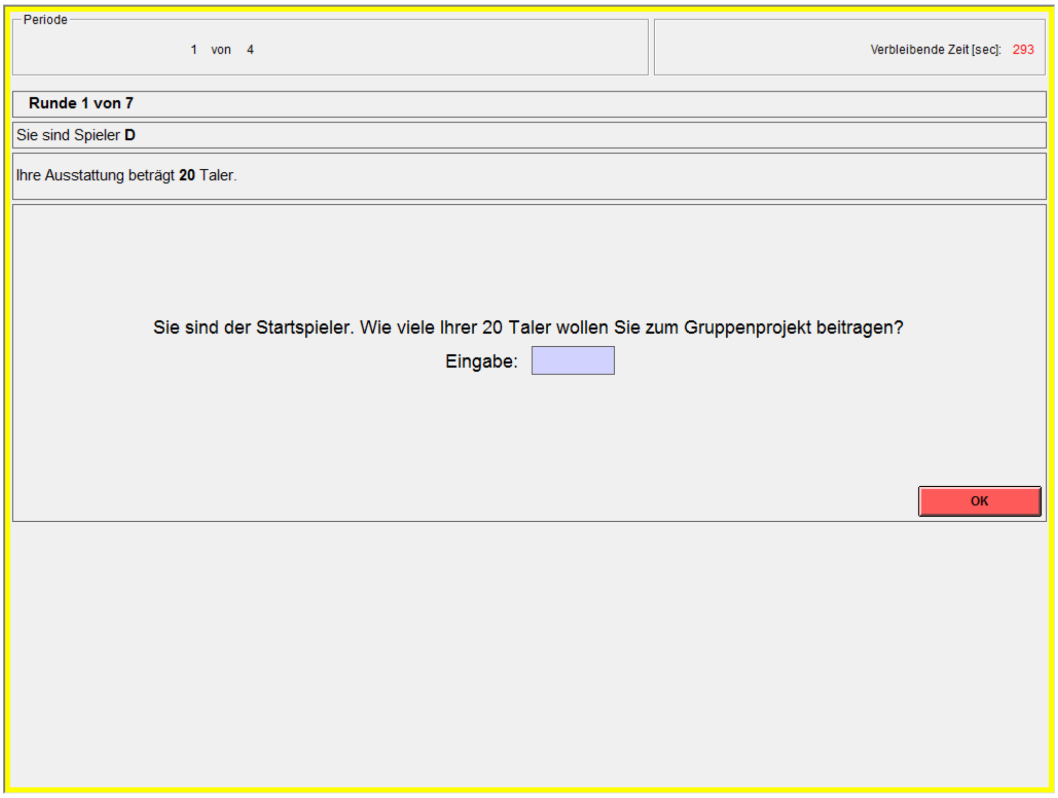
Der Startspieler

Zu Beginn jeder Periode, wird ein **Startspieler** zufällig bestimmt. Dieser bleibt Startspieler für die komplette Periode – d.h. für die gesamten 7 Runden. Alle Gruppenmitglieder werden darüber informiert, wer der Startspieler ist (**A**, **B**, **C** oder **D**). Jede Runde besteht nun aus den folgenden zwei Abschnitten:

1. Der ausgewählte Startspieler kann sich nun **zuerst** für einen individuellen Beitrag entscheiden (siehe *Screenshot 2*). Wenn Sie NICHT der Startspieler sind, klicken Sie einfach auf „OK“ um fortzufahren, während der Startspieler seinen individuellen Beitrag wählt (siehe *Screenshot 3*).
2. Die anderen Spieler werden über den Beitrag des Startspielers informiert und können daraufhin ihren eigenen individuellen Beitrag wählen (siehe *Screenshot 4*).

Ihre aktuelle Ausstattung wird Ihnen oben am Bildschirm angezeigt. Dies ist der Betrag, den Sie maximal wählen können.

Typischer Bildschirm als Startspieler



Runde 1 von 7

Sie sind Spieler **D**

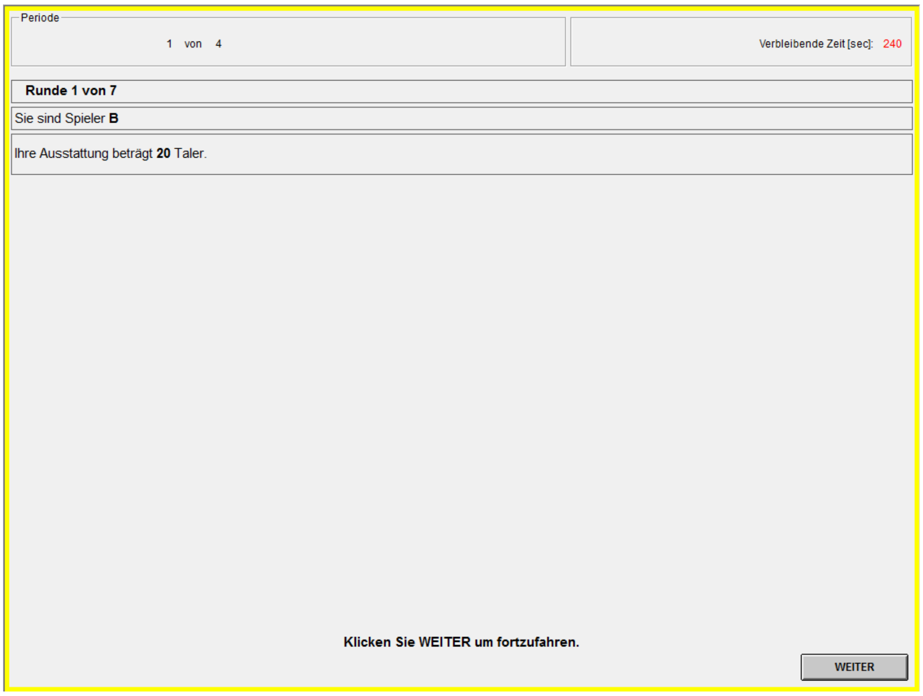
Ihre Ausstattung beträgt **20** Taler.

Sie sind der Startspieler. Wie viele Ihrer 20 Taler wollen Sie zum Gruppenprojekt beitragen?

Eingabe:

Screenshot 2

Typischer Bildschirm bevor der Startspieler seine Entscheidung getroffen hat



Periode

1 von 4

Verbleibende Zeit [sec]: 240

Runde 1 von 7

Sie sind Spieler **B**

Ihre Ausstattung beträgt **20** Taler.

Klicken Sie WEITER um fortzufahren.

Screenshot 3

Typischer Bildschirm nachdem der Startspieler seine Entscheidung getroffen hat

Periode

1 von 4

Verbleibende Zeit [sec]: 239

Runde 1 von 7

Sie sind Spieler **B**

Ihre Ausstattung beträgt **20** Taler.

Der Startspieler **D** hat [redacted] von **20** Taler beigetragen.

Wie viele Ihrer 20 Taler wollen Sie zum Gruppenprojekt beitragen?

Eingabe:

Screenshot 4

Ablauf im Experiment

(i) Zu Beginn werden Sie gebeten eine Reihe von **Kontrollfragen** zu beantworten. Durch die Beantwortung dieser Fragen können Sie kein Geld verdienen. Diese Fragen sind lediglich dazu da, um sicherzugehen, dass Sie das Spiel und die Regeln korrekt verstanden haben.

(ii) Danach erhalten Sie die Möglichkeit an einem **Beispielrechner** zu testen, welche Ausstattung Sie hätten, wenn Sie und die anderen Mitglieder in Ihrer Gruppe einen bestimmten Beitrag wählen würden (maximal 20 Taler, wie in Runde 1). Ihren Beitrag können Sie unter „Ihr Beitrag" mithilfe eines Schiebereglers einstellen und den Beitrag der anderen Gruppenmitglieder bei den Schiebereglern darunter. Sie können an diesem Beispielrechner verschiedene Kombinationen testen. Auch dieser Beispielrechner ist nur dazu da, sich mit dem Prinzip der Aufgabe vertraut zu machen und Ihre Eingaben hier haben keinerlei Einfluss auf den weiteren Verlauf des Experimentes. Beachten Sie bitte, dass Sie diesen Beispielrechner maximal für 180 Sekunden (= 3 Minuten) nutzen können. Danach geht das Experiment für Sie automatisch weiter (Sie können hier nicht aktiv weiter klicken).

(iii) Nach der Testphase mit dem Beispielrechner beginnt die **eigentliche Aufgabe** und Sie starten mit der ersten Periode wie oben beschrieben. Jede Periode läuft genau gleich ab, allerdings werden in jeder Periode zufällig neue Gruppen gebildet.

Code für Teil 2: 471

Instruktionen

Herzlich willkommen zu diesem wirtschaftswissenschaftlichen Experiment! Während des Experimentes haben Sie die Möglichkeit, eine Aufgabe auszuführen, welche in den nachfolgenden Instruktionen im Detail erklärt werden wird. Dabei können Sie einen nicht unerheblichen Geldbetrag gewinnen. Wie hoch Ihre Auszahlung letztendlich sein wird, hängt von Ihren Entscheidungen und den Entscheidungen der anderen Teilnehmer ab. Während des Experiments ist es Ihnen untersagt, mit den anderen Teilnehmern zu kommunizieren. Bitte lesen Sie die vorliegenden Instruktionen gründlich durch. Sollten Sie vorab oder während des Experiments noch Fragen haben, heben Sie bitte Ihre Hand und ein Experimentator wird zu Ihrem Platz kommen.

Allgemeiner Aufbau

Das Experiment besteht aus einem **Teil 1** und einem **Teil 2**. Diese beiden Teile sind unabhängig voneinander – d.h. Ihre Entscheidungen in Teil 1 haben keinen Einfluss auf den Ausgang von Teil 2 und umgekehrt. Sie bekommen zunächst Instruktionen für Teil 1. Sobald dieser Teil abgeschlossen ist, bekommen Sie Instruktionen für Teil 2. Sowohl in Teil 1 als auch in Teil 2 können Sie Geld verdienen. Ihr endgültiger Verdienst besteht aus der Summe Ihrer Verdienste aus Teil 1 und Teil 2. Zusätzlich bekommen Sie am Ende des Experiments eine Teilnahmeprämie von **4 EUR** ausbezahlt. Diese bekommen Sie in jeden Fall, unabhängig von Ihren Entscheidungen im Experiment.

Ihre endgültige Auszahlung wird sich also folgendermaßen zusammensetzen:

Gesamtauszahlung = 4 EUR + Verdienst in Teil 1 + Verdienst in Teil 2

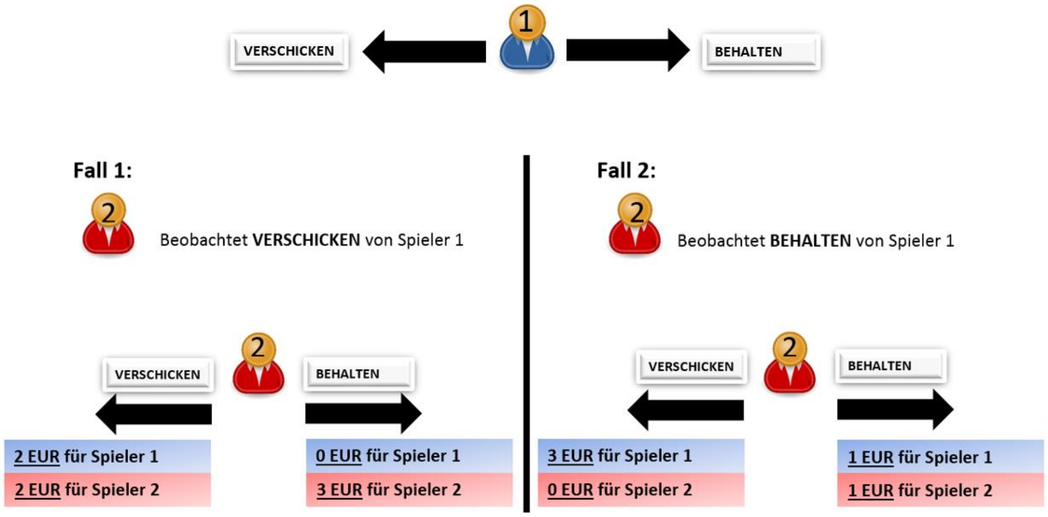
Ihre Gesamtauszahlung beträgt also in jedem Fall mindestens 4 EUR.

Teil 1

In Teil 1 werden Sie mit einem zufällig ausgewählten Experimental-Teilnehmer aus diesem Raum gruppiert, welcher Ihr Mitspieler für diesen Teil ist. Einer von Ihnen bekommt zufällig die Rolle als „Spieler 1“ und der andere als „Spieler 2“. Jeder von Ihnen erhält nun **1 EUR** vom Experimentator. Sie können sich nun überlegen, ob Sie diesen Euro BEHALTEN oder an Ihren Mitspieler VERSCHICKEN wollen. Wenn der Euro verschickt wird, verdoppelt er sich für Ihren Mitspieler. Ihr Mitspieler steht vor derselben Entscheidung wie Sie.

Diese Entscheidungssituation findet sequentiell statt – d.h. die Spieler treffen Ihre Entscheidungen nacheinander. Dies ist in der unten angehängten Grafik auch noch einmal dargestellt.

Zunächst trifft **Spieler 1** **(BLAU)** eine Entscheidung. **Spieler 2** **(ROT)** kann diese Entscheidung beobachten und trifft dann ebenfalls eine Entscheidung. Sie treffen im Experiment sowohl für die Rolle als Spieler 1 als auch für die Rolle als Spieler 2 eine Entscheidung. Bitte folgen Sie dazu einfach den Anweisungen auf dem Bildschirm. Am Ende des Experimentes wird ausgelost, ob Sie oder Ihr Mitspieler die Rolle des „Spieler 1“ bekommen. Der andere bekommt automatisch die Rolle des „Spieler 2“. Durch die Kombination Ihrer Entscheidungen wird dann schließlich Ihre Auszahlung gebildet, wie in der unten angehängten Grafik dargestellt. Die Auszahlung für Spieler 1 ist hier in BLAU dargestellt und die Auszahlung für Spieler 2 ist in ROT dargestellt.



Beispiel

Spieler 1 entscheidet sich für VERSCHICKEN.

Spieler 2 entscheidet sich für VERSCHICKEN wenn Spieler 1 VERSCHICKT und für BEHALTEN wenn Spieler 1 BEHÄLT.

In diesem Szenario erhalten also beide Spieler jeweils **2 EUR**.

Beispiel

Spieler 1 entscheidet sich für BEHALTEN.

Spieler 2 entscheidet sich für VERSCHICKEN wenn Spieler 1 VERSCHICKT und für VERSCHICKEN wenn Spieler 1 BEHÄLT.

In diesem Szenario erhält Spieler 1 **3 EUR** und Spieler 2 **0 EUR**.

Teil 2

Teil 2 besteht aus **4 Perioden** und jede Periode besteht ihrerseits aus **7 Runden**. Dies ist in der nachfolgenden Tabelle noch einmal verdeutlicht.

Perioden	1	2	3	4
Runden	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

In Teil 2 könne Sie Taler verdienen. Die Umrechnung beträgt dabei

10 Taler = 1 Euro

Am Ende des Experiments bekommen Sie die Ausstattung an Talern, die Sie besitzen, in EUR ausbezahlt. Für Ihre Auszahlung in Teil 2 wird eine **zufällige Periode ausgewählt**. Das heißt nur **eine der vier Perioden ist relevant für Ihre Auszahlung**. Sie wissen aber vorher nicht, welche dies ist, sondern erfahren dies erst am Ende des Experimentes.

Zu Beginn jeder Periode werden Gruppen aus jeweils **4 Teilnehmern** gebildet. Diese Gruppen sind fest für die komplette Periode – d.h. sie werden innerhalb einer Periode nicht mehr durchmischt. Jedes Gruppenmitglied wird entweder als **A**, **B**, **C** oder **D** bezeichnet. Für jede neue Periode werden Sie **zufällig einer neuen Gruppe** zugeordnet. Das heißt auch Ihre Bezeichnung (**A**, **B**, **C** oder **D**) kann sich ändern.

Die Aufgabe

Zu Beginn jeder Periode sind Sie mit **20 Talern** ausgestattet. Sie können Ihre Ausstattung an Talern in jeder Runde ganz oder teilweise in ein **Gruppenprojekt** investieren (*individueller Beitrag*). Der Teil, den Sie NICHT investieren, wandert in Ihren **Privattopf** und diesen behalten Sie für sich. Die Investitionen **aller 4 Gruppenmitglieder** wandern in einen **Gruppentopf**. Der Inhalt des Gruppentopfs wird danach **um 50 % erhöht** und unter allen Gruppenmitgliedern gleichmäßig verteilt, unabhängig davon wie viel jeder Einzelne dazu beigetragen hat.

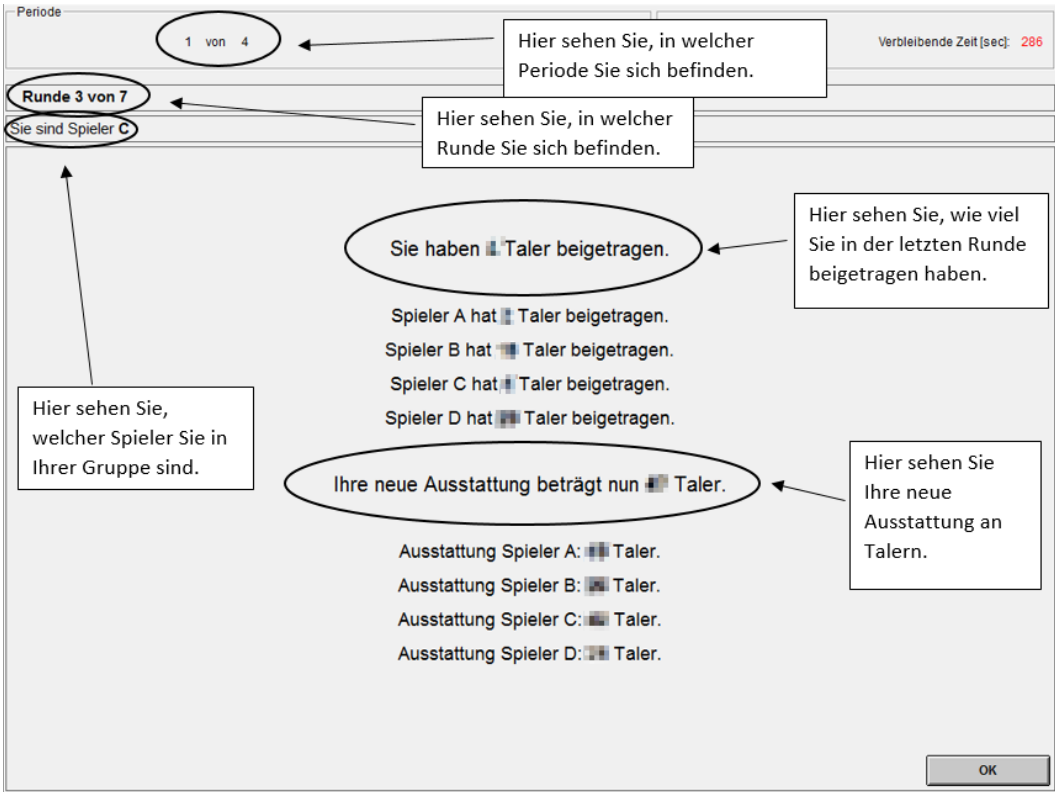
Die neue Ausstattung eines Teilnehmers am Ende einer Runde wird dann folgendermaßen berechnet:

$$\textbf{Neue Ausstattung} = \underbrace{\textbf{Alte Ausstattung} - \textbf{individueller Beitrag}}_{= \textbf{\textit{Privattopf}}} + \frac{\mathbf{1.5 * Gruppentopf}}{\mathbf{4}}$$

Nach jeder Runde erfahren Sie Ihre neue Ausstattung. **Zusätzlich sehen Sie auch** wie viel die anderen Mitglieder in Ihrer Gruppe beigetragen haben und deren aktuelle Ausstattung (siehe *Screenshot 1*).

Alle Beträge werden immer auf ganze Taler-Beträge gerundet.

Für die weiteren Runden gilt, dass jeder Spieler einen beliebigen individuellen Beitrag zum Gruppentopf wählen kann, welcher jedoch maximal so groß sein kann wie die aktuelle Ausstattung an Talern. Im Gegensatz zu Runde 1 kann die Ausstattung an Talern in den Runden 2 – 7 kleiner oder größer als 20 sein.



Hier sehen Sie, in welcher Periode Sie sich befinden.

Hier sehen Sie, in welcher Runde Sie sich befinden.

Hier sehen Sie, welcher Spieler Sie in Ihrer Gruppe sind.

Sie haben [redacted] Taler beigetragen.

Hier sehen Sie, wie viel Sie in der letzten Runde beigetragen haben.

Spieler A hat [redacted] Taler beigetragen.
Spieler B hat [redacted] Taler beigetragen.
Spieler C hat [redacted] Taler beigetragen.
Spieler D hat [redacted] Taler beigetragen.

Ihre neue Ausstattung beträgt nun [redacted] Taler.

Hier sehen Sie Ihre neue Ausstattung an Talern.

Ausstattung Spieler A: [redacted] Taler.
Ausstattung Spieler B: [redacted] Taler.
Ausstattung Spieler C: [redacted] Taler.
Ausstattung Spieler D: [redacted] Taler.

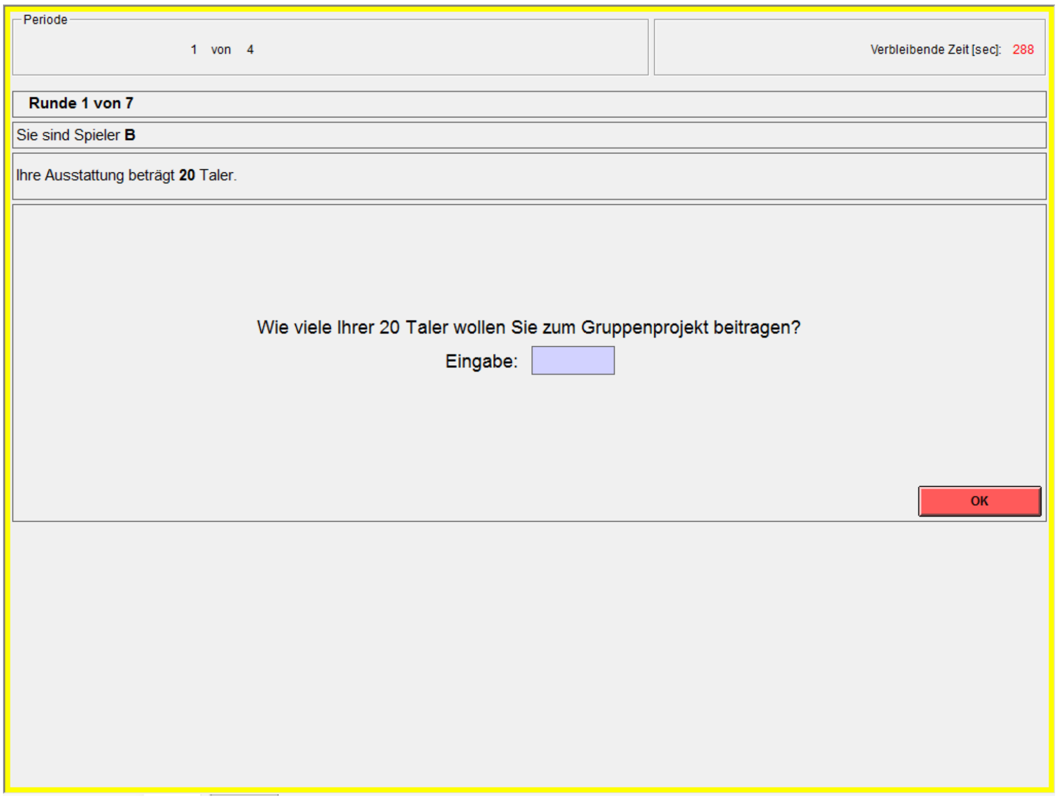
Screenshot 1

Die Spieler

In jeder Runde wählen alle Gruppenmitglieder (**A**, **B**, **C** und **D**) ihren individuellen Beitrag simultan. (Ein typischer Entscheidungsbildschirm ist in *Screenshot 2* dargestellt). Das heißt, alle Gruppenmitglieder erfahren immer erst am Ende eine Runde, welches Gruppenmitglied wieviel zum Gruppentopf beigetragen hat.

Ihre aktuelle Ausstattung wird Ihnen oben am Bildschirm angezeigt. Dies ist der Betrag, den Sie maximal wählen können.

Typischer Bildschirm eines Spielers bei der Wahl des individuellen Beitrags



Runde 1 von 7

Sie sind Spieler **B**

Ihre Ausstattung beträgt **20** Taler.

Wie viele Ihrer 20 Taler wollen Sie zum Gruppenprojekt beitragen?

Eingabe:

Screenshot 2

Ablauf im Experiment

(i) Zu Beginn werden Sie gebeten eine Reihe von **Kontrollfragen** zu beantworten. Durch die Beantwortung dieser Fragen können Sie kein Geld verdienen. Diese Fragen sind lediglich dazu da, um sicherzugehen, dass Sie das Spiel und die Regeln korrekt verstanden haben.

(ii) Danach erhalten Sie die Möglichkeit an einem **Beispielrechner** zu testen, welche Ausstattung Sie hätten, wenn Sie und die anderen Mitglieder in Ihrer Gruppe einen bestimmten Beitrag wählen würden (maximal 20 Taler, wie in Runde 1). Ihren Beitrag können Sie unter „Ihr Beitrag" mithilfe eines Schiebereglers einstellen und den Beitrag der anderen Gruppenmitglieder bei den Schiebereglern darunter. Sie können an diesem Beispielrechner verschiedene Kombinationen testen. Auch dieser Beispielrechner ist nur dazu da, sich mit dem Prinzip der Aufgabe vertraut zu machen und Ihre Eingaben hier haben keinerlei Einfluss auf den weiteren Verlauf des Experimentes. Beachten Sie bitte, dass Sie diesen Beispielrechner maximal für 180 Sekunden (= 3 Minuten) nutzen können. Danach geht das Experiment für Sie automatisch weiter (Sie können hier nicht aktiv weiter klicken).

(iii) Nach der Testphase mit dem Beispielrechner beginnt die **eigentliche Aufgabe** und Sie starten mit der ersten Periode wie oben beschrieben. Jede Periode läuft genau gleich ab, allerdings werden in jeder Periode zufällig neue Gruppen gebildet.

Code für Teil 2: *471*

E

RECIPROCITY AND LEADERSHIP: A THEORETICAL EXAMPLE FOR THE LEADER'S CURSE

THE FRAMEWORK

Let there be two countries L and F who have preferences over private consumption and public good consumption of Cobb-Douglas type, i.e. consider the case where this utility component of country i is given by $v_i = x_i G$ for $i = L, F$ where x_i denotes private consumption. The public good G is produced by a summation technology, i.e. $G = g_L + g_F$ where g_i is the public good contribution of country i for $i = L, F$ and public good productivity is equal to 1 such that $g_i = w_i - x_i$ where w_i denotes the initial endowment (we will later make the additional assumption of equal endowments).

Let us further assume like in Buchholz and Sandler (2017) that a reciprocity component enters the utility function which is denoted by $\varphi_i(g_F, g_L) = \alpha_i((g_L - \hat{g}_L)(g_F - \hat{g}_F))$ with $\hat{g}_F$ and $\hat{g}_L$ being reference values for country F and L respectively. For simplicity, we assume that each country considers the public good supply of the other country as the point of reference.

The reciprocity term enters additive in the utility function such that we attain the (additive separable) utility function $u_i = v_i + \varphi_i(g_F, g_L)$ for country i where j denotes the other country:

$$u_i = x_i G + \alpha_i(g_i - \hat{g}_j)(g_j - \hat{g}_i). \tag{1}$$

Setting $\hat{g}_i = g_j$, $\hat{g}_j = g_i$, $G = g_i + g_j$ and $g_i = w_i - x_i$ yields:

$$u_i = (w_i - g_i)(g_i + g_j) - \alpha_i(g_i - g_j)^2 \tag{2}$$

THE NASH EQUILIBRIUM:

Country i for $i = L, F$ maximizes utility u_i which is given by (1): $u_i = (w_i - g_i)(g_i + g_j) - \alpha_i(g_i - g_j)^2$ with respect to g_i such that the first-order condition (f.o.c., herafter) is:

$$\frac{\partial u_i}{\partial g_i} = -(g_i + g_j) + (w_i - g_i) - 2\alpha_i(g_i - g_j) = 0 \tag{3}$$

Solving (3) for g_i gives us:

$$g_i = \frac{w_i - (1 - 2\alpha_i)g_j}{2 + 2\alpha_i} \tag{4}$$

and due to symmetry:

$$g_j = \frac{w_j - (1 - 2\alpha_j)g_i}{2 + 2\alpha_j}. \tag{5}$$

Inserting the reaction function of j, g_j^r which is given by (5) in (4) gives:

$$g_i = \frac{w_i}{2+2\alpha_i} - \frac{1-2\alpha_i}{2+2\alpha_i}\frac{w_j-(1-2\alpha_j)g_i}{2+2\alpha_j} \tag{6}$$

Solving this term for g_i gives:

$$g_i = \frac{(2+2\alpha_j)w_i-(1-2\alpha_i)w_j}{3+6\alpha_j+6\alpha_i} \tag{7}$$

and due to symmetry:

$$g_j = \frac{(2+2\alpha_i)w_j-(1-2\alpha_j)w_i}{3+6\alpha_i+6\alpha_j}. \tag{8}$$

In the case of equal endowments, public good contributions g_i and g_j are independent of the reciprocity parameters α_i and α_j. To show this, set: $w = w_i = w_j$:

$$g_i = \frac{(2+2\alpha_j)w-(1-2\alpha_i)w}{3+6\alpha_j+6\alpha_i} = \frac{(1+2\alpha_j+2\alpha_i)w}{3+6\alpha_j+6\alpha_i} = \frac{1}{3}w \tag{9}$$

and due to symmetry: $g_j = \frac{1}{3}w$.

Both countries' PG contributions are strictly larger than zero in this case and the countries can afford their contribution as $g_{i,j} = \frac{1}{3}w < w$. Public good supply thus is $G = \frac{1}{3}w + \frac{1}{3}w = \frac{2}{3}w$ and utilities are:

$$u_i = \left(w - \frac{1}{3}w\right)\frac{2}{3}w - \alpha_i\left(\frac{1}{3}w - \frac{1}{3}w\right)^2 = \frac{4}{9}w^2(= u_j) \tag{10}$$

such that the reciprocity term does not alter the Nash equilibrium in our example.

THE STACKELBERG EQUILIBRIUM

Obtaining the reaction function of the follower:

Maximizing the utility of the follower $u_F = (w_F - g_F)(g_L + g_F) - \alpha_F(g_F - g_L)^2$ which is given by (2) with respect to g_F gives the f.o.c.:

$$\frac{\partial u_F}{\partial g_F} = -(g_F + g_L) + (w_F - g_L) - 2\alpha_F(g_F - g_L) = 0. \tag{11}$$

This yields the reaction function:

$$g_F^R = \frac{w_F - (1-2\alpha_F)g_L}{2+2\alpha_F} \tag{12}$$

such that crowding-in occurs, i.e. $\frac{\partial g_F}{\partial g_L} > 0$ for $\alpha_F > \frac{1}{2}$.

Public good contribution of the leader:

The leader's utility is given by (2) : $u_L = (w_L - g_L)(g_L + g_F) - \alpha_L(g_L - g_F)^2$. Inserting g_F^R in the utility function of the leader yields:

$$u_L = (w_L - g_L)\left(g_L + \frac{w_F - (1-2\alpha_F)g_L}{2+2\alpha_F}\right) - \alpha_L\left(g_L - \frac{w_F - (1-2\alpha_F)g_L}{2+2\alpha_F}\right)^2 \tag{13}$$

which can be rewritten as:

$$u_L = (w_L - g_L)\left(\frac{w_F}{2+2\alpha_F} + \frac{1+4\alpha_F}{2+2\alpha_F}g_L\right) - \alpha_L\left(\frac{3}{2+2\alpha_F}g_L - \frac{w_F}{2+2\alpha_F}\right)^2. \tag{14}$$

Maximizing u_L with respect to g_L gives the f.o.c.:

$$\frac{\partial u_L}{\partial g_L} = -\left(\frac{w_F}{2+2\alpha_F} + \frac{1+4\alpha_F}{2+2\alpha_F}g_L\right) + (w_L - g_L)\frac{1+4\alpha_F}{2+2\alpha_F} - 2\alpha_L\left(\frac{3}{2+2\alpha_F}g_L - \frac{w_F}{2+2\alpha_F}\right)\frac{3}{2+2\alpha_F} = 0. \tag{15}$$

Solving the f.o.c. for g_L yields:

$$g_L = \frac{(1+4\alpha_F)(2+2\alpha_F)w_L - (2+2\alpha_F-6\alpha_L)w_F}{2(1+4\alpha_F)(2+2\alpha_F)+18\alpha_L}. \tag{16}$$

In the case of equal endowments, i.e. $w = w_i = w_j$, this reduces to:

$$g_L = \frac{8\alpha_F{}^2 + 8\alpha_F + 6\alpha_L}{2(1+4\alpha_F)(2+2\alpha_F)+18\alpha_L}w. \tag{17}$$

Obviously, the public good contribution of the leader is positive if either one of the two countries has reciprocal preferences. For our special case, inserting the public good contribution of the leader into the reaction function of the follower gives:

$$g_F = \frac{w}{2+2\alpha_F} - \frac{(1-2\alpha_F)}{2+2\alpha_F}\frac{8\alpha_F{}^2 + 8\alpha_F + 6\alpha_L}{2(1+4\alpha_F)(2+2\alpha_F)+18\alpha_L}w \tag{18}$$

and $g_L > g_F$ holds as soon as:

$$g_L = \frac{8\alpha_F{}^2 + 8\alpha_F + 6\alpha_L}{2(1+4\alpha_F)(2+2\alpha_F)+18\alpha_L}w > \frac{1}{3}w \tag{19}$$

such that the leader contributes more than the follower as soon as his contribution exceeds the one of a player in the Nash-Game The leader does, however, never fare worse compared to the Nash-Game as he could always choose the contribution level of the Nash-Game which would lead to the public good supply and utility level in the Nash-Game.

Total public good supply in the Stackelberg Case, $G = g_L + g_F$ then is using eq. (17) and (18):

$$G = \frac{w}{2+2\alpha_F} + \frac{(1+4\alpha_F)}{2+2\alpha_F}\frac{8\alpha_F{}^2 + 8\alpha_F + 6\alpha_L}{2(1+4\alpha_F)(2+2\alpha_F)+18\alpha_L}w. \tag{20}$$

Numerical Example 1:

To illustrate this, let us first consider a non-reciprocal leader and a reciprocal follower ($\alpha_L = 0$, $\alpha_F = 1$). Then the public good contribution of the leader is according to (17):

$$g_L = \frac{8+8}{2(1+4)(2+2)}w = \frac{16}{40}w = \frac{4}{10}w$$

and the follower contributes according to (18):

$$g_F = \frac{w}{2+2} - \frac{1-2}{2+2}\frac{16}{40}w = \frac{14}{40}w = \frac{7}{20}w$$

such that $g_L > g_F$, i.e. the leader contributes more. Total public good supply is $G = g_L + g_F = \frac{3}{4}w$. Consequently, the utilities of both countries are:

$$u_L^S = \frac{6}{10}\frac{3}{4}w^2 = \frac{9}{20}w^2 > \frac{4}{9}w^2 = u^N$$

and

$$u_F^S = \frac{13}{20}\frac{3}{4}w^2 - \left(\frac{1}{20}\right)^2 w^2 = \frac{39}{80}w^2 - \left(\frac{1}{20}\right)^2 w^2 > \frac{4}{9}w^2 = u^N.$$

Both countries attain a larger utility compared to the Nash case, the leader, however, attains a lower utility compared to the follower's one as:

$$u_L^S = 0.45w^2 < 0.485w^2 = u_F^S.$$

Numerical Example 2:

Let us now consider the case where both have reciprocal preferences ($\alpha_L = 1$, $\alpha_F = 1$). Then the public good contribution of the leader is according to (17):

$$g_L = \frac{8+8+6}{2(1+4)(2+2)+18}w = \frac{22}{58}w = \frac{11}{29}w$$

and the follower contributes according to (18):

$$g_F = \frac{w}{2+2} - \frac{1-2}{2+2}\frac{11}{29}w = \frac{10}{29}w$$

such that $g_L > g_F$, i.e. the leader contributes more again. Total public good supply is $G = g_L + g_F = \frac{21}{29}w$.

Consequently, the utilities of both countries are:

$$u_L^S = \frac{18}{29}\frac{21}{29}w^2 - \left(\frac{1}{29}\right)^2 w^2 \approx 0.4483w^2 > \frac{4}{9}w^2$$

and

$$u_F^S = \frac{19}{29}\frac{21}{29}w^2 - \left(\frac{1}{29}\right)^2 w^2 \approx 0.4733w^2 > \frac{4}{9}w^2.$$

Both countries attain a larger utility compared to the Nash case, the leader, however, once more attains a lower utility compared to the follower's one as: $u_L^S \approx 0.4483w^2 < 0.4733w^2 \approx u_F^S$.

BIBLIOGRAPHY

Ahlquist, John S., and Margaret Levi. 2011. “Leadership: What it means, what it does, and what we want to know about it.” *Annual Review of Political Science* 14:1–24. (Cit. on pp. 102, 103).

Akerlof, George A. 1982. “Labor contracts as partial gift exchange.” *The Quarterly Journal of Economics* 97 (4): 543–569. (Cit. on p. 74).

Ambrus, Attila, and Parag A. Pathak. 2011. “Cooperation over finite horizons: A theory and experiments.” *Journal of Public Economics* 95 (7-8): 500–512. (Cit. on pp. 132–134).

Andreoni, James. 1988. “Privately provided public goods in a large economy: The limits of altruism.” *Journal of Public Economics* 35 (1): 57–73. (Cit. on pp. 6, 10, 42).

Andreoni, James, and Douglas B. Bernheim. 2009. “Social image and the 50–50 norm: A theoretical and experimental analysis of audience effects.” *Econometrica* 77 (5): 1607–1636. (Cit. on p. 79).

Andreoni, James, William Harbaugh, and Lise Vesterlund. 2003. “The carrot or the stick: Rewards, punishments, and cooperation.” *American Economic Review* 93 (3): 893–902. (Cit. on p. 109).

Andreoni, James, and Martin McGuire. 1993. “Identifying the free riders: A simple algorithm for determining who will contribute to a public good.” *Journal of Public Economics* 51 (3): 447–454. (Cit. on p. 10).

Arbak, Emrah, and Marie-Claire Villeval. 2013. “Voluntary leadership: motivation and influence.” *Social Choice and Welfare* 40 (3): 635–662. (Cit. on pp. 116, 118, 119, 128).

Arce M., Daniel G. 2001. “Leadership and the aggregation of international collective action.” *Oxford Economic Papers* 53 (1): 114–137. (Cit. on p. 102).

Arrow, Kenneth. 1962. “Economic Welfare and the Allocation of Resources for Invention.” In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, ed. by R. Nelson, 609–626. New York: Princeton University Press. (Cit. on p. 59).

Ashraf, Nava, Colin F. Camerer, and George Loewenstein. 2005. “Adam Smith, behavioral economist.” *Journal of Economic Perspectives* 19 (3): 131–145. (Cit. on p. 74).

Axelrod, Robert. 1981. “The emergence of cooperation among egoists.” *American Political Science Review* 75 (2): 306–318. (Cit. on p. 81).

Axelrod, Robert, and Robert O. Keohane. 1985. “Achieving cooperation under anarchy: Strategies and institutions.” *World Politics* 38 (1): 226–254. (Cit. on p. 82).

BMU. 2017. *Germany's Third Biennial Report under the United Nations Framework Convention on Climate Change*. Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. (Cit. on p. 70).

BMWi. 2016. *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland 1990-2015*. Berlin: Bundesministerium für Wirtschaft und Energie. (Cit. on pp. 62, 63, 66).

BSW Solar. 2015. *Statistische Zahlen der deutschen Solarstrombranche (Photovoltaik)*. `https://www.solarwirtschaft.de/fileadmin/media/pdf/2015_4_BSW_Solar_Faktenblatt_Photovoltaik.pdf`. (Cit. on p. 65).

Bagwell, Kyle, and Robert W. Staiger. 1999. "An economic theory of GATT." *American Economic Review* 89 (1): 215–248. (Cit. on p. 84).

Barbieri, Stefano. 2012. "Communication and Early Contributions." *Journal of Public Economic Theory* 14 (3): 391–421. (Cit. on p. 7).

Bárcena-Ruiz, Juan Carlos. 2006. "Environmental taxes and first-mover advantages." *Environmental and Resource Economics* 35 (1): 19–39. (Cit. on p. 50).

Barrett, Scott. 2003. *Environment and Statecraft: The Strategy of Environmental Treaty-Making*. Oxford(UK): Oxford University Press. (Cit. on p. 36).

Bass, Bernard M., and Ronald E. Riggio. 2006. *Transformational leadership*. Mahwah(New Jersey)/London: Lawrence Erlbaum. (Cit. on p. 102).

Battaglini, Marco, Salvatore Nunnari, and Thomas R Palfrey. 2016. "The dynamic free rider problem: A laboratory study." *American Economic Journal: Microeconomics* 8 (4): 268–308. (Cit. on p. 127).

Bechtel, Michael M., and Kenneth F. Scheve. 2013. "Mass support for global climate agreements depends on institutional design." *Proceedings of the National Academy of Sciences* 110 (34): 13763–13768. (Cit. on p. 83).

Beiser-McGrath, Liam F., and Thomas Bernauer. 2019. "Commitment failures are unlikely to undermine public support for the Paris agreement." *Nature Climate Change* 9 (3): 248–252. (Cit. on p. 83).

Berg, Joyce, John Dickhaut, and Kevin McCabe. 1995. "Trust, reciprocity, and social history." *Games and Economic Behavior* 10 (1): 122–142. (Cit. on p. 75).

Bergstrom, Theodore, Lawrence Blume, and Hal Varian. 1986. "On the private provision of public goods." *Journal of Public Economics* 29 (1): 25–49. (Cit. on pp. 4, 28, 40).

Bernauer, Thomas. 2013. "Climate change politics." *Annual Review of Political Science* 16:421–448. (Cit. on pp. 84, 88).

Blanco, Mariana, Dirk Engelmann, and Hans Theo Normann. 2011. "A within-subject analysis of other-regarding preferences." *Games and Economic Behavior* 72 (2): 321–338. (Cit. on p. 90).

Boadway, Robin, and Masayoshi Hayashi. 1999. "Country size and the voluntary provision of international public goods." *European Journal of Political Economy* 15 (4): 619–638. (Cit. on p. 17).

Bodansky, Daniel. 2016. "The Paris climate change agreement: A new hope?" *American Journal of International Law* 110 (2): 288–319. (Cit. on p. 2).

Bolton, Gary E., and Axel Ockenfels. 2000. "ERC: A theory of equity, reciprocity, and competition." *American Economic Review* 90 (1): 166–193. (Cit. on p. 80).

Bracha, Anat, Michael Menietti, and Lise Vesterlund. 2011. "Seeds to succeed? Sequential giving to public projects." *Journal of Public Economics* 95 (5-6): 416–427. (Cit. on p. 121).

Bradburn, Michael J., Jonathan J. Deeks, and Dennis G. Altman. 1999. "Metan-an alternative meta-analysis command." *Stata Technical Bulletin* 8 (44): 1–44. (Cit. on p. 107).

Brandt, Urs Steiner. 2004. "Unilateral actions: The case of international environmental problems." *Resource and Energy Economics* 26 (4): 373–391. (Cit. on p. 7).

Brazys, Samuel, Adrian O. Hagan, Diana Panke, and Oliver Westerwinter. 2017. "Can' t Buy Me Love ? Specific and Diffuse Reciprocity in International Relations." *Working Paper*. (Cit. on p. 85).

Buchholz, Wolfgang, Richard Cornes, and Dirk T.G. Rübbelke. 2014. "Potentially harmful international cooperation on global public good provision." *Economica* 81 (322): 205–223. (Cit. on pp. 8, 12).

Buchholz, Wolfgang, Lisa Dippl, and Michael Eichenseer. 2015. "Technological transfers in global climate policy." *CESifo Working Paper No. 5548*. (Cit. on pp. 4, 7, 28, 50, 69).

— . 2017. "Technological transfers in global climate policy—A strategic perspective." In *Climate Finance: Theory and Practice*, ed. by D.T.G. Rübbelke I. Galarraga and A. Markandya, 271–295. Singapore: World Scientific. (Cit. on pp. 28, 35).

— . 2019. "Subsidizing renewables as part of taking leadership in international climate policy: The German case." *Energy Policy* 129:765–773. *Available at doi: 10.1016/j.enpol.2019.02.044*. (Cit. on pp. 56, 58).

Buchholz, Wolfgang, and Michael Eichenseer. 2016. "Prisoner's Dilemma." *Encyclopedia of Law and Economics*: 1–5. (Cit. on pp. 1, 2).

— . 2017. "Strategic Coalition Formation in Global Public Good Provision." In *The Theory of Externalities and Public Goods*, ed. by W. Buchholz and D.T.G. Rübbelke, 61–84. Cham(Switzerland): Springer International. *The final publication is available at springerlink.com (doi: 10.1007/978-3-319-49442-5_4)*. (Cit. on pp. 4, 8).

— . 2019. "Advantageous leadership in public good provision: The case of an endogenous contribution technology." *Journal of Economics* 126 (1): 1–17. *The final publication is available at springerlink.com (doi: 10.1007/s00712–018–0613–5)*. (Cit. on pp. 4, 40).

Buchholz, Wolfgang, Christian Haslbeck, and Todd Sandler. 1998. "When does partial co-operation pay?" *FinanzArchiv/Public Finance Analysis* 55 (1): 1–20. (Cit. on pp. 6, 8).

Buchholz, Wolfgang, Alexander Haupt, and Wolfgang Peters. 2013. "International environmental agreements, fiscal federalism, and constitutional design." *Review of International Economics* 21 (4): 705–718. (Cit. on p. 8).

Buchholz, Wolfgang, and Kai A. Konrad. 1994. "Global environmental problems and the strategic choice of technology." *Journal of Economics* 60 (3): 299–321. (Cit. on pp. 6, 7, 28, 38, 40, 44).

Buchholz, Wolfgang, Kai A. Konrad, and Kjell Erik Lommerud. 1997. "Stackelberg leadership and transfers in private provision of public goods." *Review of Economic Design* 3 (1): 29–43. (Cit. on p. 43).

Buchholz, Wolfgang, and Wolfgang Peters. 2001. "The overprovision anomaly of private public good supply." *Journal of Economics* 74 (1): 63–78. (Cit. on p. 34).

Buchholz, Wolfgang, and Todd Sandler. 2017. "Successful leadership in global public good provision: Incorporating behavioural approaches." *Environmental and Resource Economics* 67 (3): 591–607. (Cit. on pp. 5, 7, 8, 73, 121, 147, 170).

Burger, Bruno, Klaus Kiefer, Christoph Kost, Sebastian Nold, et al. 2018. *Photovoltaics Report. Version August 27, 2018*. Freiburg: Fraunhofer Institute for Solar Energy Systems. `https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf`. (Cit. on pp. 60, 63).

Burton-Chellew, Maxwell N., Claire El Mouden, and Stuart A. West. 2016. "Conditional cooperation and confusion in public-goods experiments." *Proceedings of the National Academy of Sciences* 113 (5): 1291–1296. (Cit. on p. 77).

Cadigan, John, Patrick T. Wayland, Pamela Schmitt, and Kurtis Swope. 2011. "An experimental dynamic public goods game with carryover." *Journal of Economic Behavior & Organization* 80 (3): 523–531. (Cit. on p. 127).

Cappelen, Alexander W., Bjørn-Atle Reme, Erik Ø. Sørensen, and Bertil Tungodden. 2016. "Leadership and Incentives." *Management Science* 62 (7): 1944–1953. (Cit. on pp. 108, 116–120, 128).

Cartwright, Edward J., Joris Gillet, and Mark Van Vugt. 2013. "Leadership by Example in the Weak-Link Game." *Economic Inquiry* 51 (4): 2028–2043. (Cit. on p. 122).

Cartwright, Edward J., and Denise Lovett. 2014. "Conditional cooperation and the marginal per capita return in public good games." *Games* 5 (4): 234–256. (Cit. on pp. 105, 113, 114).

Cartwright, Edward J., Denise Lovett, and Anna Stepanova. 2017. "The first follower effect in a public good game." *Working Paper*. (Cit. on p. 111).

Centorrino, Samuele, and Laura Concina. 2013. "A competitive approach to leadership in public good games." *Working Paper. Toulouse School of Economics*. (Cit. on p. 120).

Charness, Gary, and Matthew Rabin. 2002. “Understanding social preferences with simple tests.” *The Quarterly Journal of Economics* 117 (3): 817–869. (Cit. on p. 81).

Chen, Cuicui, and Richard Zeckhauser. 2018. “Collective action in an asymmetric world.” *Journal of Public Economics* 158:103–112. (Cit. on pp. 5, 7).

Chu, Jonathan A. 2019. “A Clash of Norms? How Reciprocity and International Humanitarian Law affect American Opinion on the Treatment of POWs.” *Journal of Conflict Resolution* 63 (5): 1140–1164. (Cit. on p. 85).

Clark, Kenneth, and Martin Sefton. 2001. “The sequential prisoner's dilemma: Evidence on reciprocation.” *The Economic Journal* 111 (468): 51–68. (Cit. on pp. 75, 86).

Coate, Stephen, and Martin Ravallion. 1993. “Reciprocity without commitment: Characterization and performance of informal insurance arrangements.” *Journal of Development Economics* 40 (1): 1–24. (Cit. on p. 75).

Coats, Jennifer C., Timothy J. Gronberg, and Brit Grosskopf. 2009. “Simultaneous versus sequential public good provision and the role of refunds—an experimental study.” *Journal of Public Economics* 93 (1-2): 326–335. (Cit. on p. 123).

Coats, Jennifer C., and William S. Neilson. 2005. “Beliefs about Other-Regarding Preferences in a Sequential Public Goods Game.” *Economic Inquiry* 43 (3): 614–622. (Cit. on p. 123).

Cornes, Richard. 2016. “Aggregative environmental games.” *Environmental and Resource Economics* 63 (2): 339–365. (Cit. on pp. 8, 28).

Cornes, Richard, and Roger Hartley. 2007. “Aggregative public good games.” *Journal of Public Economic Theory* 9 (2): 201–219. (Cit. on pp. 8, 28, 42).

Cornes, Richard, and Todd Sandler. 1996. *The theory of externalities, public goods, and club goods (2nd ed.)* Cambridge(UK): Cambridge University Press. (Cit. on pp. 1, 4, 7, 8, 28, 36, 40, 42, 44, 45, 121).

Cox, James C., Daniel Friedman, and Steven Gjerstad. 2007. “A tractable model of reciprocity and fairness.” *Games and Economic Behavior* 59 (1): 17–45. (Cit. on p. 81).

Cramton, Peter, Axel Ockenfels, and Jean Tirole. 2017. “Policy brief—translating the collective climate goal into a common climate commitment.” *Review of Environmental Economics and Policy* 11 (1): 165–171. (Cit. on p. 89).

Croson, Rachel T.A. 1996. “Contributions to public goods: altruism or reciprocity?” *Working Paper. University of Pennsylvania.* (Cit. on p. 76).

Czaika, Mathias, Hein de Haas, and María Villares-Varela. 2018. “The global evolution of travel visa regimes.” *Population and Development Review* 44 (3): 589. (Cit. on p. 84).

DWD. 2018. *Globalstrahlungskarten, Monats- und Jahressummen.* `https://www.dwd.de/DE/leistungen/solarenergie/lstrahlungskarten_su.html`. (Cit. on pp. 65, 68).

Dana, Jason, Roberto A. Weber, and Jason Xi Kuang. 2007. “Exploiting moral wiggle room: Experiments demonstrating an illusory preference for fairness.” *Economic Theory* 33 (1): 67–80. (Cit. on p. 79).

Dannenberg, Astrid. 2015. “Leading by example versus leading by words in voluntary contribution experiments.” *Social Choice and Welfare* 44 (1): 71–85. (Cit. on pp. 106–109, 116, 119, 120, 128).

Dannenberg, Astrid, Bodo Sturm, and Carsten Vogt. 2010. “Do equity preferences matter for climate negotiators? An experimental investigation.” *Environmental and Resource Economics* 47 (1): 91–109. (Cit. on p. 124).

De Coninck, Heleen, and Ambuj Sagar. 2015. “Technology in the 2015 Paris Climate Agreement and beyond.” *International Centre for Trade and Sustainable Development (ICTSD) Issue Paper 42*. (Cit. on p. 6).

De La Tour, Arnaud, Matthieu Glachant, and Yann Ménière. 2011. “Innovation and international technology transfer: The case of the Chinese photovoltaic industry.” *Energy Policy* 39 (2): 761–770. (Cit. on p. 60).

— . 2013. “Predicting the costs of photovoltaic solar modules in 2020 using experience curve models.” *Energy* 62:341–348. (Cit. on pp. 59, 60).

De Oliveira, Angela C.M., Rachel T.A. Croson, and Catherine Eckel. 2015. “One bad apple? Heterogeneity and information in public good provision.” *Experimental Economics* 18 (1): 116–135. (Cit. on p. 78).

Del Río, Pablo. 2012. “The dynamic efficiency of feed-in tariffs: The impact of different design elements.” *Energy Policy* 41:139–151. (Cit. on p. 58).

Detemple, Julian, Michael Kosfeld, and Markus Kröll. 2019. “Confusion does not explain conditional cooperation in public-goods experiments.” *Unpublished Manuscript*. (Cit. on pp. 97, 99).

Dluhosch, Barbara, and Daniel Horgos. 2013. “(When) Does Tit-for-tat Diplomacy in Trade Policy Pay Off?” *The World Economy* 36 (2): 155–179. (Cit. on p. 84).

Dohmen, Thomas, Armin Falk, David Huffman, and Uwe Sunde. 2009. “Homo reciprocans: Survey evidence on behavioural outcomes.” *The Economic Journal* 119 (536): 592–612. (Cit. on p. 90).

Donovan, C., and C. Corbishley. 2016. “The cost of capital and how it affects climate change mitigation investment.” *London: Grantham Institute Briefing Paper No. 15*. (Cit. on p. 67).

Dufwenberg, Martin, and Georg Kirchsteiger. 2004. “A theory of sequential reciprocity.” *Games and Economic Behavior* 47 (2): 268–298. (Cit. on p. 80).

EPIA. 2014. *Global Market Outlook for Photovoltaics 2014-2018*. `https://resources.solarbusinesshub.com/solar-industry-reports/item/global-market-outlook-for-photovoltaics-2014-2018`. (Cit. on pp. 59, 62, 63).

Eckert, Heather. 2003. “Negotiating environmental agreements: Regional or federal authority?” *Journal of Environmental Economics and Management* 46 (1): 1–24. (Cit. on p. 8).

Edenhofer, Ottmar, Christian Flachsland, Michael Jakob, and Kai Lessmann. 2015. "The Atmosphere as a Global Commons Challenges for International Cooperation and Governance." In *The Oxford Handbook on the Economics of Global Warming*, ed. by W. Semmler and L. Bernard. Oxford UK: Oxford University Press. (Cit. on p. 7).

Eichenseer, Michael, and Johannes Moser. 2019a. "Conditional cooperation: Type stability across games." *Working Paper. Available at SSRN 3384821*. (Cit. on pp. 77, 90, 127, 129).

— . 2019b. "Leadership in dynamic public good provision: Endogenous growth and inequality." *Working Paper. Available at SSRN 3269341*. (Cit. on pp. 90, 101, 126).

Erev, Ido, and Amnon Rapoport. 1990. "Provision of step-level public goods: The sequential contribution mechanism." *Journal of Conflict Resolution* 34 (3): 401–425. (Cit. on p. 123).

Falk, Armin, and Urs Fischbacher. 2006. "A theory of reciprocity." *Games and Economic Behavior* 54 (2): 293–315. (Cit. on p. 81).

Falkner, Robert. 2016. "The Paris Agreement and the new logic of international climate politics." *International Affairs* 92 (5): 1107–1125. (Cit. on pp. 70, 85).

Fallucchi, Francesco, R. Andrew Luccasen, and Theodore L. Turocy. 2018. "Identifying discrete behavioural types: a re-analysis of public goods game contributions by hierarchical clustering." *Journal of the Economic Science Association*: forthcoming. (Cit. on pp. 77, 90, 93, 95–98).

Fehr, Ernst, and Simon Gachter. 2000. "Cooperation and Punishment in Public Goods Experiments." *American Economic Review* 90 (4): 980–994. (Cit. on pp. 78, 109).

Fehr, Ernst, and Simon Gächter. 2000. "Fairness and retaliation: The economics of reciprocity." *Journal of Economic Perspectives* 14 (3): 159–181. (Cit. on pp. 75, 90).

Fehr, Ernst, and Simon Gächter. 1998. "Reciprocity and economics: The economic implications of Homo Reciprocans." *European Economic Review* 42 (3): 845 –859. (Cit. on p. 78).

Fehr, Ernst, and Klaus M. Schmidt. 1999. "A theory of fairness, competition, and cooperation." *The Quarterly Journal of Economics* 114 (3): 817–868. (Cit. on pp. 80, 124).

— . 2006. "The economics of fairness, reciprocity and altruism–experimental evidence and new theories." In *Handbook of the Economics of Giving, Altruism and Reciprocity*, ed. by S.-C. Kolm and J. M. Ythier, 1:615–691. Amsterdam: Elsevier/North-Holland. (Cit. on p. 75).

Fehr, Ernst, Erich Kirchler, Andreas Weichbold, and Simon Gächter. 1998. "When social norms overpower competition: Gift exchange in experimental labor markets." *Journal of Labor Economics* 16 (2): 324–351. (Cit. on p. 75).

Figuières, Charles, David Masclet, and Marc Willinger. 2012. "Vanishing leadership and declining reciprocity in a sequential contribution experiment." *Economic Inquiry* 50 (3): 567–584. (Cit. on pp. 111, 112, 115).

Finus, M., and A. Caparrós. 2001. *Game Theory and International Environmental Cooperation*. Cheltenham(UK)/Northampton(MA): Edward Elgar. (Cit. on p. 5).

Finus, Michael, and Dirk T.G. Rübbelke. 2013. "Public good provision and ancillary benefits: The case of climate agreements." *Environmental and Resource Economics* 56 (2): 211–226. (Cit. on p. 37).

Fischbacher, Urs. 2007. "z-Tree: Zurich toolbox for ready-made economic experiments." *Experimental Economics* 10 (2): 171–178. (Cit. on p. 132).

Fischbacher, Urs, and Simon Gächter. 2010. "Social Preferences, Beliefs, and the Dynamics of Free Riding in Public Goods Experiments." *American Economic Review* 100 (1): 541–56. (Cit. on pp. 78, 90).

Fischbacher, Urs, Simon Gächter, and Ernst Fehr. 2001. "Are people conditionally cooperative? Evidence from a public goods experiment." *Economics Letters* 71 (3): 397–404. (Cit. on pp. 77–79, 86, 90, 92, 93, 113, 132).

Foucart, Renaud, and Grégoire Garsous. 2018. "Climate change mitigation with technology spillovers." *Environonmental and Resource Economics* 71 (2): 507–527. (Cit. on p. 69).

Foucart, Renaud, and Cheng Wan. 2018. "Strategic decentralization and the provision of global public goods." *Journal of Environmental Economics and Management* 92:537–558. (Cit. on pp. 8, 24).

Frackenpohl, Gerrit, Adrian Hillenbrand, and Sebastian Kube. 2016. "Leadership effectiveness and institutional frames." *Experimental Economics* 19 (4): 842–863. (Cit. on pp. 113, 114, 116).

Frank, Morgan R., Nick Obradovich, Lijun Sun, Wei Lee Woon, Brad L. LeVeck, and Iyad Rahwan. 2018. "Detecting reciprocity at a global scale." *Science Advances* 4 (1): eaao5348. (Cit. on p. 83).

Frondel, Manuel, Stephan Sommer, and Colin Vance. 2015. "The burden of Germany's energy transition: An empirical analysis of distributional effects." *Economic Analysis and Policy* 45:89–99. (Cit. on p. 71).

Frondel, Manuel, Nolan Ritter, Christoph M. Schmidt, and Colin Vance. 2010. "Economic impacts from the promotion of renewable energy technologies: The German experience." *Energy Policy* 38 (8): 4048–4056. (Cit. on p. 71).

Fukuyama, Francis. 1989. "The end of history?" *The National Interest*, no. 16: 3–18. (Cit. on p. 1).

Gächter, Simon, and Elke Renner. 2018. "Leaders as role models and 'belief managers' in social dilemmas." *Journal of Economic Behavior & Organization* 154:321–334. (Cit. on pp. 106, 107, 114, 116, 117, 128, 129, 133, 134, 137).

Gächter, Simon, Daniele Nosenzo, Elke Renner, and Martin Sefton. 2010. "Sequential vs. simultaneous contributions to public goods: Experimental evidence." *Journal of Public Economics* 94 (7-8): 515–522. (Cit. on p. 121).

— . 2012. “Who makes a good leader? Cooperativeness, optimism, and leading-by-example.” *Economic Inquiry* 50 (4): 953–967. (Cit. on pp. 113, 114, 119, 120, 127, 129, 134).

Gächter, Simon, Friederike Mengel, Elias Tsakas, and Alexander Vostroknutov. 2017. “Growth and inequality in public good provision.” *Journal of Public Economics* 150:1–13. (Cit. on pp. 126, 127, 132).

Gallagher, Kelly Sims. 2013. *Climate Technology & Development Case study: Innovation and Technology Transfer Across Global Value Chains: Evidence from China's PV Industry*. Medford(MA): Tufts University. (Cit. on p. 61).

Giacalone, Robert A., and Jerald Greenberg. 1997. *Antisocial behavior in organizations*. Thousand Oaks/New York/New Delhi: Sage. (Cit. on p. 75).

Gintis, Herbert, Samuel Bowles, Robert Boyd, and Ernst Fehr. 2003. “Explaining altruistic behavior in humans.” *Evolution and human Behavior* 24 (3): 153–172. (Cit. on p. 78).

Glachant, Matthieu, Damien Dussaux, Yann Ménière, and Antoine Dechezleprêtre. 2013. “Greening global value chains: Innovation and the international diffusion of technologies and knowledge.” *The World Bank Policy Research Working Paper 6467*. (Cit. on p. 6).

Gleick, James. 1986. “Prisoner's Dilemma Has Unexpected Applications.” *The New York Times*: 17.06.1986. (Cit. on p. 142).

Goeschl, Timo, and Johannes Lohse. 2018. “Cooperation in public good games. Calculated or confused?” *European Economic Review* 107:185–203. (Cit. on p. 77).

Goldemberg, José, and Patricia Maria Guardabassi. 2012. “Climate Change and 'historical responsibilities'.” *Ambiente & sociedade* 15 (1): 201–206. (Cit. on p. 70).

Goldstein, Joshua S. 1991. “Reciprocity in superpower relations: An empirical analysis.” *International Studies Quarterly* 35 (2): 195–209. (Cit. on p. 83).

Goldstein, Joshua S., and Jon C. Pevehouse. 1997. “Reciprocity, bullying, and international cooperation: Time-series analysis of the Bosnia conflict.” *American Political Science Review* 91 (3): 515–529. (Cit. on p. 83).

Goldstein, Joshua S., Jon C. Pevehouse, Deborah J. Gerner, and Shibley Telhami. 2001. “Reciprocity, triangularity, and cooperation in the middle east, 1979-97.” *Journal of Conflict Resolution* 45 (5): 594–620. (Cit. on p. 83).

Gouldner, Alvin W. 1960. “The norm of reciprocity: A preliminary statement.” *American Sociological Review* 25 (2): 161–178. (Cit. on p. 74).

Greiner, Ben. 2015. “Subject pool recruitment procedures: Organizing experiments with ORSEE.” *Journal of the Economic Science Association* 1 (1): 114–125. (Cit. on p. 132).

Gürerk, Özgür, Bernd Irlenbusch, and Bettina Rockenbach. 2009. “Motivating teammates: The leader's choice between positive and negative incentives.” *Journal of Economic Psychology* 30 (4): 591–607. (Cit. on pp. 109, 128).

Gürerk, Özgür, Thomas Lauer, and Martin Scheuermann. 2018. "Leadership with individual rewards and punishments." *Journal of Behavioral and Experimental Economics* 74:57–69. (Cit. on pp. 106–109, 115, 128).

Güth, Werner, Rolf Schmittberger, and Bernd Schwarze. 1982. "An experimental analysis of ultimatum bargaining." *Journal of economic behavior & organization* 3 (4): 367–388. (Cit. on p. 75).

Güth, Werner, Vittoria M. Levati, Matthias Sutter, and Eline Van der Heijden. 2007. "Leading by example with and without exclusion power in voluntary contribution experiments." *Journal of Public Economics* 91 (5): 1023–1042. (Cit. on pp. 102, 106–110, 115, 118, 126, 128, 154).

Hafner-Burton, Emilie M., Brad L. LeVeck, and David G. Victor. 2017. "No false promises: How the prospect of non-compliance affects elite preferences for international cooperation." *International Studies Quarterly* 61 (1): 136–149. (Cit. on p. 83).

Hafner-Burton, Emilie M., Stephan Haggard, David A. Lake, and David G. Victor. 2017. "The behavioral revolution and international relations." *International Organization* 71 (S1): S1–S31. (Cit. on p. 124).

Haigner, Stefan D., and Florian Wakolbinger. 2010. "To lead or not to lead. Endogenous sequencing in public goods games." *Economics Letters* 108 (1): 93–95. (Cit. on pp. 106–108, 111, 118, 120, 128).

Hamilton, Jonathan H., and Steven M. Slutsky. 1990. "Endogenous timing in duopoly games: Stackelberg or Cournot equilibria." *Games and Economic Behavior* 2 (1): 29–46. (Cit. on p. 50).

Harmon, Christopher. 2000. *Experience curves of photovoltaic technology*. `https://ideas.repec.org/p/wop/iasawp/ir00014.html`. (Cit. on p. 59).

Hartig, Björn, Bernd Irlenbusch, and Felix Kölle. 2015. "Conditioning on what? Heterogeneous contributions and conditional cooperation." *Journal of Behavioral and Experimental Economics* 55:48–64. (Cit. on p. 78).

Hartley, Jean. 2012. "Political leadership and its development." In *The Psychology of Politicians*, ed. by A. Weinberg, 97–120. Cambridge(UK): Cambridge University Press. (Cit. on p. 102).

Hattori, Keisuke. 2005. "Is Technological Progress Pareto-Improving for a World with Global Public Goods?" *Journal of Economics* 84 (2): 135–156. (Cit. on p. 44).

Hattori, Keisuke, and Takahiro Kitamura. 2013. "Endogenous timing in strategic environmental policymaking." *Environmental and Resource Economics* 55 (2): 199–215. (Cit. on p. 50).

Hattori, Keisuke, and Mai Yamada. 2018. "Skill diversity and leadership in team production." *Journal of Institutional and Theoretical Economics* 174 (2): 351–374. (Cit. on pp. 45, 46).

Helland, Leif, Jon Hovi, and Håkon Sælen. 2018. "Climate leadership by conditional commitments." *Oxford Economic Papers* 70 (2): 417–442. (Cit. on p. 112).

Hermalin, Benjamin E. 1998. “Toward an Economic Theory of Leadership: Leading by Example.” *American Economic Review* 88 (5): 1188–1206. (Cit. on pp. 7, 102, 110, 126).

Herrmann, Benedikt, and Christian Thöni. 2009. “Measuring conditional cooperation: A replication study in Russia.” *Experimental Economics* 12 (1): 87–92. (Cit. on p. 77).

Herrmann, Benedikt, Christian Thöni, and Simon Gächter. 2008. “Antisocial punishment across societies.” *Science* 319 (5868): 1362–1367. (Cit. on p. 78).

Hestermeyer, Holger P. 2009. “Vienna Convention on Diplomatic Relations (1961).” *Max Planck Encyclopedia of Public International Law*. (Cit. on p. 84).

Hett, Florian, Mario Mechtel, Henning Müller, Felix Schmidt, Daniel Schunk, and Valentin Wagner. 2018. “Do Children Cooperate Conditionally? Adapting the Strategy Method for First-Graders.” *Working Paper*. (Cit. on p. 78).

Higgins, Julian P.T., and Sally Green. 2011. *Cochrane handbook for systematic reviews of interventions*. The Cochrane Collaboration. `http://handbook.cochrane.org`. (Cit. on pp. 108, 154).

Hilton, Isabel. 2016. “China emerges as global climate leader in wake of Trump’s triumph.” *The Guardian*: 22.11.2016. (Cit. on p. 54).

Hoel, Michael. 1991. “Global environmental problems: the effects of unilateral actions taken by one country.” *Journal of Environmental Economics and Management* 20 (1): 55–70. (Cit. on pp. 6, 7, 23).

Hombach, Bodo. 2013. *Deutsche Stromrevolution in armen Ländern*. Handelsblatt. 15.01.2013. (Cit. on p. 71).

IEA PVPS. 2016. *2015 Snapshot of Global Photovoltaics Markets. Report IEA PVPS T129:2016*. Paris:IEA PVPS. `http://www.iea-pvps.org/fileadmin/dam/public/report/PICS/IEA-PVPS_-__A_Snapshot_of_Global_PV_-_1992-2015_-_Final_2_02.pdf`. (Cit. on p. 61).

IPCC. 2015. *Assessing Transformation Pathways*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge(UK)/New York: Cambridge University Press. (Cit. on p. 41).

Ihori, Toshihiro. 1996. “International public goods and contribution productivity differentials.” *Journal of Public Economics* 61 (1): 139–154. (Cit. on pp. 6, 28, 40, 44).

Jack, B. Kelsey, and Maria P. Recalde. 2015. “Leadership and the voluntary provision of public goods: Field evidence from Bolivia.” *Journal of Public Economics* 122:80–93. (Cit. on pp. 123, 124).

Jacoby, Henry D., Y.-H. Henry Chen, and Brian P. Flannery. 2017. “Informing transparency in the Paris Agreement: The role of economic models.” *Climate Policy* 17 (7): 873–890. (Cit. on p. 87).

Jamasb, Tooraj, and Jonathan Köhler. 2008. "Learning curves for energy technology and policy analysis: a critical assessment." In *Delivering a low-carbon electricity system: technologies, economics and policy*, ed. by M. Grubb, T. Jamasb, and . M. G. Pollitt, 314–331. Cambridge(UK)/New York: Cambridge University Press. (Cit. on p. 60).

Joas, Fabian, Michael Pahle, Christian Flachsland, and Amani Joas. 2016. "Which goals are driving the Energiewende? Making sense of the German Energy Transformation." *Energy Policy* 95:42–51. (Cit. on p. 58).

Jones, Benjamin F., and Benjamin A. Olken. 2005. "Do leaders matter? National leadership and growth since World War II." *Quarterly Journal of Economics* 120 (3): 835–864. (Cit. on p. 126).

Joskow, Paul L. 2011. "Comparing the costs of intermittent and dispatchable electricity generating technologies." *American Economic Review Papers & Proceedings* 101 (3): 238–41. (Cit. on p. 64).

Kaul, Inge. 1999. "Defining global public goods." In *Global public goods: International cooperation in the 21st century*, ed. by I. Kaul, I. Grunberg, and M. Stern, 2–19. Oxford(UK)/New York: Oxford University Press. (Cit. on p. 1).

Kaul, Inge, Isabelle Grunberg, and Marc Stern. 1999. *Global Public Goods: International Cooperation in the 21st Century*. Oxford(UK)/New York: Oxford University Press. (Cit. on p. 1).

Kaul, Inge, Pedro Conceicao, Katell Le Goulven, and Ronald U. Mendoza. 2003. *Providing global public goods: Managing globalization*. New York/Oxford(UK): Oxford University Press. (Cit. on pp. 122, 125).

Keller, Wolfgang. 2004. "International Technology Diffusion." *Journal of Economic Literature* 42 (3): 752–782. (Cit. on p. 6).

Keohane, Robert O. 1986. "Reciprocity in international relations." *International Organization* 40 (1): 1–27. (Cit. on pp. 81–84, 86).

— . 2005. *After hegemony: Cooperation and discord in the world political economy*. Princeton University Press. (Cit. on p. 81).

Keohane, Robert O., and Lisa L. Martin. 1995. "The promise of institutionalist theory." *International Security* 20 (1): 39–51. (Cit. on p. 82).

Keohane, Robert O., and Michael Oppenheimer. 2016. "Paris: Beyond the climate dead end through pledge and review?" *Politics and Governance* 4 (3): 142–151. (Cit. on pp. 86, 87, 89).

Keohane, Robert O., and David G. Victor. 2016. "Cooperation and discord in global climate policy." *Nature Climate Change* 6 (6): 570–575. (Cit. on pp. 87, 88).

Kertzer, Joshua D., Kathleen E. Powers, Brian C. Rathbun, and Ravi Iyer. 2014. "Moral support: How moral values shape foreign policy attitudes." *The Journal of Politics* 76 (3): 825–840. (Cit. on p. 82).

Keser, Claudia, and Frans Van Winden. 2000. "Conditional Cooperation and Voluntary Vontributions to Public Goods." *Scandinavian Journal of Economics* 102 (1): 23–39. (Cit. on pp. 76, 132).

Keuschnigg, Marc, and Jan Schikora. 2014. "The dark side of leadership: An experiment on religious heterogeneity and cooperation in India." *The Journal of Socio-Economics* 48:19–26. (Cit. on p. 124).

Kimbrough, Erik O., and Alexander Vostroknutov. 2016. "Norms make preferences social." *Journal of the European Economic Association* 14 (3): 608–638. (Cit. on pp. 80, 81).

Kirchkamp, Oliver, and Wladislaw Mill. 2018. "Conditional Cooperation and the Effect of Punishment." *Working Paper*. (Cit. on p. 79).

Kocher, Martin G., Todd Cherry, Stephan Kroll, Robert J. Netzer, and Matthias Sutter. 2008. "Conditional cooperation on three continents." *Economics Letters* 101 (3): 175–178. (Cit. on pp. 77, 95).

Komai, Mana, and Philip J. Grossman. 2009. "Leadership and group size: An experiment." *Economics Letters* 105 (1): 20–22. (Cit. on pp. 112, 113).

Kosfeld, Michael. 2019. "The role of leaders in inducing and maintaining cooperation: The CC strategy." *The Leadership Quarterly*: forthcoming. (Cit. on pp. 75, 90, 127, 129).

Kurzban, Robert, Peter DeScioli, and Erin O'Brien. 2007. "Audience effects on moralistic punishment." *Evolution and Human Behavior* 28 (2): 75–84. (Cit. on p. 79).

Lamp, Nicolas. 2018. "Legislative Innovation in the Trade and Climate Regimes." In *Global Environmental Change and Innovation in International Law*, ed. by Neil Craik, Cameron S. G. Jefferies, Sara L. Seck, and Tim Stephens, 270–295. Cambridge(UK)/New York: Cambridge University Press. (Cit. on pp. 86, 87).

Lazear, Edward P., Ulrike Malmendier, and Roberto A. Weber. 2012. "Sorting in experiments with application to social preferences." *American Economic Journal: Applied Economics* 4 (1): 136–63. (Cit. on p. 80).

Le Guin, Ursula K. 2000. *The Left Hand of Darkness*. New York: Ace Books/ Penguin Random House. (Cit. on p. iv).

LeVeck, Brad L., D. Alex Hughes, James H. Fowler, Emilie M. Hafner-Burton, and David G. Victor. 2014. "The role of self-interest in elite bargaining." *Proceedings of the National Academy of Sciences* 111 (52): 18536–18541. (Cit. on p. 124).

Ledyard, John O. 1995. "The Handbook of Experimental Economics." Chap. Public Goods: A Survey of Experimental Research. Greenwich: Princeton University Press. (Cit. on p. 76).

Levati, Vittoria M., Matthias Sutter, and Eline Van der Heijden. 2007. "Leading by Example in a Public." *Journal of Conflict Resolution* 51 (5): 793–818. (Cit. on pp. 102, 106–110, 115, 118, 128).

Levine, David K. 1998. "Modeling altruism and spitefulness in experiments." *Review of Economic Dynamics* 1 (3): 593–622. (Cit. on p. 81).

Lindahl, Erik. 1919. *Die Gerechtigkeit der Besteuerung: eine Analyse der Steuerprinzipien auf Grenznutzentheorie*. Lund: Gleerupska Universitetsbokhandeln. (Cit. on p. 4).

Liu, Jialu, and Don Goldstein. 2013. "Understanding China's renewable energy technology exports." *Energy Policy* 52:417–428. (Cit. on p. 61).

Malmendier, Ulrike, Vera L. te Velde, and Roberto A. Weber. 2014. "Rethinking reciprocity." *Annual Review of Economics* 6 (1): 849–874. (Cit. on p. 80).

Matthey, Astrid, and Tobias Regner. 2015. "Do reciprocators exploit or resist moral wiggle room? An experimental analysis." *Working Paper. Jena Economic Research Papers*. (Cit. on p. 80).

Mayer, Johannes, Simon Philipps, Noha Saad Hussein, Thomas Schlegl, and Charlotte Senkpiel. 2015. *Current and Future Cost of Photovoltaics Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems.* 1–80. Berlin: Agora Energiewende. (Cit. on pp. 59, 60).

McCannon, Bryan C. 2018. "Leadership and motivation for public goods contributions." *Scottish Journal of Political Economy* 65 (1): 68–96. (Cit. on pp. 106, 107, 128).

McDermott, Rose. 2002. "Experimental methodology in political science." *Political Analysis* 10 (4): 325–342. (Cit. on p. 125).

Mideksa, T. 2016. "Leadership and climate policy." *Discussion Paper, University of Oslo*. (Cit. on p. 7).

Miettinen, Topi, Michael Kosfeld, Ernst Fehr, and Jörgen Weibull. 2017. "Revealed Preferences in a Sequential Prisoners' Dilemma: A Horse-Race Between Five Utility Functions." *Working Paper*. (Cit. on pp. 75, 86, 90, 129).

Mikulaschek, Christoph. 2018. "Issue linkage across international organizations: Does European countries' temporary membership in the UN Security Council increase their receipts from the EU budget?" *The Review of International Organizations* 13 (4): 491–518. (Cit. on p. 85).

Minas, Stephen. 2016. *Keeping the Paris Agreement's climate technology promise*. `https://www.eco-business.com/opinion/keeping-the-paris-agreements-climate-technology-promise/`. (Cit. on p. 56).

Monopolkomission. 2009. *Strom und Gas 2009: Energiemärkte im Spannungsfeld von Politik und Wettbewerb. Sondergutachten 54.* (Cit. on p. 71).

Morrow, James D. 2007. "When do states follow the laws of war?" *American Political Science Review* 101 (3): 559–572. (Cit. on p. 84).

Moxnes, Erling, and Eline Van der Heijden. 2003. "The effect of leadership in a public bad experiment." *Journal of Conflict Resolution* 47 (6): 773–795. (Cit. on pp. 102, 106, 107, 128).

Müller, Benito, and Xolisa Ngwadla. 2016. "The Paris Ambition Mechanism." *Working Paper*. (Cit. on p. 85).

NDC Partnership. 2018. *Climate-Watch NDCs*. `http://ndcpartnership.org/climate-watch/ndcs`. (Cit. on p. 56).

Neij, Lena. 1997. "Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology." *Energy Policy* 25 (13): 1099–1107. (Cit. on p. 59).

Nemet, Gregory F. 2006. "Beyond the learning curve: Factors influencing cost reductions in photovoltaics." *Energy Policy* 34 (17): 3218–3232. (Cit. on p. 60).

Netztransparenz. 2017. *Prognose der EEG-Umlage 2018 nach EEV*. `https://www.netztransparenz.de/portals/1/Content/EEG-Umlage/EEG-Umlage\202017/20171016_Ver%C3%B6ffentlichung_EEG-Umlage\_2018.pdf`. (Cit. on p. 62).

— . 2018a. *EEG-Jahresabrechnungen*. `https://www.netztransparenz.de/EEG/Jahresabrechnungen`. (Cit. on p. 67).

— . 2018b. *EEG-Vergütungs- und Umlagekategorien*. `https://www.netztransparenz.de/EEG/Verguetungs-und-Umlagekategorien`. (Cit. on pp. 61, 66, 67).

Neugebauer, Tibor, Javier Perote, Ulrich Schmidt, and Malte Loos. 2009. "Selfish-biased conditional cooperation: On the decline of contributions in repeated public goods experiments." *Journal of Economic Psychology* 30 (1): 52–60. (Cit. on pp. 78, 128).

Newell, Richard G. 2010. "International climate technology strategies." In *Post-Kyoto International Climate Policy - Implementing Architectures for Agreement*, ed. by Joseph E. Aldy and Robert N. Stavins, pp. 403–438. Cambridge(UK)/ New York: Cambridge University Press. (Cit. on p. 6).

Nordhaus, William. 2015. "Climate clubs: Overcoming free-riding in international climate policy." *American Economic Review* 105 (4): 1339–70. (Cit. on p. 37).

Normann, Hans-Theo, and Holger A. Rau. 2015. "Simultaneous and sequential contributions to step-level public goods: One versus two provision levels." *Journal of Conflict Resolution* 59 (7): 1273–1300. (Cit. on pp. 123, 125).

Nosenzo, Daniele, and Martin Sefton. 2011. "Endogenous move structure and voluntary provision of public goods: Theory and experiment." *Journal of Public Economic Theory* 13 (5): 721–754. (Cit. on p. 121).

Noussair, Charles, and Cindy Soo. 2008. "Voluntary contributions to a dynamic public good: Experimental evidence." *Economics Letters* 98 (1): 71–77. (Cit. on p. 127).

Noussair, Charles, and Steven Tucker. 2007. "Public observability of decisions and voluntary contributions in a multiperiod context." *Public Finance Review* 35 (2): 176–198. (Cit. on p. 79).

OECD. 2017. *Investing in Climate, Investing in Growth*. Paris: OECD Publishing. `https://www.oecd-ilibrary.org/content/publication/9789264273528-en`. (Cit. on p. 70).

Obama, Barack. 2007. "Renewing American Leadership." *Foreign Affairs* 86 (4): 2–16. (Cit. on p. 102).

— . 2017. "The irreversible momentum of clean energy." *Science* 355 (6321): 126–129. (Cit. on p. 70).

Ockwell, David, Ambuj Sagar, and Heleen De Coninck. 2015. "Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: Towards a needs driven approach." *Climatic Change* 131 (3): 401–415. (Cit. on p. 6).

Olson, Mancur. 1971. "Increasing the incentives for international cooperation." *International Organization* 25 (4): 866–874. (Cit. on p. 1).

Ostrom, Elinor. 1998. "A behavioral approach to the rational choice theory of collective action: Presidential address, American Political Science Association, 1997." *American Political Science Review* 92 (1): 1–22. (Cit. on p. 81).

Pariente-David, Silvia. 2016. "The Cost and Value of Renewable Energy: Revisiting Electricity Economics." *IAEE Energy Forum. Second Quarter 2016*: 21–23. (Cit. on p. 64).

Parisi, Francesco, and Nita Ghei. 2003. "The role of reciprocity in international law." *Cornell International Law Journal* 36:93–124. (Cit. on p. 84).

Pegels, Anna, and Wilfried Lütkenhorst. 2014. "Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV." *Energy Policy* 74:522–534. (Cit. on p. 69).

Peinhardt, Clint, and Todd Sandler. 2015. *Transnational cooperation: An issue-based approach*. Oxford(UK)/New York: Oxford University Press. (Cit. on pp. 4, 70).

Pogrebna, Ganna, David H. Krantz, Christian Schade, and Claudia Keser. 2011. "Words versus actions as a means to influence cooperation in social dilemma situations." *Theory and Decision* 71 (4): 473–502. (Cit. on pp. 106, 107, 109, 115, 128).

Popp, David. 2011. "International technology transfer, climate change, and the clean development mechanism." *Review of Environmental Economics and Policy* 5 (1): 131–152. (Cit. on p. 6).

— . 2015. "Climate-friendly technological change for developing countries." In *The Oxford Handbook of the Macroeconomics of Global Warming*, ed. by W. Semler and L. Bernard. Oxford(UK)/New York: Oxford University Press. (Cit. on p. 6).

Potters, Jan, Martin Sefton, and Lise Vesterlund. 2005. "After you—endogenous sequencing in voluntary contribution games." *Journal of Public Economics* 89 (8): 1399–1419. (Cit. on p. 128).

— . 2007. "Leading-by-example and signaling in voluntary contribution games: an experimental study." *Economic Theory*: 169–182. (Cit. on p. 110).

Préget, Raphaële, Phu Nguyen-Van, and Marc Willinger. 2016. "Who are the voluntary leaders? Experimental evidence from a sequential contribution game." *Theory and Decision* 81 (4): 581–599. (Cit. on pp. 116, 119).

Puttaswamy, Nagalakshmi, and Mohd Ali. 2017. "How Did China become the largest Solar PV Manufacturing Country?" *Working Paper*. (Cit. on p. 61).

Rabin, Matthew. 1993. "Incorporating fairness into game theory and economics." *The American Economic Review* 83 (5): 1281–1302. (Cit. on p. 80).

Rajmaira, Sheen. 1997. "Indo-Pakistani Relations: Reciprocity in Long-Term Perspective." *International Studies Quarterly* 41 (3): 547–560. (Cit. on p. 83).

Rathbun, Brian C. 2007. "Hierarchy and community at home and abroad: Evidence of a common structure of domestic and foreign policy beliefs in American elites." *Journal of Conflict Resolution* 51 (3): 379–407. (Cit. on p. 82).

— . 2011. "Before hegemony: Generalized trust and the creation and design of international security organizations." *International Organization* 65 (2): 243–273. (Cit. on p. 82).

Rege, Mari, and Kjetil Telle. 2004. "The impact of social approval and framing on cooperation in public good situations." *Journal of Public Economics* 88 (7): 1625–1644. (Cit. on p. 79).

Regner, Tobias. 2018. "Reciprocity under moral wiggle room: Is it a preference or a constraint?" *Experimental Economics* 21 (4): 779–792. (Cit. on p. 80).

Rhodes, Carolyn. 1989. "Reciprocity in trade: The utility of a bargaining strategy." *International Organization* 43 (2): 273–299. (Cit. on p. 83).

Rivas, M. Fernanda, and Matthias Sutter. 2011. "The benefits of voluntary leadership in experimental public goods games." *Economics Letters* 112 (2): 176–178. (Cit. on pp. 106–108, 114, 120, 128, 154).

Rivas, Maria Fernanda, and Matthias Sutter. 2008. "The dos and don'ts of leadership in sequential public goods experiments." *Working Paper.* (Cit. on p. 109).

Rockenbach, Bettina, and Irenaeus Wolff. 2017. "The effects of punishment in dynamic public-good games." *Working Paper.* (Cit. on pp. 127, 128).

Röpke, Luise. 2013. "The development of renewable energies and supply security: A trade-off analysis." *Energy Policy* 61:1011–1021. (Cit. on p. 64).

Rubin, Edward S., Inês M.L. Azevedo, Paulina Jaramillo, and Sonia Yeh. 2015. "A review of learning rates for electricity supply technologies." *Energy Policy* 86:198–218. (Cit. on pp. 59, 60).

Sadrieh, Abdolkarim, and Harrie A.A. Verbon. 2006. "Inequality, cooperation, and growth: An experimental study." *European Economic Review* 50 (5): 1197–1222. (Cit. on p. 127).

Sahin, Selhan Garip, Catherine Eckel, and Mana Komai. 2015. "An experimental study of leadership institutions in collective action games." *Journal of the Economic Science Association* 1 (1): 100–113. (Cit. on pp. 106, 107, 122, 123, 128).

Sandler, Todd. 1992. *Collective action: Theory and applications.* New York: Harvester Wheatsheaf. (Cit. on p. 7).

— . 2004. *Global Collective Action.* Cambridge(UK)/New York: Cambridge University Press. (Cit. on pp. 4, 5).

— . 2015. "Collective action: fifty years later." *Public Choice* 164 (3-4): 195–216. (Cit. on pp. 104, 122).

— . 2017a. "Environmental cooperation: contrasting international environmental agreements." *Oxford Economic Papers* 69 (2): 345–364. (Cit. on p. 5).

— . 2017b. "International Peacekeeping Operations: Burden Sharing and Effectiveness." *Journal of Conflict Resolution* 61 (9): 1875–1897. (Cit. on p. 125).

Schmidt, Tobias S., and Sebastian Sewerin. 2017. "Technology as a driver of climate and energy politics." *Nature Energy* 2 (6): 17084. (Cit. on p. 70).

Schmidt, Ulrich, and Philipp C. Wichardt. 2018. "Inequity Aversion, Welfare Measurement and the Gini Index." *Social Choice and Welfare* 52 (3): 585–588. (Cit. on p. 145).

Schwerhoff, Gregor. 2016. "The economics of leadership in climate change mitigation." *Climate Policy* 16 (2): 196–214. (Cit. on pp. 7, 40, 102, 103).

Simma, Bruno. 2008. "Reciprocity." *The Max Planck Encyclopedia of Public Internanional Law, online edition*. `www.mpepil.com`. (Cit. on p. 84).

Sinn, Hans-Werner. 2012a. *Denkfabrik. Abgesang auf das EEG.* Wirtschaftswoche. 10.02.2012. (Cit. on p. 71).

— . 2012b. *The green paradox: A supply-side approach to global warming*. Cambridge(MA): The MIT press. (Cit. on pp. 5, 23, 71).

Solar Power Europe. 2016. *Global Market Outlook for Solar Power 2015-2019*. `https://resources.solarbusinesshub.com/solar-industry-reports/item/global-market-outlook-for-solar-power-2015-2019`. (Cit. on pp. 59, 62, 63).

Sonnemans, Joep, Arthur Schram, and Theo Offerman. 1999. "Strategic behavior in public good games: When partners drift apart." *Economics Letters* 62 (1): 35–41. (Cit. on p. 76).

Stern, David I., John C.V. Pezzey, and N. Ross Lambie. 2012. "Where in the world is it cheapest to cut carbon emissions?" *Australian Journal of Agricultural and Resource Economics* 56 (3): 315–331. (Cit. on p. 41).

Stern, Nicholas. 2015. *Why are we Waiting? The Logic, Urgency, and Promise of Tackling Climate Change*. Cambridge(MA)/London: The MIT Press. (Cit. on p. 37).

Stiglitz, Joseph E. 1999. "Knowledge as a global public good." In *Global Public Goods – International Cooperation in the 21st Century*, ed. by I. Kaul, I. Grunberg, and M. Stern, 308–325. New York: Oxford University Press. (Cit. on p. 69).

Stogdill, Ralph M. 1974. *Handbook of leadership: A survey of theory and research.* New York: Free Press. (Cit. on p. 102).

Stram, Bruce N. 2016. "Key challenges to expanding renewable energy." *Energy Policy* 96:728–734. (Cit. on p. 64).

Stranlund, John K. 1996. "On the strategic potential of technological aid in international environmental relations." *Journal of Economics* 64 (1): 1–22. (Cit. on pp. 7, 50).

Sugden, Robert. 1984. "Reciprocity: The supply of public goods through voluntary contributions." *The Economic Journal* 94 (376): 772–787. (Cit. on pp. 75, 81).

Sutter, Matthias. 2016. "Die Effizienz von Führung–Verhaltensökonomische Einsichten zur Bedeutung von Unsicherheit." In *Führen in ungewissen Zeiten*, ed. by O. Geramanis and K. Hermann, 175–187. Wiesbaden: Springer. (Cit. on p. 111).

Sutter, Matthias, and Fernanda Rivas. 2014. "Leadership, reward, and punishment in sequential public goods experiments." In *Reward and punishment in social dilemmas*, ed. by Paul A.M. Van Lange, Bettina Rockenbach, and Toshio Yamagishi, 133–160. Cambridge(UK)/ New York: Cambridge University Press. (Cit. on pp. 108–111, 115, 118, 128).

Teyssier, Sabrina. 2012. "Inequity and risk aversion in sequential public good games." *Public Choice* 151 (1): 91–119. (Cit. on pp. 114, 120).

The Economist. "Pollution—awry in the sky." *Dec 16th, 425(9071):49–50*. (Cit. on p. 53).

Thöni, Christian, and Stefan Volk. 2018. "Conditional cooperation: Review and refinement." *Economics Letters* 171:37 –40. (Cit. on pp. 77, 90, 93, 95, 98).

Tingley, Dustin, and Michael Tomz. 2014. "Conditional cooperation and climate change." *Comparative Political Studies* 47 (3): 344–368. (Cit. on pp. 83, 88).

Trancik, Jessica, Patrick Brown, Joel Jean, Goksin Kavlak, and Magdalena Klemun. 2015. *Technology Improvement and Emissions Reductions as Mutually Reinforcing Efforts: Observations from the Global Development of Solar and Wind Energy*. Cambridge(MA): Massachusetts Institute of Technology. `https://dspace.mit.edu/handle/1721.1/102237`. (Cit. on pp. 56, 60, 63, 70).

United Nations. 2016. *Paris Agreement*. `https://treaties.un.org/doc/Treaties/2016/02/20160215%2006-03%20PM/Ch_XXVII-7-d.pdf`. (Cit. on p. 56).

Van Vugt, Mark, and David De Cremer. 1999. "Leadership in social dilemmas: The effects of group identification on collective actions to provide public goods." *Journal of Personality and Social Psychology* 76 (4): 587–599. (Cit. on p. 102).

Van der Heijden, Eline, and Erling Moxnes. 2013. "Leading by Example to Protect the Environment." *Journal of Conflict Resolution* 57 (2): 307–326. (Cit. on pp. 115, 120).

Van der Weele, Joel J., Julija Kulisa, Michael Kosfeld, and Guido Friebel. 2014. "Resisting moral wiggle room: How robust is reciprocal behavior?" *American Economic Journal: Microeconomics* 6 (3): 256–64. (Cit. on p. 80).

Van der Zwaan, Bob, and Ari Rabl. 2003. "Prospects for PV: A learning curve analysis." *Solar Energy* 74 (1): 19–31. (Cit. on p. 59).

Varian, Hal R. 1994. "Sequential contributions to public goods." *Journal of Public Economics* 53 (2): 165–186. (Cit. on pp. 7, 102, 121, 146).

Vesterlund, Lise. 2003. "The informational value of sequential fundraising." *Journal of public Economics* 87 (3-4): 627–657. (Cit. on p. 110).

Vicary, Simon. 2018. "Is three a crowd? Small group provision of a public good." *Metroeconomica* 69 (1): 70–85. (Cit. on p. 8).

Volk, Stefan, Christian Thöni, and Winfried Ruigrok. 2012. "Temporal stability and psychological foundations of cooperation preferences." *Journal of Economic Behavior & Organization* 81 (2): 664–676. (Cit. on p. 90).

Warr, Peter. 1983. "The private provision of a public good is independent of the distribution of income." *Economics Letters* 13 (2-3): 207–211. (Cit. on p. 36).

Weber, Roberto A., Colin F. Camerer, and Marc Knez. 2004. "Timing and virtual observability in ultimatum bargaining and "weak link" coordination games." *Experimental Economics* 7 (1): 25–48. (Cit. on p. 122).

Weber, Till O., Ori Weisel, and Simon Gächter. 2018. "Dispositional free riders do not free ride on punishment." *Nature Communications* 9 (1): 1–9. (Cit. on p. 79).

Wene, Clas-Otto. 2000. *Experience Curves for Energy Technology Policy. Technical Report, International Energy Agency.* `https://www.oecd-ilibrary.org/content/publication/9789264182165-en`. (Cit. on pp. 59, 60).

Wicksell, Knut. 1896. *Finanztheoretische Untersuchungen*. Jena: Gustav Fischer. (Cit. on p. 4).

Wren, J. Thomas. 2007. *Inventing leadership: The challenge of democracy.* New horizons in leadership studies. Northampton(MA): Edward Elgar Publishing. (Cit. on pp. 73, 102).

Wright, T. P. 1936. "Factors Affecting the Cost of Airplanes." *Journal of the Aeronautical Sciences* 3 (4): 122–128. (Cit. on p. 59).

Yelle, Louis E. 1979. "The Learning Curve: Historical Review and Comprehensive Survey." *Decision Science* 10 (2): 302–328. (Cit. on p. 59).

Zehnder, Christian, Holger Herz, and Jean-Philippe Bonardi. 2017. "A productive clash of cultures: Injecting economics into leadership research." *The Leadership Quarterly* 28 (1): 65–85. (Cit. on p. 102).

Zhang, Fang, and Kelly Sims Gallagher. 2016. "Innovation and technology transfer through global value chains: Evidence from China's PV industry." *Energy Policy* 94:191–203. (Cit. on p. 60).