SEEKING THE LEVIATHAN, THE GENERAL WILL AND THE INVISIBLE HAND IN RURAL GUINEA, WEST AFRICA:

A SCIENCE OF HUMAN NATURE

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Chapter 1

Introduction

In my thesis, I confronted empirical observations I made in two field studies in Guinea with theoretical predictions deduced from the works of Thomas Hobbes, Jean-Jacques Rousseau and Adam Smith. I was interested in specific aspects of the use and allocation of natural resources and investigated whether the work of the classical scholars could help understanding those aspects. Natural resources are elemental for the development and wealth of human societies. Determining factors leading to a sustainable use and fair allocation of natural resources is therefore not only of central interest from a scientific perspective, but also from a political, a philosophical, and a practical point of view.

The history of the Western world has been shaped by turmoil, revolutions, unrests and wars. Stable and peaceful periods were short and rare. Since the antique time of old Greece, western philosophers have thought about ways to reach peace and stability. From a philosophical point of view, the problem of social order is: how can stability and peace be reached through political means? Three central solutions to the problem of social order were repeatedly worked out and presented in varying forms by western philosophers from different historical eras: the first solution centres around the use of coercion and the enforcement of security; the second solution centres around collectivistic values and ideals; the third solution centres around the doctrine of the balance of diverging interests (Russel 2012).

In the modern era, Thomas Hobbes (1588-1679), Jean-Jacques Rousseau (1712-1778) and Adam Smith (1723-1790) were the most influential representatives of these three doctrines. Their ideas were groundbreaking and influential. Key concepts used to understand and shape societies today, such as the state, the community and the market have their origins in the works of these scholars (Nonnenmacher 1989). According to Hobbes, humans are voracious, violent and in a constant quest for power. This is due to their characteristics as natural beings and their right to do anything necessary in order to guarantee their self-preservation. This is the natural right of any human being. As long as humans do not concede their natural right, neither peace nor stability can emerge. Instead, humans stay in a state of brutal anarchy, which is the state of nature. Peace and stability can therefore only emerge when humans concede their natural right and unite under the rule of an external authority to which all the rights necessary to rule at will are provided to keep individuals under control. The sole duty of this authority, known as the Leviathan, is to guarantee the right for bodily integrity of individuals and to protect individuals from a violent death. Rousseau disagrees with Hobbes' description of the natural state of man. He argues that man in his natural state is just a solitary animal, without interest and need for other humans. However, humans gradually evolved, lost their independence and became social animals. As social beings, humans are voracious, violent and in a constant quest for power. For Rousseau, the natural state of society is a state of brutal anarchy, and this coincides more or less to Hobbes' state of nature. And just as Hobbes, Rousseau argues that the individuals must be kept under control for stability and peace to emerge. However, Rousseau does not accept the Leviathan as a solution to the problem of social order, arguing that the rule of the Leviathan would only lead to further fights and conflicts. Instead, the only rightful authority could come from a collective body made of the people, and dictating the laws through a general will. The general will is representing the opinions and moral values of all citizens within a society to questions of general interest and is captured through majority vote. If all individuals of a society share the same beliefs and values, the general will is leading to lasting social order. Smith, on the other hand, disagrees with Hobbes and Rousseau in fundamental ways. He believes that humans have always been social beings and have always cooperated in order to reach common goals in daily life. These cooperative activities do not result from a pro-social predisposition, but from the self-interest of humans. The self-interest of humans must therefore not be kept under control, as it is the basis of social order. Smith also argues that humans do not only have a natural right to self-preservation, but also to live in freedom. A society can only reach peace and stability as long as these two natural rights are guaranteed. This condition is best met when the actions of free individuals, following solely their self-interests, are coordinated through an invisible hand on a free market. A good government should therefore only interfere as little as possible into the daily business of its people, allowing the market mechanism to guarantee for the optimal outcome. Although the three scholars had fundamentally differing views on human nature, the natural rights of humans as well as key aspects of the society, they took a similar approach, comparing humans in their primitive form with humans in their civilized form:

> "Optimist and pessimist alike agreed that civilisation was to be defined in terms of this distinction between nature and culture and by the movement of the latter away from the former. [...] This then is modernity's key foundational narrative. It has been employed in numerous ways and to justify diverse political ends, from monarchism to regicide, but its ontological status remains ambiguous." (Smith 2002, p. 408)

As their work is so influential, I provide a detailed description of the basic ideas of the three scholars on the problem of social order in chapter 2 regarding my philosophical foundations: "Wer sich auf Aristoteles oder Platon, auf Hobbes oder Locke, auf Rousseau oder Kant, auf Marx oder Max Weber beruft, sollte zumindest wissen, wovon er spricht." (Nonnenmacher 1989, p. 4).
Philosophy is a central element of human knowledge, because it strongly influences the way people think and as it shaped the different dogmatic traditions that influence science today. Scientific investigation is however based upon scientific theories and not upon philosophical ideas. The central tool of theoretical investigation I use in my work is game theory. Game theory provides a mathematical framework allowing to analyse situations in which a number of actors interact, thereby affecting each other's welfare. Game theory can therefore be used to analyse a wide range of situations involving strategic interactions between individuals. Potential candidates for a game-

theoretical analysis are for example the family planning of couples, the price setting of companies, the level of aggressiveness displayed by individuals involved in a fight, or the effect of a new criminal law on crime rates. Based upon a few simple assumptions, a game-theoretical analysis allows to deduce the best options available for actors in a given situation and to make predictions on the most likely outcome. In social science, game theory is frequently applied to the problem of social order. However, in contrast to the problem of social order discussed in political philosophy, the problem of social order of interest in game theory is more general and centres around cooperation. More specifically, it asks how cooperation can emerge in situations where the incentives should drive rational actors into defection? Situations in which the rationality of individuals leads to sub-optimal outcomes at the group level are known as social dilemma situations. The analysis of social dilemma situations is of high relevance, because political, economic and social problems frequently occur in such social dilemma situations. Unsurprisingly, concepts and tools used to analyse social dilemma situations in game theory are linked to the works of Hobbes, Rousseau and Smith. While the classical scholars formulated influential and ground-breaking ideas, they did not use a consistent, deductive theoretical framework. By incorporating their ideas into a game-theoretical framework, the structure underlying their arguments can be formalized, allowing to gain more general insights through a more consistent analysis. The most basic social dilemma in game theory, for example the prisoner's dilemma, is characterized as a formalization of Hobbes' state of nature and is used to demonstrate, among others, the limits of rational cooperation. The stag hunt game, another important game-theoretical model, formalizes a short story of Rousseau and is used to explain the evolutionary path of societies towards civilization. Although game theory can be applied to a wide range of situations, each single game-theoretical analysis is interested in uncovering the presence of equilibria in the respective game. Such a game-theoretical equilibrium is an analytical equivalent to Smiths' metaphor of the invisible hand. In chapter 3 regarding my theoretical foundations, I describe game-theoretical concepts that are important for the understanding of my work and show how the ideas of Hobbes, Rousseau and Smith are incorporated into a game-theoretical framework.

The tragedy of the common is a very prominent social dilemma. In short, the tragedy of the commons refers to situations where humans overexploit a natural resource they are relying on, thereby destroying their livelihood. As long as a better outcome would have been possible, for example by exploiting the resource in a more sustainable way, the overexploitation of natural resources is a problem of social order and a social dilemma. In my fourth chapter, I first give a brief description of the fundamental importance of natural resources for the development of human societies. Not only minerals and fossil fuels are essential for the well-being of humans. Humanity would also not have survived without wildlife and ecosystem services, for example clean air and clean water. Population and economic growth are closely linked to the use of natural resources: increases in per capita resource use leads to increases in per capita population growth. However, at some point, the overexploitation of a natural resource leads to a collapse of society if the resource needed is not available anymore. Such a collapse occurring due to overexploitation of natural resources is a recurring phenomenon in human history, and contemporary societies live in a constant fear of a societal collapse due to their unsustainable use of natural resources:

> "Contemporary unease over natural resource scarcity, energy insecurity, global war-

> ming and other environmental consequences is to be expected, given the rapid rate of environmental change caused by the global economy and human populations over the twentieth century." (Barbier 2011, pp. 4-5)

The tragedy of the commons, as a game-theoretical model, has a specific structure and relies on some basic assumptions. The main assumption underlying the tragedy of the commons refers to the specific economic characteristics of common goods. Common goods are goods that are possessed by a group of people, but the consumption of the good cannot be shared. This means that the consumption of one unit of the good by one individual excludes other individuals from consuming this specific unit. In a narrow interpretation, the tragedy of the commons is only applicable to the exploitation of common goods. The main solutions to the tragedy of the commons can be linked directly to the works of Hobbes, Rousseau and Smith, promoting either strong state regulations, community rights, and normative values, or the enforcement of market mechanisms in situations where these are missing or only weakly implemented. I apply the different mechanisms proposed by Hobbes, Rousseau and Smith to the analysis of two distinct aspects of natural resource use. The first concerns the sustainability of natural resource use. The second concerns the fair allocation of a natural resource among a group of individuals who share the resource. I deduce and discuss hypothesis related to drivers of sustainable natural resource use and fair natural resource allocation from the works of Hobbes, Rousseau and Smith. These hypotheses are then put to an empirical test in my two empirical studies in chapters 7 and 8.

Besides an underlying theory and theoretical predictions, a scientific investigation relies on a sound empirical basis. Although Hobbes, Rousseau and Smith made big claims about mechanisms underlying phenomena observed in the real world, they did not follow a data-driven approach in their work. Instead, they mainly relied on their capacity to reason about the world and the perception they had of it. To do justice to the scholars, I must admit that some rudimentary calculations based on observed quantities can be found in Rousseau's and Smith's work. They must have felt the necessity of a data-driven scientific approach, which was strongly advocated by David Hume:

> "If we take in our hand any volume; of divinity or school metaphysics, for instance; let us ask, *Does it contain any abstract reasoning concerning quantity or number?* No. *Does it contain any experimental reasoning concerning matter of fact and existence?* No. Commit it then to the flames: for it can contain nothing but sophistry and illusion." (Hume 2007 [1748], p. 144, italics as in the original)

However, they lacked the statistical tools, the understanding of the logical structure guiding causal inference, as well as the corresponding scientific ideology. These evolved after their time and are discussed in chapter 5 on my methodical foundations. On the other hand, the comparative approach of classical scholars has proven fruitful and is being applied in the contemporary science of human nature approach. Similarly to the classical scholars, the main focus of the contemporary science of human nature approach is based on the comparison of humans from different cultures. The contemporary science of the approach on the human nature highlights cross-cultural studies, explicitly including samples of non-Western cultures. This is important, because although Western societies are overrepresented in scientific samples, they do not represent humanity as a whole. We can only hope to make reliable inferences about a common human nature by comparing humans from different cultural groups. This is, however, no trivial enterprise, because even the concept of causality is highly controversial. Different positions related to causal inference can be linked to the ground-breaking work of Hume's "An Enquiry Concerning Human Understanding". I discuss these positions putting a special focus on counterfactual causality. The concept of counterfactual causality provides the foundation for experimental research and is the most relevant concept of causality for my work. I furthermore shortly discuss Popper's falsificationism, as it provides the epistemological foundation for statistical hypotheses testing and represents the position I am following in my work. The methodology underlying statistical hypotheses testing was developed by the frequentist school to statistical inference. I build upon statistical hypotheses testing to describe different types of regression models in a more detailed manner and discuss the main approaches used when confronted with the question of which variables and which regression models to use for statistical inference. I complete my methodological chapter with a simulation study that evaluates the performance of different analytical tools of statistical inference. Based on a simulated experimental data, modelling different types of outcome variables and treatment effects, I show that mixed effects regression models provide the most reliable and accurate estimates for the true treatment effect. Consequently, I used mixed effects regression models as my main analytical tool for statistical inference in my two empirical studies in chapters 7 and 8.

In chapter 6, I describe the extensive field work I conducted in Guinea during a period of nine months. I describe the institutional framework my fieldwork was embedded in and give a qualitative report of my field work. In this report, I explain different important aspects of my field work, using a number of images for illustrative purpose. These aspects include the preparation and logistics of the field work, the people working with me, the equipment needed, the living conditions in the field, as well as the different dimensions of the human population and their environment I was especially interested in. For my field work, I relied on a sample of Malinke and Fulbe people in a remote region of rural Guinea. This sample is interesting, because it is made of people living in traditional, small-scale societies that are partly in transition to more complex and socially stratified societies and belong to two broader cultural groups. The material I collected during this field work provides the foundation for the empirical test of my theoretical hypotheses.

In my first empirical study, chapter 7, I linked the data I collected during my field work with biological transect data on wild mammal abundance collected in the same area during the same period which allowed for an estimation of the influence of the human population on the wild mammals living in the same area. Considering wild mammals in the area as a natural resource, I tested the predictive value of factors considered as important by Hobbes, Rousseau and Smith for explaining the observed distribution of wild mammals. This allowed me to determine whether these factors favoured a sustainable natural resource use or not. In my second empirical study, chapter 8, I conducted a field experiment with the human population in the area. In this experiment, the participating subjects shared a natural resource they held in common. The outcome of interest was the allocation of the resource among the different subjects. More specifically, I was interested in identifying factors favouring fair sharing of the resource in the experiment. Again, by linking the experimental data with other data I had collected in the study area, I tested the predictive value of factors considered important by Hobbes, Rousseau and Smith in explaining fair sharing.

I conclude my work with a discussion summarizing the results of my empirical studies related to the works of Hobbes, Rousseau and Smith. I discuss and evaluate to what extent the work of the three classical scholars is still valuable today and helps us to understand observed patterns of natural resource use in a context they were clearly not considering (chapter 9). I close my discussion by generalizing the results from my field studies to a more global context and applying the lessons learned to the global environmental crises of global species loss and global warming.

Chapter 2

Philosophical foundation

Western philosophy has strongly influenced the contemporary perception of humans and society. Different political and scientifical schools are closely linked to dogmatic traditions reaching back to western philosophers (Russel 2012). The main representants of the most influential modern dogmatic traditions are Thomas Hobbes (1588-1679), Jean-Jacques Rousseau (1712-1778) and Adam Smith (1723-1790). Their ideas related to the problem of social order and their concepts of the “Leviation”, the “general will” and the “invisible hand” still form the political-philosophical core of today’s consideration on society (Nonnenmacher 1989). Most importantly, these scholars had differing views on the reasons responsible for violence and instability in society and proposed different institutional solutions to reach security and stability. The fragility of peace and stability in human societies is known as the problem of social order in political philosophy. In this chapter, I provide a detailed description of the three scholars’ thoughts and ideas related to the problem of social order and the institutional mechanisms they proposed as solutions to this problem. I close the chapter with a short discussion of their works and their relevance for sociology.

2.1 Thomas Hobbes

Thomas Hobbes formulated the first systematic work on political thoughts in modern times and influenced nearly all political theories afterwards (Nonnenmacher 1989, p. 13). His most influential work "Leviathan or the Matter, Forme and Power of a Commonwealth Ecclesiastical and Civil" legitimates absolutism and authoritarianism, highlighting the importance of an absolute ruler and coercive strenght to enforce social order (Nonnenmacher 1989, pp. 45-49; Russel 2012, pp.563-564). Ultimately, policies promoting strong leadership can be linked to Hobbes. This is Hobbes’ political legacy. His major philosophical legacy was his conception of the “state of nature”. He argued that humans were no social beings by nature and asked how life in society could be reached, without recurring to greater metaphysical goods, as was done by philosophers before his time: “It is true, that certain living creatures, as Bees and Ants, live sociably one with another [...] and therefore some man may perhaps desire to know, why Man-kind cannot do the same.” (Hobbes 2012 [1651], p. 119). The (Hobbesian) problem of order had a lasting influence on political philosophy after his time: all important works of political philosophy discuss the Hobbesian problem of order and the Leviathan (Ellis 1971, p. 692; Nonnenmacher 1989). In this section, I first introduce the problem of social order as described by Hobbes in his state of nature, followed by the description of the solution he suggested to overcome the problem of social order, which is known as the Leviathan.

2.1.1 The state of nature

Hobbes' state of nature describes a period when people live in brutal anarchy, without a government. In such a state, everyone has the right to use violence, and people live in fear of dying a violent death, a direct consequence of human nature and natural rights. Hobbes describes humans as being insatiable in their desires. The use of power is the only way they have to fulfil their desires and humans are therefore continuously looking for means to increase their power. As all humans are equally trying to satisfy their insatiable desires (Hobbes 2012 [1651], pp. 70-86), they face three main reasons for conflicts:

> "So that in the nature of man, we find three principall causes of quarrel. First, Competition; Secondly, Diffidence; Thirdly, Glory. The first, maketh men invade for Gain; the second, for Safety; and the third, for Reputation. The first use Violence, to make themselves Masters of other mens persons, wives, children and cattell; the second, to defend them; the third, for trifles, as a word, a smile, a different opinion, and any other signe of undervalue, either direct in their Persons, of by reflexion in their Kindred, their Friends, their Nation, their Profession, or their Name." (Hobbes 2012 [1651], p. 88).

The main reason for a conflict, i.e. competition, relates to the sparse resources of the material world. As the desires of humans are insatiable, the material world will however always be sparse. Even if a solution to the sparseness of the material world was found, this would not put an end to conflicts, as the conflicts between humans also extend to the immaterial world: even a smile can lead to conflicts. Finally, in such a state, where humans fear being mastered by other humans, just like cattle, a preemptive strike is the most effective mean to survive:

> "And from this diffidence of one another, there is no way for any man to secure himselfe, so reasonable, as Anticipation; that is, by force, or wiles, to master the persons of all men he can, so long, till he see no other power great enough to endanger him: And this is no more than his own conservation requireth, and is generally allowed." (Hobbes 2012 [1651], pp. 87-88).

The famous metaphor used by Hobbes to describe the state of nature as a war of all against all however, does not mean that humans are continuously fighting against each other. The state of nature is more precisely characterized by constant insecurity and fear, because of the knowledge that fights and wars might erupt at any time and for any reason (Hobbes 2012 [1651], pp. 88-89). According to Hobbes, the natural right of every man is self-preservation. In the state of nature, this means that everyone has the right to everything in order to guarantee his self-preservation:

> "It followeth, that in such a condition, every man has a Right to every thing; even to one anothers body. And therefore, as long as thin naturall Right of every man to every thing endureth, there can be no security to any man." (Hobbes 2012 [1651], p. 91).

Although there are laws of nature which could lead to peace if they were applied (Hobbes cites 19 such rules) (Hobbes 2012 [1651], pp. 92-109), none of these rules really matter in the state of nature, as they are not binding: "[...] Covenants, without the Sword, are but Words, and of no strength to secure a man at all." (Hobbes 2012 [1651], p. 117). The state of nature has dramatic consequences for humanity as it undermines cooperation between people, hindering the emergence of society, science, arts, as well as any economic development:

> "In such condition, there is no place for Industry; because the fruit thereof is uncertain: and consequently no Culture of the Earth; no Navigation, nor use of the commodities that may be imported by Sea; no commodious Building; no Instruments of moving, and removing such things as require much force; no Knowledge of the face of the Earth; no account of Time; no Arts; no Letters; no Society; and which is worst of all, continuall feare, and danger of violent death; And the life of man, solitary, poore, nasty, brutish, and short." (Hobbes 2012 [1651], p. 89).

Hobbes' state of nature is simple, compelling and based solely upon a few basic assumptions. The selfish, impulsive and voracious nature of humans, combined with their natural right to do anything in order to secure their self-preservation, supports a state of brutal anarchy in which nothing is safe and secured.

2.1.2 The Leviathan

Hobbes claims that the destiny of mankind is to overcome the state of nature by building states in which people live peacefully and work together in order to reach material wealth. Such a state can however only be built through the subordination of all man under the will of one sovereign. The humans need to concede their natural right and their power to one external authority:

> "The only way to erect such a Common Power, as may be able to defend them from the invasion of Forraigners, and the injuries of one another, and thereby to secure them in such sort, as that by their owne industrie, and by the fruites of the Earth, they may nourish themselves and live contentedly; is, to conferre all their power and strength upon one Man, or upon one Asselmbly of men, that may reduce all their Wills, by plurality of voices, unto one Will [...]" (Hobbes 2012 [1651], p. 120).

Only a very strong motive can induce people, who love their freedom and the reign over other people, to accept the rule of someone else. This motive is the fear of death, which is omnipresent in the state of nature: "The Passions that encline men to Peace, are Feare of Death [...]" (Hobbes 2012 [1651], p. 90). The subordination of all men under one will happen by the means of a social contract: "*I Authorise and give up my Rigth of Governing my selfe, to this Man, or to this Assembly*

of men, on this condition, that thou give up thy Right to him, and Authorise all his Actions in like manner." (Hobbes 2012 [1651], p. 120, italics as in the original). The result of this social contract is described by Hobbes in the following way: "For by Art is created that great LEVIATHAN called a COMMON-Wealth, or STATE, (in latine CIVITAS) which is but an Artificiall Man [...]" (Hobbes 2012 [1651], p. 9, upper cases as in the original). The consequences of this simple contract are huge. The state of nature is put to an end, because only the Leviathan has the right to use violence. In detail, this means that the sovereign is given the right to represent the subjects, to decide on the necessary means for peace and defense, to decide on the doctrines which are intended for the subjects, to decide on the property rights of the subjects, to dictate the laws which the subjects have to obey, to make war and peace as he likes to, to choose all ministers, magistrates, counselors and officers, to punish and reward subjects as he pleases and to create new laws. All those rights are inseparable and indivisible. No subject has the right to question the actions of the sovereign, to punish the sovereign, to change the sovereign or to be freed from the sovereign (Hobbes 2012 [1651], p. 121-128). If one subject however objects with the sovereign, he is put back into the state of nature and can "[...] be destroyed by the rest [...]" (Hobbes 2012 [1651], p. 123). The only duty of the Leviathan is to get the subjects out of the state of nature and to relieve them from their fear of a violent death. To this end, the Leviathan needs to defend the subjects from the aggressions and offences of others. The measures described above serve this sole purpose. As the natural right of anyone in the world is to survive, subjects have the right to disobey the sovereign only if he commands them to hurt or kill themselves or to act in a way that could directly harm themselves. They are furthermore not bound to confess against themselves if interrogated by the sovereign (Hobbes 2012 [1651], p. 151).
In Hobbes, the selfishness of humans in the state of nature hinders the emergence of trust at the lowest levels of human interactions, thereby hindering cooperative activities that could lead to stable and peaceful societies. The state of nature can only be overcome if people unite and create a strong absolutist state by giving up their power and their natural right. However, the participation of people ends there. After having created the absolutist state, humans have no power anymore and are subject to its rules. On the other hand, this condition is necessary for trust to emerge, because only in this way arising threats through human selfishness are banned.

2.2 Jean-Jacques Rousseau

Jean-Jacques Rousseau formulated the first radical criticism of the commercial society (Nonnenmacher 1989, p. 194). He is seen as the founder of romanticism (Russel 2012, p. 693) and was the philosopher of the French revolution (Rousseau 1977 [1754], p. 18; Nonnenmacher 1989, p. 194). Engels argued that Rousseau made use of the dialectical method and Marxist arguments before Hegel and Marx were even born (Rousseau 1977 [1754], pp. 37-39). On the other hand, his work is full of contradictions, and he is also admired by conservatives and reactionaries alike (Nonnenmacher 1989, p. 194). Russel claims that Hitler was an aftereffect of Rousseau (2012, p. 693). In his first important work, “Discours sur les sciences et les arts”, Rousseau criticized the decadence of the commercial society (Nonnenmacher 1989, p. 194). His second important work, “De l’inégalité parmis les hommes”, describes the co-evolution of property, inequality and society. In his most famous work, “Du contrat social”, Rousseau elabourates the principles of constitutional law and argues that only a government subordinated to the general will of the people is legitimate. It is one of the most read and most influential works of political philosophy. All political ideologies of modern times have been associated with it (Nonnenmacher 1989, p. 243-244). In this section, I first describe the natural state of man, Rousseau’s counterargument to Hobbes’ state of nature. Then, I discuss Rousseau’s evolutionary view on human societies, his description of the problem of social order, and the solution he suggests.

2.2.1 The natural state of man

Rousseau builds upon an evolutionary theory of human societies. At the beginning, humans were solitary animals without any social institution. This is Rousseau’s natural state of man.
Rousseau argued that the human nature cannot serve as the foundation for any right and law in society. In this point, he followed Hobbes (Rousseau 1977 [1754], p. 94). However, he argued that humans in the state of nature described by Hobbes (section 2.1.1) were already socialized and far from their true state of nature. Hobbes’ conclusions about the human nature must therefore be wrong (Rousseau 1977 [1754], p. 116). One must imagine a human being without any social institution in order to be able to have a picture of the human in his state of nature: the human as some unsocial animal species. As such, humans are subject to natural selection that supports fit individuals and kills all others. The human animal has no capacity of reasoning and his only needs are food, rest and sexual reproduction . He is a solitary animal without any need for the company and help of other humans, and without the knowledge of language. The human animal is neither good nor bad, as those are moral qualities not known in nature and only useful for the life in society (Rousseau 1977 [1754], pp. 72-95). In this state of nature, time passes by without changes and humans live the life of self-sufficient, solitary animals, without tradition, culture, science or economic progress:

> “Concluons qu’errant dans les forêts, sans industrie, sans parole, sans domicile, sans guerre et sans liaison, sans nul besoin de ses semblables comme sans nul désir de leur nuire, peut-être même sans jamais en reconnaître aucun individuellement, l’homme sauvage, sujet à peu de passions, et se suffisant à lui-même, n’avait que les sentiments et les lumières propres à cet état; qu’il ne sentait que ses vrais besoins, ne regardait que ce qu’il croyait avoir intérêt de voir, et que son intelligence ne faisait pas plus de progrès que sa vanité. Si par hasard il faisait quelque découverte, il pouvait d’autant moins la communiquer qu’il ne reconnaissait pas même ses enfants. L’art périssait avec l’inventeur. Il n’y avait ni éducation, ni progrès; les générations se multipliaient inutilement; et, chacune partant toujours du même point, les siècles s’écoulaient dans toute la grossièreté des premiers âges; l’espèce était déjà vieille, et l’homme restait toujours enfant.” (Rousseau 1977 [1754], p. 103).

However, the human animal differs from all other animals in three important aspects. First, his behaviour is not completely determined by instincts, but he has also a free will. Second, he can therefore adapt to all kind of situations. Third, he is able to improve himself (Rousseau 1977 [1754], pp. 72-80). These properties, which are only found in humans among all animals, are the foundation for an evolutionary process which will transform humans, their environment and the way they live.

In Rousseau, the natural state of man is characterized by the lack of any social institution. Humans are best conceived as a solitary animal species in the natural state of man. As long as this state persists, there is no problem of social order, because the live of humans is only subject to the rules of natural selection. As there are no social institutions in nature, nature cannot serve as the foundation for society.

2.2.2 From nature to society

Humans did however not stay in the natural state of man, but sequentially developed into social beings. This evolution included different stages, and at each of these stages, humans built new social institutions. According to Rousseau (1977 [1754], pp. 109-110), the process that led to the emergence of complex societies took ages and entirely changed humans and their way of living. This process can be described in five major steps as follows.

Living in groups The most significant obstacle to the building of societies among humans was the solitary, self-sufficient lifestyle of humans in their natural state (section 2.2.1). The growth of the human population and their spread across the world, combined with major catastrophic events, like earthquakes, floods or deluges, eventually forced humans to share the same territory. Humans then started to live in groups and experienced the advantages that could be reached by working together. These first cooperative activities focused on security and economic concerns and were based on mutual agreements (Rousseau 1977 [1754], pp. 109-114).

The first societies The institution of property was the founding moment of society: "Le premier qui ayant enclos un terrain s'avisa de dire : Ceci est à moi, et trouva des gens assez simples pour le croire, fut le vrai fondateur de la société civile." (Rousseau 1977 [1754], p. 108). In this first phase of society building, humans started to reason about measures to increase their security. They also realized that they were superior to other animals. Language became necessary to coordinate their activities, and they started to live in families: they built homes in which women and men lived together with their children. This was the beginning of a first revolution with broad implications: the social institution of family, basic notions of property, the sexual division of labour, as well as conjugal and parental love emerged. On the other hand, property and love also led to quarrels, fights, jealousy, as well as anger among people, and the human species started to soften. Once humans became used to living together, the ties and relationships between them became so strong and important that everyone wanted to be treated with respect. Contempt had to be punished and humans became cruel and bloodthirsty, because the best protection one could find against any offense committed by others was a severe punishment. This is the stage of development most "peuples sauvages" (small scale, non-European societies at the time of Rousseau) had reached. Rousseau argued that this stage of development was best for mankind: while being free and independent, as if they had been in their natural state, they still enjoyed the benefits of a life in society. This is due to the fact that everyone was independent and responsible for his own material wealth, and the inequality between humans was still mainly determined by the physical differences between them. He argued that all further development would only improve the condition of individuals at the expense of the species (Rousseau 1977 [1754], pp. 110-117).

Inequality and conflicts However, mankind did not stay at the development level of "peuples sauvages", but invented agriculture and metallurgy. These inventions required the division of labour necessary and humans were now able to produce more than they needed. On the other hand, they were not free anymore, because they depended on others and had to work for others. The inequality between humans increased wide above a level justified by the physical differences between them. The land was divided among the appropriators and when they were recognized as the owners of their land by all others, the first laws of justice were established in order to protect their property. The legal property led to violent conflicts because of the rivalry, the competition and the differing interests of the people. All wanted to make profit at the expense of others and when the whole land was divided, the only way to increase one's property was to take it away from others (Rousseau 1977 [1754], pp. 117-122). Society, at this stage of development, was in a constant state of war:

> "Il s'élevait entre le droit du plus fort et le droit du premier occupant un conflit perpétuel qui ne se terminait que par des combats et des meurtres *(q)*. La société naissante fit place au plus horrible état de guerre [...]" (Rousseau 1977 [1754], p. 123, italics as in the original).

The first governments This state of war was especially unbearable to the wealthy people, as not only their life was at peril, but also their property. The solution they found to end this state of war was to bundle their forces in order to create a state that would protect and defend all members of the society through wise laws and the necessary power to do so. The governments of these states were, however, clearly in favour of the rich people. The natural freedom that people still enjoyed up to this point was however irrevocably abolished. Property and inequality were fixed as unalterable rights and all people had the duty to work and to serve the wealthy and the powerful. The form of the first governments depended on the inequality among the subjects in the area where the government was founded: if one man owned everything, then he was elected as the unique governor and the government was a monarchy; if a group of people among the subjects owned more than all others together, then they were elected together to form an aristocratic government; finally, if there was no big difference among the subjects, they kept the government in common and formed a democracy. The first governments were created by the subjects with the aim to serve and protect their freedom (Rousseau 1977 [1754], pp. 124-136).

The natural state of society While all governments are at first legitimate and elected, with wealth, merit, and age as main criteria for a government position, the people in power become accustomed to the rules and start to consider the state as their own property. The same reason that necessitates a state, the conflicts over properties, also leads to conflicts over state control control. Eventually, one particular seizes the control over the whole state, and the society ends in despotism. Sooner or later, all societies end in despotism. Despotism is the natural state of the society. This state is similar to the natural state of man in important aspects. The equality between humans is restored: just like in the natural state, where the survival of humans depends on natural selection, the survival of humans in the natural state of the society depends on the goodwill of the despot. While natural selection supports the fit individuals and kills the others in the natural state of man, the society supports the fit individuals and kills the others in the natural state of society (Rousseau 1977 [1754], pp. 129-142). However, while in the natural state of man, fitness is purely defined by the physical attributes of individuals, in the society, fitness is defined by social institutions. This is why in some societies, physically inferior people command physically superior people, a situation which would never occur in the natural state of man:

> "Il suit encore que l'inégalité morale, autorisée par le seul droit positif, est contraire au droit naturel toutes les fois qu'elle ne concourt pas en même proportion avec l'inégalité physique; distinction qui détermine suffisamment ce qu'on doit penser à cet égard de la sorte d'inégalité qui règne parmi tous les peuples policés; puisqu'il est manifestement contre la loi de nature, de quelque manière qu'on la définisse, qu'un enfant commande à un vieillard, qu'un imbécile conduise un homme sage, et qu'une poignée de gens regorge de superfluités, tandis que la multitude affamée manque du nécessaire." (Rousseau 1977 [1754], p. 145)

While the problem of social order does not occur in the natural state of man, it becomes relevant the more humans build social institutions and become interdependent. This is essentially due to the fact that humans in society are not only subject to natural selection but also to social selection. The more this social influence increases, the more the problem of social order threatens the stability of society. At the final stage of the evolution of society, humans are entirely socialized, with a government, a legal system, private property, and division of labour. At this final stage of development, which is described by Rousseau as the natural state of society, society is constantly threatened to sink into nepotism, as individuals fight for the control over the means of power. According to Rousseau, individual self-interest is the root for life in society, but at the same time constantly threatens the stability of society. The only solution to reach stability is to build a government legitimized and controlled by the people. This is the topic of the next section on the social contract.

2.2.3 The social contract

Rousseau argued that the foundation for social order was to be found in social conventions and not in nature (Rousseau 1966 [1762], p. 41). Similarly to Hobbes (section 2.1.1), he argued that humans needed to associate and build societies if they wanted to survive. However, in contrast to Hobbes (section 2.1.2), he claimed that it was inconceivable that humans gave up their freedom in order to live as slaves. Such a contract, where one party would be given all available means and the duty to command, while the others had to obey, could not serve as the foundation for society. Instead, he argued that humans would only be willing to unite with others and build a society, if they were afterwards not only more secure and prosperous, but also as free as before (Rousseau 1966 [1762], pp. 50-51 and Rousseau 1966 [1762], pp. 124-138).

The state as a collective body This problem is solved by creating a collective body which is made up of all single members and which is guided by the general will of its members:

> "*Chacun de nous met en commun sa personne et toute sa puissance sous la suprême direction de la volonté générale ; et nous recevons en corps chaque membre comme partie indivisible du tout*." (Rousseau 1966 [1762], pp. 51-52, italics as in the original).

This collective body, which unites the resources and strengths of all individual members, is the state. The united members are the people, and the single members are subjects when subjected to the rule of the state, and are citizens when taking part in a sovereign act. In such a state, the people is the sovereign. After the state has been built according to the principles stated in the social contract, no one can offend any member of the state without offending the state and the state cannot be offended without having the members of the state also being offended (Rousseau 1966 [1762], pp. 52-54). In this way, all members have a higher likelihood to survive with the state than without the state. Furthermore, as the state is made up of all members of the people, it cannot have any particular interest, which is against the interest of the people. This condition guarantees that no member of the state is subject to any rule he did not consent to.

The general will The state and all its actions are the result of the general will of its people. The general will represents the common interest of the people and needs to be formulated in general, abstract conventions. Those conventions have the characteristics of laws which are written down in a constitution and define the terms of cohabitation in and with the state. When the state is founded and its constitution drafted, all members must agree to the constitution. Those who do not agree do not belong to the state and have to leave its territory. Afterwards, new legislations only need the approval of the majority of the citizens in order to respond to the general will (Rousseau 1966 [1762], pp. 63-150).

However, when laws are implemented, the general case needs to be applied to a particular case. In order to ensure that the laws are always abstract conventions related to general affairs, it is important that those responsible for the implementation of the laws do not have the power of legislation. Otherwise, legislation might become influenced by particular interests and cease to reflect the general will (Rousseau 1966 [1762], p. 78).

The government While the power of legislation belongs to the people, the power of implementing the rule of law must therefore be delegated to a public agent. It is the duty of this public agent, the government, to apply the laws in exactly the same way as stated by the general will. The people in charge of this duty are the magistrates. When the magistrates are made up of the majority of the citizens, the government is democratic, when the magistrates are made up of the minority of the citizens, the government is aristocratic, and when there is only one magistrate, it is a monarchic government (Rousseau 1966 [1762], pp. 97-105).

The government can be conceptualized as a second collective body within the collective body of the state. As long as the government abides to the constitution and follows the general will, the rule of law is guaranteed. However, as the magistrates in the government have their own particular interests, the state needs to invest resources to control the magistrates and ensure that they do not abuse their position of power to impose their own particular interest (Rousseau 1966 [1762], pp.

101-103).

The state in private ownership As the magistrates continually try to enforce their particular interests and to use the power of the state for their own purpose, they will eventually be able to take over the state. As soon as this happens, the social contract is broken and the citizens of the state are not obliged by their consent to obey the laws but are forced by the ruler to do so (Rousseau 1966 [1762], pp. 125-127). In the long run, all societies end up in despotism. This is due to the fact that, while the incentives to use the power of the state to pursue particular interests are very strong, the sovereign only has limited means to prevent this takeover: "Telle est la pente naturelle et inéviatble des gouvernements les mieux constitués. Si Sparte et Rome ont péri, quel État peut espérer de durer toujours?" (Rousseau 1966 [1762], p. 128).
According to Rousseau, the stability and peace of a society can only be guaranteed through a collective regime, where the government and the state is in control of the people. In this state, all citizens decide on all matters of general interest. However, and this is the key point, these collective decisions will only lead to social order as long as the citizens speak with one voice. According to Rousseau, diverging interests would only weaken the sovereing, leading to fights and instability. It is therefore essential for the peace and stability to foster a strong and homogeneous general will.

2.2.4 The reign of the general will

We have seen in the last section that Rousseau strongly argued in favour of the general will as the main garant for social order. In this section, I describe the means available to form and support a strong and powerful general will.

Common norms foster the general will According to Rousseau, social order primarily depends on the capacity of the people of a society to create a state and to express a general will which is strong and clear enough to dispose of the means of the state and to control the government. Although he clearly had a pessimistic view on the capacity of people to express such a general will and restrain particular interests, he argued that the norms of the people can promote such a general will:

> "A ces trois sortes de lois, il s'en joint une quatrième, la plus importante de toutes; qui ne se grave ni sur le marbre ni sur l'airain, mais dans les coeurs des citoyens; qui fait la véritable constitution de l'État; qui prend tous les jours de nouvelles forces; qui, lorsque les autres lois vieillissent ou s'éteignent, les ranime ou les supplée, conserve un peuple dans l'esprit de son institution, et substitue insensiblement la force de l'habitude à celle de l'autorité. Je parle des moeurs, des coutumes, et surtout de l'opinion; partie inconnue à nos politiques, mais de laquelle dépend le succès de toutes les autres : partie dont le grand législateur s'occupe en secret, tandis qu'il paraît se borner à des règlements particuliers qui ne sont que le cintre de la voûte, dont les moeurs, plus lentes à naître, forment enfin l'inébranlable clef." (Rousseau 1966 [1762], p. 91).

The more the laws of the state coincide with the norms of its members, the stronger and the more durable the state will be. However, when the norms vary among the citizens of the state, there is no complete agreement on general affairs and the state needs to make use of coercive measures to impose social order (Rousseau 1966 [1762], p. 99). In a state where all citizens share the same norms, there is unanimity on all general affairs, the individuals' interests coincide with the general will and it is impossible to impose any particular interest on the state. In contrast, when there is no unanimity on general affairs, not all individuals' interests coincide with the general will and it becomes possible to impose laws which only serve particular interests, compromising the rule of the general will (Rousseau 1966 [1762], pp. 146-147).

Using norms to rule It follows from these thoughts that the state needs to rule mainly by making use of, shaping and controlling the norms of its members, using laws only to support these norms and applying censorship to conserve these norms (Rousseau 1966 [1762], pp. 145-146). Following the example of the best state ever, i.e. Sparta, the state has to teach the relevant norms to its people (Rousseau 1977 [1754], p. 138), prohibitting all activities which could lead to changes in the believes and norms of the people, like science and arts, and luxury, which corrupts all norms (Rousseau 1964 [1750], pp. 12-21). Finally, the state should actively hinder the emergence of any sub-society or interest group, making sure that general affairs are only decided among autonomous citizens following their own personal interests (Rousseau 1966 [1762], p. 67).

2.3 Adam Smith

Adam Smith was the first scholar to build a coherent economic theory which is still relevant today (Nonnenmacher 1989, p.144). He is a prominent representative of economic liberalism (Nonnenmacher 1989, p.121), who emphases the importance of the unintended consequences of individual actions for the society as a whole. Smith's first important publication, the "Theory of moral sentiments" is a social-psychological work, explaining the emergence of moral norms. It was highly appreciated during his lifetime (Nonnenmacher 1989, p.161). The "Lectures on Justice, Police, Revenue and Arms" is a report of lectures by Adam Smith. The report was made by a student and already contained the substance of "An inquiry into the nature and causes of the wealth of nations" (Smith 1896 [1763], p. xiv). The "Wealth of nations" is considered as the bible of economic liberalism and is his most prominent work today (Nonnenmacher 1989, p.121). In the wealth of nations, Smith elabourates the mechanism of the invisible hand. In this section, I first describe Smith's evolutionary perspective on society. According to Smith, the evolution of society is triggered by two simple mechanisms and undergoes four major stages. Then, I discuss the economic definition of the problem of social order, as well as its economic solution as suggested by Smith.

2.3.1 The evolution of society

In contrast to Hobbes (section 2.1) and Rousseau (section 2.2), Smith argued that humans have always been social beings. In the following, I will briefly describe Smiths evolutionary perspective on society.

Humans as social beings Unlike Hobbes (section 2.1) and Rousseau (section 2.2), Smith believed that humans had always lived in societies: "It is thus that man, who can subsist only in society, was fitted by nature to that situation for which he was made." (Smith 1986 [1759], p. 132). He clearly negated the existence of a state of nature and discredited the idea that a social contract laid the foundation for social order. Instead, he argued that there are two omnipresent factors in human societies favouring the emergence of social order. The first factor is authority. Authority may be based on age or superior abilities, which are the natural sources of authority, as well as on wealth or descending from an important family, which are the social sources of authority (Smith 1896 [1763], pp. 2-12). Ultimately, "Upon this disposition of mankind, to go along with all the passions of the rich and the powerful, is founded the distinction of ranks, and the order of society." (Smith 1986 [1759], p. 79). The second factor is utility: people form societies because they benefit from it (Smith 1896 [1763], p. 10). Like Hobbes (section 2.1), Adam Smith claimed that all people want to survive and that survival is a natural right. He furthermore added freedom as a second natural right (Smith 1896 [1763], p. 8). The ability to guarantee the natural rights of individuals is the criteria Smith uses to evaluate a given society.

The material foundation of society Although humans have always lived in societies, these evolve during time. Changes in production processes and the resulting improvement of living conditions strongly influence the type of government and society. The driving factors behind these economic processes are the division of labour and the accumulation of wealth. Societies thereby evolve from hunter and fisher societies, the first human societies, to commercial societies, continually enhancing the ability of societies to provide themselves with necessaries and conveniences: "As subsistence is, in the nature of things, prior to conveniency and luxury, so the industry which procures the former, must necessarily be prior to that which ministers to the latter." (Smith 1993 [1776], p. 228).

Hunter and fisher societies Hunter and fisher societies form the first type of human societies. People in hunter and fisher societies live from hunting, fishing and gathering. They live in poor economic conditions and are just able to meet their most basic needs. In this type of society, "[...] there is properly no government at all. [...] they live according to the laws of nature." (Smith 1896 [1763], pp. 14-15). This is due to the fact that these societies are not able to generate any economic surplus and accumulate wealth. Governments however exist in order to secure wealth "[...] and to defend the rich from the poor." (Smith 1896 [1763], p. 15). Without wealth, there are no crimes of property. In the hunter and fisher societies, individuals care for themselves and live in freedom and security. The legislative, judicial and executive powers belong to the people (Smith 1896 [1763], p. 17). Unfortunately, hunters and fishers are extremely poor, and the natural rights of individuals depend on favourable conditions. In times of need, the natural rights of the weak are not preserved any more: Smith gives examples of hunter and fisher societies who abandon, or even kill, the weak members of the society out of pure necessity (Smith 1993 [1776], p. 8).

Pastoralist societies The domestication of animals lays the foundation for the emergence of the first regular governments. The appropriation of cattle allows to accumulate wealth and those with the biggest herds have more wealth than others. This inequality of wealth provides the wealthiest with power over the rest: as the only way to spend their wealth is by giving presents to the less wealthy, they are able to creat a relationship of dependency and to rule over them. The chieftains of pastoralist societies have dictatorial powers. Although pastoralist societies are able to clearly improve the living standards and the likelihood of survival of their members, the subjects entirely depend on the will of the chieftains and have no freedom (Smith 1896 [1763], p. 16).

Farmer societies The final two stages of the evolution of societies start with the cultivation of the soil. In societies of farmers, the division of labour leads to significant increases in the production of food. Being able to sell the surplus, the people accumulate so much wealth that they eventually start to build fortified towns to protect themselves and their moveable goods from invaders. The towns grow and become marketplaces. Craftsmen, artists and scientists pursue their business there. In the towns, the chieftains from the countryside are unable to support their authority and the first republican governments emerge there (Smith 1896 [1763], pp. 22-23). In the countryside however, the chieftains keep their absolute powers: "[...] every great landlord was a sort of petty prince. His tenants were his subjects. He was their judge, and in some respects their legislator in peace, and their leader in war." (Smith 1993 [1776], p. 234). As long as the most important economic activity is agriculture, the chieftains in the countryside are predominant, hindering further economic progress in the countryside and the society as a whole remains under their authoritarian regime (Smith 1993 [1776], pp. 234-238).

The commercial society This changes when the economic importance of the towns increases even further. Through trade and manufacturing, towns accumulate so much wealth that they are able to influence the rest of the society. First, town business expands into the countryside and forms alliances with landowners. Second, trade and manufacturing activities supply the landowners with plenty of goods. Instead of spending their wealth on the support of their subjects, the landowners start to spend their wealth for luxury and manufactured goods. In this way, they further promote trade and manufacturing and provide income to craftsmen, artificers and tradesmen. Manufacture and commerce thus gradually lead to good government, social order, as well as security and liberty for all individuals of society (Smith 1993 [1776], pp. 259-266). In the commercial society, there are no subjects any more, but only free men trading goods and services among each other:

> "When the division of labour has been once thoroughly established, it is but a very small part of a man's wants which the produce of his own labour can supply. He supplies the far greater part of them by exchanging that surplus part of the produce of his own labour, which is over and above his own consumption, for such parts of the produce of other men's labour as he has occasion for. Every man thus lives by exchanging, or becomes in some measure a merchant, and the society itself grows to be what is properly a commercial society." (Smith 1993 [1776], p. 31).

As has been shown in this section, Smith has a materialistic view on society. On the other hand, similarly to Hobbes (2.1), he also adopts the idea of natural rights. Besides of the natural right to self-preservation, humans also have the natural right to freedom. As long as both are preserved, social order can be supported. However, when one of both is lacking, social order cannot be maintained. Eventually, enduring social order will be reached in the commercial society.

2.3.2 The economic solution to the problem of social order

According to Smith, the problem of social order is a function of the production and the allocation of wealth: social order cannot be sustained as long as the optimal production and allocation of wealth is not reached. He argues that humans do cooperate on a regular basis because it is in their best interest. It follows that the self-interest of humans, combined with a predisposition to barter, lays the foundation for social order. This view is completely contrary to Hobbes (section 2.1) and Rousseau (section 2.2), which both argued that human selfishness was detrimental to society.

The economic human nature In contrast to Hobbes (section 2.1) and Rousseau (section 2.2), Smith argued that the egoistic interests of humans were fostering, not hindering, society. From his point of view, the problem of order is a problem of scarce resources, not of the human nature. This becomes obvious when considering the hunter and fisher societies: in these societies, humans live according to their natural rights, as long as the living conditions are favourable (section 2.3.1). The economic solution to the problem of order therefore aims at enhancing the wealth of the society, while granting the natural rights to the people living in a society. The human nature even supports the economic solution, because humans care best for themselves (Smith 1986 [1759], p. 127), have a continual desire to improve their condition (Smith 1993 [1776], p. 203) and have the predisposition to trade one thing for another. This propensity to trade with others is unique in humans and allows for the division of labour:

> "Without the disposition to truck, barter, and exchange, every man must have procured to himself every necessary and conveniency of life which he wanted. All must have had the same duties to perform, and the same work to do." (Smith 1993 [1776], p. 24).

The exchange of goods and services occurs by mutual consent, where everyone seeks his own advantage: "Give me that which I want and you shall have this which you want." (Smith 1993 [1776], p. 22). Ultimately, the division of labour is based on the human characteristics mentioned above.

The division of labour Smith puts such a focus on the division of labour, as it allows to significantly increase the output of a man's labour. He elabourates that a worker is able to produce about 20 pins a day by working on his own. In a simple factory, where the 18 distinct operations needed to produce a pin are divided among ten workers, the daily output of a worker is increased to 4800 pins due to the division of labour (Smith 1993 [1776], pp. 12-13). When every member of a society specializes on the production of what he does best, providing his produce for exchange to all others, "[...] the most dissimilar geniuses are of use to one another [...]" (Smith 1993 [1776], pp. 12-13). This exchange among members of a society leads to wealth among all members of a society:

> "It is the great multiplication of the productions of all the different arts, in consequence of the division of labour, which occasions, in a well-governed society, that universal opulence which extends itself to the lowest ranks of the people. Every workman has a great quantity of his own work to dispose of beyond what he himself has occasion for." (Smith 1993 [1776], p. 18)

The market The exchange of the product of labour takes place on the market. In order to be able to exchange a product, people need to agree about the exchangeable value of the product. In order to increase the efficiency of this exchange, the products are exchanged for money. The nominal value of a product is the price in monetary units that determines its exchangeable value. Every product has a natural price. This natural price equals the cost of its production, which comprises the wages for the workers, the rent for the owners of the buildings or lands, and the profit for the capital employed (Smith 1993 [1776], pp. 34-50). The society therefore consists of people primarily living of the wages, people primarily living from the rents, and people primarily living from the benefits. Smith refers to these groups of people as the three orders (Smith 1993 [1776], p. 155) or classes (Smith 1993 [1776], p. 386) of society. The market price is the actual price at which a product is sold on the market. This price is determined by the quantity of a product which is brought to the market and the demand of those people willing to pay its natural price. If the quantity falls short of the demand, the market price rises above the natural price. If the quantity exceeds the demand, the market price sinks below the natural price. If the quantity is just enough to supply the demand, the market price coincides with the natural price. In the long run, the market price always tends towards the natural price because of the reactions of the involved actors. When the market price is higher than the natural price, more producers enter the market to make profit and the quantity increases, leading to lower market prices. When the market price is lower than the natural price, producers leave the market as they lose money and the quantity decreases, leading to higher market prices (Smith 1993 [1776], pp. 54-56). Actors on the market decide in which sectors to be involved solely on the basis of the gains which can be obtained. They try to maximize these gains, and by doing so, they maximize the wealth of the society as a whole, because on aggregate, this behaviour leads to an equality between market and natural prices and an optimal allocation of available resources.

Using the market to rule The magnitude of the extent in wealth, which is generated through the division of labour is limited by the size of the market (Smith 1993 [1776], p. 26). In order to benefit from the whole potential of the division of labour, a society needs to ensure that the market is free and maximally extended. This means that no restriction to trade is established (Smith 1993 [1776], p. 295), that no sector is supported or constrained by the state (Smith 1993 [1776], p. 293), that no monopoly is allowed (Smith 1993 [1776], p. 358) and that interests of companies do not influence government decisions (Smith 1993 [1776], pp. 368-373). All these measures would influence the market price and lead to a misallocation of resources.

When interferences in the market are omitted, a system of natural liberty is established in which all men are free to pursue their own interests, as long as they do not act against the law. In such a system of natural liberty, the sovereign has three duties. First, the sovereign has to protect the society from the invasion and violence of other societies by establishing a military force. Second, the sovereign needs to establish an administration of justice to protect the members of society from oppression and injustice by other members of society. Third, the sovereign needs to provide the society with public institutions and public works. Those are characterized by the fact that the whole society benefits from them, while no individual would be able to provide them. Those public institutions and works are mainly provided in order to facilitate the commerce and include infrastructure like roads, canals, bridges, harbours, as well as post offices, and educational facilities

(Smith 1993 [1776], pp. 391-433). The whole economic project of Smith can be narrowed down to one sentence:

> "The establishment of perfect justice, of perfect liberty, and of perfect equality, is the very simple secret which most effectually secures the highest degree of prosperity to all the three classes." (Smith 1993 [1776], p.386).

Because the free market allows for the maximal amount of wealth and its optimal allocation, the market mechanism can be used to support social order. Adopting a free market economy is therefore one of the conditions for social order. The other condition lays in a state that protects its citizens from wars and crimes. Consequently, the last stage of Smiths evolution of societies is the commercial society that guarantees both freedom and safety for its citizens.

2.3.3 The normative integration of individuals into society

Although Smith emphasized the importance of self-interests for the functioning of a society (section 2.3.2), he argued that humans would still need to behave according to normative rules for social order to prevail. These rules would then keep reckless and harmful egoism under control. Interestingly, similarly to the invisible hand that balances the different materialistic interests of individuals on the market, the same mechanism works to balance the different normative values of people in society.

Sympathy In a given situation, the people not involved, the spectators, analyse the situation from the point of view of the involved individuals, the actors, and even feel their passions. This ability is called sympathy: "Sympathy, [...], may now, however, without much impropriety, be made use of to denote our fellow-feeling with any passion whatever." (Smith 1986 [1759], p. 4). When spectators analyse the situation actors are involved in, they may judge their actions and passions. However, their judgement is never objective, as they are always guided by their own passions, standards and faculties (Smith 1986 [1759], pp. 14-19). The criteria used to judge the behaviour of actors involved in a specific situation is propriety:

> "In the suitableness or unsuitableness, in the proportion or disproportion which the affection seems to bear to the cause or object which excites it, consists the propriety or impropriety, the decency or ungracefulness of the consequent action." (Smith 1986 [1759], p. 18).

If the passion and behaviour of an actor in a situation correspond to the passion and behaviour a spectator would have in the same situation, they are judged as proper. If not, they are judged as improper. For the actors, it is crucial to feel in harmony with the spectators: "Compared with the contempt of mankind, all other evils are easily supported." (Smith 1986 [1759], p. 96). Although humans have the ability to sympathize with others, a spectator will never be able to reconstruct and feel a situation in exactly the same way as an actor, and the actors are well aware of this. They therefore need to sympathize with the spectators too, adapting their passion and behaviour in order to have the sympathy of the spectators (Smith 1986 [1759], pp. 24-25). The capacity of individuals to sympathize with other individuals depends strongly on their mutual relationship (Smith 1986 [1759], pp. 188-189). As the judgement of a spectator not only depends on his own feelings, standards and faculties, but also on his relationship with the actor, no judgement of a spectator can ever be truly objective.

The impartial spectator The same behaviour might be judged in a completely different way by different spectators: "In order to defend ourselves from such partial judgments, we soon learn to set up in our own minds a judge between ourselves and those we live with." (Smith 1986 [1759], p. 188). This judge, called the impartial spectator, is entirely objective, equitable and honest. Actors therefore imagine how the impartial spectator would judge their passion and behaviour in a specific situation, instead of sympathizing with spectators. If they believe the impartial spectator would approve of their behaviour, then their behaviour must be proper, independent of what spectators might believe. If, on the contrary, the impartial spectator must disagree with their behaviour, then it is improper to act this way (Smith 1986 [1759], pp. 188-189). Unfortunately, such rational and objective reasoning is nearly impossible, because individuals are always biased by their self-love, their own sentiments, and experiences (Smith 1986 [1759], p. 199).

Norms emerge out of daily interactions This is why people lay down general rules to avoid any behaviour which is punishable, contemptible or odious and instead foster behaviour which is approvable and favourable. By following these rules, they can be sure of always acting in the proper way. Those rules are built by observing, for all possible kinds of situations, the judgements triggered by different kinds of behaviour. When this is done, the proper behaviour for all different kinds of situations is chosen as a general rule, and "[...] fixed in our mind by habitual reflection [...]" (Smith 1986 [1759], p. 204). Those rules have an enormous relevance for human societies as they shape the behaviour of people and correct the bias which self-love incorporates into the decision of what is proper to do in a specific situation. It is only because of these rules that people become trustworthy and predictable. The sense of duty, which results from these rules, is "[...] the most essential difference between a man of principle and honour and a worthless fellow." (Smith 1986 [1759], p. 209). These rules of morality are like divine laws and so important for the working of societies, that it seems natural to enforce them with the help of god (Smith 1986 [1759], pp. 210-212). Society would not be able to sustain without such laws : "But upon the tolerable observance of these duties, depends the very existence of human society, which would crumble into nothing if mankind were not generally impressed with a reverence for those important rules of conduct." (Smith 1986 [1759], p.210). In the commercial society, where everyone is supposed to act selfishly for his own benefit, selfish behaviour, which is judged as inappropriate, becomes sanctioned, as everyone follows a fairness norm:

> "In the race for wealth and honours, and preference, he may run as hard as he can, and strain every nerve and every muscle, in order to outstrip all his competitors. But if he should hustle, or throw down any of them, the indulgence of the spectators is entirely at an end. It is a violation of fair play, which they cannot admit of." (Smith 1986 [1759], p. 128).

2.4 Conclusion: philosophical foundation

Hobbes, Rousseau and Smith used a similar approach in their works on political philosophy. They compared societies at different stages of development and made conclusions about the reasons leading to the differences they were interested in. However, apart from this similarity of their approaches, the scholars differed in fundamental ways. Most importantly, the works of the scholars are not mutually compatible. Let us for example have a look at their diverging views related to the natural rights of humans. According to Hobbes, humans have only one natural right: self-preservation. This exclusive focus on self-preservation justifies the use of coercive power and the rule of an absolutist government with dictatorial powers as long as the bodily integrity of the citizens is guaranteed. The reference to natural rights allows social institutions to be justified by reflecting a natural order. Smith also makes use of natural rights to justify certain types of social institutions. In contrast to Hobbes, he argues that humans have two natural rights: self-preservation and freedom. The Leviathan proposed by Hobbes is not justifiable if one takes into account that humans also have the natural right of freedom, since the Leviathan is intended to rule by putting massive limitations on the freedom of people. Since self-preservation and freedom are both natural rights, strong limitations need to be put in place to restrict the actions of the Leviathan to a necessary minimum level. At the same time, the invisible hand of the market guarantees for a maximum level of freedom. Finally, from Rousseau's point of view, there are no natural rights at all. Social institutions are therefore conventions and do not represent the natural order in any way. In principle, this social constructivist view on society allows for the justification of a wide range of social institutions. However, Rousseau's negative assumption regarding the selfish nature of humans in the natural state of society, led him to the conclusion that society will always end in despotism. The three scholars also had fundamentally differing views on the role of the individual's self-interest for society, the historical development of societies, the problem of social order, as well as the institutional arrangements needed as a solution to the problem of social order. Based on these fundamental differences, the three scholars can be categorized into three broad dogmatic traditions with regard to the problem of social order: first, social order through an absolutist regime, with Hobbes as the main representative; second, social order through a collectivistic regime, with Rousseau as a main representative; third, social order through the balancing of individual interests, with Smith as a main representative. From a sociological point of view, the work of Hobbes, Rousseau and Smith are of high interest for two reasons. First, their comparative approach, although not methodologically sound, is compelling. Assuming there is a common human nature, it makes sense to study people from different cultures that seem very different at first sight. Having detected the factors responsible for the observed differences allows then to discern what they have in common. This must be the human nature. Second, the scholars focused on social institutions to explain differences in humans and societies. This is a fundamental sociological explanation. Their insights even allow to deduce hypotheses. From Hobbes' point of view, the key social institution is a coercive government: people under the rule of such a government should be pacified and therefore more cooperative and trustful than people lacking such a government. From Rousseau's point of view, the key for social order is normative homogeneity, which is influenced by private property and the composition of the people of society.

A homogeneous society with low levels of inequality should be better positioned to enforce the rule of law and to control the government than a heterogeneous society with high levels of inequality. Finally, from the perspective of Smith, the main social institution to promote social order is the free market. People integrated in a free market economy should be more pacified and therefore more cooperative and trustful than people not integrated in a free market economy. At heart, these institutional explanations for human sets of behaviour are purely sociological and therefore a good starting point for a sociological study. Unfortunately, as long as the whole dogmatic rat-tail of the scholars is kept, it is not possible to extract single aspects of their work and consider those together in a unified framework. In the next chapter 3, I discuss how game theory can be used to incorporate the different concepts proposed by Hobbes, Rousseau and Smith into one common theoretical framework.

Chapter 3

Theoretical foundation

As discussed in the chapter 2 on my philosophical foundation, the works of Hobbes, Rousseau and Smith are highly influential and have a clearly sociological core. It is, however, difficult to assess the scientific value of their work. This is due to the fact that their key insights are mostly based on dogmatic arguments and unverifiable assumptions. As a consequence, their works are only partly mutually compatible and their legacy rests mainly on the influence of dogmatic thoughts that are still important in the realms of politics, economics, philosophy, as well as social sciences.

On the other hand, the political philosophical problem of social order, as discussed by Hobbes, Rousseau and Smith, and its solutions are still of high relevance in social sciences, being the subject of game-theoretical analyses. In these analyses, the problem of social order is reformulated and centres around a situation involving a minimum of assumptions and parameters that can be measured and tested. Following this reformulation, the political philosophical problem of social order, which is essentially about the constant threat of violence and instability a society faces, is reformulated into the problem of cooperation, which centres around the constant threat of defection occurring in strategic interactions.

In this chapter, I provide a brief description of game theory and the game-theoretical concepts which are important for the understanding of my work. I describe and discuss the game-theoretical tools used to formalize the concepts and ideas of Hobbes, Rousseau and Smith and incorporate those into one common game-theoretical framework. This is mainly done by sticking to a small set of basic assumptions and renouncing on key dogmatic arguments found in the works of the scholars. I close this chapter by discussing the consequences of the game-theoretical formalization of the problem of social order and concepts discussed by Hobbes, Rousseau and Smith. On the one hand, the conclusions reached by applying this formalization are not always compatible with the original concepts formulated by the three classical scholars. On the other hand, this formalization allows to incorporate the different concepts of the three classical scholars in one common theoretical framework, allowing to deduce precise and falsifiable theoretical predictions.

3.1 The equilibrium as a formalization of Smith's invisible hand

In his work, Smith (section 2.3) described how the actions of individuals, following nothing but their own self-interest, leads to unintended results at the aggregated level of society. In a free market economy, for example, individuals looking to maximize their individual gain, at the same time also maximize the wealth of the whole society:

> "But the annual revenue of every society is always precisely equal to the exchangeable value of the whole annual produce of its industry, or rather is precisely the same thing with that exchangeable value. As every individual, therefore, endeavors as much he can both to employ his capital in the support of domestic industry, and so to direct that industry that its produce may be of the greatest value; every individual necessarily labors to render the annual revenue of the society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention." (Smith 1993 [1776], p. 292).

By acting in this way, they unconsciously favour the rule of law and strengthen the security and freedom of all individuals:

> "A revolution of the greatest importance to the public happiness, was in this manner brought about by two different orders of people, who had not the least intention to serve the public. To gratify the most childish vanity was the sole motive of the great proprietors. The merchants and artificers, much less ridiculous, acted merely from a view to their own interest, and in pursuit of their own pedlar principle of turning a penny wherever a penny was to be got. Neither of them had either knowledge or foresight of that great revolution which the folly of the one, and the industry of the other, was gradually bringing about." (Smith 1993 [1776], p. 268)

Selfish motives are even responsible for the most altruistic acts:

> "It is not the love of our neighbour, it is not the love of mankind, which upon many occasions prompts us to the practice of those divine virtues. It is a stronger love, a more powerful affection which generally takes place upon such occasions, the love of what is honourable and noble, of the grandeur, and dignity, and superiority of our own characters." (Smith 1986 [1759], pp. 193-194)

In this context, social norms emerge out of the daily interactions between the individuals of the society:

> "The general rules which determine what actions are, and what are not, the objects of each of those sentiments, can be formed no other way than by observing what actions actually and in fact excite them." (Smith 1986 [1759], p. 204)

The best result for society as a whole is reached when everyone pursues his own interest: "By pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it" (Smith 1993 [1776], p. 292).
Adam Smith's assumptions about the rationality of human individuals and the concept he uses (the invisible hand) to explain how social institutions and social order emerge from aggregated individual behaviour are central elements in game theory. In the rest of this section, I describe how these concepts are incorporated in a game theoretical analysis.

3.1.1 Orthodox game theory

Here, I briefly summarize the basics of game theory which are important to understand my work. More can be found, for example, in Myerson 2004.
Orthodox game theory provides a mathematical framework to analyse situations involving multiple actors making decisions that have an effect on one another's welfare. In orthodox game theory, a game describes any social situation involving strategic interactions between multiple actors. The actors are called players. The decisions made by players in games are solely based on their utility payoffs. Players maximize their expected utility payoff and are, in this sense, rational. Players are furthermore intelligent: they can make the same inferences about the situation as any external observers (Myerson 2004, pp. 1-4). The different ways how players can act in a game are called moves. A strategy of a player then consists of a rule determining which move to play (Myerson 2004, pp. 41-44). When randomization is used between different pure strategies, the rule is called a mixed strategy (Myerson 2004, p. 156), when no randomization occurs, it is a pure strategy (Myerson 2004, p. 91). I am only going to consider pure strategies in this work. Games can be represented in different ways (Myerson 2004, pp. 37-51). The most convenient way to describe a game is the normal representation of a game in a strategic form. In this representation, the players, their moves, as well as their utility payoffs are all shown in a tabular form. For example, in the pricing game (table 1), player 1 and his moves are shown in the rows, and player 2 and his moves are shown in the columns. The payoffs resulting from the different combinations of moves are shown in the cells. The first number in each cell is the payoff of player 1, and the second number in each cell shows the payoff of player 2. All information shown in this table is common knowledge. This means, that "[...] every player knows that every player knows it, and so on [..]" (Myerson 2004, p. 64). Players then make their strategic decisions independently and simultaneously (Myerson 2004, p. 50).

3.1.2 Competition on a free market

The pricing game (table 1) is used to model the effect of competition on market prices (Moorthy 1985). In this game, two identical airlines, player 1 and player 2, serve the same route and compete for customers in a free market. The pure strategies of both players are either to sell tickets for 200$ or for 300$. The consumers base their choices only on the price, favouring lower prices. The players have two moves: they can offer flight tickets for 200$ or for 300$. When both players offer tickets for 300$, they both earn 10,000$. When player 1 sells his tickets for 200$, while player 2 offers tickets for 300$, player 1 earns 13,000$ and player 2 earns 4000$. When player 1 offers tickets for 300$ while player 2 asks 200$ for the flight, player 1 earns 4000$ and player 2 earns 13,000$. When both players sell their tickets for 200$, they both earn 8'000$.

Table 1: The pricing game (Moorthy 1985, p. 264).

	Player 2: Ticket for 300 $	Player 2: Ticket for 200 $
Player 1: Ticket for 300 $	10,000$; 10,000$	4000$; 13,000$
Player 1: Ticket for 200 $	13,000$; 4000$	8000$; 8000$

Player 1 will choose his strategy based on his belief of which move player 2 will choose. If player 1 believes that player 2 will offer tickets for 300$, player 1 would maximize his expected payoff by offering tickets for 200$. If player 1 believes that player 2 will offer tickets for 200$, player 1 would maximize his expected payoff by also offering tickets for 200$. For player 1, offering tickets for 200$ is always the better move, independently of player 2's move: it is the best response (Myerson 2004, p. 89) to all moves of player 2. Player 2 will reason in the same way as player 1 and also offer tickets for 200$. In the pricing game, both players will choose the strategy to offer tickets for 200$. Only following their own egoistic interests, the competition between the two airlines leads to low prices for the consumers. This simple analysis highlights the importance of competition in a free market for the welfare of consumers and society as a whole, supporting Smith's arguments in favour of a free market (section 2.3.2).

3.1.3 Nash equilibrium

In the pricing game (table 1), the strategy profile that both players choose 200$ is a Nash equilibrium. A Nash equilibrium is characterized by the fact that no player can profit by deviating unilaterally from the predicted equilibrium strategy. Not all games have a Nash equilibrium in pure strategies and some games may even have multiple pure strategy Nash equilibria. But in all games with a finite number of pure strategies and a finite number of players, there exists at least one mixed strategy Nash equilibrium (Myerson 2004, pp. 93-96). The Nash equilibrium is one of the most important concepts in game theory: if we assume that players are rational and intelligent, as long as there is a Nash equilibrium in the game, they will have to act like predicted by the equilibrium. Otherwise, assumptions about non-rational behaviour are needed (Myerson 2004, p. 105). The fact that no player has an interest in deviating unilaterally from the equilibrium also means that the state emerging from an equilibrium is self-enforcing (Myerson 2004, p. 250). In our example on the pricing game (table 1), there is no need for any external authority to enforce the lower price, because it is in the best interest of the players to offer tickets for the lower price. However, sometimes it may be challenging for the players to coordinate on an equilibrium (Clark et al. 2001, pp. 495-496). The game-theoretical concept of a Nash equilibrium is a formalization of Adam Smith's metaphor of the "invisible hand". This is well described in the following quote:

> "Nothing enforces such a self-policing social contract beyond the enlightened self-interest of those who regard themselves as a party to it. Such duties and obligations as are built into the contract are honored, not because members of society are committed in some way to honor them, but because it is *in the interest* of each individual citizen with the power to disrupt the contract not to do so, unless someone else chooses to act against his own best interests by deviating first. The social contract therefore operates *by consent* and so does not need to rely on any actual or hypothetical enforcement mechanism. In game-theoretic terms, it consists simply of an agreement to coordinate on an *equilibrium*." (Binmore 1994, p. 30, italics as in the original)

3.1.4 Pareto efficiency

While consumers surely prefer lower prices to higher prices, the situation for the airlines is a different one. In fact, both airlines would be better off if they both offered their tickets for 300$. A criteria used for assessing the efficiency of allocations is Pareto efficiency. A given allocation is strongly Pareto efficient if there is no possible alternative allocation that would make at least one player better off, while at the same time not diminishing the welfare of any other players. Allocations are weakly Pareto efficient if there is no possible alternative allocation that would increase the welfare of both players (Myerson 2004, p. 378). In the pricing game (table 1), with both players offering tickets for 300$, there is a Pareto improvement to both players offering tickets for 200$. The Nash equilibrium in the pricing game (table 1) is therefore not Pareto efficient.

3.1.5 Social dilemmas

Situations with equilibrium strategies leading to non-Pareto efficient allocations are classified as social dilemmas. In social dilemma situations, people have no other option than to act in a disadvantageous or detrimental way: "A group of people facing a social dilemma may completely understand the situation, may appreciate how each of their actions contribute to a disastrous outcome, and still be unable to do anything about it." (Kollock 1998, p. 184-185). Social dilemmas can be formalized as two-person games with the two moves to cooperate or to defect. The four different outcomes in social dilemmas are R (reward) for mutual cooperation, P (punishment) for mutual defection, S (sucker) for cooperation when the other player defects and T (temptation) for defection when the other player cooperates ($T > R > P > S$). In social dilemma situations mutual cooperation is always a Pareto improvement to mutual defection ($R > P$). When mutual cooperation is undermined by the fear of the players ($P > S$), the situation is modelled as a stag hunt game (section 3.3). When mutual cooperation is undermined by the greed of the players ($T > R$), the situation is modelled as a chicken game. When fear and greed are present, as in our pricing game, the situation is modelled as a prisoner's dilemma (section 3.2) (Macy and Flache 2002, p. 7229).

Social dilemmas are game-theoretical models for the problem of social order. Of course, only a fraction of situations that can be potentially described by a game-theoretical social dilemma are characterized by political unrest or violence present in a political problem of social order. Our example in the pricing game (table 1), for example, is not what most people would have in mind when thinking of a social dilemma. However, most political problems of social order can be described in the terms of a game-theoretical social dilemma.

3.1.6 Economic goods

The essential feature of the problem of social order, as characterized by Adam Smith, is the suboptimal allocation of economic goods. As long as the allocation of economic goods is suboptimal, social order cannot be lasting. Smith argued that the free market is optimal in allocating economic goods among individuals of a society. Therefore, societies should adopt free market economic systems (section 2.3.2).
However, the market mechanism can only work in situations where the "exclusion principle" applies. This means that the consumption of a good by a certain individual depends on the ability of this individual to pay for the good. If this requirement is not met, the market mechanism fails to allocate the economic good in an optimal way. Two criteria can be used to determine whether the "exclusion principle" applies to a good. First, the consumption of the good needs to be rival. This means that the consumption of the good by one individual leads to a decrease in the benefit which can be obtained by other individuals by consuming the good. Second, it must be possible to grant property rights to the good and exclude individuals without property rights from its consumption (table 2). When both conditions apply, the market mechanism works. This is the case for private goods, where the allocation through the market is optimal (Samuelson 1954, p. 388). For the other three types of goods (common goods, club goods and public goods), also called social goods, the market mechanism fails (Musgrave and Musgrave 1989, pp. 42-45).

Table 2: The four types of economic goods (adapted from Musgrave and Musgrave (1989, p. 44)).

	Exclusion: Feasible	Exclusion: Not feasible
Consumption: Rival	private good: shoes, car	common good: Forest, wild salmon
Consumption: Not rival	club good: Pay TV, gym	public good: national defense, clean air

In the case of public goods, not only is the consumption non-rival, but it is also not feasible to grant property rights on the good. The provision of a public good is therefore a social dilemma (section 3.4). This has already been recognized by Smith. He argued that the incentive structure underlying the production of public goods would not favour its provision on the free market. The provision of public goods is therefore one of the main duties of governments:

> "The third and last duty of the sovereign or commonwealth is that of erecting and maintaining those publick institutions and those publick works, which, though they may be in the highest degree advantageous to a great society, are, however, of such a nature, that the profit could never repay the expence to any individual or small number of individuals, and which it, therefore, cannot be expected that any individual or small number of individuals should erect or maintain." (Smith 1993 [1776], p. 413).

The market mechanism also fails in the allocation of common and club goods. In the case of common goods, the consumption is rival, but no property rights to the good are granted. Individuals exploiting a resource held in common, face a social dilemma (section 4.3). For club goods, the consumption is non-rival but property rights can be granted.
As a result, the "invisible hand" of the market leads to the optimal allocation of goods only in the case of private goods. For all other types of goods, the market mechanism leads to suboptimal outcomes that can be characterized as social dilemmas since the individual rationality fails to provide the optimal outcome in these situations.

3.1.7 Evolutionary game theory

Besides orthodox game theory, there exists also a branch of game theory that is mainly used in biology to model evolutionary processes. In this so-called evolutionary game theory, game-theoretical tools are used to analyse the behaviour of actors involved in strategic interactions without making use of assumptions of rationality and common knowledge. In fact, the actors in evolutionary game theory have no choice. They always play the same pure strategy (Skyrms 2000, pp. 272-273).
In a seminal paper published in Nature in 1973, Maynard Smith and Price applied game-theoretical tools to understand the behaviour of animals of the same species involved in conflicts: the aim of the study was to uncover why individuals of the same animal species are most of the time observed making use of ritualized tactics and inefficient weapons when fighting against each other (limited war strategies), instead of using the maximally efficient fighting styles and weapons (maximal war strategies). Introducing the key concept of an Evolutionary Stable Strategy (ESS), they showed that limited war strategies were superior to maximal war strategies: while being able to decrease the payoff of individuals using maximal war strategies through retaliation, they were able to reduce their own loss obtained through an uninjured retreat in favour of an aggressive individual by obtaining access to future opportunities (Smith and Price 1973, pp. 15-16). The evolutionary approach to game theory focuses on the composition of a population with pure strategies played by its individuals. At the beginning of the analysis, the first state, the population consists of a number of haploid individuals all playing one pure strategy, which is genetically imprinted. The individuals of the population encounter, play a given game with the imprinted strategy and produce offsprings according to their payoffs resulting from the payoff matrix of the game. The offsprings play the same strategies as their parents. After each encounter, a new state emerges, potentially changing the population and its composition with strategies. In this framework, a state is an equilibrium when all strategies used by individuals in the population have the same payoff. If the population always returns to the same equilibrium state, after having been disturbed by the introduction of

new strategies, the state is an evolutionary stable state (Taylor and Jonker 1978, pp. 146-149). Interestingly, no single pure strategy can be an ESS, because its population can always be invaded by a mutant-, or a combination of strategies. On the other hand, mixed strategies can be ESS (Smith and Price 1973, p. 17; Boyd and Lorberbaum 1987, p. 59). Hence, "[...] no behaviorally uniform population can be evolutionary stable." (Smith and Price 1973, p. 17).
Although the orthodox and the evolutionary game theory may differ in their conclusions, especially when the evolutionary game theory allows dominated strategies to be played or even being fixated on, both still follow a logic of payoff maximization (Skyrms 2000, pp.273- 275). Evolutionary game theory allows to analyse how genetics influences the behaviour of individuals and the outcomes at the population level. Assuming that each strategy represents a genetic variation, the reproductive success of the different genes and their composition within the population can be modelled with simple games. A whole branch of science, known as socio-biology, is devoted to studying the genetic component of human social behaviour and makes use, among others, of the evolutionary game theory (section 8.1.3).

3.2 Hobbes' state of nature and the prisoner's dilemma

In Hobbes (section 2.1), one of the unfortunate consequences of the state of nature for mankind is that it undermines cooperation between people: "If a Covenant be made, [...], in the condition of meer Nature, [...] he which performeth first, does but betry himselfe to his enemy; contrary to the Right (he can never abandon) of defending his life, and means of living." (Hobbes 2012 [1651], p. 96). This is due to the fact that, in the state of nature, agreements are not binding and nobody can be trusted: "[...] Covenants, without the Sword, are but Words, and of no strength to secure a man at all." (Hobbes 2012 [1651], p. 117). As a result, people are stuck in a state where everyone is against everyone, not working together and living a miserable life: "And the life of man, solitary, poore, nasty, brutish, and short" (Hobbes 2012 [1651], p. 89).
Hobbes's state of nature has found a representation in game theory as the prisoner's dilemma (Binmore 1994, p. 118; Lomborg 1996, pp. 278-279). In the rest of this section, I describe and discuss the prisoner's dilemma and the different suggested solutions.

3.2.1 The prisoner's dilemma

We have already been confronted with the structure underlying the prisoner's dilemma in the pricing game (table 1). The prisoner's dilemma is used as a prime example to illustrate problems arising in rational cooperation and has been the subject of innumerable studies (Binmore 1994, pp. 102-103; Kollock 1998, pp. 185-186). In its original version, the prisoner's dilemma is a two-persons, one shot game where the two players have the options either to cooperate or to defect (table 3). The payoffs are ranked in the following way: "$T_i > R_i > P_i > S_i + T_i < 2R_i, (i = 1, 2)$" (Rapoport and Dale 1966, p. 269), leading to a situation where both players defect and are worse off than if both players cooperated ($P_i < R_i$). Fear ($P_i > S_i$) and greed ($T_i > R_i$) of the players are responsible for this outcome (Macy and Flache 2002, p. 7229). In the prisoner's dilemma, mutual defection is the only Nash equilibrium.

Table 3: Payoff matrix of the prisoner's dilemma.

	Player 2: Cooperation	Player 2: Defection
Player 1: Cooperation	$R1; R2$	$S1; T2$
Player 1: Defection	$T1; S2$	$P1; P2$

Hobbes's state of nature is characterized by the people's fear to die a violent death (section 2.1.1). The state of nature described by Hobbes is very drastic and dramatic. From my point of view, the pricing game (table 1) is not a good illustration of Hobbes' state of nature, although it has its structure. The following example might better represent the Hobbesian spirit and serve as an illustrative model of Hobbes' state of nature. Assuming that two people, player 1 and player 2, have the following possibilities to make a living: they could either work together (cooperation) and catch a stag (4; 4), or they could go their own way (defection) and independently catch a hare (3;3). Mutual cooperation would lead to a better state for both of them than mutual defection. In order to be able to catch a stag, they would however have to divide the work. One player would have to track and drive the stag and the other player would have to catch the stag. For both of them, the best state would be to track and drive the stag, ambush the catcher and kill him. Then, the tracker could take as much meat as possible and would not have to share the stag with the other player. The catcher, on the other hand, would be dead. Knowing this, both would want to track the stag: not being able to coordinate, they would fail in catching a stag. In order to survive, they would have to rely on solitary hare hunting. Because of the fear and the greed of the people, in the state of nature, no spontaneous cooperation between people can emerge. As a result, the living conditions of humans cannot improve (table 4).

Table 4: Payoff matrix of the prisoner's dilemma (own example).

	Player 2: Cooperation	Player 2: Defection
Player 1: Cooperation	4; 4	0; 7
Player 2: Defection	7; 0	3; 3

Although the prisoner's dilemma is supposed to be a formalization of Hobbes' state of nature, it differs in important ways from it. Most importantly, it only assumes that humans are rational. They simply want to maximize their outcome. In Hobbes, humans are however not only rational. They are also impulsive, obsessive and voracious. These differences are important, because the reduction of the state of nature to a problem of rational cooperation allows to find solutions which would not be possible in Hobbes' state of nature. In the next sections, I describe different ways of how a cooperative equilibrium can be reached in the prisoner's dilemma.

3.2.2 The iterated prisoner's dilemma

While in the one shot prisoner's dilemma (the prisoner's dilemma described in the prior section) unconditional defection is the only rational strategy, when the prisoner's dilemma is played repeatedly for an unknown number of times by the players (this is the infinitely iterated prisoner's dilemma (IPD)), cooperation might emerge from a Nash equilibrium without leaving the framework of the prisoner's dilemma. This is possible, because then, the best strategy of one player depends on the strategy of the other player (Myerson 2004, pp. 308-309). In this case, both players have an ongoing relationship with a common history and future: "This makes possible sophisticated strategies which use this history" (Axelrod 1980, p. 380). In fact, if the players are patient enough, all average payoffs equal or above the mutual defection level can result from a Nash equilibrium in the infinitely IPD. This is known from the folk theorems (Myerson 2004, pp. 331-332). Unfortunately, there is no clear rule to determine which Nash equilibrium should be selected. This may lead to a situation, where two players choose strategies from different Nash equilibria in the infinitely IPD and end up in a state which is not a Nash equilibrium (Lomborg 1996, p. 281). When the number of times the two players are going to play the prisoner's dilemma is known (this is the finitely IPD), defection remains however the only rational strategy (Myerson 2004, pp. 309-310).

3.2.3 Tit-for-tat and Pavlov

It is noteworthy that some strategies clearly perform better than others in the infinitely IPD. This is shown by comparing the performance of different strategies playing the infinitely IPD against each other (Axelrod 1980; Nowak and Sigmund 1993; Lomborg 1996). Probably the most famous strategy in the infinitely IPD is tit-for-tat. This strategy starts the first round of the game by cooperating and then always copies the move played by the other player in the previous round of the game. Tit-for-tat was the best performing strategy in both infinitely IPD tournaments organized by Axelrod. The success of tit-for-tat in the infinitely IPD tournaments is explained by the fact that this strategy is nice (proposing cooperation at the beginning and never defecting first), provocable (it sanctions defection from the other player) and forgiving (it cooperates again after an isolated defection from the other player) (Axelrod 1980, pp. 380-394). Tit-for-tat illustrates how norms of reciprocity can lead to cooperation between rational actors in the infinitely IPD by capitalizing on the advantage cooperators get from interacting together, while not becoming over-exploited from defectors. Another strategy, Pavlov, which performs well in the infinitely IPD, can be summarized by win-stay and loose-shift. This strategy simply keeps the same move if it was successful in the previous round (rewarded with R or T) and changes move if it worked badly (punished with P or S). Pavlov is more robust to errors and mutations than tit-for-tat (Nowak and Sigmund 1993, p. 58). It can be a cooperating strategy, like tit-for-tat, but unlike tit-for-tat, Pavlov also takes advantage of an unconditional cooperator by exploiting him until the end of the game.

3.2.4 The nucleus and the shield

Although some important aspects related to the emergence of cooperation in the infinitely IPD can be worked out by focusing on single strategies, it should be highlighted that cooperation in a population where all individuals play the same pure strategy is not evolutionary stable (Smith and Price 1973, p. 17; Boyd and Lorberbaum 1987, p. 59). This means that in a population of individuals playing the infinitely IPD, when cooperation emerges as an equilibrium from a strategy which is played by all players, it is always possible that some alternative strategy might prove itself superior and invade the population (Myerson 2004, p. 122). In the infinitely IPD, for cooperation to be a stable state among individuals of a population, they need to play a variety of different strategies. The most stable environment for cooperation is reached when the population consists of a core of individuals playing very cooperative strategies, the nucleus, surrounded by a periphery of individuals playing a diversity of more cautious, defecting strategies, the shield: "Thus, the answer to Axelrod's question, of what is the most robust strategy in the infinitely IPD game, has never been a single strategy, but is instead a set of strategies internally partitioned between a highly cooperative nucleus and a diverse and cautious shield. The partitioning into nucleus and shield and the diversity inside the shield constitutes the social structure that evolves to deal with a Hobbesian IPD world." (Lomborg 1996, p. 298).

3.2.5 The shadow of the future

The introduction of uncertain future interactions, the shadow of the future, has profound implications for the prisoner's dilemma.
In order to illustrate the strategic implications of repeated interactions among players within the framework of infinitely IPD, let us consider that player 1 and player 2 have the options to either defect in all rounds (ALLD) or to play tit-for-tat. In our example from table 4, the following equation helps us to determine at which probability (p) of another trial tit-for-tat and ALLD will do equally well when playing against tit-for-tat: $4+\frac{4p}{1-p} = 7 + \frac{3p}{1-p}$ (the left-hand-side of the equations considers the payoffs for tit-for-tat against tit-for-tat, while the right-hand-side considers the payoffs for ALLD against tit-for-tat): with a probability of another trial of 0.75, neither strategy is a best response to tit-for-tat (table 5).

Table 5: Tit-for-tat against ALLD in the infinitely IPD from table 4 with p=0.75 .

p=0.75	Player 2: Ttit-for-tat	Player 2: ALLD
Player 1: Tit-for-tat	16; 16	9; 16
Player 1: ALLD	16; 9	12; 12

With a probability of another trial being 0.75. Neither strategy is a best response to tit-for-tat.

At probabilities below 0.75 ALLD is a best response to tit-for-tat, not changing anything to the structure of the prisoners dilemma (table 6).

Table 6: Ttit-for-tat against ALLD in the infinitely IPD from table 4 with p=0.2 .

p=0.2	Player 2: Tit-for-tat	Player 2: ALLD
Player 1: Tit-for-tat	5; 5	0.075; 7.75
Player 1: ALLD	7.75; 0.075	3.75; 3.75

With a probability of another trial being 0.2, ALLD is clearly the best response to tit-for-tat.

When the probability is above 0.75, the best response to tit-for-tat is to play tit-for-tat as well (table 7).

Table 7: Tit-for-tat against ALLD in the infinitely IPD from table 4 with p=0.9 .

p=0.9	Player 2: tit-for-tat	Player 2: ALLD
Player 1: tit-for-tat	40; 40	27; 34
Player 1: ALLD	34; 27	30; 30

With a probability of another trial being 0.9, Tit-for-tat is clearly the best response to Tit-for-tat.

The introduction of a shadow of the future allows for the emergence of rational cooperation within the framework of the prisoner's dilemma. The structure of the prisoners dilemma in table 7 now has the same structure as the stag hunt game (section 3.3), which is characterized by a cooperative as well as a defecting equilibrium. Here, it is possible for cooperation to emerge from an equilibrium strategy, directly resulting from the self-interest of individuals. In contrast to Hobbes' state of nature, social order in the prisoner's dilemma does not depend on a Leviathan. Most importantly, by allowing the actors to interact for an uncertain number of times in the prisoner's dilemma, social order can result without coercion, simply from the self-interest of actors. This conclusion is clearly not compatible with Hobbes' description of the state of nature. I am going to discuss the stag hunt game in more detail in the next section (section 3.3).

3.3 Rousseau and the stag hunt

In his book "De l'inégalité parmi les hommes", Rousseau claims that humans gave up their independent, self-sufficient lifestyle found in the natural state of man, since they could achieve more with joint forces. However, by doing so, they put themselves at the mercy of others and risked to get nothing at all:

> "S'agissait-il de prendre un cerf, chacun sentait bien qu'il devait pour cela garder fidèlement son poste; mais, si un lièvre venait à passer à la portée de l'un d'eux, il ne faut pas douter qu'il ne le poursuivît sans scrupule, et qu'ayant atteint sa proie il ne se souciât fort peu de faire manquer la leur à ses compagnons." (Rousseau 1977 [1754],

pp. 111-112).

Rousseau's short story about the stag hunt describes the ambiguous relationship between the rationality of individuals and communities, which is at the heart of the game-theoretical modelling of social dilemma situations. Not surprisingly, the story has found a game-theoretical counterpart which is the topic of the following sections.

3.3.1 The stag hunt game

Rousseau's story about the stag hunt has been adopted by game theorists as a tool to model the evolution of social behaviour (Bergstrom 2002; Macy and Flache 2002; Skyrms 2004; Pacheco et al. 2009; Perc and Szolnoki 2010). In it's most basic form, the stag hunt game involves two players (player 1 and player 2) with the options of either hunting stag or hunting hare (table 8). Hunting stag has an expected payoff (R_i) higher than hunting hare, if both players hunt stag. If only one player hunts stag, the expected payoff of the stag hunter (S_i) is 0. Hunting hare has an expected payoff (P_i) which is lower than hunting stag, but higher than 0 and not depending on the action of the other player ($R_i > P_i > S_i$). In some variations of the stag hunt game, the expected payoff of the hare hunter is higher if the other player hunts stag (T_i) than if the other player also hunts hare (P_i) ($R_i > T_i > P_i > S_i$) (Skyrms 2004, pp.3-4). For the rest of this work, I will refer to the first version of the stag hunt game, because it better captures Rousseau's story.

Table 8: Payoff matrix of the basic stag hunt game.

	Player 2: Hunt stag (cooperate)	Player 2: Hunt hare (defect)
Player 1: Hunt stag (cooperate)	*R1*; *R2*	*S1*; *P2*
Player 1: Hunt hare (defect)	*P1*; *S2*	*P1*; *P2*

In contrast to the prisoner's dilemma (section 3.2), the stag hunt game has a cooperative Nash equilibrium (both hunt stag) as well as a non-cooperative Nash equilibrium (both hunt hare): when player 1 hunts stag, it is always best for player 2 to also hunt stag and when player 1 hunts hare, it is always best for player 2 to also hunt hare. This allows for the spontaneous emergence of cooperation among rational actors. As the payoff of hunting hare does not depend on the strategy of the other player, hunting hare minimizes the risk and is the risk-dominant equilibrium (Skyrms 2004, p.3). This equilibrium represents the state of nature, where humans do not cooperate (either because they cannot trust each other, like in Hobbes's state of nature (section 2.1.1), or because they live a self-sufficient, independent life, like in Rousseau's natural state of man (section 2.2.1)). When the players coordinate on the defective equilibrium (both hunt hare), the stag hunt game is a social dilemma, because the defecting equilibrium is Pareto-dominated by the cooperative equilibrium (both hunt stag).

The cooperative equilibrium Pareto-dominates the non-cooperative equilibrium, since it leads to a higher payoff for both players than the non-cooperative equilibrium. This equilibrium represents

a state where a social contract has been established between the two players (Binmore 1994, p. 121-122; Skyrms 2004, p. 9). It has been shown in the previous section (table 7) that the problem of cooperation in the infinitely IPD can be transformed into the problem of cooperation in the stag hunt game (Skyrms 2004, p. 9; Bergstrom 2002, pp. 73-74). In this case, the stag hunt game is no social dilemma, as the cooperative equilibrium (both hunt stag) is Pareto efficient.
The game-theoretical concepts used to transform the Hobbesian state of nature (the prisoner's dilemma) into Rousseau's model for societal development at the lowest levels of his model of human evolution (the stag hunt game) misrepresent the thoughts of Hobbes and Rousseau in some important aspects. On the one hand, as discussed in the previous section 3.2.1, Hobbes did not allow for such a simple solution to the problem of social order in his work. On the other hand, Rousseau used his story as an explanation for the reason why people moved from a solitary lifestyle in the natural state of man to a life in communities at the lowest level of the development of human societies. According to Rousseau, this first step of community building follows directly from the self-interest of humans and is no problem of social order at all. The problem of social order however emerges as soon as social institutions have been built and becomes existential at the end of the evolution of societies, where humans struggle for wealth and the control of the means of power (section 2.2). The stag hunt game should therefore not be seen as a general model for the evolution of societies, but only for the first step of this evolution.

3.3.2 The problem of cooperation in the stag hunt game

The problem of cooperation in the stag hunt game is a social dilemma of limited dimension. The condition needed to reach the Pareto efficient equilibrium is trust. For player 1 to hunt stag, he needs to trust that player 2 will also hunt stag. In the stag hunt game from table 9, player 1 needs to believe that player 2 hunts stag with a probability higher than 0.75 in order to also hunt stag ($R1 * p > P1 * p + P1 * (1 - p)$ (Binmore 1994, p. 123)).

Table 9: Payoff matrix of the stag hunt game (Bergstrom 2002, p.70).

	Player 2: Hunt stag (cooperate)	Player 2: Hunt hare (defect)
Player 1: Hunt stag (cooperate)	4; 4	0; 3
Player 1: Hunt hare (defect)	3; 0	3; 3

When people prefer not to take the risk and hunt hare (defective equilibrium), the only way they can start hunting stag (cooperative equilibrium) is by changing their beliefs about the actions of others. Hunting stag must stop being considered as a risky enterprise (Skyrms 2004, p. 10). Social norms can help to reach this goal: as noted by Adam Smith, norms of morality make people become predictable and trustworthy (section 2.3.3). Rousseau himself puts a strong focus on the importance of social norms for the enforcement of a social contract (section 2.2.4): when everyone follows the general will to hunt a stag, there is no reason to believe that anyone will hunt hare. Rousseau's view on the normative education of people is very radical and considered as "brainwashing" by Binmore (1994, p. 135). In fact, when all people are brainwashed to hunt stag, the game would change its structure, as it would entirely remove the defecting strategy to hunt hare.

However, even without considering socialization and normative education ("brainwashing"), there are mechanisms which can lead to the emergence of stag hunting norms within the framework of the stag hunt game. First, one possibility is to consider the spatial structure where the interactions of players take place. When there is a small cluster of stag hunters within a broader population of hare hunters, the hare hunters neighbouring the stag hunters' cluster might become tempted to imitate the stag hunters in order to also gain the same higher payoffs. This means a shift from a strategy which focuses on playing the best response against your neighbourhood to a strategy which focuses on imitating the most successful strategy played in your neighbourhood: "[...] we can say that local interaction opens up possibilities of cooperation that do not exist in a more traditional setting, and that imitation dynamics is often more conducive to cooperation than best-response dynamics." (Skyrms 2004, p. 41). Then, introducing reinforcement learning, the players can choose with which neighbours to play, based on past experiences. Stag hunters will play exclusively with other stag hunters, while hare hunters will only have the option to play with hare hunters. In the long run, stag hunters will prosper while hare hunters will lag behind (Skyrms 2004, pp. 95-99). Finally, the exchange of information by actors prior to their interactions can lead the players to choose the stag hunting strategy. This is the case, even for so called "cheap talk" (cost-free communication) (Skyrms 2004, pp. 67-73).

In contrast to the prisoner's dilemma, a cooperative equilibrium in the stag hunt game can be reached in the one-shot stag hunt game. The stag hunt game explicitly allows for the spontaneous emergence of cooperation among rational actors as an equilibrium. The necessary condition is trust. Here, two main dogmatic differences between Hobbes and Rousseau become obvious. Hobbes denies the possibility that trust even matters in the state of nature. The solution to the problem of social order can only be achieved through an all-powerful state that counteracts the self-interests of individuals. Trust can only emerge once the people have transfered their rights and power to an external authority, opening the path to a civilized society. According to Rousseau, the problem of social order is a product of life in society: once people have entirely become interdependent, due to private property and division of labour, the problem of social order becomes existential. The only solution is an all-powerful state with the people as the sovereign. Unfortunately, also this solution is doomed to fail: eventually, some selfish individuals take control of the state and the people lose their sovereignty. In Hobbes as well as in Rousseau, the reason for the problem of social order is the selfishness of humans. In Hobbes, the selfishness of humans hinders the emergence of a society. In Rousseau, the selfishness of humans threatens the stability of a society.

3.4 Public goods and free riding

Without doubt, the state is the key to social order. In Smith, the state makes sure that the free market channels the constructive power of human selfishness and provides the public goods that the free market does not. In Hobbes and Rousseau, the state is the public good necessary to protect humanity from human selfishness. As a result, state institutions and services are probably the most important public goods. As a quick reminder, public goods are goods which are enjoyed in the same way by all individuals of a group. This means that the consumption of the good by one individual of the group does not lead to a fewer amount of the good for other individuals of the group (Samuelson 1954, p. 387). Furthermore, no member can be excluded from consuming the good (table 2). Interestingly, individuals involved in the provision of a public good face a social dilemma. In the further part of this section, I discuss the structure of the social dilemma underlying the provision of public goods and solutions available to support the provision of public goods.

3.4.1 The state as a public good

In the "social contract", Rousseau characterizes the state as a public good to its citizens. All citizens contribute to the state by providing everything they have (Rousseau 1966 [1762], pp. 51-52). As a result, the citizens receive protection and security from the state: "[...] on ne peut offenser un des membres sans attaquer le corps [...]" (Rousseau 1966 [1762], p. 54). However, the citizens would be best off if they did not contribute to the state, but still benefitted from its protection, and by acting in this way, the state would not be erected:

> "En effet chaque individu peut comme homme avoir une volonté particulière contraire ou dissemblable à la volonté générale qu'il a comme citoyen. Son intérêt particulier peut lui parler tout autrement que l'intérêt commun; son existence absolue et naturellement indépendante peut lui faire envisager ce qu'il doit à la cause commune comme une contribution gratuite, dont la perte sera moins nuisible aux autres que le payement n'en est onéreux pour lui, et regardant la personne morale qui constitue l'État comme un être de raison parce que ce n'est pas un homme, il jouirait des droits du citoyen sans vouloir remplir les devoirs du sujet; injustice dont le progrès causerait la ruine du corps politique." (Rousseau 1966 [1762], p. 54)

Rousseau's reasoning concerning the erection of a public body by selfish subjects describes the reasoning of rational actors when deciding on their contribution to a public good. Individuals trying to achieve their rational self-interest will reach a suboptimal outcome, because by failing to contribute to the provision of the public good, the individuals will not receive the benefit of the public good, which would have exceeded the costs necessary to help purchasing the public good for the whole population. They fail to provide the public good, because it is in their best interest to let the others provide the good and only profit from it. Behaviour which is driven by such a type of reasoning is known as free riding.

3.4.2 Free riding

Free riding behaviour can well be modelled with a simplified 10-persons game, where an individual plays against a collective to provide a public good (table 10). While the common interest of the group is to provide the public good, which is worth twice its cost, the individual wants to maximize his payoff. The payoffs are calculated as benefits less costs. In this game, the individual and the collective either cooperate in the provision of the public good, by paying one unit, or defect, by not paying the necessary unit. By analysing the individual's payoffs in the individual vs. the collective game (table 10) and comparing them with the payoffs in the prisoner's dilemma (table 3), it becomes clear that the motives of the individual to provide a public good are the same as in the prisoner's dilemma: the individual is always best off when not contributing to the collective good, independently of the collective's move. As all individuals of the group see the game matrix from the point of view of the individual and since the collective's action is made up of aggregated individual behaviour, the public good will not be provided. Not contributing to the public good is known as free riding (Marwell and Ames 1981, p. 296).

Table 10: Payoff matrix of the individual vs. collective game.

	Collective: Contribute (cooperate)	Collective: Do not contribute (defect)
Individual: Contribute (cooperate)	1; 1	-0.8; 0.2
Individual: Do not contribute (defect)	1.8; 0.8	0; 0

Per capita average of collective payoffs (Hardin 1971, p. 473)

3.4.3 Group characteristics and public good provision

However, the conclusion that rational actors will never contribute to a public good is not necessarily true. According to a range of theoretical considerations, the characteristics of a group strongly influence its capacity to provide collective goods to its members.

In his work on collective action, Olson argues that the provision of a public good depends on the cost of the public good C, the level of the public good T, the size of the group S_g, the individual gain V_i and the group gain V_g: the public good will be provided as soons as the total cost of the public good is exceeded by the individual gain ($V_i/V_g > C/V_g$). The optimal allocation of the public good is reached when the cost of the public good and the gain to the group increase at the same rate ($dV_g/dT = dC/dT$) (Olson 1971, pp. 23-24). Accordingly, group size and group inequality are two group characteristics that should positively influence the capacity of groups to provide public goods. This is due to the fact that the likelihood to find individuals who are willing to provide the public good independent of others decreases with group size and increases with group inequality. Due to its inherent logic, the public good will usually not be provided, and if so, not in an optimal way (Olson 1971, pp. 28-29).

Similarly, homogeneity of preferences within individuals of a group positively influences the provision of public goods. This is shown by applying the theorem of the median voter (Black 1948) to the public good provision. Assuming that a committee votes on a specific issue with a multitude of options, that each member of the committee is able to rank these options in a clear order of preferences (Black 1948, p. 23), and that a simple majority rule is used to make a decision (Black 1948, p. 25), the theorem of the median voter states that the option which is favoured by the median voter will be adopted by the committee (Black 1948, p. 28). In the case of the provision of a public good, the members of the committee decide by majority rule on the size and the type of the public good to provide. The result of this vote will coincide with the preference of the median voter. The more homogeneous the preferences of the voters, the shorter the median distance from the median voter. When the preferences among the voters are entirely homogeneous, there is only one opinion, and the optimal amount of the public good will be provided (Alesina et al. 1999, pp. 1249-1251).

Finally, according to Putnam, group homogeneity in general should favour the capacity of a group to provide a public good. The social capital of individuals is made up of ties to similar people (bonding social capital) and ties to un-similar people (bridging social capital). Group homogeneity positively affects both, the bridging and the bonding of individuals' social capital. In this way, the social capital of individuals is increased by group homogeneity. This is known from the constrict theory (Putnam 2007, pp. 138-144). As a result, homogeneous groups have a high cohesion and are well suited to overcome social dilemma.

Interestingly, prominent micro theoretical models of human behaviour suggest that group homogeneity and inequality influence the provision of public goods. According to those, homogeneity should positively influence public good provision. Based on his philosophy of the general will, Rousseau concludes the same. But then, micro-economic theory teaches that income inequality positively influences public good provision. This hypothesis is contrary to Rousseau's thoughts on the functioning of the general will (section 2.2).

Although public good provision is a social dilemma, it is clear that no developed economy would function without public goods. Even the free market depends on public goods: "Almost any government is economically beneficial to its citizens, in that the law and order it provides is a prerequisite of all civilized economic activity." (Olson 1971, p. 13). As a result, societies have proven that they are able to overcome the social dilemma underlying the provision of public goods in many instances. Until now, I have only discussed solutions to overcome social dilemma that essentially increase the benefit, of or the preference for cooperation. Some very effective means available to support cooperation in social dilemma are however based on punishment (Olson 1971, p. 13; Olson 1971, p. 44; Boyd and Richerson 1992, p. 185). The enforcement of social order through punishment is the topic of the next section.

3.5 Punishment

So far, I have elabourated concepts enhancing cooperation in social dilemmas which are based on mechanisms increasing the payoffs which individuals can obtain through cooperation (section 3.2, section 3.3). Those mechanisms mainly rely on reciprocity (section 3.2.3). However, there is also the possibility to enforce cooperation in social dilemmas by decreasing the payoffs individuals can obtain through defection. This is possible through punishment. From a game-theoretical perspective, punishment is a retaliatory infliction of payoff reduction (Clutton-Brock and Parker 1995, p. 209). This idea is central in Hobbes' work (section 2.1), but also plays an important role in Rousseau (section 2.2) and Smith (section 2.3). The study of punishment is of high relevance for sociology, since punishment is closely linked to the concept of a norm. The relationship between punishment and norms is described by Homans in the following way:

> "A norm, then, is an idea in the minds of the members of a group, an idea that can be put in the form of a statement specifying what the members or other men should do, ought to do, are expected to do, under given circumstances [...] A statement of the kind described is a norm only if any departure of real behavior from the norm is followed by some punishment." (Homans 1950, p. 123).

Tit-for-tat (section 3.2) has a retaliatory element implemented in its strategy. When tit-for-tat is the sucker in a given round, it will defect in the next round. This is however no punishment in a pure sense of the word: it only prevents the opponent to continue exploiting one's good will by withdrawing cooperation, not directly altering the payoffs of the other player through some form of retribution. Cooperation which is enforced through punishment differs from cooperation which is enforced through reciprocity because it works in bigger groups (Boyd and Richerson 1992, p. 185).

What follows is a discussion of a number of solutions to the problem of social order that are based on punishment. In decentralized punishment regimes, the punishment is imposed autonomously by any individual. In centralized punishment regimes, the enforcement of punishment is transferred to a central authority. Usually, this authority is the state.

3.5.1 Decentralized punishment

Vengeance

When punishment is imposed by an individual who did suffer directly by the action of another individual, we speak of second party punishment (Fehr and Fischbacher 2004, 64). Vengeance is one example for second party punishment and comprises a threat to inflict harm when one gets hurt. This can be modelled the following way: players can inflict harm at personal cost to other players. The incurred cost on the opponent player is (v), with marginal cost between 0 and 1 (c). When a player receives the payoff of a sucker, inflicting harm on the defecting player generates a utility bonus (table 11). Vengeance can be introduced to the prisoner's dilemma and changes the payoffs of the players (Friedman and Singh 2001, pp. 3-4). In the prisoner's dilemma from table 4, when $v > 3 * c$, mutual cooperation becomes a Nash equilibrium: "Thus the threat of vengeance can deter defection and support fully cooperative, socially efficient behavior (C,C) as a Nash equilibrium." (Friedman and Singh 2001, p.5).

Table 11: The prisoner's dilemma from table 4 with vengeance.

	Player 2: Cooperation	Player 2: Defection
Player 1: Cooperation	4; 4	0-v; 7-$\frac{v}{c}$
Player 1: Defection	7-$\frac{v}{c}$; 0-v	3; 3

The incurred cost of vengeance for the opponent is v, with marginal costs, c, between 0 and 1 (adapted from Friedman and Singh 2001, p.4)

Third party punishment

When punishment is imposed by an individual who did not suffer directly by the action of another individual, we speak of third-party punishment. Third-party punishment applies to a much larger set of norm violations than second party punishment, because often, when a norm violation occurs, nobody is hurt directly. Furthermore, when the violation of a norm by an individual concerns a whole group, the damage resulting from the norm violation might be negligible to a particular member of the group (Fehr and Fischbacher 2004, p. 64). In the infinitely IPD, I have elabourated that no pure strategy can be evolutionary stable and support cooperation (section 3.2). However, this fact is only true as long as dyadic strategies are taken into consideration. In a group of 10 players playing the infinitely IPD, when player 1 uses a strategy that only considers the actions of one particular other player, player 2 for example, his strategy is dyadic. Tit-for-tat and Pavlov (section 3.2) are dyadic strategies. If player 1 uses instead a strategy that considers the actions of more than one other player, his strategy is social (Bendor and Swistak 2001, p. 1512). When social strategies are considered, (at least) one pure strategy exists, which is evolutionary stable and which can support a cooperative equilibrium in a population playing the infinitely IPD. This strategy is called conformity (CNF). CNF starts each round of the infinitely IPD by classifying all other players either as friends or foes. In the first round of the game, all other players are friends. Then all players who cooperate with friends or defect against foes in a given round become friends in the next round. The players who cooperate with foes or defect against friends in a given round become foes in the next round. CNF always cooperates with friends and defects against foes (Bendor and Swistak, 2001, pp. 1514-1516). The fact that CNF can support a stable cooperative state within a population playing the infinitely IPD highlights the importance of norm enforcement through third-party punishment for cooperation within groups (Bendor and Swistak 2001, p. 1533).

Ostracism

In section 3.4, I explained that groups had to resort to some kind of coercive mechanisms in order to ensure that the members of the group succeed in providing a public good. Rousseau, for example, argued that when a state is erected, all people that live in the territory of the state, but failed or were not willing to contribute to it, had to leave the territory of the state (Rousseau 1966 [1762], p. 96; Rousseau 1966 [1762], p. 148). This most basic form of punishment is known as ostracism and is a common and harsh form of punishment in humans (Mahdi 1986, pp. 147-148; Hirschleifer and Rasmusen 1989, pp. 103-105). When an opportunity for ostracism is introduced within a group of players playing the IPD, cooperation can result as an equilibrium strategy even in the finitely IPD (Hirschleifer and Rasmusen 1989, pp. 93-97).

Second-order free riding

Usually, groups resort to less extreme forms of punishment than ostracism to ensure that their members contribute to the public good. For example, each member of a group could sanction defecting members of the group by reducing their payoff at personal costs (Fehr and Gächter 2000, p. 980). This form of punishment is called diffused, because it is done in an uncoordinated way by any member of the group. By doing so, they reduce the payoff of the defecting player, but have to dedicate a part of their own payoff to account for the costs of punishment. Since punishment is costly to the punisher, players are always better off if they do not punish. Rational players are therefore not expected to punish (Fehr and Gächter 2000, pp. 982-983). A group which builds a sanctioning system to enforce a norm requiring cooperation, provides a public good (section 3.4) to its members: all members of the group are better off with the sanctioning system than without, independently of whether they contributed to it or not. This is known as the second-order free-rider problem (Heckathorn 1989, pp. 79-80). On the other hand, an opportunity to punish defecting members can support full cooperation in the provision of a public good (Fehr and Gächter 2000, p. 987).

Altruistic punishment

The second-order free-rider problem can be solved by assuming that enough members of the group have a predisposition for altruistic punishment: they do punish norm deviation, even if this punishment does not yield any material benefit for the punishers, but is costly (Fehr and Gächter 2002, p. 137). Altruistic punishment can be the result of a strong emotional reaction to free riding: the negative emotions among cooperators caused by free-riders trigger punishment (Fehr and Gächter 2002, p. 139), which in turn leads to a rewarding feeling (de Quervain et al. 2004, pp. 1256-1257). Because second-order free-riders (those who do not punish non-cooperators, but cooperate in the main activity) are better off than punishers who also cooperate in the main activity, a third-order, where non-punishers are punished, can be introduced to stabilize punishment.

This, however, also introduces a third-order free-rider problem:

> "Do people really punish people who fail to punish other non-punishers, and do people punish people who fail to punish people, who fail to punish non-punishers of defectors and so on, *ad infnitum*? Although the infinite recursion is cogent, it seems like a mathematical trick." (Henrich and Boyd 2001, p. 80, italics as in the original).

However, when there are punishers in a group and punishment is sufficiently costly to decrease the payoffs for defectors below the payoffs for cooperators, defections will only occur on very rare occasions. In this case, the payoffs of second-order free-riders and punishers will not differ substantially. Occasions in which a second-order free-rider needs to be punished are even less likeyl and the difference between punishers and non-punishers will decrease the more we ascend to higher-order punishing. Eventually, at some stage this difference becomes 0. From this stage on, punishment can transmit back and stabilize cooperation at the first order (Henrich and Boyd 2001, p. 81). As long as members of a group stabilized at a cooperative equilibrium have higher payoffs than members of a group stabilized at a non-cooperative equilibrium (this is the case as long as the costs of punishment and cooperation are smaller than the benefits of cooperation), individuals from non-cooperative groups might start to imitate individuals from cooperative groups. In this way, a group beneficial behaviour from one group can be transmitted to other groups through cultural group selection. Once the cooperative equilibrium has become widespread among human societies, natural selection could further stabilize this cooperative equilibrium by favouring genes that initiate punishment and cooperation. Such individuals would have a higher fitness than individuals without those genes, because they would not suffer from punishment (Henrich and Boyd 2001, pp. 86-87). Due to such co-evolutionary processes, a predisposition for altruistic punishment could indeed find its way into the human genome. It is noteworthy that such co-evolutionary processes could be relevant in the evolution of any types of strategies discussed in this chapter and are not restricted to altruistic punishment.

We have seen in this section that the diffuse threat of punishment by any individual can enforce cooperation in social dilemma situations. This is a surprising finding. All classical scholars highlighted the need for a centralized punishment authority (chapter 2). In Hobbes, the reason for the failure of social order in the state of nature was the fact that no trust could emerge in a state of anarchy, where everyone had the right to make use of violence. Interestingly, a game-theoretical analysis reveals the opposite insight: "In a world not quite Hobbesian, a threat of all against all might, ironically, help overcome distrust." (Hardin 1971, p. 479).

3.5.2 Centralized punishment

While diffused altruistic third-party punishment (section 3.5.1) and decentralized punishment in general is certainly an important aspect for the working of societies, humans also tend to rely on centralized institutions for punishment. These institutions reflect the Leviathan as suggested by Hobbes (section 2.1.2) and depend on the erection of a monopoly of violence in society. Although some societies manage to enforce social order without centralized institutions for punishment, those societies are characterized by low levels of differentiation and complexity. Complex and highly differentiated societies always rely on centralized institutions for punishment. As suggested by Hobbes (section 2.1), those institutions are the foundation for erecting any complex and differentiated society. They induce people to restrain and control themselves, guaranteeing that everyone plays according to the rules (Elias 1997 [1939], pp. 326-336).

> "But in civill estate, where there is a Power set up to constrain those that would otherwise violate their faith, that feare is no more reasonable; and for that cause, he which by the Covenant is to perform first, is obliged so to do." (Hobbes, 2012 [1651], p. 96)

Under the auspices of the Leviathan, the prisoner's dilemma (section 3.2.1) is defused, because defection becomes too costly and is no option any more. When punishment occurs in a coordinated manner, second-order free-riding (section 3.5.1) is not relevant (Boyd et al. 2010, p. 620). This is especially the case when there is only one punisher in a given society (Boyd and Richerson 1992, p. 183). Because central institutions are more prone to overcome coordination failures and second-order free-riding problems, they are more efficient in punishing than decentralized forms of punishment (Baldassarri and Grossman 2011, p. 11023).

3.6 Conclusion: theoretical foundation

In this chapter, I showed how the problem of social order and solutions suggested in Hobbes, Rousseau and Smith can be reformulated in order to allow for a game-theoretical analysis. This approach, however, strongly simplifies the underlying structure and the philosophical arguments of the scholars. More specifically, it is assumed that humans are rational and intelligent utility maximizers that are confronted with the options of either cooperating or defecting in a specific situation. Then, the option which guarantees the maximal expected utility is chosen. The problem of social order analysed in game theory is a problem of rational cooperation. The assumptions made are those of rationality. The game-theoretical analysis of the problem of social order, as discussed in orthodox game theory, is therefore a formalization of the problem of social order from Smith's perspective. In most situations, the diverging self-interests of individuals are balanced by an invisible hand, leading to equilibrium states that are characterized as being optimal and self-enforced. This means that no other outcome would be better, and that no individual has an incentive to deviate unilaterally from the state of equilibrium. In some situations, however, the self-interests of individuals lead to outcomes that are not optimal. These situations are characterized as social dilemmas and are the game-theoretical equivalent to the political-philosophical problem of social order.

At first glance, this representation of the problem of social order seems not to fit well with the political-philosophical problem of social order introduced by Hobbes and adapted by Rousseau. Both scholars did not agree with the doctrine of the balance of diverging interests. From their point of view, diverging interests would ultimately lead to violent conflicts among the parties involved, with the winner being the most powerful party. The problem of social order is therefore not limited to a narrow set of situations where the rationality of individuals fails in generating the optimal outcome, but lies at the heart of society. Their solutions to the problem of social order therefore centre around the elimination of the divergence in individual interests. In Hobbes, the solution is an absolute ruler, in Rousseau, a collectivistic regime.

At second glance, the structure underlying most, if not all, political conflicts can be described with a game theoretical social-dilemma. This allows to make clear predictions about the expected outcome if the actors involved behave in a rational way as expected. This approach furthermore allows to put the assumptions of rationality to an empirical test and to make predictions about different mechanisms that should allow to overcome the social dilemma. The game-theoretical analysis of social dilemma is therefore a fruitful approach to the scientific analysis of the problem of social order. While opting for a dogmatic approach close to Smith, it nevertheless gives up a vast amount of assumptions and dogmatic arguments found in the works of the classical scholars and sticks to a limited set of assumptions and parameters that can be quantified and put to an empirical test in the context of a scientific study. Finally, accepting certain limitations, the concepts of Hobbes and Rousseau can nevertheless be incorporated to some extent in a game-theoretical framework.

In the next chapter, I will focus on one specific social dilemma known as the tragedy of the commons. The tragedy of the commons has been highly influential and convinced many people that humans will eventually over-exploit all resources they are depending on, leading to their collapse. I will give a detailed overview of global and historical patterns of natural resource use, discuss the extent to which natural resource use is a social dilemma and apply concepts of Hobbes, Rousseau and Smith, as well as the game theoretical tools introduced in this chapter to discuss mechanisms suggested to reach sustainability in natural resource use and fairness in natural resource allocation.

Chapter 4

Natural resource use: a problem of social order

Natural resources lay the material foundation of any society. First, like all other organisms, humans rely on natural resources for their survival. Second, human societies rely on natural resources for their growth and development. Since most natural resources are limited, natural resource-led development however risks ending in tragedy, because once key resources become overexploited, society will collapse. Such collapses have occurred frequently in human history and are the result of a social dilemma: individuals following their rational self-interest overexploit the resources they rely on and as a result dig their own grave.

In the first two sections, I describe the historical and global patterns of natural resource use. I briefly discuss the specific pattern observed in the different historical era of natural resource use and draw conclusions on the factors determining whether an overexploitation of natural resources will lead to a societal collapse or not. Humans not only rely on minerals and fuels for their survival, but also on wild plants, wild animals, as well as ecosystem services. I evaluate and discuss the importance of wildlife and ecosystem services for humans and difficulties arising when evaluating their economic values. In the third section, I discuss the tragedy of the commons, the social dilemma used to model the overexploitation of a natural resource held in common, as well as its relevance for contemporary society.

Although the tragedy of the commons has convinced numerous people that humans will eventually destroy the material basis they rely on, it is obvious that a sustainable natural resource use is possible. While a collapse of society, the most serious threat to social order, may happen due to the overexploitation of a key resource, different mechanisms have been suggested to achieve sustainability in natural resource use. Social order is not only threatened by the overexploitation of natural resources, but also by the unfair allocation of natural resources. Here again, a number of mechanisms have been suggested to favour the fair allocation of natural resources. In the fourth section, I discuss different mechanisms from the works of Hobbes, Rousseau and Smith that are supposed to support the sustainability of natural resource use, as well as the fair allocation of natural resources. Based on these mechanisms, I deduce hypotheses which lay the theoretical foundation for my two empirical studies in chapters 7 and 8.

4.1 Natural resources and human societies

Natural resources are a key factor for the development and the wealth of societies. In this section, I first briefly discuss the concept of natural-resource-based economic development. Then, I present a summary of the patterns of global and historic natural resource use, as well as factors determining whether a society will collapse due to the over-exploitation of natural resources or not. I conclude this section by discussing the relationship between natural resource use and population growth.

4.1.1 Natural-resource-based economic development

Natural resources are all raw materials provided by the earth and used by humans. Typically, the term encompasses sunlight, wind, water, soils, minerals, fuels, animals and plants. Natural resources are either available in form of exhaustible stocks (as is the case for minerals), or in a continually renewable manner (as is the case for animals) (Glavic and Lukman 2007, p. 1876). All living beings rely on the exploitation of natural resources for their survival. The fertility of individuals is furthermore a function of the controllability, richness and predictability of important natural resources. Of course, these general facts apply to humans as well (Low and Heinen 1993, pp. 9-10).

However, natural resources also strongly influence human societies, as they lay their material foundation and enable economic growth and development. Following Schumpeter, any good is basically made up of natural resources (land), labour or a combination of both. Land and labour are thus the two original productive factors (2012 [1911], pp. 17-19). Economic growth and development then result as a change in the way how land and labour are combined. Changes in the combination of labour and land can occur, for example, when a society gains access to a new source of raw materials (Schumpeter 2012 [1911], p. 66). This aspect of economic development, natural-resource-based economic development, has been one of the driving forces of human history (Barbier 2005; Barbier 2011). From the perspective of natural-resource-based economic development, the human history can roughly be divided in five key historical periods (Barbier 2005, pp. 106-107).

4.1.2 The era of hunting and gathering

The first historical period of natural-resource-based economic development, the era of hunting and gathering, lasted from the emergence of humans (around 7 million years ago) to about 8500 BC. During this period, all humans survived exclusively by gathering wild plants and hunting wild animals (Barbier 2005, p. 107). Human population size was low, with an estimated 500,000 people living on earth in 40,000 BC. This figure increased to about 6 million humans in 10,000 BC (figure 1), corresponding to an average population growth of 0.008% per year. During the era of hunting and gathering, population size and growth was very low and the overexploitation of natural resources was no threat to society. Only very little is definitely known for this period of time, but it seems that the impact of humans on natural resources was very limited. This changed however during the agricultural transition phase.

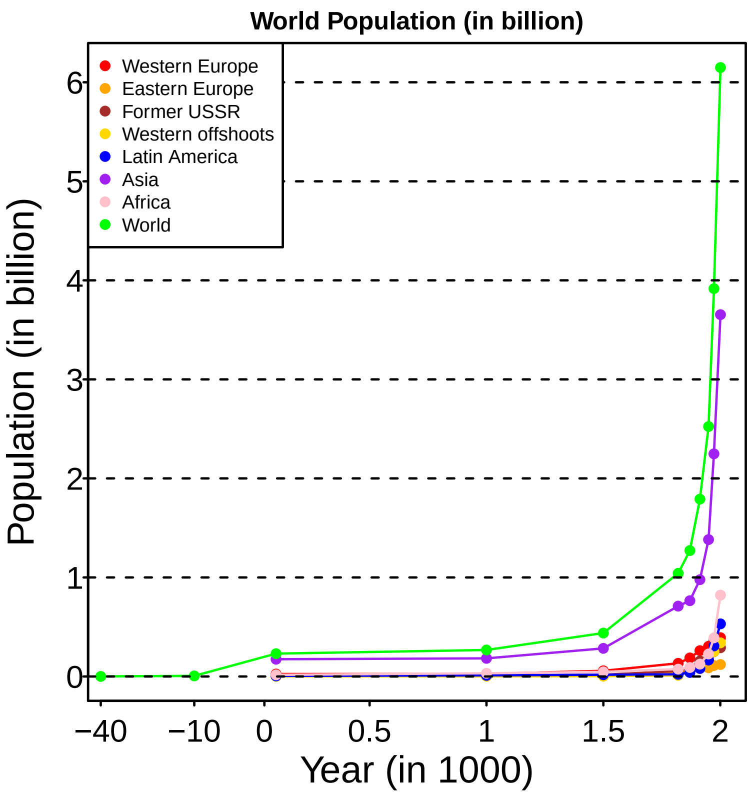

Figure 1: Historical development of population size at continental and global level.
The figure is based on a table from Barbier (2005, p. 109). Western offshoots include the USA, Canada, New Zealand and Australia.

4.1.3 The agricultural transition phase

The second historical period of natural-resource-based economic development, the agricultural transition phase, was determined by the most important economic development in human history. During this period, which lasted around 8600 years, from 8500 BC to 100 AD, humans fundamentally changed their lifestyle: after completing the agricultural transition, they mainly relied on domesticated animals and grown plants for their survival. This fundamental economic change took several millenia to spread across the whole world, with all regions of the world making similar agricultural transitions. The human population grew to 230 million individuals, corresponding to an average population growth of 0.037% per year (Barbier 2005, pp. 107-108, figure 1). The agricultural transition also resulted in the creation of the first towns, and in a core-periphery economic system, where an urbanized, industrial and dominant core traded manufactured goods for primary products and raw materials from less-developed and less-dominant periphery regions. This core-periphery economic system has persisted to this day (Barbier 2005, p. 111). The beginning of the agricultural transition phase goes along with the extinction of the megafauna. The megafauna encompasses all large animals weighing more than 44 kg. With few exceptions, most of the megafauna had disappeared from earth until 10,000 years ago (Barnosky et al. 2004, p. 70; Koch and Barnosky 2006, p. 216). Although the exact reasons of this extinction are not entirely clear, scholars agree that humans played a decisive role (Alroy 2001; Barnosky et al. 2004; Surovell et al. 2005; Koch and Barnosky 2006). It is even possible that the extinction of the megafauna was triggered by the agricultural transition (Smith 1975). In any case, the extinction of the megafauna, which was a key resource to hunters and gatherers, did not result in a collapse of the human societies at that time, but was instead followed by a further development of the economic system. This was however only possible because the basic agricultural techniques were already well known at that time (Barbier 2005, p. 113). The extinction of the megafauna, which occurred during the agricultural transition phase, is an example for a massive overexploitation of a key natural resource. The only reason why this overexploitation did not end in a societal collapse was that humans were able to resort to other ways of subsistence.

4.1.4 The era of Malthusian stagnation

The third historical period of natural-resource-based economic development, "the era of Malthusian stagnation" (Barbier 2005, p. 113), was characterized by low population- and low economic growth. In this 900-years period (from 100 AD to 1000 AD), the world population grew on average by 0.01% per year and the GDP per capita stayed more or less constant. The world population had reached about 270 million people in the year 1000 (Barbier 2005, pp. 114-115, figures 1 and 2).
Although important technological innovations were made during the Malthusian stagnation phase, strongly improving the efficiency of agricultural economies, these only led to small increases in population growth. Malthusian resource-based economic systems are characterized by two conditions: first, at least one factor of production is fixed and essential; second, an increase in real income leads to an increase in population growth, dissipating the initial income gain. As a consequence, Malthusian economic systems lead to constant populations and per capita incomes. Under favourable conditions, increases in the efficiency of the production simply result in increased production outputs and population levels, not substantially altering the per capita income. Under unfavourable conditions, the increased population- and production levels, triggered through increases in productive efficiency, are not sustained by the resource base. A cycle of resource depletion and population decline follows the initial increase in population and production (Barbier 2005, pp. 115-116). Boom and bust cycles, characterized by initial population growth, resource depletion and population ultimately declining, are relevant for all economic systems relying on renewable resources. Such cycles can create violent conflicts over the relevant resource and have frequently been observed in human history (Brander and Taylor 1998, pp. 134-135).
The boom and bust cycles described above can be observed when societies overexploit natural resources. These patterns have been recurrent from the emergence of the first city states in 3000 BC to the rise of the world economy in 1000 AD. Only important trade activities, which emerged later on, allowed societies to decouple the local population from the local stock of natural resources.

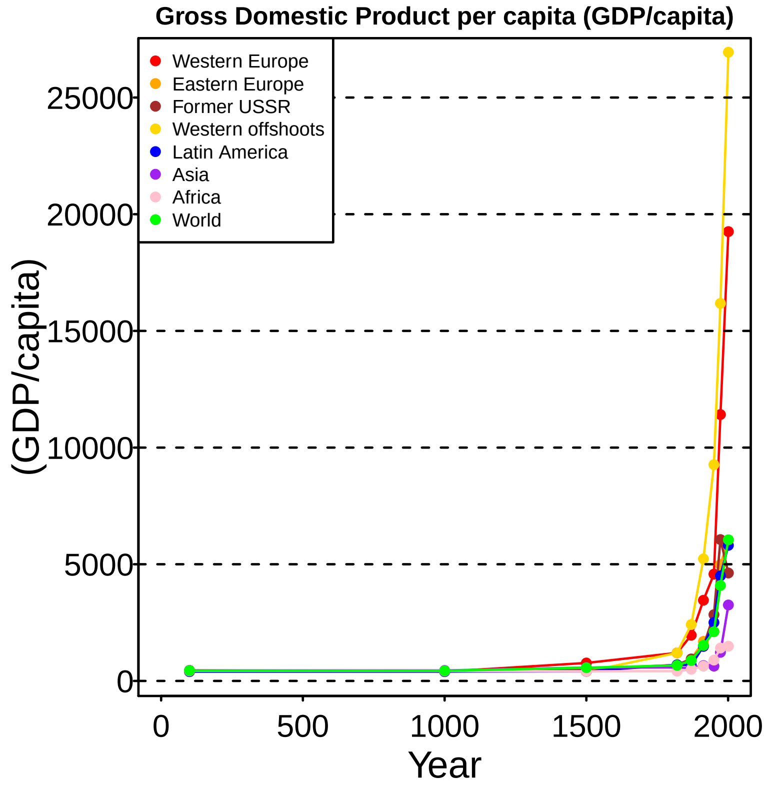

Figure 2: Historical development of GDP per capita at continental and global level.
The figure is based on a table from Barbier (2005, p. 114). Western offshoots include the USA, Canada, New Zealand and Australia.

4.1.5 The emergence of the world economy

The fourth historical period of natural-resource-based economic development, "the emergence of the world economy (from 1000 to 1500)" (Barbier 2005, p. 117) was characterized by the emergence and the expansion of international trade between regions and countries and marked the beginning of the world economy. This development put an end to the period of Malthusian stagnation, significantly increasing average annual population growth and GDP per capita. During this period of time, the world population increased at an annual average rate of 0.1%, reaching 438 million in 1500 and the GDP per capita grew from 436$ to 566$ per person (figures 1 and 2). International trade altered the Malthusian equilibrium between per capita income and population growth by allowing economies to gain access to their essential production factors from other regions of the world. This made population growth beyond the regional resource base possible. China and the Islamic world became the dominant economic world regions between around 1000 and 1500 (the North). While they controlled the leading manufacturing industries, the other regions of the world, mainly Russia, Western Europe and Africa (the South), provided them with the necessary raw materials. Although the dominant regions have changed over time, with Europe and the other Western nations increasingly becoming the dominant region (the North) after 1500,

the world economy can generally be well described with a North-South model of unequal development, where one region specializes in providing the raw natural resources and the other region specializes in manufacturing (Barbier 2005, pp. 117-123; Krugman 1979).
Although natural resource use continuously increased during the era of the emergence of the world economy, the societies at that time were able to avoid collapses by importing the necessary natural resources.

4.1.6 The great frontier and the rise of Western Europe

The fifth historical period of natural-resource-based economic development, "The Great Frontier and the Rise of Western Europe (from 1500 to 1913)" (Barbier 2005, p. 124), was characterized by the industrialization and the rise of Western Europe as the economically dominant world region, the colonization of America and the use of coal as a cheap source of energy. Finding and exploiting new untouched sources of natural resources, after having depleted the existing ones, became the basis for economic development during and following this era (Barbier 2005, pp. 123-125). World population size increased to 1.8 billion and the GDP per capita to 1525$ per person (figures 1 and 2).
In the following period, from 1913 to the present days, economic development and growth is still determined to an important extent by the use of natural resources and is building upon the principles of core and periphery-, world- and frontier economics. Population- and economic growth rates remain at globally- and historically high levels. I would like to point out the following insights gained from the brief summary of global and historic patterns of natural resource use. First, natural resources have continuously been exploited during human history. Second, they have been overexploited at repeated occasions, with the severe consequence of a societal collapse. Third, some societies have managed to avoid such societal collapses although having overexploited key natural resources: they were either able to find a local substitute to the key natural resource, or they were able to import the key natural resource through trade activites.

4.1.7 Global historic patterns of population and economic growth, as well as natural resource use

The brief overview of natural resource use patterns revealed that natural resources have always been a key to societal development. Overall, there clearly is a relationship between GDP per capita- and population growth. Both are relatively low (between 0 and 2.7) and strongly correlate (figure 3). GDP per capita growth is an economic process that generates new productive activities, allowing more individual consumption. GDP per capita growth cannot increase due to population growth. Population growth, on the other hand, is strongly influenced by GDP per capita-, as well as GDP growth. Low growth rates can have substantial effects when maintained over long periods of time: cumulated annual average growth rates of 0.8% between 1700 and 2012 led to an increase of the worlds population size by a factor of 10 (Piketty 2013, pp. 126-129).

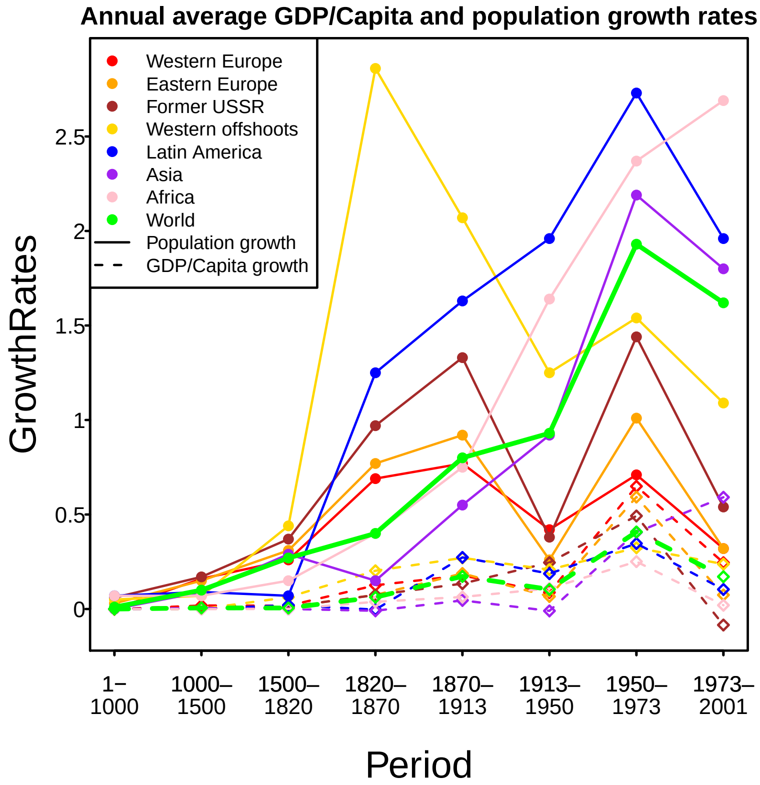

Figure 3: Historical development of average annual GDP per capita- and population growth rates. *The figure is based on own calculations and a table from Barbier (2005, p. 110). Western offshoots include the USA, Canada, New Zealand and Australia.*

The use of natural resources continually increased over time (figure 4; Hylander and Meili 2003, p. 17; Mudd 2007, p. 46; Mudd 2010, p. 12; Höök 2010, p. 34; Mudd 2012, p. 3; Yellishetty et al. 2011, p. 81; 4). This is, as discussed above, due to a demographic- as well an economic trend. New raw materials are of crucial importance for the development of new technologies and economic activities (for example Cobalt, rare earths and Lithium play a key role; figure 5). The industry is therefore constantly looking for new sources of raw materials and recent, futuristically-sounding projects involve the use of plants to gather rare earths, the mining of the deep sea (Federal Ministry of Education and Research 2017) or space (Futurezone 2018). It is important to keep in mind that only very few economic activities are really independent from natural resource use. Even the modern economic sectors of "green technologies" or artificial intelligence, which are considered to be either clean or entirely immaterial, rely on a substantial input of natural resources.

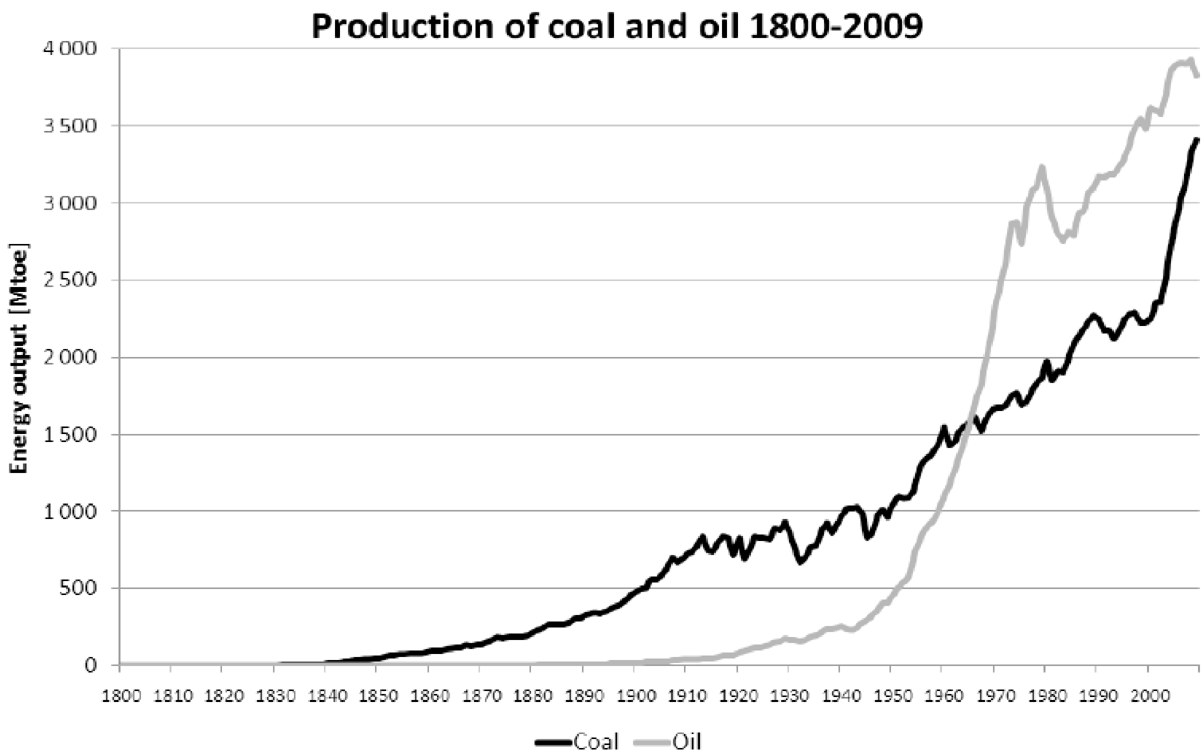

Figure 4: Global historical production trends for coal and oil.
Coal (grey line) and oil (black line) production (million tons/year) from 1800 to 2010 (Höök 2010, p. 34).

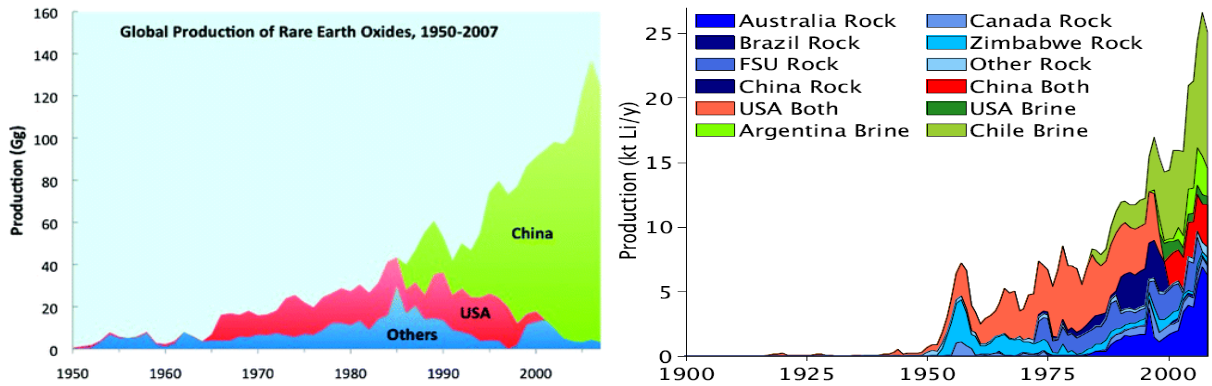

Figure 5: Global historical production trends for raw earths and Lithium.
Left) Rare earths production (gigagram/year) from 1950 to 2007, by producer (Du and Graedel 2011, p. 4096). Right) Lithium production (kilotons/year) from 1900 to 2000, by producer (Mohr et al. 2012, p. 67).

The historical growth in population size and economic activity shaped the landscape of planet earth, leading to the conversion of undisturbed ecosystems to cropland, pasture, or urban areas (figure 6). While these three categories made up 0 % of the global land surface in the year 10,000 BC (Goldewijk et al. 2010, p. 75, Goldewijk et al. 2011, p. 571), cropland accounted for 10.6%, pasture for 24.3% and urban areas for less than 0.5% of the global land surface in the year 2000

(Goldewijk et al. 2010, p. 75, Goldewijk et al. 2011, p. 571). As will be discussed later in this chapter, the conversion of undisturbed ecosystem into productive or residential areas has a negative effect on the earth's biodiversity and ecosystem services, which, on the other hand, lay the foundation for human well-being.

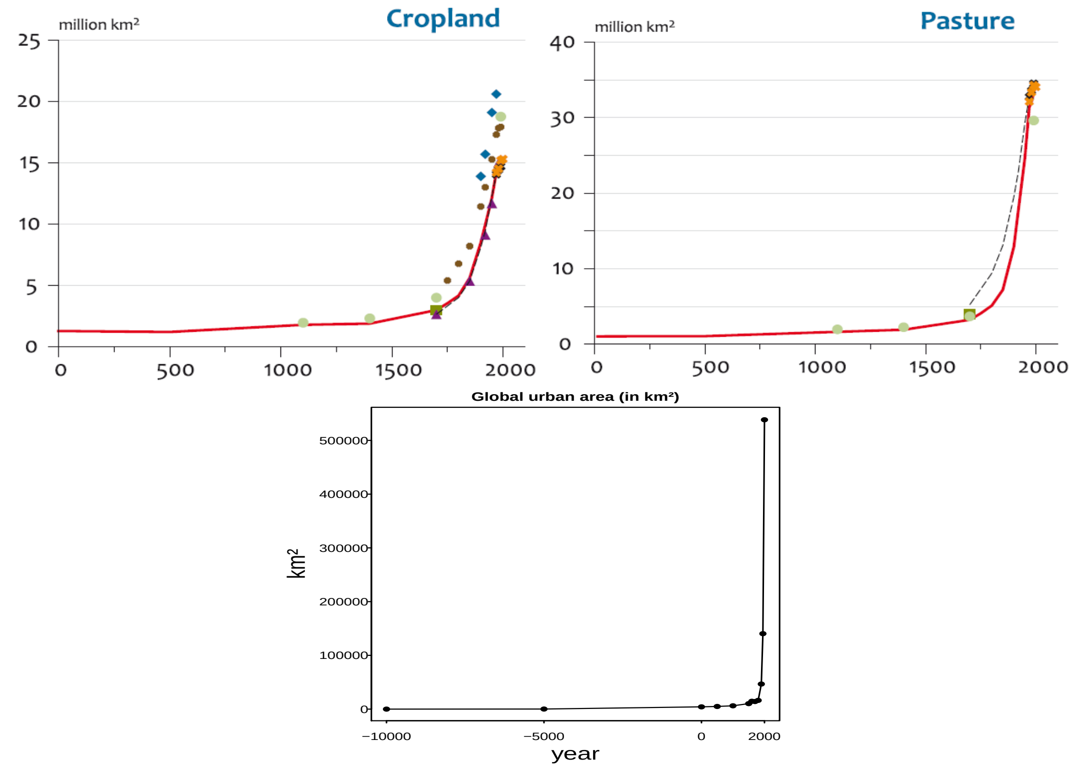

Figure 6: Global historical trends of human-induced land use change.
Top left) Global cropland surface (million square km) from year 0 to 2000 (red line is the linear trend) (Goldewijk et al. 2011, p. 82). Top right) Global pasture surface (million square km) from year 0 to 2000 (red line is the linear trend) (Goldewijk et al. 2011, p. 82). Bottom) Urban area (square km) from 10,000 BC to 2000 AD (the figure is based on a table from Goldewijk et al. (2010, p. 571))

4.2 Wildlife as a natural resource

Wildlife has been the most important natural resource for the survival of the human species since its emergence. During most of its time on earth, the human species survived exclusively by exploiting wild animals and plants (Prescott-Allen and Prescott-Allen 1986, p. 1, Barbier 2005, p. 107). Wildlife encompasses all species of wild animals and plants that reproduce without human intervention and whose habitat can regenerate without human intervention (Prescott-Allen and Prescott-Allen 1986, p. 2). The contribution of wildlife to the human economy has a physical as well as a psychological component. The physical component includes the provision of raw materials, biological diversity and services. The psychological component includes the provision

of recreational , scientific, cultural or religious use. The extent to which these different contributions can be economically quantified differs strongly. While the economic value of raw materials can be easily assessed by taking into account market prices, this approach becomes more difficult with a decreasing material component of the contribution and the availability of market prices (Prescott-Allen and Prescott-Allen 1986, pp. 4-5).
It is very difficult to reliably quantify the economic value of wildlife. However, contrary to what most people would think, wildlife is still an important natural resource, even for people in industrialized countries. In this section, I first give a detailed summary of the results of a study with a detailed estimate of the economic value of wildlife for the United States from 1976 to 1980. Then, I focus on two key products, timber and fish, to describe the global historical pattern of the exploitation of wildlife. Finally, I explain how a more general view on ecosystems can help understanding the value of nature for the well-being and the economic wealth of human societies.

4.2.1 Quantifying the economic value of wildlife

Wildlife plays an important role for human economy. This is not only the case for the fraction of the global human population still living as hunters and gatherers (Marlowe 2005, p. 56), but holds also for modern industrialized economies. Between 1976 and 1980, the value of wildlife used by the US-economy amounted to 30 billion US$: “$1 of every $22 generated in the United States is attributable to wildlife–91 cents of that dollar comes from wild harvested resources, 7 cents comes from wild-supported agriculture, and 2 cents from wildlife-based recreation.” (Prescott-Allen and Prescott-Allen 1986, p. 409). It is important to highlight that this figure also includes imported wildlife products. In their extensive analysis, the different quantifiable contributions of the wildlife to the US economy are classified into 9 distinct categories (Prescott-Allen and Prescott-Allen 1986). The most important category, logging (Prescott-Allen and Prescott-Allen 1986, p. 410), is an economic activity mainly conducted to obtain pulp, fuel, timber, turpentine, terpenes and rosin. In 1972, the US produced 11.81 billion cubic feet of timber worth 6.4 billion US$. The authors estimated that 96% of this timber came from wild trees (Prescott-Allen and Prescott-Allen 1986, pp. 9-11). Fishing was the second most important wildlife-based industry in the US (Prescott-Allen and Prescott-Allen 1986, p. 410). Between 1976 and 1980, an average of 26.7 million tons of wild fish were taken annually by commercial landings in the US. This catch was worth 1.8 billion US$. About half of this catch was used for the food industry and the rest for other industrial purposes (Prescott-Allen and Prescott-Allen 1986, pp. 49-50). After logging and fishing, trapping and collecting is the third economic activity specialized in harvesting wild species. This activity yields a variety of products ranging from ornamental items to pets. The annual average value of skins and furs harvested in the US was 122 million US$ for the period 1976-1980. In the same period, the US imported ornamental and pet species with an annual average value of about 346 million US$ (Prescott-Allen and Prescott-Allen 1986, pp. 67-68). The contribution of wildlife for food and industrial products is closely related to its harvesting. Between 1976 and 1980, the United States imported and produced food and industrial products from wildlife with an average annual value of 229 million US$. The most valuable domestic products were pecans (121.5 million US$), blueberries (48.8 million US$), maple syrup (13.6 million US$) and wild rice (4.2 million US$ (Prescott-Allen and Prescott-Allen 1986, pp. 149-150). The third most valuable contribution of wildlife to the US economy was made in form of domestication and crop improvement (Prescott-Allen and Prescott-Allen 1986, p. 410). This activity amounted to annual average values of 168.6 million US$ for new crops, 178.7 million US$ for new livestock, 182.1 million US$ for new aquaculture species and 706.6 million US$ for new domesticated timber trees in the time period of 1976-1980 (Prescott-Allen and Prescott-Allen 1986, p. 274). The fourth most important contribution of wildlife to the US economy was made in form of recreational use (Prescott-Allen and Prescott-Allen 1986, p. 410). In 1980, the 53.9 million US Americans who fished on a regular basis spent 17.3 billion US$ on recreational fishing and the 19.4 million US Americans who hunted on a regular basis spent 8.5 billion US$ on recreational hunting. A total of 94.6 million US Americans spent 6.6 billion US$ on non-consumptive wildlife use. The economic value of harvested wild animals is not considered when calculating the value generated through recreational hunting and -fishing. Only the expenses for travelling and equipment are taken into consideration (Prescott-Allen and Prescott-Allen 1986, pp. 363-364). Non-consumptive wildlife use includes activities such as feeding-, observing- and photographing wildlife or visiting parks and natural areas (Prescott-Allen and Prescott-Allen 1986, p. 382). The contribution of wildlife to the medical sector of the US is difficult to estimate. First of all, it is nearly impossible to distinguish between plant-derived ingredients of wild- or domesticated plants (Prescott-Allen and Prescott-Allen 1986, p. 100). Secondly, market prices for important medicinal wild plants are difficult to access (Prescott-Allen and Prescott-Allen 1986, p. 122). Nevertheless, wildlife plays an important role for modern medicine: about 1.5% of the 15,871 active ingredients listed in the Canadian Drug Identification Code of 1981, and 3.7% of the drugs considered as essential by the World Health Organization in 1979 originated from wild plants (Prescott-Allen and Prescott-Allen 1986, p. 103 and Prescott-Allen and Prescott-Allen 1986, p. 141). An important contribution of wildlife to the medical sector of the US also came in form of animals for medical research: in 1977, 34,000 nonhuman primates and 60,795 other wild animals were used in health-related activities (Prescott-Allen and Prescott-Allen 1986, p. 144 and Prescott-Allen and Prescott-Allen 1986, p. 148). Finally, wildlife contributed to the US economy by delivering pollination and pest control services. The mean annual value of crops imported or grown by the US whose production or propagation depended on wild pollinators was 1.34 billion US$ for the time period of 1976-1980 (Prescott-Allen and Prescott-Allen 1986, p. 356). Pests control based on wildlife furthermore allows farmers to cut their pesticide use and make substantial savings (Prescott-Allen and Prescott-Allen 1986, p. 362).

This section aimed at giving a brief but extensive overview of the value of wildlife for modern economies. The study presented here reveals that wildlife accounts for approximatly 5% of the GDP of the most important industrialized nation. Of course, the current state of affairs might have changed, since the period of time considered by Prescott-Allen and Prescott-Allen (1986) dates already back 40 years, but I am not aware of a more recent similarly comprehensive investigation of the macroeconomic value of wildlife for industrialized economies.

4.2.2 Global historic pattern of wildlife use

The short summary of the contribution of wildlife to the US economy for the period of 1976-1980 has shown that wildlife plays an important economic role, even for industrialized societies. This summary also revealed that wildlife affects a variety of aspects of the US economy. A look at the historical development of the global output of the logging- and the fishing industry shows that the exploitation of these two key wildlife resources clearly increased during the last centuries and decades (figure 7).

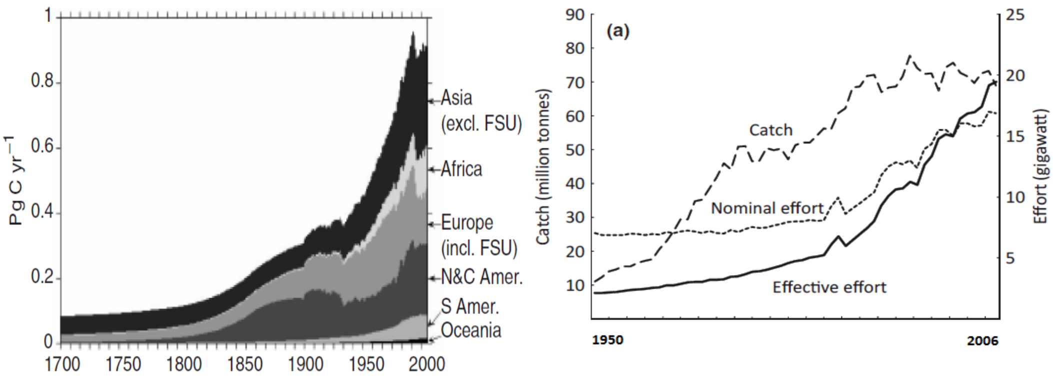

Figure 7: Global historical production trends of the fishing and logging industry.
Left) Logging. Wood production (Petragram Carbon ^-1/year) from 1700 to 2000 (Hurtt et al. 2006, p. 1212). Right) Fishing. Catch of fish (million tonnes/year) from 1950 to 2006 (Watson et al. 2013, p. 498).

4.2.3 Ecosystem services

The valuation of wildlife is a complex matter. However, by focusing solely on the economic value of wildlife, ecological, social and cultural aspects are neglected (Pascual et al. 2017, p. 10). But even the economic value of wildlife is made up of different components, that are in part mutually exclusive. This is due to the fact that wildlife contributes to the human economy in two different ways. When wildlife is harvested or exploited as a resource, its value can be estimated by considering the market value of the output generated through this economic activity. When the same wildlife is left untouched, it contributes to the services of the ecosystem of which it is an integral part. However, there are no market values for ecosystem services (TEEB for Business Coalition/Trucost 2013, p. 14). In Schumpeters terminology (2012 [1911], pp. 17-19), ecosystem services are economic goods provided by the land without requiring any labour. The services provided by the ecosystems can be classified as provisioning-, regulating-, supporting-, or cultural services. Key ecosystem services encompass for example the purification and the regulation of the flow of water, the regulation of air quality, the removal of pollutants from the atmosphere or the provision of conditions for growing food (TEEB 2018). When exploiting wildlife, ecosystem services may become disturbed or even destroyed at the same time. Only considering the market value of the output generated through the exploitation of wildlife, without considering its effect on the targeted ecosystem services, leads to biased economic valuations of economic activities exploiting wildlife: the exploitation of wildlife is a valuable economic activity only when the value of the output generated through its exploitation exceeds the induced losses in ecosystem services. This can be expressed with an impact ratio as follows: “Direct environmental cost per unit of revenue” (TEEB for Business Coalition/Trucost 2013, p. 8). Let us consider some examples from 2009. Cattle ranching and farming in South America generated a total of 16.6 billion US$ in revenues and destroyed ecosystem services worth 312.1 billion US$, leading to an impact ratio of 18.7. In Northern America, the same activity generated a total of 22.9 billion US$ and destroyed ecosystem services worth 31.7 billion US$, leading to an impact ration of 1.4. Accordingly, cattle ranching and farming was a more valuable economic activity in Northern America than in South America. In none of the regions, did benefits however exceed costs. Soy bean farming in South America, on the other hand, had an impact ratio of 0.9 and was therefore economically valuable (TEEB for Business Coalition/Trucost 2013, p. 57). Following this approach, the authors estimated that the global processing and production of the regional sectors considered in their analysis destroyed ecosystems worth 7.3 trillion US$ in 2009. This analysis only included ecosystem services related to water consumption, land use, air pollution, land and water pollution, greenhouse gas emissions as well as waste (TEEB for Business Coalition/Trucost 2013, p. 8).

I showed in this section that nature plays a vital role for the well-being of humans. On the one hand, wildlife is a natural resource that can be exploited by humans for their private consumption. On the other hand, ecosystems provide services, such as clean air and water, that are essential for the survival of humans. Although it can be argued that the importance of nature for the survival of humans decreases with the economic development of societies, it is still a fact that the role of nature for human well-being is essential at any stage of economic development.

4.3 Resource depletion as a social dilemma

Although natural resources play an undoubtedly essential role for human societies (sections 4.1 and 4.2), humans have repeatedly overexploited key natural resources. Prominent examples are the deforestation of the Easter Island (Brander and Taylor 1998) or the desiccation of the Aral sea (Micklin 2007). Societies that overexploit their natural resources risk to collapse. Such collapses have occurred numerous times in the history of human societies (Brander and Taylor 1998; Diamond 2005; Barbier 2011). In this section I first describe the uniquely high natural resource use of contemporary human societies and discuss threats to human well-being that are occurring due to this heavy use of natural resources. In the second part of this section, I discuss the tragedy of the commons, its structure and assumption, and the use of this social dilemma as a model for the overexploitation of natural resources by humans.

4.3.1 Contemporary natural resources use

The situation of contemporary societies is unique from a historical perspective. World population size and economic production are at record heights, and actual trends indicate that both will keep growing in the near future (section 4.1). Continuous growth at high levels of population size and economic activity has led scholars to question the sustainability of this growth: "*How may the expanding global population and material economy interact with and adapt to the earth's limited carrying capacity over the coming decades?*" (Meadows et al. 2004, p. 137, italics as in the original). The authors of "Limits to Growth: The 30 Year Update", concluded that contemporary societies would collapse if they continued to grow as in the past decades (Meadows et al. 2004, pp. 167-179). The question of the earths carrying capacity has however been subject to debates, with other scholars arguing that the carrying capacity is not rigid and as strongly determined by economic and social considerations, individual and collective choices, as by natural limits (Cohen 1995, p. 343, Seidl and Tisdell 1999, pp. 403-404). While the debates about natural limits to human population growth and a collapse of contemporary societies are highly speculative, there seems to be a consent among scholars that, overall, key natural resources are becoming scarce: "That world oil production is set to pass a peak is now a reasonably accepted concept, although its date is far from consensual." (de Almeida and Silva 2009, p. 1267). Peak oil describes the point in time when supply in conventional oil will begin to decrease. This will have a tremendous effect on economic output because of the key role oil plays for contemporary economies: oil serves as a feedstock and fuel in industry and transportation (Murphy and Hall 2011, p. 52). Some estimates suggest that a decline in world oil supply by 1% would directly translate into a 1% decline in GDP per capita (Hirsch 2008, p. 888). Besides peak oil, there is also peak minerals. The fact that a resource becomes rare, after having been exploited during an extended period of time, usually implies that easily accessible, high quality parts of the resource have already been harvested. This has two consequences. First, more effort is needed in order to obtain the same amount of the resource. Second, the quality of the harvested resource decreases (Prior et al. 2012, p. 578). Over the last decades, this pattern has been observed for oil, key minerals and fish (Prior et al. 2012, pp. 579-580; Watson et al. 2013, p. 498; Saellh et al. 2015, p. 433; Court and Fizaine 2017, p. 152).

The continued growth in human population and economic activities has a strong impact on the ecosystems of the world. The irrigated area, for example, increased from 63 million hectares in 1900 to 306 million hectares in 2005 (Siebert et al. 2015, p. 1530). The increased use of freshwater not only altered the natural flow of rivers, but also led to an increased pollution of freshwater resources: the main sources of pollution are agriculture, mining, hazardous waste, urban wastewater as well as natural-, geogenic- and biogenic contaminants (Schwarzenbach et al. 2010, p. 114). As a result, most freshwater sources are polluted to some extent: in Germany, only 6.7% of all 8995 evaluated rivers were classified as in good or very good ecological shape by the German ministry for environment (Bundesministerium fuer Umwelt, Naturschutz und nukleare Sicherheit 2018, p. 3). The pollution is however not restricted to rivers: since the middle of the 20th century, pollution led to the emergence of more than 500 coastal sites with oxygen concentrations low enough to negatively affect the abundance and distribution of animal populations in the sea (Breitburg et al. 2018, p. 1). The oceans are furthermore also contaminated with plastic: a study in 2014 estimated that an amount of plastic weighting more than 250,000 tons was floating on the water surface. This plastic, eaten by birds and fish enters the food chain with unknown consequences for the human population (Cressey 2016, pp. 264-265). Overall, 60% of the plastic ever produced is accumulating in landfills or in the environment (Geyer et al. 2017, p. 3). Pollution is a direct threat to humans: about 16% of all deaths worldwide are related to the pollution of the environment (Landrigan et al. 2017, p. 1). The terrestrial areas also have been exposed to human pressure. 9.6% of the remaining wilderness areas have been lost in the two decades from 1990 to 2010 due to human activities. As a consequence, three of the 14 terrestrial biomes do not have any significant wilderness anymore (Watson et al. 2016, pp. 1-2). During the period from 2000 to 2012, forest cover has decreased by 2.3 million square km. Setting off the forest cover gain reached due to plantations, this translates into a loss of 16% of global forest cover during these 12 years. 32% of the forest cover loss occurred in tropical forests (Hansen et al. 2013, p. 850).

A mass-extinction of species has occurred during the last 500 years (Barnosky et al. 2011, p. 54). The pressure put on ecosystems by humans is certainly one driver of this mass-extinction (Barnosky et al. 2011, p. 56). International trade has been one of the driving factors behind the pressure put on ecosystems: the demand of developed countries for commodities in developing countries can be linked to about 30% of global species threats (Lenzen et al. 2012, p. 109). Habitat loss is however not the only reason for species decline. Let us consider the case of the Bornean orangutans. Between 1999 and 2015 about 148,500 Bornean orangutans were lost (Voigt et al. 2018, p. 763). While deforestation as well as industrial paper pulp- and palm plantations account for a major proportion of these losses, orangutan populations also declined in intact habitats. This suggests that the direct killing of orangutans for food, pet trade or other reasons is another driver of the orangutan population decline (Voigt et al. 2018, p. 766). The illegal and legal trade in wild species products is worth about 342 billion US$ annually and another driver of species extinction (Ratchford et al. 2013, pp. 8-10). With most indices (8 out of 10) for the state of biodiversity declining for the last four decades (Butchart et al. 2010, p. 1165), the decline in populations of wild species is a global issue, which is not restricted to exotic species such as the Bornean orangutan. In Germany, aerial insect biomass measured in mid-summer declined by 81.6% over a 27 year period beginning in 1986 (Hallmann et al. 2017, p. 10). Over a similar period of time, the population of European farmland birds showed a decline of 55% (EBCC 2017).

4.3.2 The tragedy of the commons

With rising population and -economic activities on the one hand, declining resources, -ecosystem services and -wildlife on the other hand, humans seem to be entering an age of ecological scarcity (Barbier 2011, p. 6). Ecological scarcity, however, has already been experienced several times in the past (Brander and Taylor 1998; Diamond 2005; Barbier 2011). But how is it possible, that humans repeatedly destroy the resources they rely on? Would this not mount to collective suicide? Obviously, this cannot be a conscious, intended choice.

It turns out that the exploitation of resources by humans is a social dilemma under given circumstances. This dilemma, known as the tragedy of the commons, was first elabourated by William

Forster Lloyd (1794-1852) and became famous after Hardin published his article "The tragedy of the commons" in 1968. Making use of the example of herdsmen using a pasture to feed their cattle, the tragedy of the commons describes the social dilemma underlying the exploitation of a resource held in common by multiple rational appropriators. As in the case of public goods (section 3.4), all individuals of a group have access to a common good (although it is theoretically feasible to exclude some from the common good). However, in the case of the common good, the consumption of the good is subject to rivalries (Kollock 1998, pp. 190-191) (table 2). The tragedy of the commons tells us that, in the long run, rational herdsmen will overgraze their pasture and lose their livelihood. This follows from the rationality of the herdsmen, the cost and benefit structure underlying their business and the fact that the pasture is open to all: while a herdsman receives the whole benefit of his additional animal on the pasture, the costs which occur to the pasture due to this additional animal are shared among all herdsmen. The private benefit of an additional animal on the pasture exceeds the private cost. As all herdsmen face the same situation, they will keep adding animals on the pasture until it is completely overgrazed:

> "Each man is locked into a system that compels him to increase his herd without limit-in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all." (Hardin 1968, p. 1244)

Underlying the situation described by Hardin, we find the same structure as in the prisoner's dilemma (table 3). Both herdsmen could keep a collectively efficient amount of animals grazing on the pasture and have a long term benefit from the resource. However, as both herdsmen strive for the maximum payoff, they end up with the worst outcome possible (table 12). The social dilemma in tragedy of the common situations involves two components: first, the resource is overused without concerns for the others; second, necessary investments needed to maintain and improve the resource are not made (Ostrom et al. 1999, p. 279). In fact, situations where humans exploit natural resources vary substantially and can be characterized as tragedy of the commons situations only if several conditions are met: first, the resource must be a common good; second, there must be multiple appropriators exploiting the common good; third, the strategies used by the appropriators to exploit the common good have to result in a suboptimal outcome from the point of view of the appropriators; finally, there must be at least one alternative set of strategies to exploit the common good which is advantageous to all appropriators (Gardner et al. 1990, pp. 336-337).

Table 12: Payoff matrix of the tragedy of the commons (Faysse 2005, p. 253).

	Herdsman 2: Collectively efficient choice	Herdsman 2: Collectively not efficient choice
Herdsman 1: Collectively efficient choice	5, 5	3, 6
Herdsman 1: Collectively not efficient choice	6, 3	1, 1

The tragedy of the commons has been a highly influential theoretical model. Not only did it strongly shape our view of the way humans exploit resources (Feeny et al. 1990, p. 2; Ostrom et al. 1999, p. 278; Stavins 2011, pp. 88-89). It was also extended to model situations involving the exploitation of resources held in commons by non-human organisms: it seems that all organisms exploiting a common resource face a trade-off between maximizing individual fitness and reducing the whole groups' fitness (Rankin et al. 2007, pp. 644-645; MacLean 2008, pp. 233-234; Gersani et al. 2001, p. 661). Furthermore, the tragedy of the commons is also applied to phenomena that are not directly related to the exploitation of resources, as for example antibiotic resistance in humans (Cully 2014, pp. 16-17; Hollis and Maybarduk 2015, p. 33), the peer review crisis (Hochberg et al. 2009, p. 2; Fox and Petchey 2010, p. 325), tax regimes of developing countries (Berkowitz and Li 2000, pp. 370-371), the online phishing industry (Herley and Florenico 2008, p. 59), the bitcoin mining industry (Heilman 2014), or the asbestos litigation process (McGovern 2002, pp. 1721-1723).

Although Hardin's tragedy of the commons has convinced many from the fact that humans will ultimately destroy the resources they depend on, humans have been exploiting natural resources for thousands of years, in some cases in sustainable ways. The key for succeeding to overcome the tragedy of the commons lays in building institutions for governing and managing the common-pool resource. This is mainly done by restricting the access to the resource and by creating incentives to invest in the resource rather than overexploiting it (Ostrom et al. 1999, pp. 278-279). According to Ostrom, this involves, among others, matching the rules governing the common good to the conditions and needs of the local population, defining clear group boundaries, ensuring participation of those affected by the rules, making sure that the rights of affected community members are respected by outside authorities, developing a system where community members monitor other members' behaviour, sanctioning rule violators, providing means for dispute resolution, and building responsibility for the governance of the common good on the entire system (Ostrom 1990, pp. 178-181).

All measures suggested to solve the tragedy of the commons are attributable to one of the three main institutional solutions. These involve a change from an open access to a state property, a communal property or a private property regime (Feeny et al. 1990, p, 1). While Hardin focused on the state property- and the private property regimes as the only solutions to overcome the tragedy of the commons (1968, p. 1245), ample evidence suggests that also the communal property regime is successful in overcoming the tragedy of the commons (Feeny et al. 1990, p, 10). These three main institutional solutions directly follow from Hobbes (section 2.1), Rousseau (section 2.2) and Smith (section 2.3). Advocates of the state property regime are worried about the limited natural resources and assume that the contemporary economic system will ultimately destroy the livelihood of humans. As a result, they ask for a strong Leviathan that keeps voracious selfish humans under control and thereby rescues humanity (Nonnenmacher 1989, pp. 269-272). Advocates of the communal property regime are, similarly to advocates of the state property regime, also concerned with the limited natural resources and also assume that the contemporary economic system will ultimately destroy their livelihood and bring an end to humanity. However, contrary to advocates of the state property regime, they do not believe in a strong Leviathan. Instead, they focus on the solidarity and normative integration of individuals within small communities (Nonnenmacher

1989, pp. 282-287). Finally, advocates of the private property regime do not necessarily believe in natural limits. They highlight that the limits are more institutional than natural and that the optimal solution is to break those institutional barriers in order to unleash the forces of the free market: only by applying the price mechanism to scarce natural resources can these really be preserved (Nonnenmacher 1989, pp. 275-277).

4.4 Means to overcome the tragedy of the commons

Although natural resources are essential for the survival of humans and the development of human societies, they are often not exploited in a sustainable way. If a key natural resource becomes overexploited, social order collapses because humans need to fight for survival. Struggles and conflicts erupt for the key natural resource that has become scarce, leading to violent outbreaks. However, even when natural resources are not overexploited, their allocation can still threaten social order. This is the case when the allocation of a key natural resource is conceived as unfair. In this section, I will deduce hypotheses based on mechanisms suggested by Hobbes, Rousseau and Smith to achieve a sustainable natural resource use, as well as a fair allocation of natural resources.

Drivers of sustainable natural resource use

As discussed in the prior section (section 4.3), the use of natural resources is a social dilemma that occurs when a natural resource is held in common. As discussed in section 3.1.6, a resource held in common is characterized by the fact that the resource is openly accessible. This means that everybody is allowed to use the resource. At the same time, the consumption of units of the resource by individuals is competitive: if one individual consumes a unit of the resource, nobody else can consume the same unit. This specific constellation leads to a situation where rational actors will increase their extraction of the resource until it is entirely depleted. The main three solutions suggested to overcome this social dilemma are based on a restriction of the access to the resource and are closely linked to the different political philosophies of Hobbes, Rousseau and Smith (chapter 2).

Following Hobbes (section 2.1), as long as the resource is open access, selfish and voracious individuals will overexploit it, until it becomes depleted. This outcome can only be avoided by a Leviathan regulating its use under a state property regime. As a consequence, we would expect the state property regime to be the only solution for a sustainable use of natural resources. Following Rousseau (section 2.2), state regulations only have a lasting influence on the behaviour of individuals if the laws of the state coincide with the moral norms of the population. This condition is more likely to be met in small communities, than in a large state. Therefore, the communal property regime should be the best solution to guarantee for a sustainable natural resource use. Adam Smith, on the other hand, focused on the effect of a private property regime on the exploitation of natural resources:

> "As soon as the land of any country has all become private property, the landlords, like all other men, love to reap where they never sowed, and demand a rent even for its natural produce. The wood of the forest, the grass of the field, and all the natural fruits of the earth, which, when land was in common, cost the labourer only the trouble of gathering them, come, even to him, to have an additional price fixed upon them. He must then pay for the licence to gather them; and must give up to the landlord a portion of what his labour either collects or produces."(Smith, 1993 [1776], p. 219)

According to this view, the overexploitation of a natural resource held in common results from the fact that the price mechanism is disabled. In a private property regime, if a resource becomes scarce, its price increases, leading to a lower demand and to lower extraction rates. It follows from these considerations that the private property regime should allow for a sustainable natural resource use.

In addition to the type of property regime, there are at least two more important factors for a sustainable natural resource use that can be deduced from the works of Rousseau and Smith. Rousseau strongly argued for the necessity to govern with the help of moral rules (section 2.2). As a reminder, Binmore qualified Rousseaus project concerning the moral education of people as "brainwashing" (1994, p. 135). It follows that the most effective measure for a sustainable use of natural resources is a moral norm that regulates the demand and/or the offer for the natural resource in question. Smith, on the other hand, promotes an economic development of human societies with the goal to maximize the wealth and the freedom of humans, thereby enforcing the natural rights of humans (section 2.3). He argues that the means for this development are the division of labour- and the market. By maximizing the extent of the market, the wealth of societies and the freedom of individuals is maximized at the same time. We have seen that increased wealth comes along with an increased exploitation of natural resources (section 4.1). As a consequence, we would expect the exploitation of natural resources to increase as the market extends. Consequently, sustainable natural resource use should decrease with an extending market. This reasoning clearly corresponds to what Smith has in mind:

> "A particular country [...] may frequently not have capital sufficient both to improve and cultivate all its lands, to manufacture and prepare their whole rude produce for immediate use and consumption, and to transport the surplus part either of the rude or manufactured produce to those distant markets where it can be exchanged for something for which there is a demand at home." (Smith, 1993 [1776], p. 219)

All hypotheses related to the sustainable use of natural resources are summarized in table 13.

Drivers of fair natural resource allocation

Social order is not only threatened when a resources becomes overexploited, but also when its allocation is perceived as unfair. This follows from the inequity aversion and the unique sense of fairness of humans. Fairness is one of the most important moral norms for social order, because conflicts might erupt due to allocations that are too far from the fairness norm (Falk et al. 2003; Brosnan and deWaal 2014). Central parts of the works of Hobbes, Rousseau and Smith focus on the allocation of resources among individuals of a society (chapter 2). We can therefore apply the works of the three scholars to deduce hypotheses about factors favouring a fair allocation of natural resources.

According to Hobbes (chapter 2.1), the necessary condition for humans to agree to a fair allocation of natural resources is the pressure from an external coercive political authority that has opted for a fair allocation. Without this condition, no fair allocation is possible. In his work, Rousseau highlights the importance of moral norms for social order (section 2.2). He argues that such moral norms would only be strong and relevant in homogeneous societies, without interest groups or other subgroups negatively affecting the moral integrity of a society. Consequently, the fairness of natural resource allocations should increase with the homogeneity of a society and decrease with the inequality of a society. Unlike Rousseau, Smith argues that moral norms are a by-product of daily interactions (section 2.3). They can therefore not be manipulated and used as governing tool. According to Smith, fairness is the central moral norm responsible for the functioning of human societies, because it keeps destructive human egoism under control. He assumes that human populations gradually build a sense of fairness with the continuous extension of the market economy in their society. It follows that the fairness of an allocation of natural resources within a society should increase with its integration within a market economy. Smith furthermore convincingly argues that humans are constantly looking for means to obtain a favourable judgment by others (section 2.3). This is one of the main motives of human behaviour. As a result, the fairness of natural resource allocations should increase to the degree that the behaviour of individuals involved in the allocation of the resource is observed or known by others. All hypotheses related to the fair allocation of natural resources are summarized in table 13.

Table 13: Hypotheses.

Scholar	Problem of social order	Prediction
Hobbes	Natural resource use	Leviathan: Sustainable natural resource use can only be implemented in a state property regime
Rousseau	Natural resource use	General will: Sustainable natural resource use is best implemented in a communal property regime
Smith	Natural resource use	Invisible hand: Sustainable natural resource use is best implemented in a private property regime
Rousseau	Natural resource use	General will: The sustainability of natural resource use increases with the salience of a moral rule regulating its offer or demand
Smith	Natural resource use	Invisible hand: Natural resource use increases with the extent of the market
Hobbes	Natural resource allocation	Leviathan: The fair allocation of natural resources is only possible under the auspice of a coercive authority opting for such an allocation
Rousseau	Natural resource allocation	General will: The fairness of the allocation of a natural resource decreases with increasing income inequality of a society
Rousseau	Natural resource allocation	General will: The fairness of the allocation of a natural resource increases with the ethnic homogeneity of a society
Smith	Natural resource allocation	Invisible hand: The fairness of the allocation of a natural resource increases with the extent of the market integration of a society
Smith	Natural resource allocation	Invisible hand: The fairness of the allocation of a natural resource increases with the transparency of the behavir of individuals responsible for the allocation of the resource

The different hypotheses tested in my observational and experimental studies (chapters 7 and 8)

4.5 Conclusion: natural resource use

In this chapter, I discussed the relevance of natural resources for humans and human societies in general. Not only do humans rely on natural resources for their survival and reproduction. Also, the economic development of human societies and human population growth depend on the supply of natural resources. While these facts are generally known, humans tend to exploit key natural resources at unsustainable rates, putting their own existence at risk. Although this behaviour may seem paradoxical at first glance, it is the expected outcome in a situation involving rational actors that exploit a natural resource held in common. The exploitation of a natural resource held in common therefore meets the criteria of a social dilemma, which can be described with the game-theoretical model of the tragedy of the commons. The tragedy of the commons is furthermore not only related to the failure of rational cooperation, but also a serious political philosophical problem of social order. After a key natural resource has become overexploited and scarce, conflicts over the scarce natural resource are to be expected. Those conflicts can lead to violence and even, in the worst case, to the collapse of society. Conflicts based on natural resources can however also erupt due to other reasons than a social dilemma. Most importantly, allocations of natural resources that are not perceived as fair may be subject to intense debates and even the cause of violent conflicts. Sustainability in the use and fairness in the allocation of natural resources are therefore two important aspects of social order.

Finding ways to promote the sustainable use and the fair allocation of natural resources is therefore important from a scientific, a philosophical, as well as a political point of view. The three classical scholars Hobbes, Rousseau and Smith devoted important parts of their work to the problem of social order and suggested different mechanisms to achieve social order. In a first step, I applied mechanisms suggested by the three scholars to the tragedy of the commons, deducing general theoretical hypotheses related to drivers of sustainable natural resource use. In a second step, I applied mechanisms suggested by the three scholars to the fairness of natural resource allocation and deduced general theoretical hypotheses related to drivers of fair natural resource allocation. My empirical work is based on these general theoretical predictions.

While philosophy and theory provide us with a framework to explain, interpret and analyse phenomena in the world, they cannot generate true knowledge on the causal mechanisms at work. This is only possible by confronting theoretical predictions with empirical observations. In the next chapter 5, I discuss the concept of causality and the tools available for causal inference. After having elaborated the most promising approach to causal inference, I describe the field work I conducted in Guinea to gather my empirical data in chapter 6. Based on this data, I conducted two scientific studies (chapters 7 and 8) in which I applied the general hypotheses developed in this chapter concerning the study of specific situations of natural resource use and natural resource allocation. This approach allowed to test the predictive value of central ideas of Hobbes, Rousseau and Smith in contexts that were not directly considered by the scholars.

Chapter 5

Methodical foundation

In chapters 2 and 3, I have discussed different philosophical and theoretical concepts related to the problem of social order. Based on these two chapters, I focused in chapter 4 on the problem of social order occuring when humans exploit natural resources and discussed mechanisms allowing to avoid the problem of social order when exploiting natural resources. My theoretical hypotheses are based on these mechanisms.

The different philosophical and theoretical concepts discussed so far have been highly influential. However, even the most influential and popular philosophy or theory is of little scientific value as long as it is not supported by empirical observations and its predictions prove wrong. It follows that scientists not only need to think about theoretical mechanisms underlying phenomena of interest and formulate related hypotheses, they furthermore also need to make observations and gather empirical data to confront their theories and ideas with reality.

In this chapter, I elabourate the concepts and the analytical tools used to confront theoretical hypotheses with empirical observations in order to draw conclusion about causal mechanisms at work in the world. In the first section, I discuss the contemporary approach to a science of human nature. This comparative approach explicitely requires to gather data from different cultural groups to be able to make scientific investigations into human nature. In this respect, the contemporary approach to a science of human nature is similar to the way how the classical scholars proceeded in their works. The second section deals with the concept of causality. Based on the the highly influential work of Hume's "Enquiry Concerning Human Understanding", I briefly discuss different concepts of causality before giving a more thorough description of the counterfactual approach to causality. This approach is of fundamental importance for science in general, because it is the theoretical basis for experimental research. While a concept of causality is certainly of fundamental importance for a scientific investigation, it is not sufficient for causal inference. We also need criteria to decide on the usefulness of our theories in explaining the patterns observed in the world. These criteria are provided by the epistemological position of falsificationism. Furthermore, we also need tools to investigate the causal mechanisms responsible for the patterns underlying our observations. These tools are provided by statistics. In the third section, I describe different tools of statistical inference by focusing on a frequentist approach. In the fourth section, I use simulated data to evaluate the performance of the different tools of statistical inference described in the third section. I close the chapter by discussing the methodical requirements for my own empirical work, which are based on the methodical insights presented in this chapter.

5.1 A science of human nature

Hobbes, Rousseau and Smith used a comparative approach to reflect about the human nature. They compared savages (native people from non-European continents) with civilized people (Europeans at their time) and found qualitative differences between them. They reasoned about these differences and claimed that they were induced by social institutions. Hobbes focused on the means of power. He claimed that people living without a central government, in the state of nature, were in a constant state of war and insecurity. This state of war was to be found in most savage societies:

> "It may peradventure be thought, there was never such a time, nor condition of warre as this; and I believe it was never generally so, over all the world: but there are many places, where they live so now. For the savage people in many places of *America*, except the government of small Families, the concord whereof dependeth on naturall lust, have no government at all; and live at this day in that brutish manner, as I said before." (Hobbes 2012 [1651], p. 89, italics as in the original).

The only way out of this state of war was the erection of a totalitarian central government, as found in the European monarchies (section 2.1). Rousseau focused on the social inequalities between people. He argued that savages were more self-sufficient than civilized people, and their societies were therefore also less inequal than civilized societies: "Telle est, en effet, la véritable cause de toutes ces différences : le sauvage vit en lui-même; l'homme sociable, toujours hors de lui, ne sait vivre que dans l'opinion des autres; et c'est, pour ainsi dire, de leur seul jugement qu'il tire le sentiment de sa propre existence." (Rousseau 1977 [1754], p. 144). According to Rousseau, the main difference between savages and civilized people was the degree of independence. While savages were nearly independent, civilized people depended on each other, relying on their private property and the division of labour (section 2.2). Smith focused on the wealth of societies. He claimed that civilized people were much more wealthy than savages: "[...] and yet it may be true, perhaps, that the accommodation of an European prince does not always so much exceed that of an industrious and frugal peasant, as the accomodation of the latter exceeds that of many an African king, the absolute master of the lives and liberties of ten thousand naked savages." (Smith 1993 [1776], p. 20). The reason for this difference was to be found in the division of labour and the resulting market economy (section 2.3).
The ideas of these three scholars have been highly influential until today (section 4.3.2). From a contemporary scientific perspective, however, the comparative work of the three classical scholars lack a sound empirical basis, as well as appropriate analytical and statistical tools. Their knowledge of the savage societies was mainly based upon anecdotic evidence of travellers, merchants and Jesuits (Smith 1896 [1763], p. 14; Rousseau 1977 [1754], p. 35-36). They used this anecdotic knowledge and combined it with their personal knowledge of their own societies to draw conclusions about the human nature by pure reasoning:

> "Voilà précisément le degré òu étaient parvenus la plupart des peuples sauvages qui

> nous sont connus; et c'est faute d'avoir suffisamment distingué les idées, et remarqué combien ces peuples étaient déjà loin du premier état de nature, que plusieurs se sont hâtés de conclure que l'homme est naturellement cruel, et qu'il a besoin de police pour l'adoucir [...]" (Rousseau 1977 [1754], p. 116).

Contemporary scientific knowledge on human nature, on the other hand, is based on empirical evidence from experimental studies. Statistical tools are then used to draw conclusions from those studies. Most of these studies are, however, based on samples collected from undergraduate students from Western universities. Such samples are known as WEIRD (Western, Educated, Industrialized, Rich, Democratic). The scientists then claim that their results can be generalized to humans in general (Henrich et al. 2010a, p. 63). This approach has been heavily criticized as it does not take account of variations in humans cross cultures (Henrich et al. 2010a, p. 82). Cultural variation in humans is however substantial, even in fields that have generally been considered psychological universals (Henrich et al. 2010a, p. 61). For example, the susceptibility to the Müller-Lyer illusion (Figure 8) varies significantly across human cultures. While Western undergraduate students are the most susceptible to the illusion, the San foragers are not at all susceptible to the illusion. Western undergraduates differ significantly from all other studied cultural groups in their susceptibility to the Müller-Lyer illusion (Henrich et al. 2010a, p. 64).

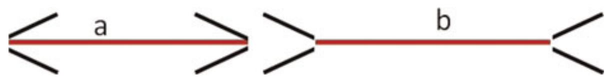

Figure 8: The Müller-Lyer illusion (Copied from Henrich et al. 2010a, p. 64).
Lines "a" and "b" have the same length.

Significant differences between western undergraduates and other cultural groups were also found in social motivation, folkbiological reasoning, spatial cognition systems, self-concepts, motivation to conform, as well as moral reasoning (Henrich et al. 2010a, pp. 66-73). Important cultural differences also occur in child-rearing practices (Segall et al. 1999, pp. 63-72), as well as in gender identity, and relations between the sexes (Segall et al. 1999, pp. 228-246). Considering the fact that WEIRD samples are outliers within a more global sample of human cultural groups on such substantial dimensions, our understanding of the human species in general should not be based solely on this one population sample (Henrich et al. 2010, p. 82). It has, furthermore, also been shown that the differences between multiple populations of the same cultural group can be as important as between single populations of different cultural groups (Lamba and Mace 2011, p. 14427). This is due to the fact that human behaviour is shaped by the socio-political, as well as the ecological context (Segall et al. 1999, p. 26). Both dimensions can vary strongly within the same cultural group, leading to such differences. A science of human nature should, therefore, combine the whole battery of modern scientific methods and analytical tools with a comparative approach, including samples of diverse cultural groups (Henrich et al. 2010a, p. 82). By following this approach, i.e. including multiple populations from each cultural group into the sample (Lamba and Mace 2011, p. 14429; Oosterbeek et al. 2004, p. 184) and thoroughly controlling for variations in the socio-political and the ecological context of the sampled populations (Lamba and Mace 2011, p. 14429), one can hope to detect human traits which are truly universal. It follows that generalizations on the human nature can only seriously be made if the sample data used for the generalization includes observations of a large number of diverse individuals from different cultural groups who show a substantial variation in their social structure and environment and do not belong to the WEIRD category.

5.2 The fundamental problem of causal inference

Although causal inference is essential for scientific knowledge, there is disagreement on the meaning of causality. This is due to the fact that causal inference is no trivial matter. The problem of causal inference concerns the following issue: “It is a question of justifying the belief that a causal sequence of events which has been observed in the past will be observed in the future.” (Ushenko 1942, p. 132). This question has been subject to much debate and reasoning from countless scholars. One of the most prominent was David Hume (1711-1776). His work ”An Enquiry Concerning Human Understanding” was highly influential for the research on causal inference (Popper 1935, p. 7; Ushenko 1942, p. 132; Lewis 1973, p. 556; Kant 1983, p. 59; Holland 1986, p. 950). In this section, I first summarize Hume’s enquiry. Then, I discuss how contemporary conceptions of causality can be linked to Hume’s work and the issues the different conceptions are struggling with. I conclude this section with a short discussion of falsificationism, a key epistemological position that is directly linked to statistical hypotheses testing and inference.

5.2.1 Hume’s enquiry concerning human understanding

Hume starts his reasoning on the problem of causal inference by distinguishing thoughts and ideas from impressions. They have in common to be products of the mind. However, the thoughts and ideas are less lifely than the impressions thatt result from our sensual perception of the world. And although we are free to have any ideas and thoughts, ideas and thoughts are always linked to the perceptions we have made: “[...] all our ideas or more feeble perceptions are copies of our impressions or more lively ones.” (Hume 2007 [1748], p. 16). Thoughts or ideas can then be combined and connected in the mind by applying the principles of resemblance, contiguity, as well as causation to those (Hume 2007 [1748], pp. 19-22).
All objects of human reasoning are either relations of ideas (algebra, arithmetic, geometry) or matter of facts. While the certainty of the relation of ideas can be discovered by operations of the thought, the truth of matter of facts can never be ascertained in the same way. Matter of facts and relation of ideas differ not only in their logical structure: beyond the records of our memory and the testimony of our senses, all reasoning concerning matter of facts is based on the relation of cause and effect (Hume 2007 [1748], pp. 28-29). This relation is defined the following way:

> “Similar objects are always conjoined with similar. Of this we have experience. Suitably to this experience, therefore, we may define a cause to be an object, followed by another, and where all the objects similar to the first are followed by objects similar to the second. Or in other words where, if the first object had not been, the

> second never had existed. The appearance of a cause always conveys the mind, by a customary transition, to the idea of the effect. Of this also we have experience. We may, therefore, suitably to this experience, form another definition of cause, and call it, an object followed by another, and whose appearance always conveys the thought to that other." (Hume 2007 [1748], p. 70)

This definition highlights five important aspects of the relation of cause and effect, as described by Hume: first, a relation of cause and effect between two objects can be discovered solely through observation and experience (Hume 2007 [1748], pp. 30-32). In order to be able to postulate a relation of cause and effect between two objects, one needs to have observed the first object, the cause, to occur prior to the second object, the effect, in a multitude of times. Only after having observed those objects occur conjoined frequently, do we start to assume a relation of cause and effect between them (Hume 2007 [1748], p. 37).
Second, the relation between the cause and the effect is a relation which is built in our mind through habits (Hume 2007 [1748], p. 43). The inference from the cause to the effect is neither of logical nature (Hume 2007 [1748], p. 38), nor based on an understanding of the mechanisms underlying the relation (Hume 2007 [1748], p. 34).
Third, what we can observe are sequences of objects. We can only see one object following another object, but never do we observe qualities of objects binding the effect and the cause (Hume 2007 [1748], p. 58-63).
Fourth, the relation between the cause and the effect assumes therefore that the future will be like the past in all important matters. Only when assuming a similarity of the past with the future, one can use experiences from the past to predict the future. As long as there is the slightest suspicion that the future will differ from the past, predictions based on experience become useless (Hume 2007 [1748], p. 38).
Fifth, it follows from these thoughts that our notion of cause and effect is based on a subjective feeling reached through our interaction with the world:

> "It appears, then, that this idea of a necessary connexion among events arises from a number of similar instances which occur of the constant conjunction of these events; nor can that idea ever be suggested by any one of these instances, surveyed in all possible lights and positions. But there is nothing in a number of instances, different from every single instance, which is supposed to be exactly similar; except only, that after a repetition of similar instances, the mind is carried by habit, upon the appearance of one event, to expect its usual attendant, and to believe that it will exist. This connexion, therefore, which we feel in the mind, this customary transition of the imagination from one object to its usual attendant, is the sentiment or impression from which we form the idea of power or necessary connexion." (Hume 2007 [1748], p. 69)

According to Hume, the justification for our assumption that sequences of events observed in the past will also be observed in the future, is therefore mainly based on custom. Different contemporary conceptions of causality can be linked to the definitions provided by Hume.

5.2.2 The problem of induction

In his broad definition of causation (section 5.2.1), Hume highlights the importance of experience to the fundamental problem of causality: "We may, therefore, suitably to this experience, form another definition of cause, and call it, an object followed by another, and whose appearance always conveys the thought to that other." (Hume 2007 [1748], p. 70). This part describes inductive reasoning. By applying inductive reasoning, one infers general statements (hypotheses or theories) from observations or experiments (Popper 1935, p. 1). This kind of reasoning not only occurs in every-day life but is also very influential in empirical sciences: "It is thus the principle of induction, rather than the law of causality, which is at the bottom of all inferences as to the existence of things not immediately given." (Russel 1915, p. 222). However, such inductive reasoning is problematic. The conclusions drawn from inductive reasoning can always prove wrong: neither can their truth be proven logically, nor is it possible to prove their truth empirically. A scientific system based on inductive reasoning must therefore reveal mistakes and logical contradictions (Popper 1935, pp. 1-3).

The problem of induction is usually illustrated by discussing issues arising in enumerative induction. The following example is from Russel (2012, p. 552). Let us assume we are interested in the family names of people in a village. After having interviewed nearly all inhabitants of the village and recorded that they all have the same name (Williams) our conclusion, based on enumerative induction, would be that all people of the village have the name Williams. This conclusion is however misleading. There is no argument against the possibility that some people in the village have another name. Another famous example has been provided by Popper (1935, p. 1). A person that has only seen white swans during his lifetime might conclude, due to enumerative induction, that all swans are white. However, there is again no argument against the possibility that swans might have another colour. As we all know, this conclusion would indeed be wrong, as there also does exist a species of black swans (*Cygnus atratus*).

5.2.3 Association

Another part of Hume's definition of causation (section 5.2.1) relates to the notion of association: "[...] we may define a cause to be an object, followed by another, and where all the objects similar to the first are followed by objects similar to the second." (Hume 2007 [1748], p. 70). The fact that two objects tend to occur subsequently does not mean that the occurrence of the first object is responsible for the occurrence of the second object: "Correlation does not imply causation." (Holland 1986, p. 945). As already mentioned by Hume (section 5.2.1), by observing that two objects tend to occur subsequently, one does not observe the underlying mechanisms binding these two objects. Strictly speaking, after observing that one object frequently follows another object, the best one can do is to estimate the conditional distribution of the second object, given the first object (Holland 1986, p. 946). While this associational measure allows us to predict the occurrence of the second object after the first object has occurred, it does not tell us anything about the reason why the second object will occur following the first object.

5.2.4 A counterfactual analysis of causation

In his definition on the relation of cause and effect (section 5.2.1), Hume already suggested an alternative to inductive reasoning and association: "[...] if the first object had not been, the second never had existed." (Hume 2007 [1748], p. 70). This definition opens up a new approach to the analysis of causation. It is the counterfactual approach, which is based on the notion that a cause must make a difference and that this difference should not have happened if there had been no cause (Lewis 1973, p. 557). Using the counterfactual approach, it is hoped to uncover the causal dependency among events (Lewis 1973, p. 562). The counterfactual approach has been formalized by Rubin (1974).

The Rubin causal model makes use of an experimental terminology to determine the conditions necessary to be able to estimate a causal effect in a counterfactual framework. In the terminology of the Rubin causal model, units of a study (subjects for example) are exposed either to an experimental treatment (E) or to a control treatment (C). If the assignment of the units to E or C is making use of some randomization mechanism, all units have the same likelihood to be exposed either to E or C and the study is an experiment. If this is not the case, the study is called an observational study. The goal of the study is to identify the typical causal effect of E, compared to C on an outcome variable (Y) for some population of units. Every study consists of trials. In a trial, a given unit is exposed to a given treatment (E or C) at a point in time (t1) and the value of the outcome variable (Y) is measured at a following point of time (t2). No unit can be exposed simultaneously to E and C. If the unit was exposed to E at t1, its value for Y is y(E) at t2. Respectively, if the unit was exposed to C at t1, its value for Y is y(C) at t2. Then, y(E) - y(C) is the causal effect for a given trial (Rubin 1974, p. 689).

Unfortunately, it is impossible to measure y(E) as well as y(C) in any single trial. If a multitude (2N) of trials are conducted in a study, the typical causal effect for the 2N trials is defined as the average causal effect (r) over all trials in the study (equation 5.1). As in the case of a single trial, it is impossible to measure y(E) as well as y(C) for any single j of 2N (Rubin 1974, p. 690).

$$r = \frac{1}{2N} \sum_{j=1}^{2N} [y_j(E) - y_j(C)] \tag{5.1}$$

However, if half of the subjects of 2N were exposed to E, $j \varepsilon S_E$, and the other half to C ,$j \varepsilon S_C$, the difference between the mean observed Y for the units exposed to E and the mean observed Y for the units exposed to C, $\bar{yd}$, can be measured (equation 5.2).

$$\bar{yd} = \frac{1}{N} \sum_{j \varepsilon S_E} y_j(E) - \frac{1}{N} \sum_{j \varepsilon S_C} y_j(C) \tag{5.2}$$

If all units react the same way to the stimuli, then the trials consist of perfectly matched pairs. In this case, it can be shown that $\bar{yd}$ equals r. The causal effect of E compared to C for a given study population can therefore be accurately estimated if the units exposed to the different trials of the study are made up of perfectly matched pairs. Although this ideal is probably never met, if all matched pairs of the study reached similar values in Y if they were not part of the study, $\bar{yd}$ should be a good proxy for r (Rubin 1974, p. 692). This can be the case either for observational studies or for experiments. And even though it is more likely that experiments meet this assumption than observational studies:

> "[...] a skeptical observer could always eventually find some variable that systematically differs in the E trials and C trials (e.g., length of longest hair on the child) and claim that yd estimates the effect of this variable rather than r, the causal effect of the E versus C treatment. Within the experiment there can be no refutation of this claim; only a logical argument explaining that the variable cannot causally affect the dependent variable or additional data outside the study can be used to counter it." (Rubin 1974, p. 693)

The statistical approach to the counterfactual analysis of causality The statistical approach to the counterfactual analysis of causality focuses on the properties of well-designed randomized experiments for the investigation of causal relations (Holland 1986, p. 945). According to this approach the most important property of a well-designed randomized experiment is that the exposure of the units of a study to either C or E is statistically independent from all other variables. This is known as the independence assumption. If this assumption holds, $\bar{yd}$ is a good proxy for r. According to the statistical approach, the key to the analysis of causality is randomization, since it guarantees that the assumption of independence holds (Holland 1986, p. 948-949).
More technically, $\bar{yd}$ is an unbiased estimator of r if randomization is properly implemented in a study. The meaning of unbiased in this context is however not entirely trivial. Given a randomization set consisting of all possible allocations of N E trials and N C trials in 2N, if a randomization mechanism is used to expose the units to E or C trials, all allocations of trials are equally likely. For all possible allocation of trials from the randomization set, $\bar{yd}$ could be calculated. Then, the average of all possible $\bar{yd}$ equals r. This property does however not tell us anything about the actual $\bar{yd}$ we calculated. It could correspond to r, but it could also be off the mark (Rubin 1974, p. 693-694). Randomization furthermore also allows to make probabilistic statements about $\bar{yd}$. By comparing a hypothesized average causal effect, $\bar{r}$, with $\bar{yd}$, one can make statements about the likelihood to observe a given $\bar{yd}$ when expecting $\bar{r}$. Typically, one would test how likely it is that $\bar{yd}$ equals 0. When this likelihood becomes too small, one can either reject the hypothesis or admit that $\bar{yd}$ is unusual (Rubin 1974, p. 694-695).

> "The ability to make precise probabilistic statements about the observed $\bar{yd}$ under various hypotheses without additional assumptions is a tremendous benefit of randomization especially since $\bar{yd}$ tends to estimate r ." (Rubin 1974, p. 695)

If the 2N units exposed to E and C in a study are taken from a larger population, M, the aim of the study usually consists in generalizing the results obtained in the study to M. Assuming that T is the average causal effect of E versus C in M, we would like to deduce T from $\bar{yd}$. This can be done when two conditions hold. First, the 2N units in the study need to be a random sample from M. This means that all units in M had the same likelihood to be selected for the study. Second, a randomization mechanism needs to determine the exposure of the 2N units of the study to E or C. If this is the case, for all possible items selected from M, $\bar{yd}$ is as an unbiased estimator of r. Furthermore the average of all $\bar{yd}$ for all possible combinations of 2N units from M equals T: $\bar{yd}$ is also an unbiased estimator of T (Rubin 1974, p. 697).

The accuracy of $\bar{yd}$ as a measure of T can be increased by increasing the size of the random sample, 2N, taken from M (Holland 1986, p. 949). Beside the independence assumption, two other assumptions, the temporal stability assumption and the unit homogeneity assumption, can be made in order to significantly simplify causal inference. The temporal stability assumption states that y(C) does not depend on the time the unit was exposed to C. Furthermore, y(E) is not affected by a prior exposure to C. When this assumption holds, one can simply expose one unit first to C, then measure y(C) and afterwards expose the same unit to E and measure y(E). Then, y(E) - y(C) can simply be measured on the same unit (Holland 1986, p. 948). The unit homogeneity assumption states that $y_1(C) = y_2(E)$ as well as $y_2(C) = y_1(E)$. If this assumption holds, y(C) - y(E) can be measured by exposing one unit to C and another unit to E (Holland 1986, p. 948).

The scientific approach to the counterfactual analysis of causality As already explained in section 5.2.4, there can be no proof within a randomized experiment that randomization worked and that the independence assumption (section 5.2.4) was met in the experiment:

> "An investigator who refuses to consider any additional variables is in fact saying that he does not care if $\bar{yd}$ is a bad estimate of the typical causal effect of the E versus C treatment but instead is satisfied with mathematical properties (i.e., unbiasedness) of the process by which he calculated it." (Rubin 1974, p. 695)

The scientific approach to the counterfactual analysis of causality therefore focuses on determining and considering all sources that could potentially influence the outcome of interest.
According to this approach, the most important task is to build a theoretical model which explains the outcome of interest. Such a model is the “all cause” model, where the outcome follows from a deterministic function of inputs (equation 5.3).

$$y(s) = g(c_s, x, u_s) \tag{5.3}$$

In this model, u_s captures the unobservable, x and c_s the observable factors at different levels influencing the outcome $y(s)$. Those factors are then related to the outcome by a specific relation g. The arguments to be included in this framework are selected according to theoretical considerations. They should be derived from internally consistent theories and together form an abstract comprehensive theoretical model of the subject of interest (Heckman 2005, pp. 26-28). If the factors in the all cause model can be varied independently, usually changing one factor while keeping the others constant, the ceteris paribus assumption holds. Then, the causal effect in this model is equal to the hypothetical effect of a change in the specific factor on $y(s)$, if all other factors are kept constant. However, if a treatment effect implies a change in several factors, the model also allows to change all relevant factors while keeping the others constant. The counterfactuals simply derive from these hypothesized changes in the model (Heckman 2005, pp. 28-29). By explicitly taking into account all possible sources responsible for variation in the outcome of interest, $y(s)$, it is possible to analyse the causal effect of a given treatment without making the independence assumption (section 5.2.4). Especially the inclusion of the unobservable factors in a theoretical model allows to make causal inferences even when the independence assumption does not hold (Heckman 2005, p. 31).

5.2.5 Deductive reasoning and falsification

As inductive reasoning can never lead to certainty about matter of facts (section 5.2.2), Karl Popper (1902-1994) proposes to use a logical deductive approach in order to generate scientific knowledge. Using instruments of logic, first of all, it is necessary to deduce empirically testable and potentially wrong conclusions from general theories. Then, those conclusions are tested regarding their logical form, as well as their empirical power. Only if the conclusions prove to be logically coherent and empirically sound, they pass the test and the theory is assumed to be reasonable. In these cases, the hypotheses are supported. If the conclusions are shown to be either logically incoherent or empirically wrong, the theory is falsified and needs to be revised (Popper 1935, pp. 5-7). By applying deductive reasoning on theories to empirically test conclusions derived from them, the problem of induction is solved: while the truth of any conclusion derived from experience can never be proven, the incorrectness of logically coherent conclusions derived from general theories can be shown by comparing them with experiences made in the real world (Popper 1935, p. 14). Falsificationism has been highly influential in empirical science, because it allows to combine a deductive theoretical approach with an empirical approach, thereby generating robust cumulative knowledge. More specifically, this epistemological position has found a complementary statistical approach, known as frequentist statistics, providing a rigid, but powerful methodical approach to causal inference. The statistical methods used to estimate a causal effect are discussed in the next section.

5.3 The estimation of a causal effect

Statistical analysis is a fundamental aspect of empirical science, because the outcome of interest may be the result of a mixture of different effects. This is true for observational-, as well as for experimental studies. Beside the factor of interest, the treatment effect for example, other unconsidered factors, but also noise and measurement errors may well influence the outcome of interest. By applying the appropriate tools of statistical inference, scientists can isolate the treatment effect from the other effects. When used appropriately, the standardized statistical tools should also allow different scientists analysing the same data to reach the same results (Mundry 2017, p. 157). The different methods of statistical data analysis vary significantly in their complexity. While the statistical methods used to estimate a treatment effect in the statistical approach are usually simple, they can become very complex in the case of the scientific approach (Heckman 2005, pp.48- 49). In this section, I first discuss the frequentist approach to statistical inference, which is closely linked to Popper's falsificationism. I illustrate its application based on the most important statistical test, the t-test. Then, I describe the main types of regression models available for statistical inference and give a brief overview on model selection and multimodel inference.

5.3.1 Statistical hypthesis testing

The philosophical foundation for the use of statistical hypotheses testing is rooted in Popper's falsificationism (section 5.2.5). The technical foundations for statistical hypothesis testing were laid by Ronald Fisher (1890-1962), Jerzy Neyman (1894-1981) and Egon Pearson (1895-1980) in the 1930s. The three scholars suggested two distinct approaches to statistical hypotheses testing, which showed similarities but also differed in important points: while Fisher focused on the construction of a null hypothesis and the determination of a p-value for the statistical test following on the data collection, Neyman and Pearson argued that the relevant p-value for the statistical test should be determined in advance and an alternative hypothesis should be formulated in conjunction with the formulation of the null hypothesis. Scientists today mostly follow a hybrid approach to statistical hypothesis testing, combining elements from Fisher, as well as Neyman-Pearson. Most commonly, such a hybrid approach to statistical hypothesis testing consists of the following four steps: first, a statistical null hypothesis (H_0) is formulated. Such a H_0 usually postulates that there is no relationship or difference between population parameters. Frequently an alternative hypotheses (H_A) is specified at the same time. H_A postulates a specific relationship or difference between populations and must then be true if H_0 is false. Second, a significance level for the statistical hypotheses test is chosen. Mostly, the conventional values of $p < 0.05$ for significant, $p < 0.01$ for very significant and $p < 0.001$ for highly significant are chosen. Those values determine the level of Type I errors that are acceptable. The type I error occurs when a correct H_0 is mistakenly rejected. For a p value of 0.05 the occurrence of a type I error is exactly 5%. This means that, given H_0 is true, the long run probability to get the observed result by chance is 5%. Third, using a random sample from a population of interest, the relevant data is collected to calculate the test statistic. Fourth, the value of the test statistic is compared with the probability distribution of the respective test statistic given a true H_0. If the probability of obtaining the calculated value is smaller than the specified significance level, one speaks of a significant result and concludes that H_0 is wrong. If the probability of obtaining the calculated value is equal to or greater than the specified significance level, a non-significant result was obtained and leads to the conclusion that H_0 must be true (Quinn and Keough 2002, pp. 32-35).

In contrast to the Type I error, the Type II error occurs when an incorrect H_0 is mistakenly accepted. By determining a specific significance level (p value), a trade-off is always made between the two types of errors: while increasing p values will lead to increased Type I error rates, decreasing p values will lead to increased Type II error rates (Quinn and Keough 2002, pp.42-43). The two sources of errors (Type I and type II errors) are always present in the context of statistical hypothesis testing. However, when the same sample is used to test a number of hypotheses independently of each other (this is known as multiple testing), they accumulate and can become very important. Assuming a significance level of $p < 0.05$, the Type I error rate is $a = 0.05$. While this level of significance leads to a mistakenly refused H_0 with a probability of 5% for a single hypothesis test, this decision error increases to 14% for three tests, 40% for 10 tests and reaches 90% for 40 tests. The probability for at least one Type I error among a number of tests conducted independently of each other on the same sample can be calculated with the equation $1-(1-a)^c$, where c is the number of tests (Quinn and Keough 2002, pp.48-49).

Depending on the data available, different statistical hypotheses tests can be implemented. While parametric tests assume that the underlying data is distributed in a specific way, non-parametric tests are less restrictive. Furthermore, there are specific tests depending on the scale, the sample size, or the variance of the underlying data (Mundry 2017, pp. 158-160).

5.3.2 The t-distribution and the t-test

The t-distribution was first introduced by “Student” in 1908 and is closely related to the normal distribution. While the normal distribution can be described with a mean, μ, and a standard deviation, σ, the standard deviation of a given sample from a normally distributed population, $\sigma/\sqrt{n}$, with a sample size of n, is not known and must be estimated from the sample with $s/\sqrt{n}$, where s is the observed standard deviation from the sample. Because of the properties of normally distributed population parameters, the t-distribution can be used to make inferences about μ when $\sigma/\sqrt{n}$ is not known. Parameters obtained from a sample can be converted to a t value. Then, it is possible to determine the probability of obtaining the specific t value, given that the sample was taken from a t-distributed population with a hypothesized parameter. The probability density of the t-distribution is determined as shown in equation 5.4:

$$f(t) = const \left(1 + \frac{t^2}{df}\right)^{-\frac{1}{2}(df+1)} \tag{5.4}$$

where *const* is defined as

$$\frac{A(df+1)}{A(df)\sqrt{2\pi df}}$$

For large values of the degrees of freedom, df, the t-distribution tends towards the standard normal distribution. As can be seen in figure 9, the deviation of the t-distribution from the standard normal distribution increases with decreasing values of df (Bulmer 1979, pp. 132-134).

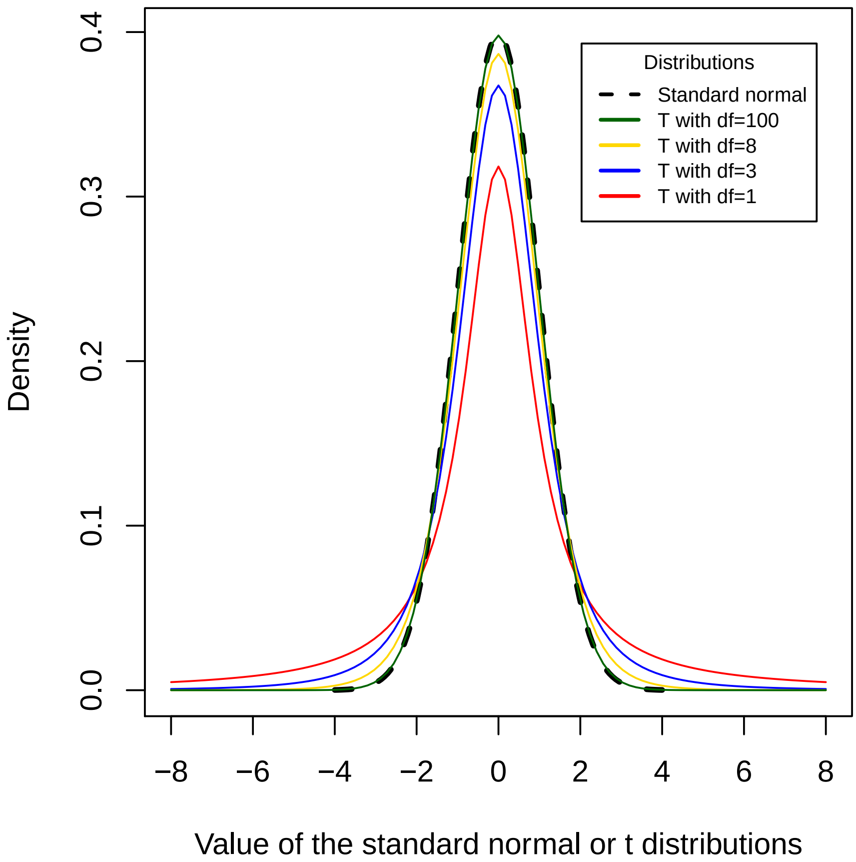

Figure 9: Standard normal and t-distributions.

Using the equation $t = (\bar{x} - \mu)/(\frac{s}{\sqrt{n}})$, where $\bar{x}$ is the observed mean, it is possible to calculate the probability that a given population parameter mean obtained from one sample is derived from a normally distributed population with a hypothesized mean. In this way, hypothesis regarding population parameter means can be tested. Let us consider an example: we want to know if the mean result of a sample of 1000 pupils in a test differs significantly from 0. Our H_0 postulates that the mean test result of the pupil sample is 0. As the test result of pupils is normally distributed and our sample is a random sample from the general pupil population, the one sample t-test can be used to test this hypothesis. The mean test result in our sample of pupils is 65.036, with a standard deviation of 6.179, leading to a t value of 332.828. This t value is larger than the t values at the conventional level of significance of $p = 0.05$. Larger t values coincide with smaller p values. The result of our one sample t-test would lead us to conclude that the test result of our pupil sample is not equal 0 (figure 10) (Quinn and Keough 2002, pp.35-37).

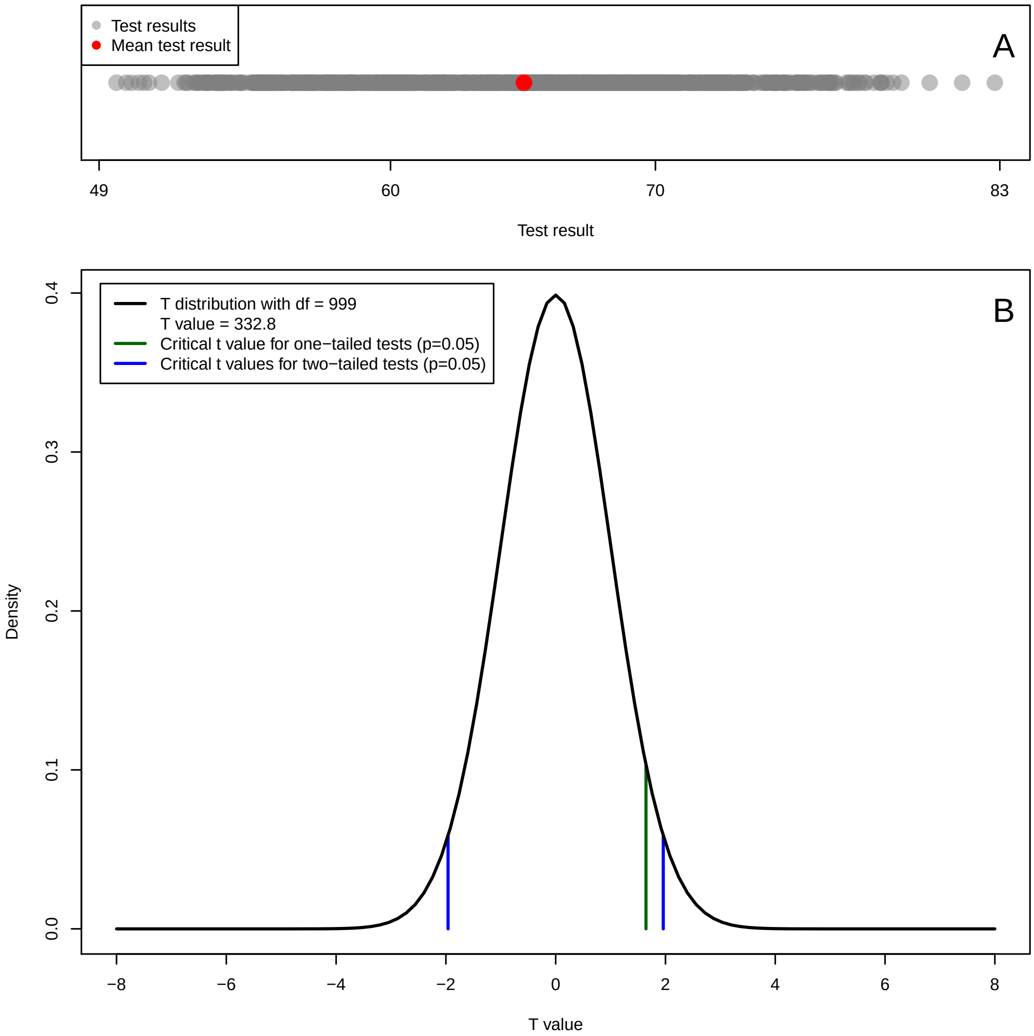

Figure 10: The one sample t-test.

A) The random sample of 1000 pupil test result values. Test results are approximately normally distributed with a mean of 65.036 *and a standard deviation of* 6.179*. B) The result of a one-sample t-test on the pupil's test results. The t value for our sample,* 332.828*, is compared with the critical t values at the conventional significance level of* $p = 0.05$*. For the one tailed test, the critical t value is 1.645. For the two tailed test, the critical t value is 1.960. If the calculated t value is larger than the critical t value, there is evidence to reject* H_0*. Most of the times, two-tailed statistical tests are conducted. The test statistic,* 332.828*, is so large that it cannot be drawn into the plot. Such a mean is highly unlikely to occur if the true mean is 0 (p<0.001).*

To test for a difference between two population parameters from normally distributed populations, one can use the two-sample t-test (equation 5.5), with $\bar{y_1}$ and $\bar{y_2}$ for the two means and $S_{\bar{y_1}-\bar{y_2}}$ for the standard error of the differences between $\bar{y_1}$ and $\bar{y_2}$.

$$t = \frac{\bar{y_1} - \bar{y_2}}{S_{\bar{y_1}-\bar{y_2}}} \tag{5.5}$$

There are two versions of the two-sample t-test: one for equal variances in the samples and one for unequal variances in the samples. One needs therefore to check for differences in the variances between the two samples and then use the appropriate test (Quinn and Keough 2002, pp.35-37). Building upon our previous example, we want to test whether there is a difference in the mean test results between male and female pupils from the sample described in figure 10 A. We test the H_0 that the difference between the male and female test results of our pupil sample is 0. The mean test result for male pupils is 64.824 and the mean test result for female pupils 65.233. The test statistics for the difference in the means of 0.409 is 1.044. This t value is smaller than the critical t value at the conventional level of $p = 0.05$. Our test does not provide any evidence to reject H_0. We would therefore conclude that there is no difference in the test results of pupils in our sample based on their sex (figure 11).

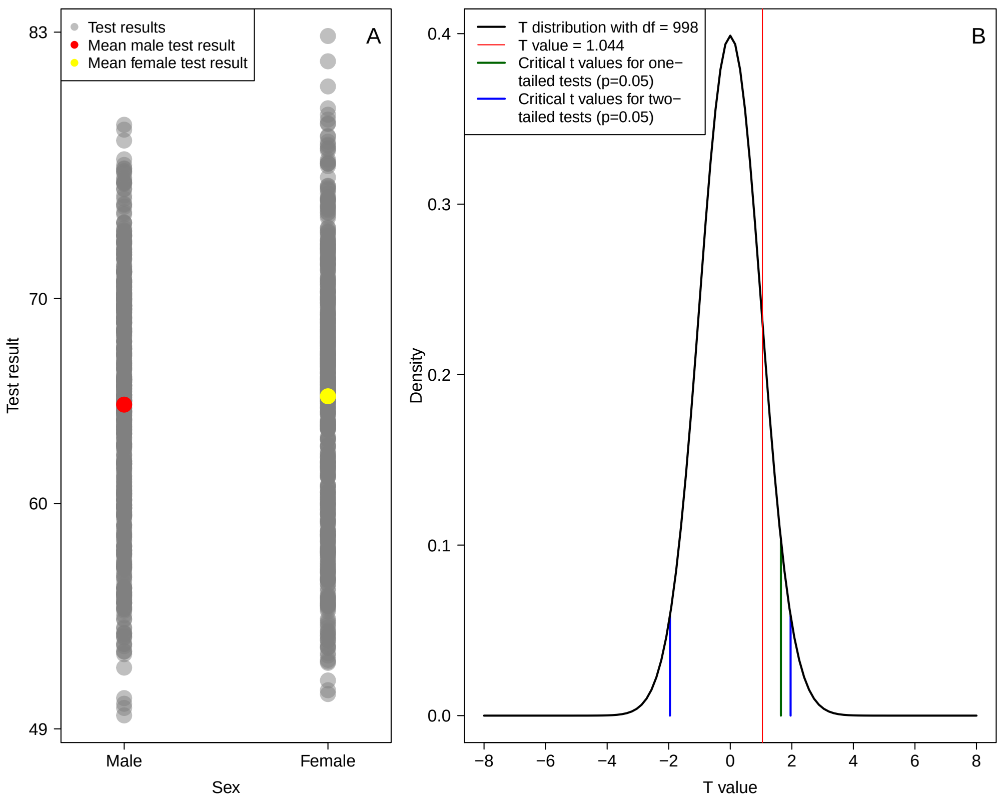

Figure 11: The two sample t-test.

A) The two samples of 481 male and 519 females from our random sample of 1000 pupils (figure 10 A). B) The result of a two-sample t-test on the H_0 that the difference in the mean test results between male and female pupils is 0. The calculated t value , 1.044, is compared with the critical t values at the conventional significance level of p = 0.05. For the one-tailed test, the critical t value is 1.645. For the two-tailed test, the critical t value is 1.960. As the calculated t value is smaller than the critical t value, there is no evidence to reject H_0. Most of the times, two-tailed statistical tests are conducted.

5.3.3 Simple linear regression

Simple linear regression is a statistical method of data analysis which assumes a linear relationship between two variables. In the simple linear regression, the variable of interest, the response- or dependent variable, Y, has a continuous scale and is a function of a single continuous independent-, or predictor variable, X. Simple linear regression is mainly used to describe the linear relationship between the two variables, to predict new Y-values based on new X-values and to determine how well the variation in Y can be explained by X (Quinn and Keough 2002, p. 78). It is however also possible to consider the relationship between a continuous dependent variable Y and a categorical variable X in the simple linear regression. For this purpose, the categorical variable is transformed into a continuous variable with the values 0 and 1 (section 5.3.6). Such variables are called dummy-variables (Quinn and Keough 2002, p.135).
Considering a set of $i = 1 - n$ observations with X and Y values, the simple linear regression model can be described with equation 5.6, where y_i is the ith observed value for Y and x_i the ith observed value for X.

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \tag{5.6}$$

β_0 is the population intercept and shows the mean value of Y when x_i is 0. β_1 is the population slope and measures the change in Y for each unit change in X. ε_i is the error term and shows the difference between the observed y_i and the predicted values for each x_i (equation 5.6). The simple linear model makes inferences on the mean values of Y for each value of X. It assumes that there is a population of Y-values for each x_i and joins the means of these populations for each x_i. The overall mean value of Y then equals $\beta_0 + \beta_1 X$ and the linear model can be reformulated as the means of Y for each x_i: $y_i = \mu_i + \varepsilon_i$, with μ_i being the mean of Y at each x_i (Quinn and Keough 2002, p. 83).
Using sample data with n observations for Y and X, the parameters of the simple linear regression model can be estimated. For the population slope, β_1, equation 5.7 allows to estimate b_1. The population intercept, β_0, is then estimated the following way: $b_0 = \bar{y} - b_1\bar{x}$. Once the parameters b_0 and b_1 are estimated, a regression line with estimated values for all x_i can be determined: $\hat{y}_i = b_0 + b_1 * x_i$, where $\hat{y}$ is the predicted value for x_i. These estimates are ordinary least square (OLS) estimates: the sum of the squared deviation between the observed values and the predicted values are minimized (Quinn and Keough 2002, pp. 85-86).

$$b_1 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{5.7}$$

The estimation for the error term, ε_i, is obtained by calculating the residual, e_i, at each x_i: $e_i = \hat{y}_i - y_i$ (Quinn and Keough 2002, p .87). The simple linear regression makes three assumptions related to the error terms ε_i: first, they are expected to be normally distributed with a mean of 0 at each x_i: estimates and test statistics are robust to this violation, as long as no other assumptions related to the residuals are violated. Second, the error terms are expected to have the same variance at each x_i: violations of this assumption, also known as heteroscedasticity, leads to unreliable estimates and test statistics. Third, the error terms should be independent and therefore also uncorrelated with each other: violation of this assumption, leads to unreliable estimates and test statistics. By calculating the residuals for each x_i resulting from a simple linear regression estimation, it is possible to roughly assess whether these assumptions have been met with the help of distribution-plots of the residuals and scatterplots of the residuals against the fitted values. If the independent residuals assumption is violated, including an autocorrelation term, controlling for the structure of the underlying data sample (section 5.3.6 and 5.3.7), or both, are means to obtain reliable estimates (Quinn and Keough 2002, pp. 92-94). The assumptions related to the error terms always apply to the underlying linear regression estimate. This means that these assumptions apply to the residuals, e_i, and not to the theoretical error terms, ε_i. Frequently, a nonnormal distribution of Y is responsible for non-normality and heteroscedasticity of residuals. In this case, transforming Y in order to make its distribution approximately normal can be a simple mean to guarantee that these assumptions hold. Furthermore, unusual X-values can have excessive influences on the estimated regression coefficients. By transforming a nonnormal distribution of X and making it approximately normal, the influence of single X-values on the results of an estimation can be balanced. Transforming Y, X, or Y and X in a way that their distributions become approximately normal, is therefore a simple mean to improve the fit of the linear regression estimation and make sure the assumptions of normality and constant variance of residuals are met. Finally, the simple linear regression model assumes a linear relationship between Y and X. When the relationship between Y and X is clearly nonlinear, transforming one or both variables can linearize the nonlinear relationship. This method is however not applicable to all types of nonlinear relationships (Quinn and Keough 2002, p. 98).

The residuals can also be used to partition the total variance in the response variable, $SS_{Total} = \sum_{i=1}^{n}(y_i - \bar{y})^2$, in a part which is explained by the regression model, $SS_{Regression} = \sum_{i=1}^{n}(\hat{y_i} - \bar{y})^2$, and a part which is not explained by the regression model, $SS_{Residual} = \sum_{i=1}^{n}(y_i - \hat{y_i})$ (Quinn and Keough 2002, p. 88). The most common measure to describe the association between Y and X in simple linear regression is R^2. R^2 measures how much of the variation in Y is explained by X (Quinn and Keough 2002, p. 92) (equation 5.8).

$$R^2 = \frac{SS_{Regression}}{SS_{Total}} = 1 - \frac{SS_{Residual}}{SS_{Total}} \quad (5.8)$$

The standard errors of b_0 and b_1, sb_0 and sb_1, are the standard deviation of their sampling distributions. Standard errors are measures for the accuracy of the predictions made based on the estimates. They can be calculated as shown in equations 5.9 and 5.10, where $MS_{residual}$ is the variance of the residuals. Using the estimates b_0 and b_1 as well as their standard errors sb_0 and sb_1, t-tests can be implemented to test the H_0 that the regression estimates are equal to 0. For the population mean, the result of a one-sample t-test (section 5.3.2) with $n-2$ degrees of freedom and the test-statistic $t = \frac{b_0 - 0}{sb_0}$ can be used to decide whether to reject H_0 or not. The procedure to test the H_0 for the population slope is identical: one just has to replace b_0 with b_1 and sb_0 with sb_1. The results of such t-tests are provided in each standard output of software packages running simple linear regressions (Quinn and Keough 2002, pp. 89-90).

$$sb_0 = \sqrt{MS_{residual}\left[\frac{1}{n} + \frac{\bar{x}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right]} \tag{5.9}$$

$$sb_1 = \sqrt{\frac{MS_{residual}}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \tag{5.10}$$

The proximity of the simple linear regression to the t-test (section 5.3.2) is highlighted by the fact that those can be replicated with simple linear regression models (tables 14 and 15).

Table 14: Simple linear regression on the test results of pupils only including the intercept.

N = 1000				
Coefficients	Estimate	Standard error	T value	P value
Intercept	65.036	0.195	332.8	<0.001

The t-test from figure 10 can be replicated with a simple linear regression only including the population intercept. The estimated mean, as well as the test statistics are identical.

Table 15: Simple linear regression on the test result of pupils including the intercept and the sex of the pupils.

N = 1000				
$R^2 = 0.001$				
Coefficients	Estimate	Standard error	T value	P value
Intercept	64.824	0.282	230.088	<0.001
Female	0.408	0.391	1.044	0.297

The mean test result of the male pupils is equal to the estimate for the intercept (64.824) and differs significantly from 0. The mean test result of the female pupils is equal to the estimate for the intercept + the estimate for Female (0.408). The difference between the two means (0.408) is not significantly different from 0. This result replicates the t-test from figure 11. The minor difference in the estimated difference is due to differences in rounding.

The value of the estimate for the regression slope, b_1, depends on the units in which Y and X are measured. It is therefore difficult to compare the estimated regression slopes from different simple linear regression models. By standardizing Y and X prior to the estimation, the resulting estimates become independent of the units of Y and X. Standardizing is achieved by subtracting the mean of the variable from each case and then dividing those by the standard deviation of the variable. A standardized variable has a mean of 0 and a standard deviation of 1 (Quinn and Keough 2002, p. 86). Standardizing is also known as z-transformation. When only X is standardized prior to the estimation, the estimated population slopes becomes independent only of the units of X.

Standardizing has two further advantages. To understand these advantages, we need to recapitulate that the population intercept shows the mean value of Y when X has a value of 0. When the value of 0 lies beyond the range of X, our population intercept is of no practical value and makes no sense. Additionally, the population intercept is estimated by extrapolating beyond the range of the observed values. Extrapolating beyond the range of the observed values should however be avoided when estimating parameters in a simple linear regression (Quinn and Keough 2002, p.

87). By standardizing X prior to the estimation, we can easily solve these issues: the value 0 of the standardized X is the mean of the original variable X and lies in the centre of the observed values. Not only do we have a meaningful population intercept, but it was also estimated without extrapolating beyond the range of the observed values (figure 12).

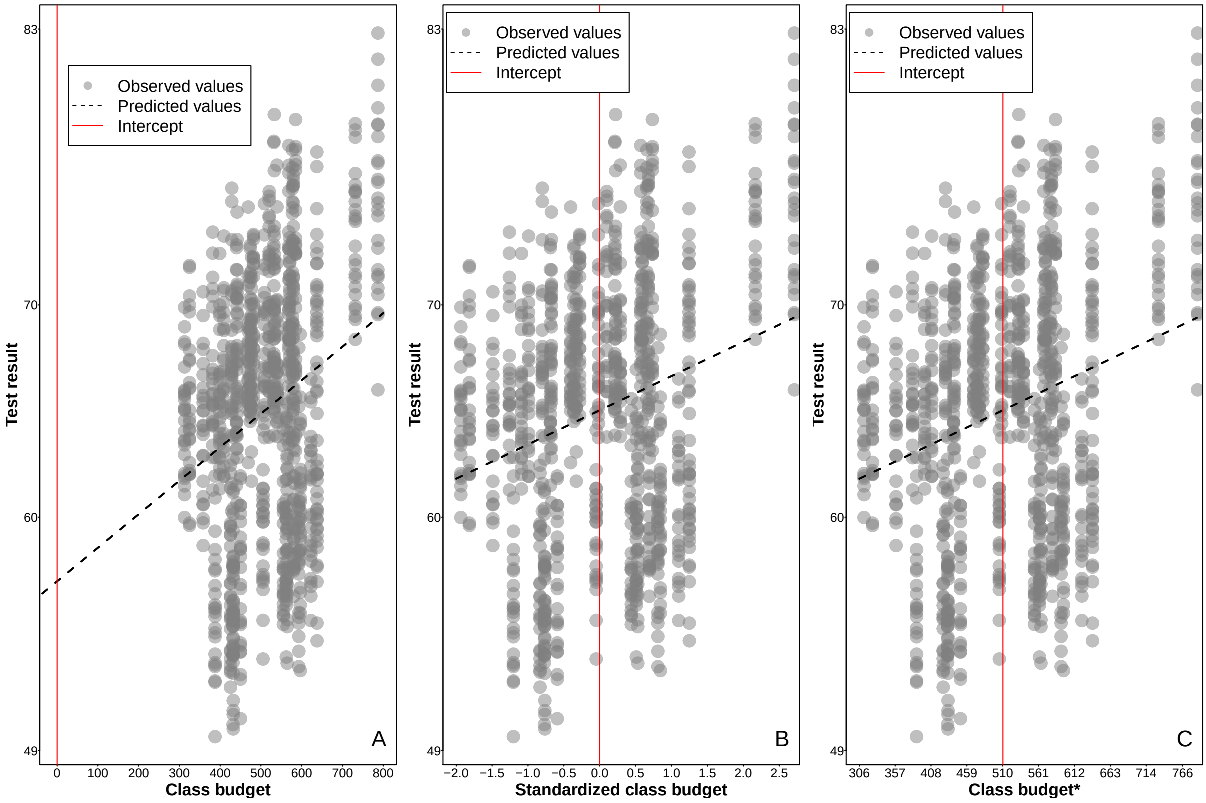

Figure 12: Unstandardized versus standardized predictor.

*A) The influence of the class budget on the pupils' test results: the population intercept (cross section of the predicted values line and the intercept line) lies beyond the range of the observed values of the class budget. Extrapolating beyond the range of the observed values is needed to estimate the intercept. Furthermore, a class budget of 0 does not make sense, and our population intercept is therefore not meaningful. B) The influence of the standardized class budget on the pupils' test result: the population intercept (cross section of the predicted values line and the intercept line) lies at the mean of the observed values of the class budget. No extrapolating beyond the range of the observed values is needed to estimate the intercept. Our population intercept is now meaningful, showing us the mean test result of pupils with a mean class budget. C) The influence of the class budget on the pupils' test result: this plot is identical to B, with the exception of the X-axis. In this plot, the ticks of the X-axis are transformed back to the original units. In this way, we can make use of the advantages of standardizing variables prior to estimation and still interpret the results in the original units. This procedure can be applied to all types of variable transformation. * Variable was standardized prior to estimation.*

5.3.4 Multiple linear regression

The simple linear regression model can be extended to include more than one predictor (Quinn and Keough 2002, p. 111). In general linear models, all combinations of continuous and categorical predictors (dummies) are allowed (Quinn and Keough 2002, pp. 77-78). In the further discussion, I am always referring to general linear models when speaking of multiple linear regression.
Considering a set of $i = 1 - n$ observations with n observations for the response variable Y and n observations for the p predictor variables X_1 - X_p, where $p \geq 2$, the multiple linear regression model is:

$$y_i = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + ... + \beta_p * x_p + \varepsilon_i \tag{5.11}$$

As in the simple linear regression model (equation 5.6), y_i is the ith observed value for Y, β_0 the population mean when all X_1 - X_p values are 0 and ε_i the error term for the ith observation. However, the population slopes β_1, β_2- β_p, of the multiple linear regression model (equation 5.11) are partial population regression slopes. This means that β_1 measures by how much Y changes for each unit change in X_1 when the other X_2 - X_p variables are held constant. The same applies to all other population slopes β_2- β_p (Quinn and Keough 2002, p. 117) (figure 13).

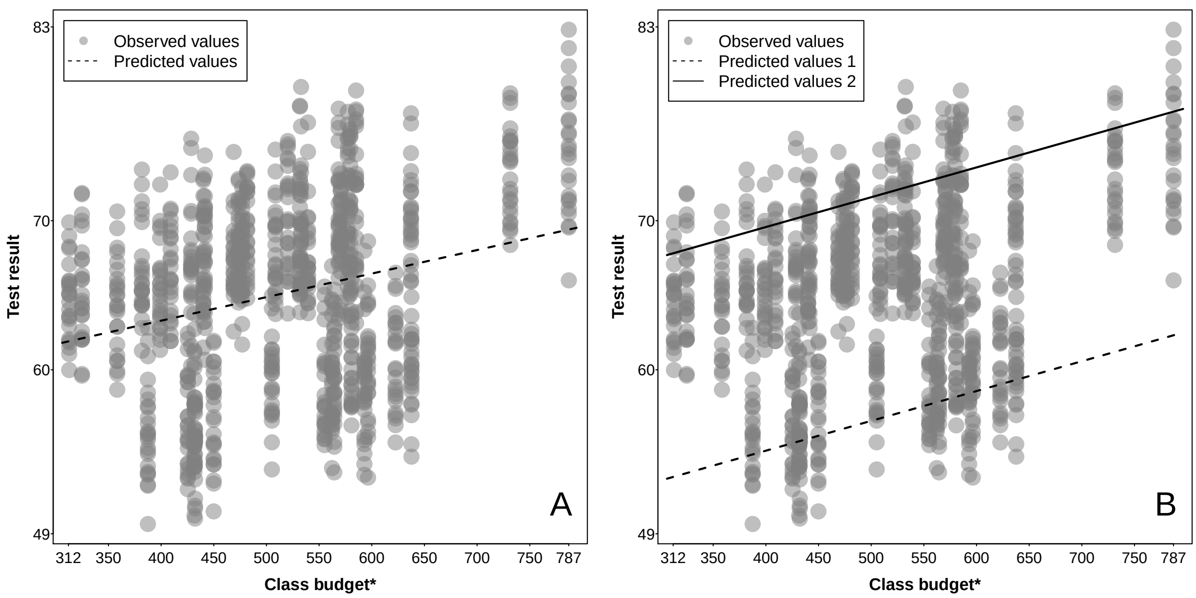

Figure 13: Population slope versus partial population slope.
A) The result of a simple linear regression model on the sample of pupils where the test result is a function of the class budget. The population regression slope (the predicted values) shows the influence of the class budget on the results in the test. B) The result of a multiple linear regression run on the same sample of pupils, where the test result is a function of the class budget, the pupils' IQ, the pupils' socioeconomic background and the quality of the class teacher. The partial population regression slope 1 (the predicted values 1) shows the influence of the class budget on the test result for pupils with average IQ, low socioeconomic background, and bad teacher qualities. The partial population regression slope 2 (the predicted values 2) shows the influence of the class budget on the test result for pupils with average IQ, high socioeconomic background,

*and good teacher qualities. * Variable was standardized prior to estimation.*

Using sample data with n observations for Y and X_1 - X_p, the parameters of the multiple linear regression model can be estimated by extending the methods used for the simple linear regression (section 5.3.3). The estimation of the multiple linear regression model can be used to determine the sample regression line, $\hat{y}_i = b_0 + b_1 * x_{i1} + b_2 * x_{i2} + ... + b_p * x_{ip}$, where $\hat{y}_i$ is the estimated value for x_{i1}, x_{i2}- x_{ip}, b_0 is the estimate for the population mean, β_0, the population intercept of the sample data, and b_1, b_2- b_p are the estimates of the partial population slopes β_1, β_2- β_p, for the sample data (Quinn and Keough 2002, pp. 118 and 120). As in the simple linear regression, t-tests can be applied to test hypotheses related to the population intercept and partial population slopes of multiple linear regression estimates. In the case of the multiple linear regression, the degrees of freedom for these tests are $n-(p+1)$, whereas p is the number of estimated parameters (Quinn and Keough 2002, p. 122).

Once the sample regression line has been determined, the residuals of the multiple regression can be calculated in the same way as in the simple linear regression. The assumptions related to the residuals in the multiple linear regression are the same as in the simple linear regression and we also assume a linear relationship between Y and X_1 - X_p, as in the simple linear regression. The methods to detect violations of these assumptions, the consequences of these violations and the means to deal with the violations also are the same as in the simple linear regression. Issues related to the meaning of the population intercept, b_0, extrapolation beyond the range of the observed values, and the application of standardization and transformation discussed in the context of the simple linear regression also apply to the multiple linear regression (section 5.3.3).

In the multiple linear regression R^2 is also a measure for the proportion of the variation in Y explained with the X_1 - X_p predictors and can be calculated in the same way (equation 5.8). However, R^2 does never decrease when more predictors are added. In fact, models with more predictors always seem to explain variation in Y better than more parsimonious versions. To account for this fact, the *adjusted* R^2 can be used as another measure of association between the predictors and the response variable in the multiple linear regression. The *adjusted* R^2 takes account of the number of predictors and can also decrease when new predictors are added to a multiple linear regression model (Quinn and Keough 2002, p. 122).

There are, however, two new issues occurring in the case of multiple linear regression, that are of no, or only minor concern in the case of the simple linear regression. First, when more than one predictor is included in a linear regression, issues might arise when these predictors are correlated. This is known as multicollinearity. Depending on the extent of multicollinearity, estimates become unstable and test statistics unreliable. In the most extreme case, when the predictors are perfectly correlated, it becomes impossible to estimate the parameters for the perfectly correlated coefficients at the same time. Multicollinearity can be detected with the help of the variance inflation factor (VIF). The VIF of X_1 gives a measure of the extent to which X_1 is a linear combination of the other $p-1$ predictors included in the multiple linear regression: $VIF = \frac{1}{1-R^2}$ (Quinn and Keough 2002, p. 128). The bigger the VIF, the more multicollinearity is an issue. Although it is widely accepted that VIF values of 10 or greater are highly problematic (Quinn and Keough 2002, p. 128), multicollinearity is an issue in most multiple regression analysis, even if the VIF values of the included predictors are low (VIF values between 1 and 2.5) (Cade 2015, p. 2373). This is

due to the fact that the scale of a given population slope from a multiple linear regression not only depends on the units of the predictor- and the response variable, but also on the other predictors included in the multiple regression. As long as there is some correlation between a number of predictors in a multiple regression, this will lead to changes in the estimates for the population slopes, depending on the constellation of the predictors included in the regression analysis (Cade 2015, p. 2372). The estimates can however be standardized with their partial standard deviation in order to be unaffected by the correlation with other predictors. Such standardized estimates can be interpreted as the rate of change in the response variable for a change in the predictor by one partial standard deviation (Cade 2015, p. 2375). When VIF values exceed a threshold, for example 10, the most simple way to deal with it is, however, to simply omit the predictor with the critical VIF value from the linear regression analysis (Quinn and Keough 2002, p. 129).
A further issue, which normally is of no concern in simple linear regression, is model complexity. Model complexity is defined by putting the sample size, n, in relation to the number of estimated parameters, k. The complexity of models is essentially limited by the sample size. Too complex models (too many estimated parameters for the sample size) might suffer from instability and from a lack of statistical power. As a rule of thumb, one can calculate the minimal sample size necessary for a given number of estimates in linear regression with the equation $n \geq 10 * k$ (Mundry 2017, p. 163).

5.3.5 Maximum likelihood and the generalized linear model

The linear regression models discussed so far (sections 5.3.3 and 5.3.4) allow to estimate the effect of some predictor variables on a response variable with a continuous scale. The specific assumptions underlying these linear regression models are related to the residuals of the estimation and to the type of the relationship between the response and the predictor variables. Linear regression models can be quite robust to violations of these assumptions and transformations of the response variable can help to increase the fit of the estimation and to meet the specific regression assumptions. When the assumptions related to linear regression models are met, most importantly the constant variance assumption of the residuals, the OLS estimate provides the best linear unbiased estimator (McElroy 1967, p. 1302), and minimizes the difference between the predicted and the observed values (section *5.3.3*). However, some types of response variables simply cannot be transformed in such ways as to meet assumptions related to the residuals. Typically, such response variables either represent counts or are binary (Quinn and Keough 2002, p. 359). For such response variables, the linear regression model can be extended and generalized in order to be able to account for other than normal error distributions and for relationships between the variance and the mean of the errors. Such regression models are called generalized linear models (Quinn and Keough 2002, pp. 77-78). Instead of OLS, in the case of generalized linear models, maximum likelihood (ML) is used to estimate the parameters.
ML is a method used to estimate population parameters in general. The idea behind ML is very simple: given a sample of data from a population, the estimate for a parameter is obtained by maximizing the likelihood to observe the actual data. This is achieved by first determining the

likelihood function, $L(y;\Theta)$ of a given parameter, Θ, given the data, y. The likelihood function is the joint probability distribution of all observations of the data, y_i, for different possible values of Θ (equation 5.12). Then, for computational reasons, the log-likelihood function is maximized in order to obtain the estimate for the parameter that maximizes the likelihood to observe the given data (equation 5.13) (Quinn and Keough 2002, pp. 23-24).

$$L(y;\Theta) = \prod_{i=1}^{n} f(y_i;\Theta) \tag{5.12}$$

$$L(\Theta) = ln\left[\prod_{i=1}^{n} f(y_i;\Theta)\right] = \sum_{i=1}^{n} ln\left[f(y_i;\Theta)\right] \tag{5.13}$$

ML is a widely applicable method for the estimation of population parameters, because it allows to consider all kinds of probability distributions, $f(y_{i;}\Theta)$, to determine the likelihood function. Obviously, ML can also be used to estimate regression parameters. Being able to assume not only normal distributions, but also binomial distributions, Poisson distribution, negative binomial and many more, widely enlarges the range of applications for regression analysis. However, analytical solutions to estimation problems are restricted to a small fraction of the cases where ML is actually used (Bolker 2007, pp. 229-231). Most of the time, complex iterative algorithms provide solutions to these estimation problems (Quinn and Keough 2002, p. 24). Assuming a chi-squared distribution of the negative log-likelihood, Likelihood Ratio Tests can be implemented to test hypothesis regarding ML parameter estimates (Bolker 2007, p. 16 and p. 255). A simple example for a ML estimation and the respective Likelihood Ratio Test is shown in figure 14.
Generalized linear models always consist of three components: first, the response variable with an underlying probability distribution; second, the predictor variables; finally, a link function that connects the response variable with the predictor variables, where β_0, β_1 and β_2 are the parameters to be estimated and $g(\mu)$ is the link function. The link function models the relationship between the predicted values and the predictor variables: $g(\mu) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...$ The link function depends on the assumed probability distribution underlying the model. The most common link functions are the identity link-, the log link- and the logit link function. For continuous response variables, the identity link function models the expected value or the mean of Y, just in the same way as in linear regression models: $g(\mu) = \mu$. For binary response variables, the logit link function is used: $g(\mu) = log\left[\mu/(1-\mu)\right]$. For count data, the log link function is used: $g(\mu) = log(\mu)$. Generalized linear models are always linear, because the response variable is first described as a function of a linear combination of predictors. Non-linearity between the response and the predictors is only implemented in a second step, with the help of the link function (Quinn and Keough 2002, pp. 359-360).

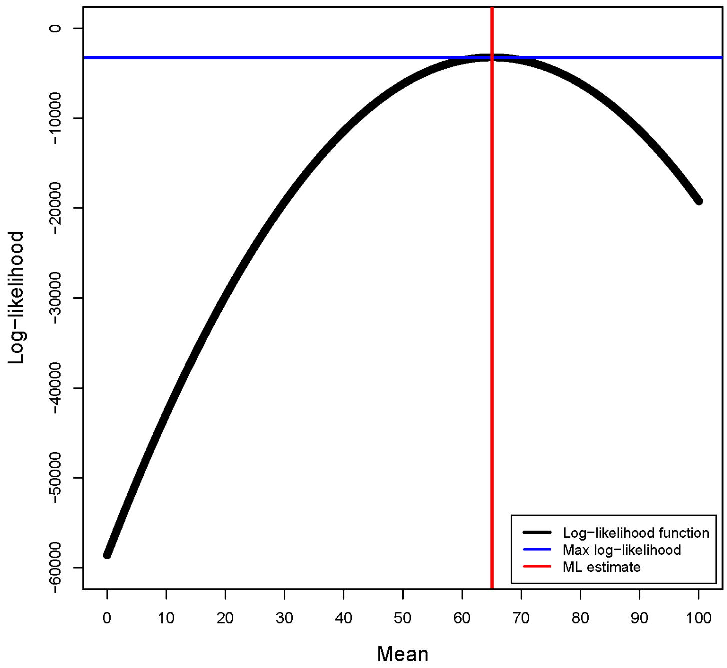

Figure 14: Maximum likelihood estimation.

Using the sample of test results from 1000 pupils (figure 10), we want to estimate the mean test result using a maximum likelihood estimation and knowing that the standard deviation is 6.179. The plot shows the log likelihood function for means between 0 and 100. The function for the probability density of a normal distribution with a standard deviation of 6.179 and mean values between 0 and 100 is maximized with a log likelihood of -3239.634 and a mean of 65.04. By comparing the log likelihood of our ML estimate with the log likelihood of a mean of 0 (-58,626.897), a Likelihood Ratio Test can be implement to test whether our estimated mean is significantly more likely than an estimated mean of 0. Such a difference in likelihoods occuring by chance is highly unlikely (p<0.001) and we would conclude that our estimated mean is a better estimation than a mean of 0 (Adapted from Bolker 2007, pp. 255-256 and R-Bloggers 2011).

While model assumptions in generalized linear models are the same as in linear regression models when the response variable is continuous, the model assumptions differ in the case of other types of dependent variables. For binary response variables, the generalized linear model is usually a logistic regression, which makes use of a logit link function. Besides the independent residuals assumption, the logistic regression makes no further specific assumptions related to the residuals of the model (Quinn and Keough 2002, pp. 368-369). For count response variables, the generalized linear model is either a Poisson or a negative binomial regression, which makes use of a log link function. Besides the independent residuals assumption, these models assume a specific ratio between the mean and the variance of the residuals. Failure to meet this assumption leads to unreliable test statistics (Quinn and Keough 2002, pp. 371-372). Apart from these specific assumptions related to the residuals of generalized linear models with binary or count response variables, all issues related to multicollinearity, model complexity, meaningful intercepts, extrapolation beyond the range of observed values, transformation and standardization discussed in the context of linear regression models also need to be considered. Finally, it is worthwhile highlighting that the linear regression model can entirely by replaced by the generalized linear model, which is a generalization of the former (Mundry 2017, p. 163). ML is also used to estimate parameters in random-effects regression models (figure 17) as well as in mixed-effects regression models (figure 19). In the further parts of this section, when I mention regression models, I referr to both, the generalized linear models as well as the general linear models.

5.3.6 Fixed and random effects regression

The independence assumption underlying regression models is violated when the observations in the sample data are related with each other (figure 15). This is the case when the observations are either temporally or spatially segregated or interconnected (Hurlbert 1984, p.198). Repeated measures, observations made at different points in time or at different locations are examples for such related observations.

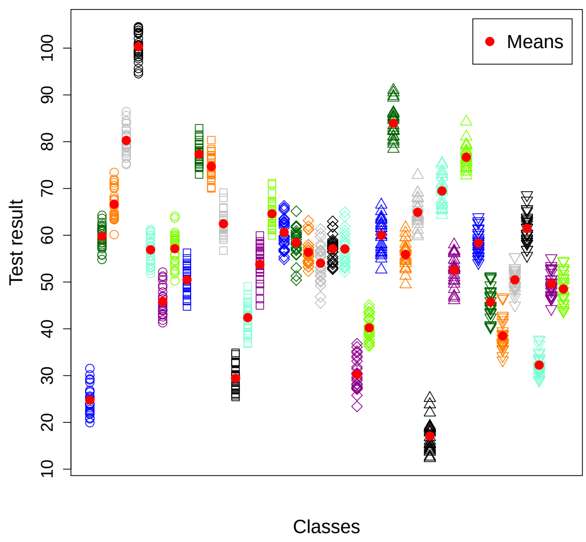

Figure 15: Clustered data.

In this example sample data, the pupils are clustered in classes. Pupils of the same class all have a similar test result. Although single test results of pupils from one class deviate from the class mean, they still are more similar to test results of pupils from the same class than to test results of pupils from other classes with a strongly differing mean test result. In this example, the test results of pupils vary by a standard deviation of 15 points between the classes.

When the sample data used to run a regression model is made up of dependent observations, the model assumptions are not met and one risks to make wrong statistical inferences (figure *16*). This is known as pseudoreplication (Chaves 2010, pp. 291-292). It is however possible to take account of the dependency in the observations by considering the variable responsible for this dependency as a factor. Such a factor, A, is modelled as a qualitative variable with a group, j, for each of its values ($j = 1 - p$) and replicate observations, i, within the groups ($i = 1 - n$). Factors can be included as estimates, α, into a regression model (equation 5.14), where yij is the value of the response for the ith replicate in the jth group, β_0 the population intercept and ε_{ij} the error term for the ith replicate in the jth group (Quinn and Keough 2002, p. 178).

$$y_{ij} = \beta_0 + \alpha_j + \varepsilon_{ij} \tag{5.14}$$

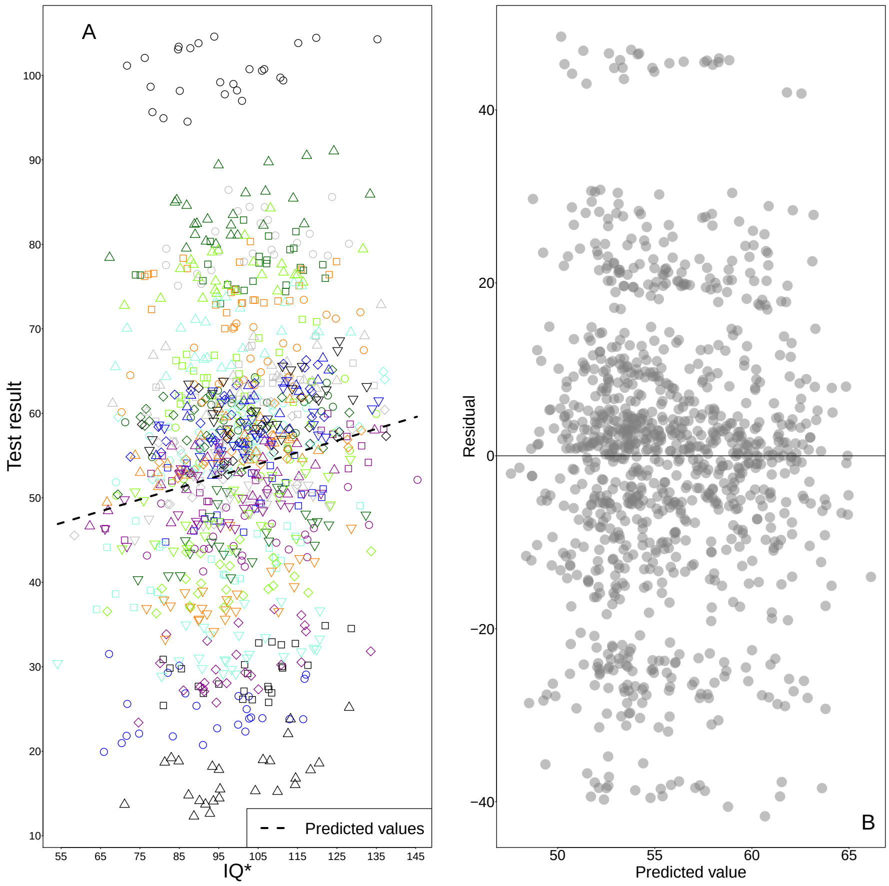

Figure 16: Violation of the independence assumption in regression models.
*A) The dataset from figure 15 is used to estimate the influence of the pupils IQ on a test result. The plot shows the result of a multiple linear regression model, where the test result is a function of the pupils' IQ, the pupils' sex and the pupils' socioeconomic background. The true effect for the pupils' IQ on the test result of 0.1 is overestimated (partial population slope estimate for pupils IQ is 0.139). B) The residual versus fitted values plot shows that the residuals are clustered and not evenly distributed around the residual = 0 line. This is a clear indication for a violation of the independent residuals assumption. * Variable was standardized prior to estimation.*

There are however different ways to model a factor. The simplest case occurs when the factor is fixed. In this case, all relevant groups of the factor are known and included in the data sample. Conclusions based on a regression analysis including such a fixed factor cannot be extrapolated beyond the groups of the factor included in the sample data (Quinn and Keough 2002, p. 176). For such fixed factors, at first p dummy variables for all values of the factor in question are generated.

Then, estimates for $p-1$ factors aer included into a multiple regression analysis: $y_{ij} = \beta_0 + \beta_1(dummy1)_{ij} + ... + \beta_{p-1}(dummy_{p-1})_{ij} + \varepsilon_{ij}$. The dummy not included in the regression is the reference and the estimates for the dummies included as predictors show the difference between the mean response in the reference group, β_0, and the mean response in the other $p-1$ dummy groups (Quinn and Keough 2002, pp. 178-179). By adding such fixed factors to a regression model with other predictors, it is possible to control for the dependency in the observations of the sample data (figure 17): the whole unobserved heterogeneity due to the factor is controled for by the dummies (Kohler and Kreuter 2012, pp. 318-319).

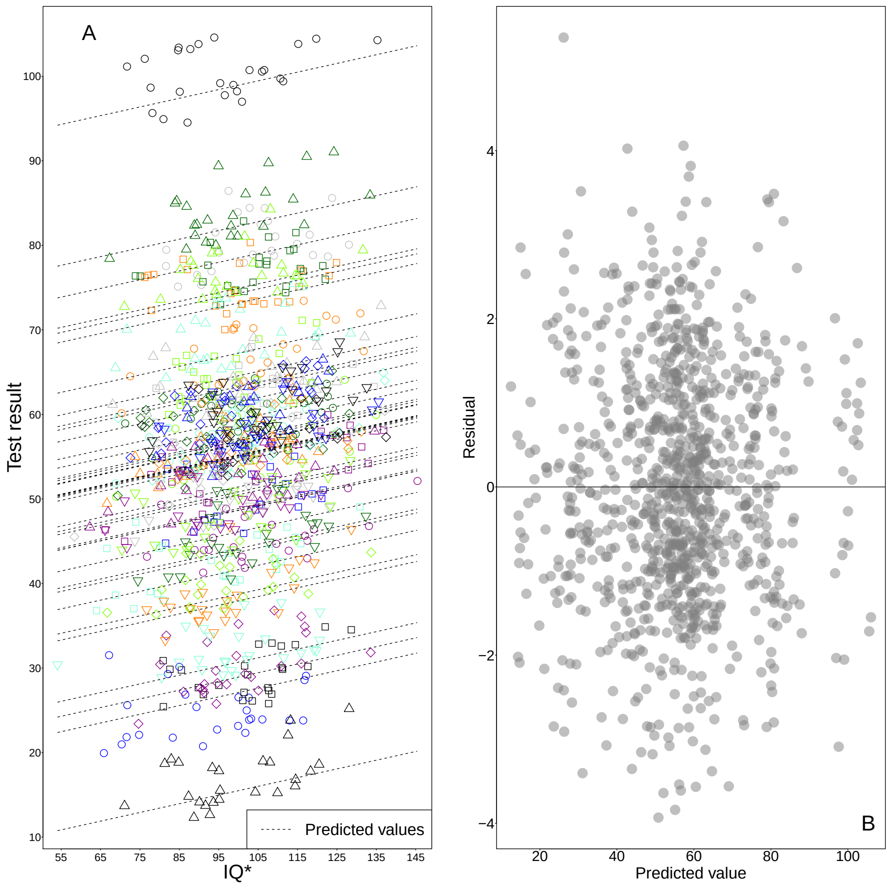

Figure 17: Fixed-effects regression.

*A) The sample data from figure 15 is used to estimate the influence of the pupils IQ on a test result. The plot shows the result of a fixed-effects linear regression model, where the test result is a function of the pupils' IQ, the pupils' sex, the pupils' socioeconomic background, as well as the fixed effect dummies for the pupils' class (in form of 39 dummy predictors with one reference dummy). The true effect for the pupils' IQ on the test result of 0.1 is estimated correctly (partial population slope estimate for pupils IQ is 0.103). Every single class has its own population intercept and partial population slope in the fixed effects regression model. The magnitude of the partial population slope of pupils' IQ is however the same in all classes. B) The residual versus fitted values plot shows that model assumptions are met. Dependency in observations is no issue any more. * Variable was standardized prior to estimation.*

This approach is known as fixed-effects regression, because it is assumed that all the other predictors have the same effect across all groups of the factors and that all values of the factor are present as dummies in the regression. In summary, the fixed effects model is just a usual regression model with the same issues and assumptions as discussed in the prior sections.
However, it is worth noting, that the fixed-effects regression model has important limitations. As mentioned above, all results of a fixed-effects regression analysis are conditional on the groups of the factors included in the analysis. It is not possible to extrapolate beyond those. Second, the fixed-effects regression analysis only allows to analyse factors responsible for differences within the groups of the factor, and is therefore also known as a "Within-Estimator". All variables not varying within the groups of the factor are perfectly multicollinear and cannot be considered simultaneously (Kohler and Kreuter 2012, pp. 320-321). This means that the fixed-effects regression model does not allow to investigate reasons for the differences between the groups of the factor.
Another way to model a factor is achieved by considering it as a normally distributed random variable with a mean of 0 and a variance of σ_α^2 (Quinn and Keough 2002, p. 178). This approach assumes that the groups of the factor present in the sample data are a random sample of all possible groups and aims at making conclusions about all possible groups (Quinn and Keough 2002, p. 176). In equation 5.14, the estimate for the random factor α_j shows the variation of the overall mean response, β_0, between the groups of the factor.
By adding such a random factor to a regression, a random-effects regression model is specified, where RI_{0j} is the random intercept and measures the variation of the population intercept, β_0, between the groups of the factor: $y_{ij} = \beta_0 + \beta_1 * x_i + ... + RI_{0j} + \varepsilon_{ij}$. Instead of estimating values for each single group of the factor, as in the case of the fixed-effects regression model, one common variance term is estimated, allowing to make generalizations (figure 18) (Barr et al. 2013, p. 259). Consequently, sampling in the random-effects regression occurs at two levels, first, at the level of the individual observations and second, at the level of the groups of the factor.
The Random-effects regression model is an extension of the regression models discussed so far. The assumptions and issues discussed so far in the context of the other regression models also apply to random-effects regression models. However, there are also specific assumptions related to the random intercept RI_{0j}: it should be normally distributed with a mean of zero and a variance equal to the variance present in the factor it was sampled from. Additionally, hypothesis tests cannot be implemented as easily as in the regression models discussed so far. This is due to two important facts. First, there is no consent on how to calculate the number of degrees of freedom in regression models including random intercepts. Second, assumptions commonly made related to the null value of parameters in hypothesis tests are violated for random intercepts (Bolker et al. 2009, pp. 131-132; Barr et al. 2013, p. 259). As a result, only approximate tests with corrections are available. The most universally applicable is a likelihood ratio test on the full model and a restricted model not including the estimate of interest. For tests considering the random intercept, additionally dividing the p value by two is an appropriate correction (Bolker et al. 2009, pp. 131-132).

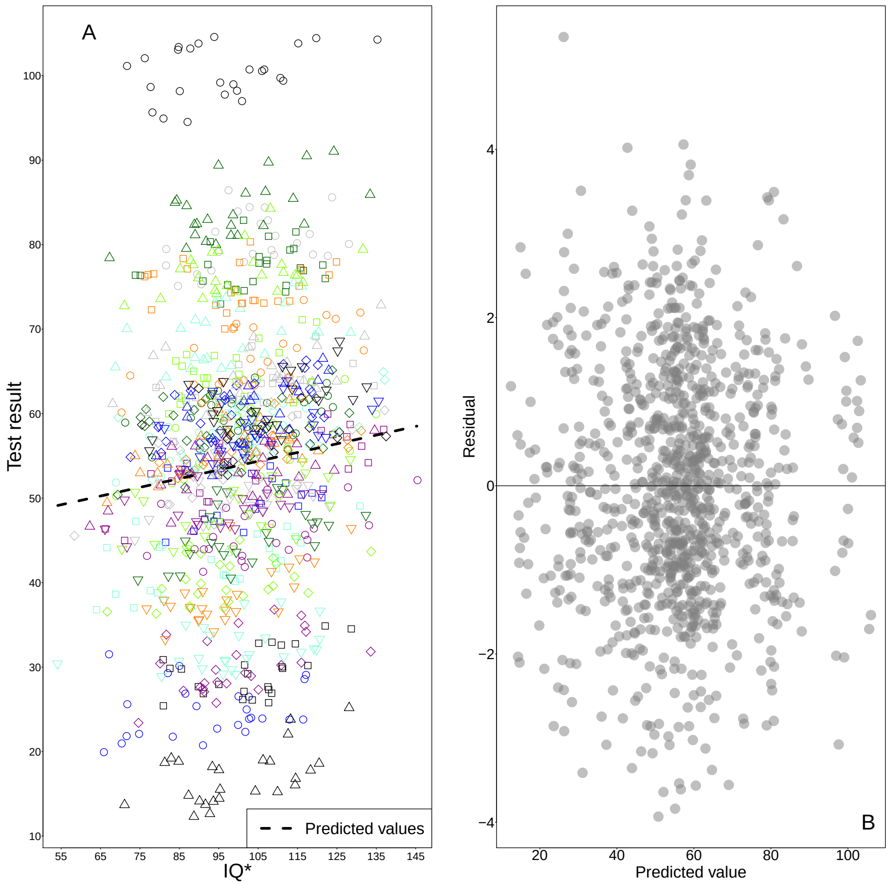

Figure 18: Random-effects regression.
*A) The sample data from figure 15 is used to estimate the influence of the pupils IQ on a test result. The plot shows the result of a random-effects regression model, where the test result is a function of the pupils' IQ, the pupils' sex, the pupils' socioeconomic background as well as the random effect for the pupils' class (in form of a class random intercept). The true effect of 0.1 is estimated correctly (partial population slope estimate for pupils IQ is 0.103). The random-effects regression estimates one partial population slope for all pupils in all classes, allowing to generalize the effect of the pupils IQ. The estimated variance parameter for the pupils' class random intercept is a standard deviation of 16.40 (true standard deviation is 15). B) The residual versus fitted values plot shows that model assumptions are met. * Variable was standardized prior to estimation.*

5.3.7 Mixed effects regression

In random-effects regression models, a random intercept can be added to a regression model to allow the population intercept to vary between the groups of a factor. In the same way, a random slope can be added to a regression model to additionally allow the effect of a predictor on the response to vary between the groups of a factor: $y_{ij} = \beta_0 + RI_{0j} + (\beta_1 + RS_{1j}) * x_i + \varepsilon_{ij}$. Such random slopes can only be specified in combination with random intercepts. As for the random intercept, it is assumed that the random slope, RS_{1j}, is normally distributed with a mean of 0 and a variance equal to the variance present in the factor it was sampled from. It is furthermore assumed that the random intercept, RI_{0j}, and the random slope, RS_{1j}, are not correlated (Barr et al. 2013, p. 259). As in the case of the random-effects regression, hypotheses testing in mixed-effects-regression models should be done with likelihood ratio tests on full- and restricted models. When only one random term is tested, additionally dividing the p value by two is an appropriate correction (Bolker et al. 2009, pp. 131-132). Beside of these specific assumptions and issues, all other assumptions and issues discussed so far in the context of the other regression models also apply to the mixed-effects regression models.

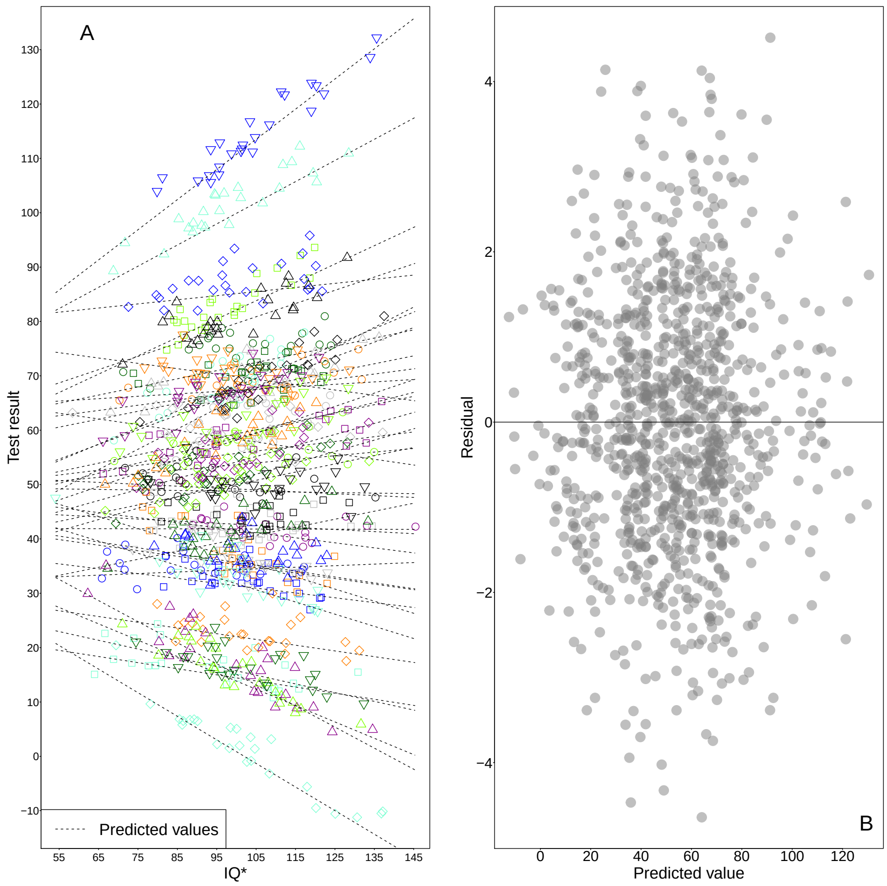

Figure 19: Mixed-effects regression model.

*A) Using a sample data where the pupils test result is not only clustered, like in figure 15, but where the influence of the pupils' IQ on the test result also varies between the classes, a mixed-effects regression model is used to estimate the influence of the pupils' IQ on the pupils' test result. The plot shows the result of a maximal mixed-effects regression model, where the test result is a function of the pupils' IQ, the pupils' sex and the pupils' socioeconomic background as well as the random effect for the pupils' class and the random slopes for the pupils' IQ, the pupils' sex and the pupils' socioeconomic background. No overall significant effect of the pupils' IQ on the pupils' test result is found (p=0.183). However, a highly significant variation of the effect of pupils' IQ on pupils' test result by 0.2 points standard deviation is found (p<0.001) This corresponds to the true dependencies underlying the data. B) The residual versus fitted values plot shows that model assumptions are met. * Variable was standardized prior to estimation.*

Mixed-effects regression models allow to control for all possible sources of variations in the response variable and should optimize the generalization of statistical inferences based on a specific sample data to other individuals, *i*, and groups, *j*, when the maximal random effects structure is specified. Given a sample data, the maximal random effects structure of a mixed-effects-regression model is reached when all possible random intercepts and random slopes are included. Such models are called maximal models. Maximal models best capture all dependencies in the sample data (figure 19). Models without maximal random effects structure, on the other hand, are misspecified and either lack statistical power or have increased Type-I error rates and also run a risk to violate model assumptions (figure 20). Maximal models can become complex, increasing the likelihood that the iterative algorithms used for the estimation fail to converge (Barr et al. 2013, p. 261).

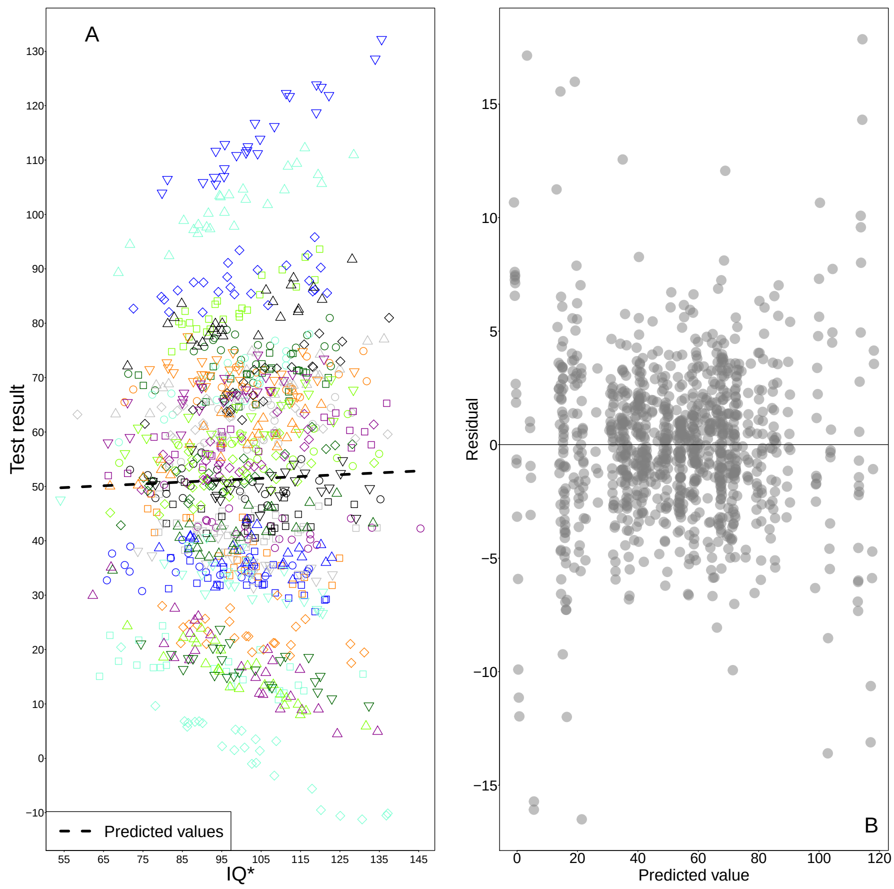

Figure 20: Misspecified random-intercept regression model.
*A) Using a sample data where the pupils test result is not only clusterd, like in figure 15, but where the influence of the pupils IQ also varies between the classes, a random-intercept regression analysis is used to estimate the influence of the pupils IQ on the pupils test result. The plot shows the result of a random-effects regression model, where the test result is a function of the pupils IQ, the pupils sex, the pupils socioeconomic background as well as the random effect for the pupils class. Although there is in reality no overall significant effect of pupils IQ on the pupils test result, the model estimates a slight positive effect of the pupils IQ on the pupils test result which is highly significant (p<0.001). B) The residual vs. fitted values plot shows that the constant residual variance assumption is violated. * Variable was standardized prior to estimation.*

5.3.8 Model selection

Besides testing hypothesis regarding specific regression estimates, one important application of the regression analysis is determining the set of predictors available in a sample data that best explain the variation in the response variable. Frequently, the focus is laid on finding parsimonious sets of predictors that best fit the observed data. There are a variety of criteria for deciding which model to select as the best model and those can lead to competing best models. Furthermore, there are also fundamentally different approaches to find the best model and investigate the effect of predictor variables on the response variable (Quinn and Keough 2002, pp. 137-140).

In stepwise procedures, a set of variable from the sample data is first defined and then sequentially entered into, or removed from, the regression model (this depends on whether one starts with a null- or a full model). At each step, a new model comprising more or fewer predictors is estimated and the changes in the overall model fit as well as the single parameter test statistics are recorded. At the end of the procedure, a final model comprising the set of predictors that have a significant effect on the response and that best explain the response variable is selected. In the forced-entry procedure, only one full model is estimated where all predictors of interest are entered simultaneously into the model. The use of a stepwise procedure in the context of hypothesis testing and model selection is however no valid option because it does not generally provide the best model, while at the same time suffering from elevated Type I error rates as a consequence of multiple testing. In contrast, forced-entry procedures produce the conventionally expected type I error rate of 5% (Mundry and Nunn, pp. 120-123; Forstmeier and Schielzeth 2011, pp. 50-52). In a strict sense, forced-entry procedures do however not select the best model, but only provide one full-model. In a first step, a single statistical test is conducted to test whether the full-model fits the data better than a null-model. If this is the case, the full-model generated through the forced-entry procedure allows however to test hypotheses related to the effect of the predictors on the response variable without suffering from elevated Type I error rates (Forstmeier and Schielzeth 2011, p. 51). Unfortunately, it is often not possible to estimate one full model including all predictors of interest. The applicability of forced-entry procedures depends on the size of the sample data and the set of variables of interest and is therefore strongly limited by model complexity and multicollinearity of predictors.

A third approach related to finding the best model and investigating the effect of predictor variables on a response variable has been brought forward in form of model averaging and information theoretic approaches (Burnham and Anderson 1998). Using information criteria, these approaches allow the comparison of non-nested models. Estimates from a number of different models are then combined to one model-averaged coefficient for each predictor (Forstmeier and Schielzeth 2011, p. 53). In the following discussion on information theoretic approaches to model selection and statistical inference, I will focus on the Akaike information criteria (AIC). The AIC estimates how well a fitted model represents an unknown mechanism generating the observed data used for the regression model. The AIC is calculated with equation 5.15, where $L(\theta)$ is the likelihood of the estimated model and k the number of parameters in the model (Burnham and Anderson 1998, p. 61).

$$AIC = -2log * L(\theta) + 2k \tag{5.15}$$

While it does not make sense to interpret one single AIC value, in contrast to single R^2 values, AIC values can be used to compare a set of models with the same response and the same observations from the same sample data, but with different combinations of predictors. The AIC implements the principle of model parsimony by incorporating a trade-off between a good model fit ($-2log * l(\theta)$ becomes smaller with increasing numbers of predictors) and the complexity of a model ($2k$ becomes bigger with increasing numbers of predictors).
When comparing a set of models with the AIC, the models are first estimated and then ranked according to their AIC values, with the best model having the smallest AIC value, AIC_{min}, on top and the other models following with increasing AIC-values (Burnham and Anderson 1998, pp. 62-64). In a second step, the differences in AIC values, $\triangle_i$, are calculated for all models in the model set with the equation $\triangle_i = AIC_i - AIC_{min}$. For AIC_{min}, $\triangle_i$ is obviously 0. Although we can rank our set of models according to AIC values, there still is uncertainty: we can never be sure that the model with the smallest AIC value is really the best model. The AIC differences can be used to get a feeling of which models have support and which models have no support of being the best model (Burnham and Anderson 1998, pp. 70-72). The AIC differences can furthermore also be used to compute the Akaike weights, w_i, where $\sum_{r=1}^{R}$ are all models included in the model set (equation 5.16). The Akaike weights simplify the interpretation of the support for a given model, as they provide us with a measure for the likelihood that a given model from a set of models is the best model. This holds true when it is assumed that the best model is included in the model set. Akaike weights are additive and their total sum equals one (Burnham and Anderson 1998, p. 75).

$$w_i = \frac{exp(-\frac{1}{2}\triangle_i)}{\sum_{r=1}^{R} exp(-\frac{1}{2}\triangle_r)} \tag{5.16}$$

Using the Akaike weights of all models in the model set, a 95% confidence set of models can be built: starting with the best model, the model with the highest Akaike weight, and continuing with decreasing Akaike weights, the sum of the Akaike weights of the models is built until it reaches 0.95. Given a set of models and the actual data, all models used to build the sum of the Akaike weights for the 95% confidence set have strong support to be the best model (Burnham and Anderson 1998, pp. 169-171). Calculating Akaike weights and building a 95% confidence set are means to deal with the uncertainty underlying the quest for a best model.
Finally, this approach can also be used to lower the uncertainty underlying inference. By using the Akaike weights of the models from the model set, model averaged coefficients can be calculated (equation 5.17), where a given coefficient from a model of the model set is β_{ij}, the respective model averaged coefficient is $\bar{\beta}_j$, and coefficients not occuring in a model are simply set to 0. Such model averaged coefficients reduce model uncertainty, model selection bias and provide much more stable inference than simply relying on one best model (Burnham and Anderson 1998, pp. 151-152). Standardizing all coefficients of all models of the model set with their partial standard deviation prior to averaging is a procedure to make sure that the model averaged coefficients are

meaningful (Cade 2015, pp. 2380-2381).

$$\bar{\beta}_j = \sum_{i=1}^{R} w_i \beta_{ij} \tag{5.17}$$

Information theoretic model selection can be used to run regression models including all possible combinations of predictor variables from a given sample data. In this way, it is appealing to simply let the data speak. This allows us to get a feeling of the structure underlying the sample data (Burnham and Anderson 1998, p. 64). The result of such a model selection analysis however entirely depends on the set of models the scientist defines at the beginning of the analysis. Information theoretic model selection is therefore also a fruitful approach when following a more theoretically driven data analysis strategy:

> "Of course, models not in the set remain out of consideration. AIC is useful in selecting the best model in the set; however, if all the models are very poor, AIC will still select the one estimated to be best, but even that relatively best model might be poor in an absolute sense. Thus, every effort must be made to ensure that the set of models is well founded." (Burnham and Anderson 1998, p. 62)

5.4 Simulation study: estimating a treatment effect

In this simulation study, I use simulated data to evaluate the performance of the different approaches to causal inference discussed in this chapter. More specifically, I compare the performance of the unadjusted treatment effect of RCTs (section 5.2.4) with the adjusted treatment effect obtained through different regression models (section 5.3) on the same RCTs data. This section mainly takes up a manuscript which is currently under review in a scientific journal. Some parts were however adapted for the purpose of this work.

5.4.1 Introduction: simulation study

The counterfactual approach to the analysis of causation is based on a notion of causation which was well summarized by David Hume in 1748: "[...] if the first object had not been, the second never had existed." (Hume 2007 [1748], p. 70). Making use of an experimental terminology, a causal effect can be determined as a treatment effect. When units of a study are exposed to an experimental treatment (E) or a control treatment (C), the mean difference in the outcome between the units exposed to E and the units exposed to C, the average treatment effect (ATE), corresponds to the typical treatment effect, if the units of the study exposed to E and C are made up of perfectly matched pairs: they all react in the same way to the stimuli. This can be the case for experimental as well as for observational studies. Unfortunately, studies consisting of perfectly matched pairs rarely occur in reality. As a solution to this issue, experimental studies make use of randomization in order to meet the independence assumption, which states that the units of a study should be

exposed to E or C independent of all other variables. If this assumption holds true, the ATE is an unbiased estimator of the typical treatment effect (Rubin 1974; Holland 1986).
Such Randomized Controlled Trials (RCTs) are commonly seen as the gold standard to causal inference and are conducted in a wide range of scientific disciplines (Grossman and Mackenzie 2005; Farrington and Welsh 2005; Druckman et al. 2006; Rubin 2008; Banerjee and Duflo 2011; Bothwell et al. 2016; Deaton, 2017; Webber and Prouse 2018).
One important controversy related to RCTs is the question of covariate adjustment. Although, about 1/3 of clinical studies adjust the ATE in their main analysis, thereby increasing the precision of the ATE (Kahan et al. 2014; Deaton, 2017), adepts of RCTs usually focus on the characteristics of well-designed randomized studies for causal inference and are reluctant to adjust the ATE (Heckman 2005). They argue that it is never clear which other variables are truly relevant. By controlling for irrelevant variables and using complex statistical methods, one might then introduce a bias into the ATE (Rubin 1974; Freedman 2008).
In this study, I use simulated data to evaluate when the unadjusted ATE is a good proxy for the typical causal effect and when the ATE should be adjusted by considering other covariates. More specifically, I use this simulation study to test the following hypothesis:
H1: The unadjusted ATE of RCTs is an unbiased estimator of the typical causal effect (Rubin 1974, p. 693).
H1a: Adjusting for irrelevant covariates leads to a bias in the ATE of RCTs (Rubin 1974, pp. 696-697 and p. 700).
H1b: Adjusting for covariates relies on additional assumptions that lead to additional bias in the ATE of RCTs (Freedman 2008, p. 181).
H2: Maximal mixed effects regression model provide ATEs of RCTs that optimize generalization of findings (Barr et al. 2013, p. 261).
H2a: Adjusting for covariates correlated with the outcome increases the precision of ATEs of RCTs (Kahan et al. 2014, p. 2).

5.4.2 Methods: simulation study

In comparison to real-world-data, where the true data generating process is unknown, all mechanisms and processes underlying the generation of simulated data are exactly known and manipulable. This makes simulation studies a valuable tool for statistical and methodological research (Mundry and Nunn 2009, Forstmeier and Schielzeth 2011, Barr et al. 2013, Schmidt-Catran and Fairbrother 2016; Bryan and Jenkins 2016). Let us consider a simple example adapted from Heckman (2005, p. 28). The outcome of interest, y_{ig}, is a function of observed (O) and unobserved variables (U) of individuals i and groups g (equation 5.18).

$$y_{ig} = O_i + U_i + O_g + U_g \tag{5.18}$$

Based on this simple framework, I first generated a dataset of 1000 individuals nested in 40 groups (25 individuals per group). The individuals had two observed variables (i.cov and i.fac) and the groups had one observed variable (g.cov), as well as two unobserved variables (g.unobs.cov and g.unobs.fac) (table 16).

Table 16: Parameters used for the generation of the dataset.

Variable	Parameters	Observed/Unobserved
i.cov	Normally distributed with a mean of 0 and a sd of 15	Observed
i.fac	Binomially distributed with probabilities of 0.4 for 1 and 0.6 for 0	Observed
g.cov	Normally distributed with a mean of 0 and a sd of 100	Observed
g.unobs.cov	Equally distributed with values between 0 and 1	Unobserved
g.unobs.fac	Binomially distributed with probabilities of 0.3 for 1 and 0.6 for 0	Unobserved

First, the 1000 individuals were evenly distributed among the 40 groups. Then, the values of individuals and groups for the different variables were set according to the parameters shown in the table.

The next step consisted in generating the outcome. This was done by simulating the effects of the observed and the unobserved characteristics of the individuals and the groups on the outcome. For this purpose, four conditions were considered, with different settings of parameters for the effects of the observed and the unobserved characteristics (table 17). Then, using the simulated dataset with the respective outcome, a random sample was drawn. I implemented four different sample sizes (n=50, n=100, n=500, n=1000=full sample). All individuals from the random sample were then randomly attributed either to the experimental control- or treatment conditions. I then simulated four different ways in which the treatment influenced the outcome. In all cases, the outcome stayed the same for individuals in the control condition (table 18).

Table 17: Parameters used for the generation of the outcome.

Condition	Effect of the observed variables on the test result (fixed effects)	Effect of the unobserved variables on the test result (intercept, noise and random effects)
Noise	i.cov: 0 i.fac: 0 g.cov: 0	g.unobs.cov: 0 g.unobs.fac: 0 g.sd: 0 i.cov.sd: 0 i.fac.sd: 0
Observed	i.cov: 0.15 i.fac: 15 g.cov: 0.1	g.unobs.cov: 0 g.unobs.fac: 0 g.sd: 0 i.cov.sd: 0 i.fac.sd: 0
Unobserved	i.cov: 0.15 i.fac: 15 g.cov: 0.1	g.unobs.cov: 15 g.unobs.fac: 10 g.sd: 0 i.cov.sd: 0 i.fac.sd: 0
Group	i.cov: 0.15 i.fac: 15 g.cov: 0.1	g.unobs.cov: 15 g.unobs.fac: 10 g.sd: 20 i.cov.sd: 0.1 i.fac.sd: 10

In all conditions, the outcome was a function of the observed and the unobserved variables of the individuals and groups. The parameter settings for each condition were defined as shown in the table and the outcome was calculated by building the sum of the products between the parameter and the respective variable values from the data set. Clustered outcomes were implemented by modelling a group random intercept with a mean of 0 and a sd equal to the g.sd. Effects of observed individual variables varying between groups were implemented by modelling random slopes with a mean of 0 and a sd for each fixed effect as shown in the table. Under all conditions, the overall mean outcome was 100 with a standard deviation of 1.5.

Table 18: Parameters used for modeling the treatment effect.

Condition	Treatment effect
Fixed treatment	Fixed effect = 0 Interaction with i.cov = 0 Treatment effect sd = 0
Correlated treatment	Fixed effect = 0 Interaction with i.cov = 1.5 Treatment effect sd = 0
Varying treatment	Fixed effect = 0 Interaction with i.cov = 0 Treatment effect sd = 5
Correlated and varying treatment	Fixed effect = 0 Interaction with i.cov = 1.5 Treatment effect sd = 5

Under all conditions, the fixed effect of treatment was 0. In the correlated treatment condition, the treatment effect however depended also on the value of i.cov. In the varying treatment condition, the treatment effect varied among the groups and in the correlated and varying condition, the treatment effect depended on i.cov and varied among the groups.

Table 19: The different statistical models implemented in the simulation.

Model	Estimation procedure
Ttest	TreatmentEffect=t.test(Treatment, Control, var.equal=TRUE, paired=FALSE)
Linear (linear regression)	linear=lm(outcome~Treatment+i.cov+i.fac+g.cov, data=sample)
Fixef (fixed effects regression)	fixef=lm(outcome~Treatment+i.cov+i.fac+g_dummies, data=sample)
Ranef (Random effects regression	ranef=lmer(outcome~Treatment+i.cov+i.fac+g.cov+ (1|g), data=sample, REML=FALSE)
Mixef (Mixed effects regression)	mixef=lmer(outcome~Treatment+i.cov+i.fac+g.cov+ (1|g)+(0+Treatment*|g)+(0+i.cov|g)+(0+i.fac|g), data=sample1, REML=FALSE) (given the data available, this corresponds to the maximal model Barr et al. 2013, p. 261)

The table shows the R notation for the different estimation procedures.

Finally, using the same sample data including the outcome for the individuals in the treatment and control groups, I used different estimation procedures to estimate the treatment effect (table 19). The two sample T-test coincided with the unadjusted ATE. The regression models adjusted the ATE by considering other variables. While the linear regression model only accounted for other observed variables, the fixed- and the random effects regression models also controlled in different ways for unobserved heterogeneity at the group level (the unobserved variables) and clustered outcomes (random intercepts). The mixed effects regression model furthermore also

controlled for varying effects of observed individual level variables (random slopes). Considering the available data, the maximal mixed effects regression model includes all random terms possible given the data (Quinn and Keough 2002; Barr et al. 2013; Bruederl and Ludwig 2015; Mundry 2017).
In summary, the simulation consisted of the five following steps: generation of the data (table 16), generation of the outcome (table 17), drawing the sample data and random assignment to the experimental groups, assignment of the treatment effect (table 18), estimation of the treatment effect (table 19). This was done for all combinations of outcomes (table 17), sample sizes and treatment effects (table 18), leading to 64 distinct combination of parameter settings for the simulation. For each of the 64 parameter setting the simulation was repeated 1000 times, leading to 64,000 simulation runs and 304,000 estimated treatment effects (for simulation runs with sample sizes equal to 50, I did not estimate the mixed effects regression model (the model was too complex for the sample size. This is why the number of estimated parameters is not equal to 64,000*5=320,000)). The simulation was conducted in R (R Core Team 2016). The random- and mixed effects regression models were estimated with the package lme4 (Bates et al. 2015) and the significance for the treatment effect of these models was calculated with a Likelihood Ratio test (Bolker et al. 2009; Barr et al. 2013).

5.4.3 Results: simulation study

Overall, the estimated ATE varied strongly. The t-test provided estimate ranges between 0.6 and 61.4 with shares of significant estimates between 3.7% and 54.4%. The linear regression provided estimate ranges between 0.6 and 56.9 with shares of significant estimates between 4.2% and 58.3%. The fixed effects regression provided estimate ranges between 0.6 and 50.3 with shares of significant estimates between 3.6% and 66.5%. The random effects regression provided estimate ranges between 0.6 and 36.8 with shares of significant estimates between 3.6% and 66.6%. The mixed effects regression provided estimate ranges between 0.6 and 22.3 with shares of significant estimates between 3.5% and 11.3%. The estimate range of the different estimation procedures were mainly influenced by the type of outcome, the type of treatment effect and the sample size. The share of significant results of the different estimation procedures were mainly influenced by the type of outcome and the type of treatment effect. The different estimation procedures showed important differences in the way their estimates reacted to changes in type of outcome and treatment effect: while the mixed effects regression provided the most consistent results across all types of outcome and treatment effect, the ranges of the t-test and linear regression estimates were most strongly influenced by the type of outcome and treatment effect. The shares of significant results of the fixed and random effects regression were highly inflated for the varying treatment effect. Increasing sample size reduced the ranges of estimates in most of the simulation conditions (figures 21 to 24).

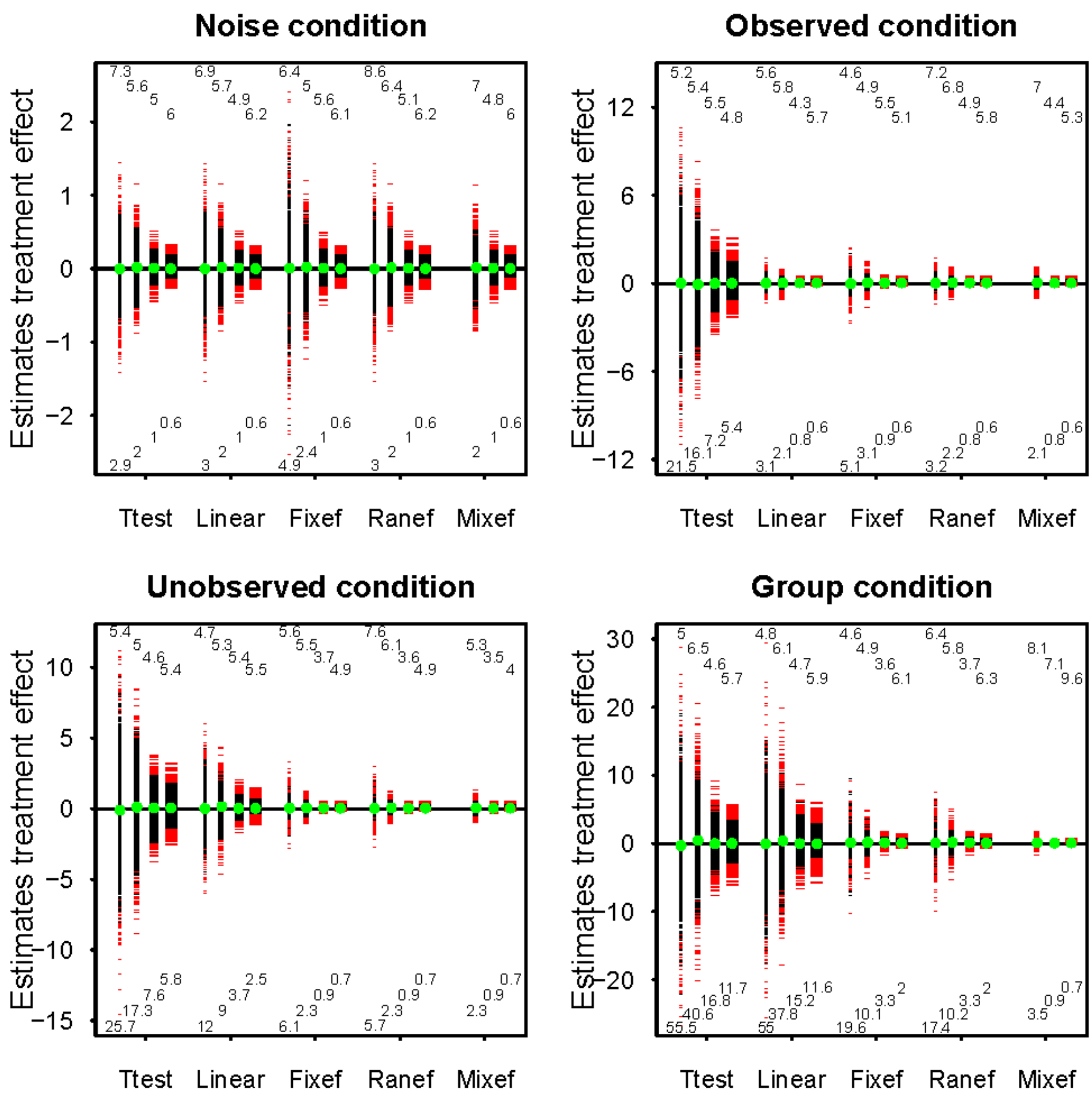

Figure 21: The estimates for the fixed treatment effect.

The plot shows all estimates for simulation runs in the fixed treatment condition (table 18). For all estimation procedures, estimates for sample sizes of 50 are shown left, estimates for sample sizes of 100 are shown second from left, estimates for sample sizes of 500 are shown second from right and estimates for full samples are shown right. Significant estimates (p values <= 0.05) are in red and non-significant estimates (p values > 0.05) in black. The share of significant estimates is written in the upper segment of the plot, above the respective sample size and estimation procedures. The range of estimates is written in the lower segment of the plot, below the respective sample size and estimation procedures. The average of all estimates is depicted with a green point.

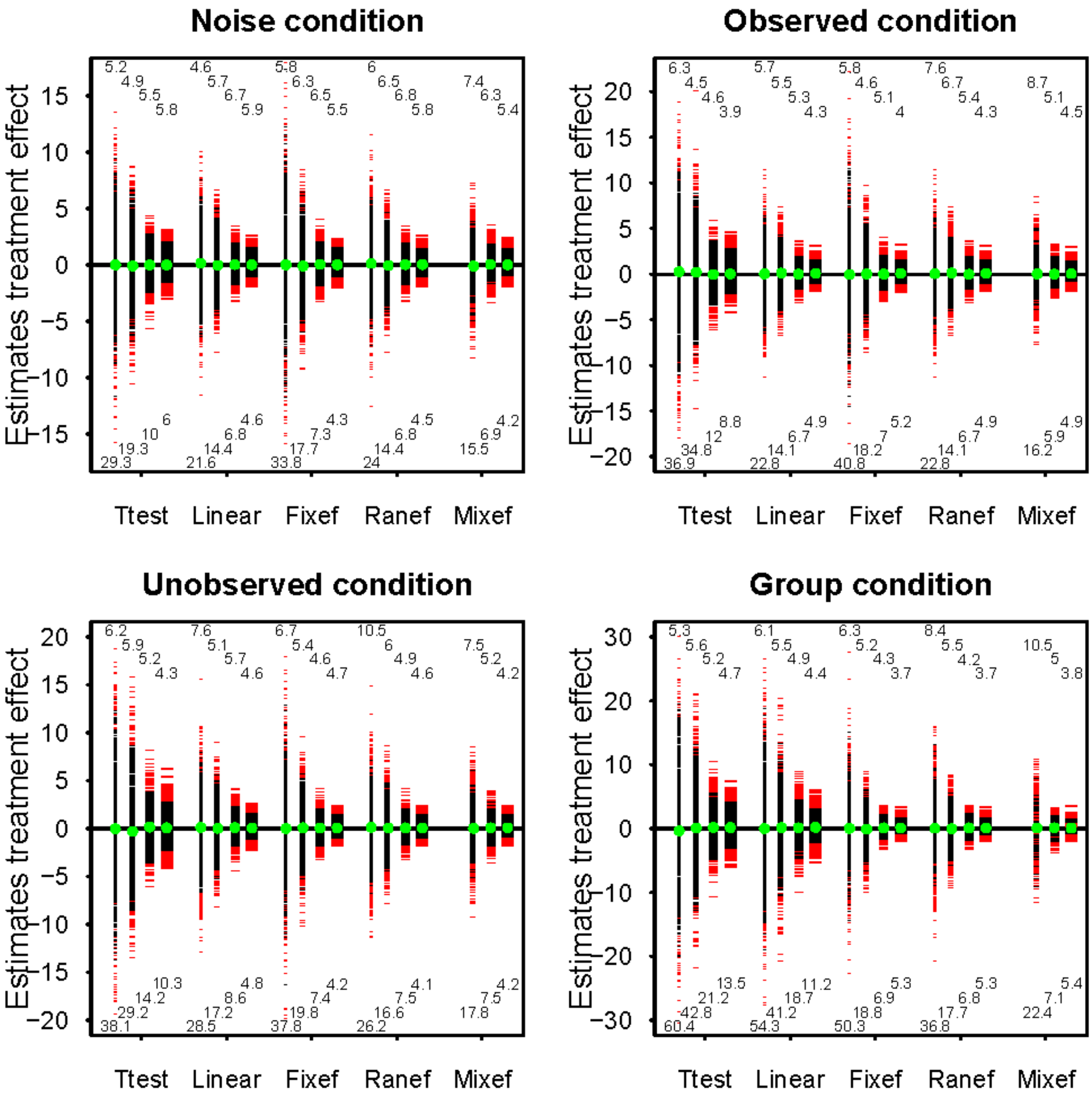

Figure 22: The estimates for the correlated treatment effect.

The plot shows all estimates for simulation runs in the correlated treatment condition (table 18). For all estimation procedures, estimates for sample sizes of 50 are shown left, estimates for sample sizes of 100 are shown second from left, estimates for sample sizes of 500 are shown second from right and estimates for full samples are shown right. Significant estimates (p values <= 0.05) are in red and non-significant estimates (p values > 0.05) in black. The share of significant estimates is written in the upper segment of the plot, above the respective sample size and estimation procedures. The range of estimates is written in the lower segment of the plot, below the respective sample size and estimation procedures. The average of all estimates is depicted with a green point.

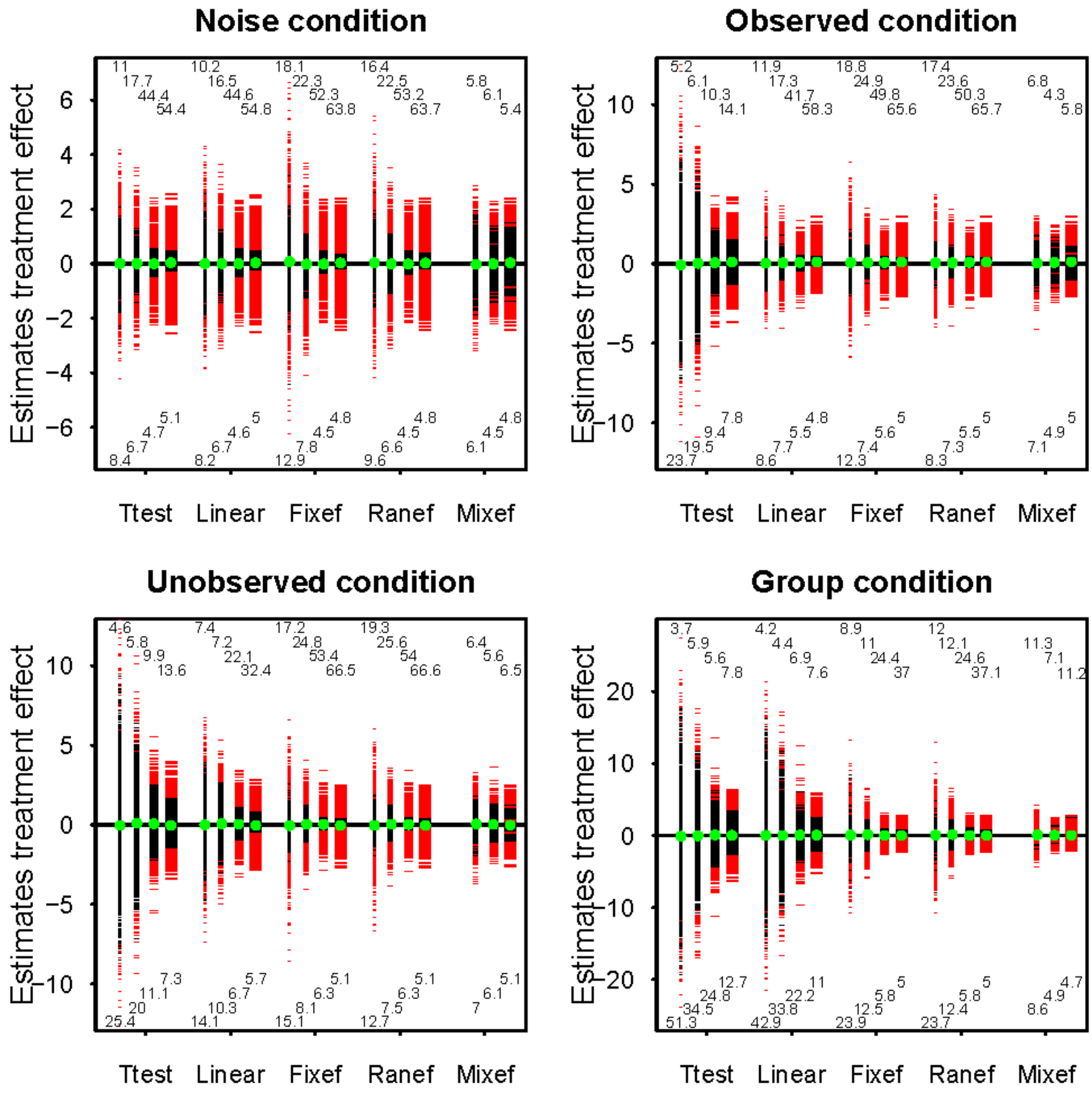

Figure 23: The estimates for the varying treatment effect.

The plot shows all estimates for simulation runs in the varying treatment condition (table 18). For all estimation procedures, estimates for sample sizes of 50 are shown left, estimates for sample sizes of 100 are shown second from left, estimates for sample sizes of 500 are shown second from right and estimates for full samples are shown right. Significant estimates (p values <= 0.05) are in red and non-significant estimates (p values > 0.05) in black. The share of significant estimates is written in the upper segment of the plot, above the respective sample size and estimation procedures. The range of estimates is written in the lower segment of the plot, below the respective sample size and estimation procedures. The average of all estimates is depicted with a green point.

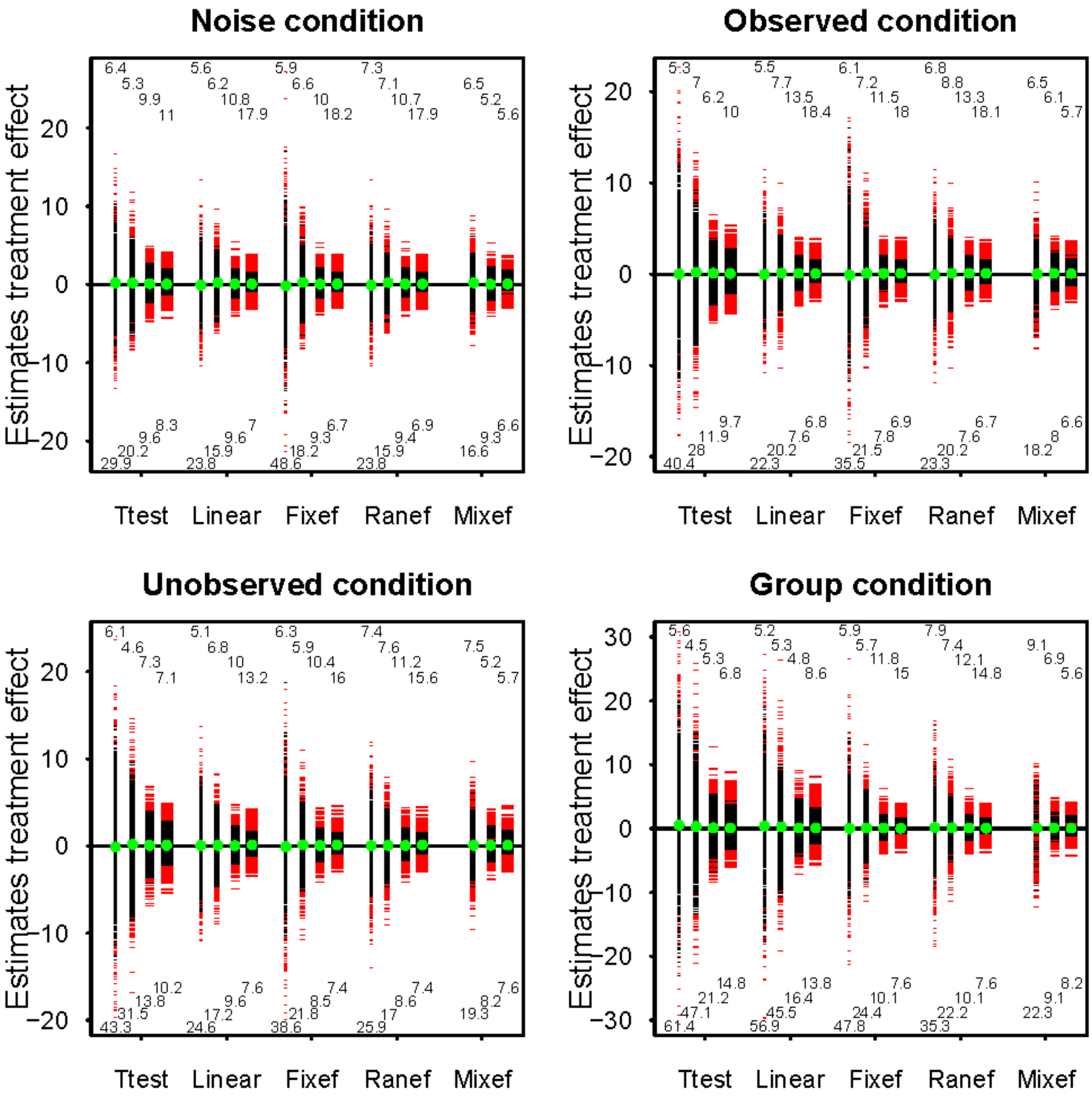

Figure 24: The estimates for the correlated and varying treatment effect.

The plot shows all estimates for simulation runs in the correlated and varying treatment condition (table 18). For all estimation procedures, estimates for sample sizes of 50 are shown left, estimates for sample sizes of 100 are shown second from left, estimates for sample sizes of 500 are shown second from right and estimates for full samples are shown right. Significant estimates (p values <= 0.05) are in red and non-significant estimates (p values > 0.05) in black. The share of significant estimates is written in the upper segment of the plot, above the respective sample size and estimation procedures. The range of estimates is written in the lower segment of the plot, below the respective sample size and estimation procedures. The average of all estimates is depicted with a green point.

Hypothesis test

H1: The unadjuted ATE of RCTs is an unbiased estimator of the typical causal effect (Rubin 1974, p. 693). This hypothesis is falsified. The unadjusted ATE was biased under several conditions of my simulation.
H1a: Adjusting for irrelevant covariates leads to a bias in the ATE of RCTs (Rubin 1974, pp. 696-697 and p. 700). This hypothesis is falsified. Under none of the conditions did adjusting for irrelevant covariates introduce a bias.
H1b: Adjusting for covariates relies on additional assumptions that leads to additional bias in the ATE of RCTs (Freedman 2008, p. 181). This hypothesis is supported. Especially the multiple linear-, the fixed effects-, as well as the random effects regression models suffered from additional bias in comparison to the unadjusted ATE in my simulation study. This was however not the case for the mixed effects regression models.
H2: Maximal mixed effects regression model provide ATEs of RCTs that optimize generalization of findings (Barr et al. 2013, p. 261). This hypothesis is supported. The mixed effects regression model provided the best, or among the best estimates under all conditions of my simulation.
H2a: Adjusting for covariates correlated with the outcome increases the precision of ATEs of RCTs (Kahan et al. 2014, p. 2). This hypothesis is supported. The precision of the adjusted ATE increased compared to the precision of the unadjusted ATE as long as the covariates were correlated with the outcome.

5.4.4 Conclusion: simulation study

When evaluating the performance of the different estimation procedures in the simulation, two aspects need to be considered: first, the treatment effect estimates should be good proxies for the true treatment effect size; second, the significances of the treatment effect estimates should provide good measures for the relevance of the true treatment effect. In the case of the first criterion, I focus on the range of the estimates. Because all estimates were unbiased, they were all 0 on average (figures 21 to 24), this criteria cannot be used to compare the estimation procedures. The smaller the range of the estimates, the better the performance of the estimation procedures. In the case of the second criterion (the significance as a measure for the relevance of the treatment effect), I will focus on the share of significant estimates. The larger the share of significant estimates, the worst the performance of the estimation procedures. Then, the overall performance of the estimation procedures was made up of these two components (the range of the estimates and the share of significant estimates).
According to these two criteria, the best performing estimation procedure was clearly the mixed effects regression. The t-test performed poorly related to the ranges of the estimates but was among the better performing ones related to the share of significant estimates. The linear regression was the worst performing one, because it had large ranges of estimates as well as inflated shares of significant estimates. The performance of the fixed as well as the random effects regression models laid somewhere in the middle: although having smaller ranges of estimates than the t-test and the

linear regression, they provided the highest shares of significant results in the varying treatment effect condition. Adjusting the ATE by considering other relevant variables did always result in smaller estimate ranges. At the same time, adjusting the ATE by considering irrelevant variables did only negatively affect the estimate ranges in the case of the fixed effects regression for sample sizes of 50. On the other hand, not accounting for clustering and variation of effects present in the data, led to an increased share of significant estimates (figures 21 to 24).
The good performance of the mixed effects regression models corroborates the finding of Barr et al.: “In sum, our investigation suggests that for confirmatory hypothesis testing, maximal LMEMs yield nearly optimal performance: they were better than all other approaches [...].” (2013, p. 272). This result was to be expected, considering the fact that the Generalized Linear Model is a generalization of the t-test and that the Generalized Linear Mixed Model generalizes the Generalized Linear Model (figure 25).

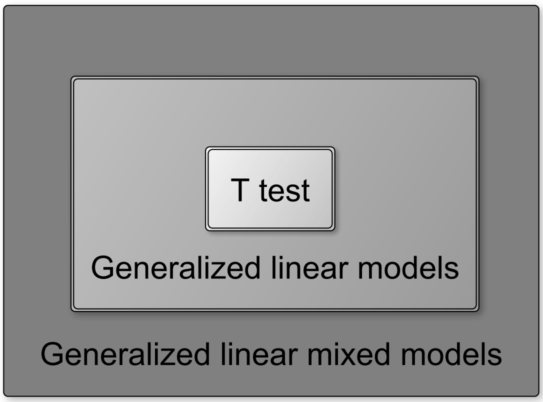

Figure 25: The relationship between the t-test, the generalized linear model and the generalized linear mixed models (adapted from Bolker 2007, p. 397 and Mundry 2017, p. 164).
The generalized linear mixed model encompasses the general linear model, which in turn encompasses the t-test.

The good performance of the mixed effects regression models comes however at a cost. First, mixed effects regression models can become very complex and their applicability relies upon large enough sample sizes. Second, there is no agreement on which method to use in order to obtain p values of estimates from mixed effects regression models. Hypothesis testing can become quite complicated (for example testing the significance of multiple random slopes) and some tests are not implemented in statistical packages. The different tests might also lead to slightly differing conclusions (Bolker et al. 2009; Barr et al. 2013). Third, the maximal mixed effects regression model might suffer from convergence issues in some cases (Bolker et al. 2009; Barr et al. 2013). Finally, the mixed effects regression models have additional assumptions related to the random terms, which are of no relevance in the case of the t-test and the generalized linear models (Quinn and Keough 2002; Barr et al. 2013; Bruederl and Ludwig 2015; Mundry 2017).
As a practical recommendation, I would recommend following a hybrid approach to causal inference. I would suggest only relying upon unadjusted ATEs when the following conditions hold: first, RCTs with large enough sample sizes are not feasible; second, the investigator is not aware of other factors than the treatment known to influence the outcome; third, it is not feasible to gather

information on other factors known to influence the outcome; fourth, clusters and variations of individual effects in the data are not an issue. In all other cases, the experimental design should allow for the adjustment of the ATE by considering other relevant factors and controlling for clustered outcomes within a maximal mixed effects regression model framework.

5.5 Conclusion: methodical foundation

In this chapter, I have discussed different methodical issues related to causal inference. Causal inference allows to make conclusions on the mechanisms underlying patterns observed in the world. Only in this way are we able to generate and accumulate knowledge on the causal laws dictating our life and world. According to the epistemological position I am following in this work, Popper's falsificationism, causal inference is the result of a combination of theoretical and empirical work. Specific and logically coherent theoretical hypotheses are confronted with empirical data. This corresponds to a test of the hypotheses and the underlying theories. As long as the theoretical predictions correspond with the observations, the theory is supported. Otherwise, the theory is falsified. My theoretical hypotheses, presented in chapter 4, postulate general mechanisms underlying human behaviour using natural resources that are deduced from the works of Hobbes, Rousseau and Smith.

Following a science of human nature approach, a sound test of these hypotheses can only be conducted if the empirical data used for this test consists of observations made on a large number of individuals with varying characteristics. These individuals should furthermore also belong to different cultural groups that are not part of the WEIRD category and that show an important variation in their environment and social structure. This is a first prerequisite for my empirical work.

I have devoted an important part of this chapter to discuss the counterfactual analysis of causal inference. This approach has been decisive for the progress of science, not only because it lays the foundation for experimental research. It also provides a terminology and an analytical framework to define causality. According to this approach, a causal effect is the difference between the value of an outcome following a treatment and the value of the same outcome when the treatment is missing. One of the main issues arising when measuring such a causal effect is, however, the fact that it is never clear that different outcomes are really attributable to the treatment. Other factors besides the treatment might also be responsible for the differences in the outcome. These other factors are known as confounders. There are two main ways to deal with confounders. On the one hand, the effect of confounders can be evened by conducting a randomized experiment. Usually, this is the approach followed in experimental studies. On the other hand, these confounders can be included as predictors in a statistical regression model, allowing to estimate their effect on the outcome and isolating the treatment effect. Usually, this is the approach followed in observational studies. However, different types of regression models allow to control for confounding effects at different degrees. In my simulation study, I have shown that mixed-effects regression models provide the best treatment effect estimates, and that the combination of a randomized experiment with such a mixed-effects regression model is a highly promising approach to causal inference.

Such an approach can however only be applied if a randomized experiment is feasible and if reliable data on important confounders is available. As a result, a sound test of my hypotheses can only be implemented if I have access to a large amount of information on my study population in order to control for confounders. Ideally, this information is combined with data from a RCT. These are the other prerequisites for my empirical work.

In the next chapter 6, I describe the field work I conducted to gather my empirical data and give a qualitative report of my study population. My study population consisted of people living in small-scale societies in a remote region of Guinea, West Africa, showing important variations in socio-economic, demographic and cultural factors. I gathered a large amount of data on a large number of different aspects during my field work in Guinea (chapter 6). In my observational study on the sustainable use of natural resources (chapter 7), I linked this data with ecological data and used mixed-effects regressions for causal inference. In my experimental study on the fair allocation of natural resources (chapter 8), I linked this data with data from a randomized experiment I conducted and used mixed-effects regressions as well for causal inference.

Chapter 6

Data basis: field work in Guinea

Humans exploiting a natural resource held in common face a problem of social order. If the resource becomes overexploited and scarce, conflicts might erupt. If the allocation of the resource is perceived as unfair, conflicts might erupt if some individuals want to modify the allocation. Key concepts used by scientists to determine solutions to overcome this problem of social order build upon the works of Hobbes, Rousseau and Smith. Based on the works of the classical scholars, I have deduced hypotheses on factors allowing to overcome the problem of social order occurring when humans use natural resources which are held in common (table 13).

Popper's falsificationism puts equal weight on the theoretical deductive and the empirical part of scientific investigations. Only the confrontation of theoretical hypotheses with empirical observation, within the framework of a statistical hypotheses test, allows to generate robust knowledge on causal mechanisms responsible for patterns observed in the world. While the theoretical hypotheses without doubt play an important part of such a hypotheses test, the result of each statistical hypotheses test is intrinsically linked to the quality of the empirical observations. This is well known from the following simple statement: garbage in, garbage out. Besides the quality of the empirical observations, two further requirements need to be met in order to be able to put my theoretical hypotheses to a sound empirical test: first, my observations need to be conducted on a non-WEIRD study population, showing importation variations in socioeconomic, demographic, environmental, as well as cultural factors; second, my observations should allow to gain insights on a large number of factors that could be important for my outcomes of interest. These two prerequisites directly result from the work presented in my methodical chapter 5.

In this chapter, I describe how I obtained my data basis used for the empirical tests of my hypotheses. Most of this data results from extensive field works I conducted in Guinea in a 12-month period between April 2013 and October 2014. First, I describe the institutional framework of my field work. Then, I give a detailed qualitative report of the work conducted to gather the data, as well as the different dimensions of the study population in which I was interested. This qualitative report also serves as a description of my study population.

6.1 The chimpanzee offset project in Guinea

The Wild Chimpanzee Foundation (WCF) is a nongovernmental, non-profit organization with the mission "[...] to enhance the survival of the remaining wild chimpanzee populations and their habitat [...]" (Wild Chimpanzee Foundation 2018). For this purpose, the WCF implements conservation programs in three West African countries (Guinea, Liberia and Ivory Coast). The conservation programs of the WCF are diverse, but focus on one of the four following pillars: scientific knowledge, law enforcement as well as community education and livelihood. By combining these three aspects, the WCF hopes to be able to successfully complete its mission (Wild Chimpanzee Foundation 2018).
In Guinea, the WCF cooperates with the Guinean government, the International Finance Corporation (IFC), the Compagnie des Bauxites de Guinée and the Global Aluminium Corporation in order to implement a biodiversity offset project according to IFC standards. As a result of this cooperation, the two mining companies agreed to finance a new national park in Guinea in order to compensate for the negative impact of their mining activities on the chimpanzees living on their concessions. Ideally, this should result in a net gain in the total Guinean chimpanzee population. Following on extensive efforts which began in 2012 with a nationwide inventory of chimpanzees, the Guinean Minister of Environment, Water and Forests signed an order for the creation of the new Moyen-Bafing National Park on the 28th September 2018 (International Finance Corporation 2017). My thesis is embedded in the preliminary work related to the creation of the Moyen-Bafing National Park. The detailed interviews and survey of the local population conducted in the course of my thesis offered an insight into the lifestyle of the local population. Combining this information with biomonitoring data of wildlife from the same area allowed to assess the compatibility of the socioeconomic practices of the local population with wildlife conservation in the area.

6.1.1 My thesis work within the WCF offset project in Guinea

The results of a nationwide inventory of chimpanzees conducted in 2012 revealed an interesting pattern: chimpanzees were most abundant in the Foutah Djallon (Wild Chimpanzee Foundation 2012, p. 12). This region has no rainforest, in contrast to the region of the Guinée Forestière, and has the second highest human population density in the country. Finding the highest abundance of chimpanzees in this part of the country is intriguing, as one would expect chimpanzees to be most abundant in their natural habitat, the rain forests, and also in the regions with the lowest human population densities. As the Foutah Djallon offered promising potential offset sites for the destructive activities of mining companies (Wild Chimpanzee Foundation 2014, p. 30), more research was necessary to understand the underlying causes of the irregularity in the distribution of chimpanzees in Guinea. This was the incentive for my thesis. After having secured support and funding (chapter 10), I went to Guinea to carry out the necessary field work. During a first trip from April 2013 to June 2013, I visited the region to gather important information and initiate the necessary preparations for the field work, to be conducted from October 2013 to June 2014. During the same period, two WCF biomonitoring teams recorded signs and sightings of wild mammals from October 2013 to March 2014. The broad area for my field work was determined by the results of the monitoring conducted in 2012 (figure 26). I decided to start working in the north east of the area, between the classified forests of Bakoun, Sobory and Boula. The next sections of this chapter describe my field work and the local population I studied. If not especially mentioned, all pictures shown in these sections were taken by me in the study area.

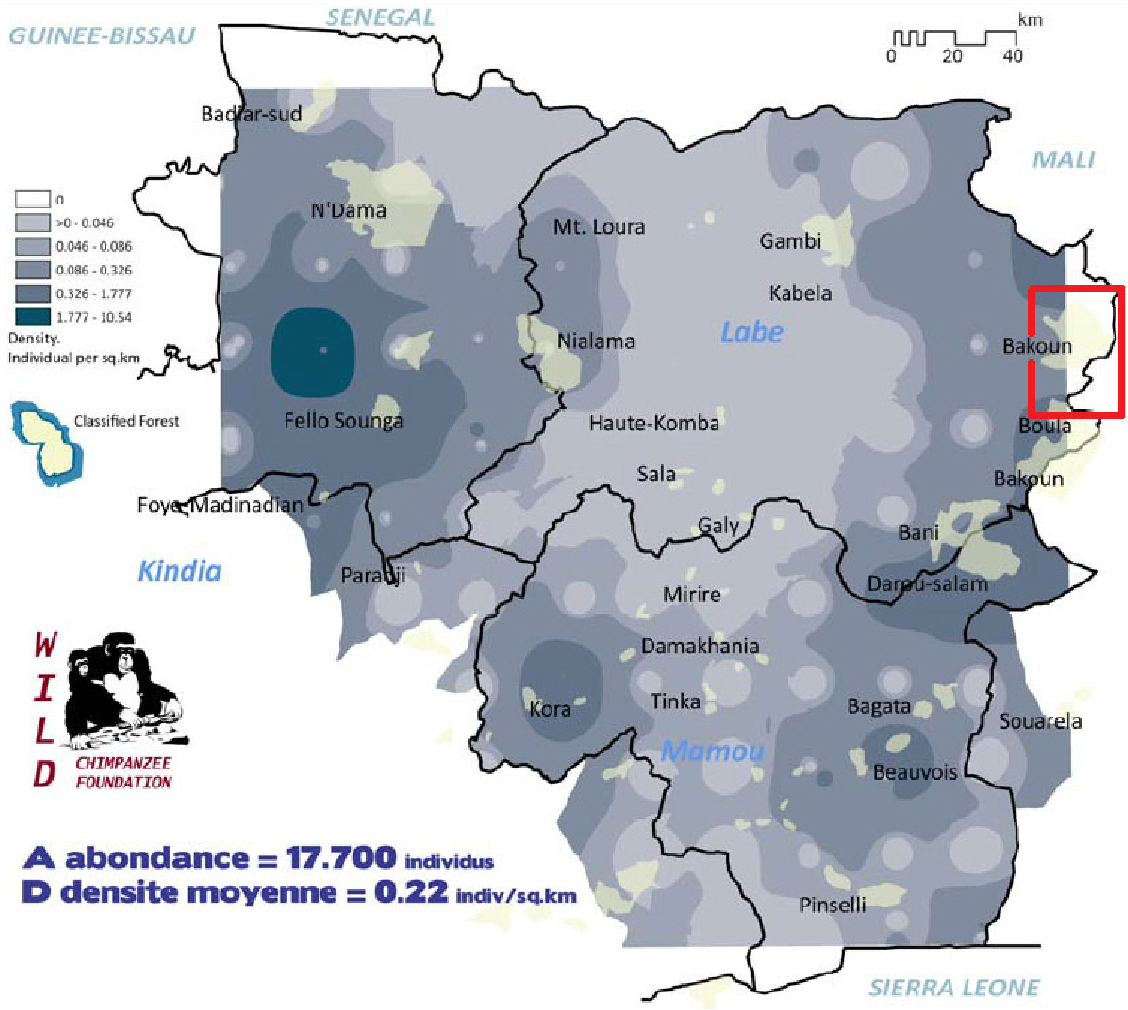

Figure 26: Distribution of chimpanzees in the Foutah Djallon region (Wild Chimpanzee Foundation 2012, p. 12).
The area where I conducted my field work is demarcated with a red rectangle.

6.1.2 Preparations for the field work

Before my first trip to Guinea in 2013, my knowledge of the study area mainly consisted of the results of the WCF nationwide inventory of chimpanzees (Wild Chimpanzee Foundation 2012), as well as the sparse information available on Google Earth (figure 27).

Figure 27: Information available through Google earth on the potential study area.

Because of the low level of information available related to the potential study area, the field work had the character of an expedition, with the aim of makíng a reliable, precise map of the area that besides environmental characteristics also included in depth information on the human population living there. As the area was inaccessible and undeveloped (even by Guinean standards), extensive preparations were necessary in order to successfully carry out the field work, e.g. to bring along most of the needed equipment. The preparations started with obtaining the necessary working permit and the procuring the necessary amount of money in cash (figure 28).

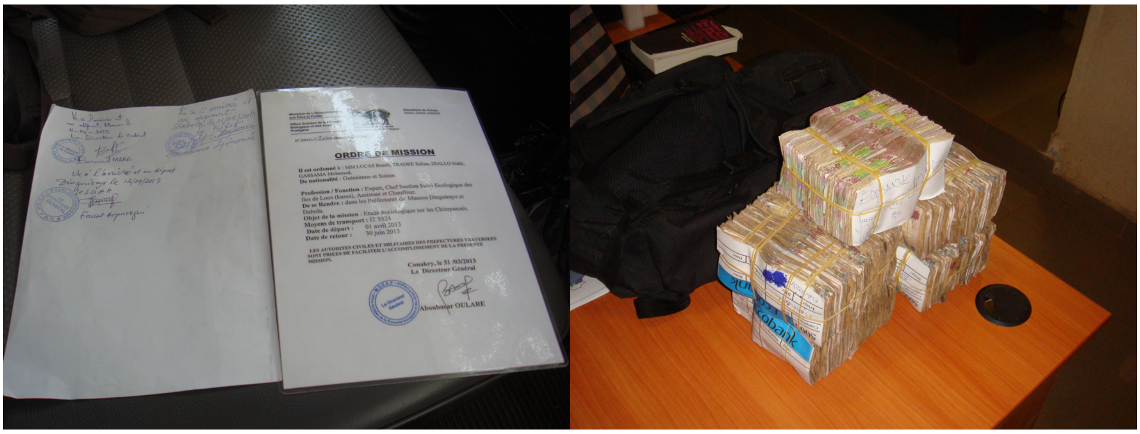

Figure 28: Working permit and money.
Left) A working permit had first to be issued by the Guinean Ministry of Environment, Water and Forests in the capital Conakry. Then, all governors in charge of the area where I wanted to work had to sign the working permit. With this official signed document the population of the study area was more or less obliged to support my work. Right) The study area was remote, without access to any banks. For this reason, I had to bring along enough cash to be able to finance all necessities on-site. The 5 million Franc Guinéen on the picture correspond to 500 euros.

Most importantly, I had to recruit a driver as well as two assistants (figure 29). The driver was responsible for driving, maintaining, packing the car, as well as for its safety (figure 30). The task of the assistants was to conduct interviews with the local people of the study area. Although the official language of Guinea is French, and the questionnaire was in French (see questionnaire in the appendix), most of the inhabitants of the study area did only speak one of the two local languages, Malinke or Fulbe. The assistants therefore had to be fluent in French, as well as at least in one of the two local languages. One of the assistants, Salian Traore, was also an employee of the Guinean Ministry of Environment, Water and Forests. The 1500 questionnaires we brought to the field were kept in a big metal box in order to protect them from the weather and any other damage. Since the whole work was conducted in an area without any electricity infrastructure, we had to make sure to provide our own source of electricity. For this purpose, we entirely relied on a solar panel, with the car battery as a back-up source for electricity. In this way, by making use of a powerbank that we always tried to keep charged, we were able to charge the laptop, the batteries for the Garmin GPS devices, our mobile phones and our torches. Finally, we also had to bring our food in order to be not too much of a charge for the local people hosting us (figure 31). We furthermore also brought along presents for the local people (figure 32). This greatly increased their acceptance for our work.

Figure 29: The whole team.

Traore, my main assistant, on the far right of the picture. The woman he is shaking hand with was the cook of the ecologist team. Ousmane, to my right, was my driver. Mohammed, the driver of the ecologist team, is to the right of Ousmane. Lamine, to my left, was my second assistant. The other people on the picture are the ecologists responsible for the biomonitoring, led by Foromo, on the far left. Both cars are Toyota Land Cruisers. The car on the left belonged to my team, the car on the right to the ecologists. All people working on these two projects were hired by the WCF.

Figure 30: The car.

The WCF provided a Toyota Land Cruiser for my field work. The car was essential for the success of the field work and was not only used as a means of transport, but also for storage. Top left) Driving the car was not an easy task in the remote study area. The roads were in bad shape and there were no bridges. Top right) The car got stuck frequently and it happened that we only managed to carry on thanks to the help of local people. Bottom left) All our material and food had to fit in the car. Bottom right) The only way was also using the top of the car.

Figure 31: Food and water.

Left) The food we brought with us had to be durable. Our diet consisted mainly of rice with palm oil or peanut cream. Then, we also had beans, canned vegetables, as well as corned beef, some pasta, vegetable oil, onions, garlic, salt and pepper. Most importantly, we took care to bring along enough green tea as well as plenty of sugar to prepare the highly appreciated Ataya. Additionally, depending on the village and the season, we were able to buy fresh vegetables, fruits *and occasionally a chicken from the village communities. Middle) Mohamed preparing Ataya. This beverage is made up of green tea with sugar and is widely consumed in Guinea, but also in other West-African countries. Right) We used the same water as the local people, which came either from draw-wells, from springs or from rivers. However, we always filtered the water with a ceramic filter. This procedure was time consuming, and we had to filter the water during a whole day to obtain one canister of drinking water.*

Figure 32: Presents.
Left) We brought along one soccer ball and 10 Cola nuts for every single village we visited to conduct the field work. The soccer balls were intended for the youths of the villages and the 10 Cola nuts were a ritual present to the elders of the communities. We gave the presents to the village communities when we introduced ourselves. In some cases, when we had the impression that the village was especially poor, we also gave a rasp to the village community. Our presents were always well received and helped to build a mutually beneficial relationship with the village communities. Middle) In each village, we interacted more with some individuals than with others. We therefore also brought along a stock of cigarettes and Cola nuts as little giveaways for smokers and adepts of Cola nuts. For some individuals who really helped us a lot, we also had watches. Those watches were however only given after careful considerations, as they represented a precious gift. Right) With the aim to increase the participations of the villagers to our survey, we brought along salt and promised a remuneration of 1 kg of salt for every household participating in our survey (chapter 8). The whole salt, approximately 900 kg, took plenty of precious room in our car.

6.1.3 Conducting the field work

The twofold objective of my field work was: on the one hand, I focused on gathering information on the locations and the names of all villages and settlements, the roads, the trails and the fields in the area. This information was then combined with topography, hydrology, as well as information about the vegetation. In this way, a precise and informative map of the area was created. On the other hand, I also focused on gathering information on the demography, the cultural practices and beliefs, as well as the economic activities of the local population.It was essential for the success

of my scientific work to be able to gather reliable information on a wide range of topics, crucial for being able to put my theoretical predictions (table 13) to a sound empirical test.
We started the field work in the central, most important village of the area. This village was Gagnakaly, and we were advised to go there by the governor of the prefecture of Dinguiraye. The aim was to interview as many people in as many villages as possible. While the assistants were interviewing the people, I was following local guides through the area to take track logs of the village boundaries, the boundaries of the fields of the villages, the trails and the roads in the area. We proceeded like that from one village to the next one, and when on some occasions, it was not possible to reach a village by car, we had to walk. We were well received in every village, and we were always provided with a hut to stay by the community, and a woman to cook for us. During the whole field work, we lived in the villages where we worked (figure 33).

Figure 33: Daily life.
Top left) Traore, Lamine, Ousmane and me with the chief and his close relatives of a village. Top right) One of the many huts in which we stayed. These huts were useful for charging the powerbank placed in the shade, while the panel was sun-exposed during the whole day. Bottom left) In the evening, Traore, Lamine, Ousmane and me shared our meal. Here, me and Lamine. Bottom right) When I had a day off from taking track-logs, I entered the data collected on the spot. In this way, I was always busy.

Mapping the area In order to map the area, we depended on the help of the local communities. The village communities selected my guides, and we discussed the work to be done (figure 34).

Figure 34: Mapping the area.

Top left) The local people in the study area had a good knowledge of their environment. However, the only map of the area we could find was misleading, as the relations between the rivers and the villages on the map were partly incorrect. Top middle) The villages in the area were inaccessible and sometimes entirely in the woods. 14 of the 69 villages where we conducted our work were not accessible by car. Top right) A guide showing me a field. We walked along the boundaries of all main fields of the villages. Bottom left) Whenever possible, we used a motorbike to take the track logs of roads or trails. Crossing a river was always a hurdle and sometimes only possible with a boat, as there were no bridges in the area. Bottom middle) Crossing a river by foot was also not always easy. Sometimes a fallen tree worked as a bridge for pedestrians. Bottom right) A guide showing me the trail used to reach a neighbouring village. The guides showed me all trails and roads leading away from their villages. In this way, we walked up to 60 km daily. I walked a total of about 2500 km to collect all these track logs. The guides received an average remuneration of 1 Euro per hour as well as cigarettes and Cola nuts.

Studying the population When studying the human population living in the study area, I was mainly interested in aspects related to the demography (figure 35), the structure (figure 36), the beliefs (figure 37), and the economic activities (agriculture (figure 38), cattle-breeding (figure 39), fruit-growing (figure 40), hunting (figure 41), gathering (figure 42), fishing (figure 43), mining, and working migration (figure 44)). I tried to record and quantify all these different aspects with standardized quantitative interviews conducted by the assistants with the population of the study area. All interviews were first conducted with the family fathers of the village communities. Then, if they agreed to, we also interviewed as many other members of the households as possible and necessary. For example, when a household was cultivating rice, we were also interested in interviewing the members of the household responsible for the cultivation of the rice. In total, we were able to interview about 86% of the households (10,463 people) living in the area (figure 45).

Figure 35: Demography.
The village communities in the study area are composed of extended families made up of family fathers with their wives (up to 4 wives), their relatives and their children. Left) The families of the chief of a village (sitting third from right in the first row) and his brother (standing on the left). Apart from Traore, Lamine and me (standing last row/behind) all other male individuals on this pictures are the two men's sons. The children are their children and the women are either their wives, their unmarried daughters or their mothers. Right) As a result of the large number of children in each household, the population of the study area is very young (median age of 14 years)

Figure 36: Structure.
Top left) In most villages, the people live in traditionally built huts and practice the same lifestyle.

Top right) The most common lifestyle is based on subsistence. Here, the top of the hut is used to store the millet from the last harvest. Every day, a share of this millet is used to make a soup. Bottom left) Some villagers, however, also produce a surplus to be sold. After the harvest, traders visit the villages to buy the people's harvest. Bottom right) Because of their economic activities, some villagers are able to build modern-fashioned houses. The presence of such houses among the traditional huts is an indication for economic inequality.

Figure 37: Beliefs.

The local population is strongly religious and practices a traditional Islam, combined with animistic beliefs. I was especially interested in the religious taboos related to the consumption of specific types of meat. Top) A man in front of the traditional mosque of his village. Bottom) A modern mosque in the middle of a village composed of traditional huts.

Figure 38: Agriculture.

The most important economic activity of the local population in the study area is agriculture (more specifically crop production). Top left) Slash and burn is used to produce crops mostly in the forests: prepared field where rice is starting to grow. We expected this practice to have a strong negative impact on the environment. Top right) In all villages, crops are also grown within the village boundaries: fresh maize growing within a village. Maize is one of the four most important crops in the study area. Middle left) Beside crop cultivation, women also produce vegetables in gardens located within the village. Middle right) The most important crop in the area are peanuts: peanut harvest drying on the soil. Bottom left) Millet is, besides peanut, the traditionally grown crop in the area: women during the millet harvest. Bottom right) Rice is another crop of major importance for the population in the study area: men during the rice harvest.

Figure 39: Cattle-breeding.

The second pillar of the local economy is cattle breeding. The local population has an intimate relationship with their animals and keeps them in close distance. Animals are sometimes held for private consumption, but mainly for ceremonial and financial purposes. Top left) Cows are the most important animals and one measure for the wealth of a man is the number of cows he owns: cows visiting my hut. Top right) Cows are also very important because of the milk they produce. Households owning enough cows are able to consume milk every day. Middle left) Sheep are omnipresent in all villages and mainly are held for ceremonial purposes. Most of them are slaughtered at Eid al-Adha: two sheep visiting me in my hut. Middle right) Also goats are omnipresent in all villages and have a similar economic value as sheep. They are however less important for the ceremonies. Bottom left) Chicken are the only animals that are consumed on a regular basis. Nearly every household owns chicken: a chicken family visiting me in my hut. Bottom right) A chicken breeding in my hut.

Figure 40: Fruit-growing.
Fruit trees are planted mainly within the villages. Plantations are very rare in the region, but begin to play a role for the local economy. Top left) Mango trees are crucial for the well-being of the population. These trees become huge and produce countless amounts of fruits. The fruits are ripe at the beginning of the wet-season. This is important, as the stock of crops from the last harvest is coming to an end or is already used up at this time of the year. If this is the case, mango is the only food available, when cattle or other precious reserves are not to be touched. Top right) Orange trees are also abundant in the region, but play a much less important role for the well-being of the locals than mango trees. Bottom left) Banana trees are grown in plantations, mainly for commercial purposes. Bottom right) Papayas, like a number of other fruit trees, are less frequent than the three mentioned before and are mainly planted for private consumption.

Figure 41: Hunting.

Hunting in the study area is practiced mostly for the sake of local meat consumption. Top left) Although most households own a gun, only a small fraction of them hunt on a regular or even professional basis. Top right) Besides hunting for meat consumption, hunters also keep the offspring of killed animals as pets. Here, a child with an infant monkey (Erythrocebus patas) Bottom left) As a consequence, the hunters in the area also supply the broader trade in pet animals. Here, a baby bushbuck. Bottom right) Also, the furs are of economic value. This picture shows a hunter's collection of bushbuck furs.

Figure 42: Gathering.

All households in the study area make use of gathered products. Wood, for example, is the only resource available for heating and is used on a daily basis. Everyone who needs wood just collects it in the forest. However, there are innumerable other products that local people gather in the study area. Some of them have an important economic value and are used for trade. Top left) The Vitellaria paradoxa trees are abundant in the study area and huge amounts of their fruits are collected. Top middle) The Vitellaria paradoxa tree fruits are used to make shea butter which is used for cooking and as an ingredient for beauty products. Top rigth) Parinari excelsa trees are also abundant in the area. Their fruits play an important role for the Guinean cuisine. Middle left) The fruits of the Parinari excelsa tree are used to produce a flavouring powder that is omnipresent in Guinea. Middle middle) Wild honey is frequently found in tree holes in the forest. In order to extract honey from a tree, a fire is laid around the tree, and then it is cut down to get out as much honey as possible. Middle right) Wild honey is used for private consumption, but is also sold on markets. Bottom left) The roofs of the traditional huts are made of grass. When the grass is high, it is gathered and stored. Bottom middle) The bark of trees is used to build ropes. Bottom right) These ropes are used in all kinds of construction works.

Figure 43: Fishing.
In all villages located close to rivers, some households practice fishing on a daily basis. Fishing is an important economic activity, as it provides the village communities with animal proteins. Top) The daily catch made by one fisher. Bottom) Lamin was very fond of fish, so whenever we had the opportunity, we bought some fresh fish.

Figure 44: Other activities.

In addition to the activities mentioned above, there are two more important economic activities practiced in the study area. Top left) A number of households trade with goods. For example, on special gatherings, they bring along industrial goods to sell them. Top right) Guinea is rich in gold and other minerals. People are searching for gold everywhere in the country: the trench of an illegal local mine. Bottom left) Women also search for gold, but have a different approach than males: surface mining is their way to search for gold. Bottom right) Finally, all families in the area are concerned with working migration. During the dry season, when there is no work in agriculture, around one quarter of the adult population of the study area leaves the area to work in the huge industrial mines or the cities of the country. This picture was taken on a Guinean road outside of the study area and shows how most Guineans travel through the country.

Figure 45: Interviews.
It was not always possible to realize a standardized interview situation during our field work. Whenever possible, face-to-face interviews were conducted in closed huts without the presence of others. The interviews were, however, sometimes also conducted outside with bystanders. We always started the interviews with the family father and, after he gave his approval, went on with interviewing other members of his household. Sometimes it took several days to finalize the interviews with one household: Traore conducting an interview under a mango tree.

6.2 Conclusion: field work

In this chapter, I have described the field work undertaken to collect observational data and information allowing to put my theoretical hypotheses (table 13) to an empirical test.
Based on the work presented in chapter 5, my data basis had to meet two requirements: first, observations needed to be made on a study population composed of individuals from different non-WEIRD cultural groups showing important variations in the social structure and in individual characteristics. My data clearly meets this first requirement: the study population was made up of Fulbe and Malinke small-scale societies. Fulbe and Malinke are the two most important ethnic groups found in Guinea who differ in important aspects: they have different conventions and customs, they speak different languages, they have distinct appearances and their antagonism has strongly shaped the history of Guinea. Although all studied village societies lived in the same

geographical area, they showed a substantial variation in key social, economic, and demographic factors. A second requirement for a sound empirical test of my theoretical hypotheses was the availability of information on a variety of factors that could potentially influence the outcomes of interest. As I was able to conduct extensive interviews with 86% of the households living in the area, my data base covers most aspects that are relevant for the two subjects of interest and therefore allows for sound empirical tests of my theoretical hypotheses (table 13).

In the next two chapters (chapters 7 and 8) I apply my general theoretical hypotheses to two specific situations, allowing for a test of their predictive values. In my observational study (chapter 7), I combined my empirical data with ecological data on the abundance of wild mammals in the study area. Considering wild mammals as a natural resource allowed to specify my general hypotheses accordingly and put them to an empirical test. In my experimental study (chapter 8), I link my empirical data to experimental data on a common pool resource game conducted in the study population. In this experiment, the common pool resource was allocated among the subjects involved in the experiment. Specifying my hypotheses accordingly, this allowed to test for their predictive value in explaining the fairness of the observed allocation.

Chapter 7

Observational study: sustainable natural resource use

In this chapter, I combine my empirical data with ecological data on the abundance of wild mammals to evaluate the impact of the local human population on the local wild mammal populations in the study area. Wild mammals are a natural resource which is used for multiple purposes by the local human population. My different general theoretical hypotheses regarding factors influencing the sustainability of natural resource use can therefore be reformulated in this context. This is a simple enterprise, where sustainability in natural resource use more or less corresponds to high abundance in wild mammals. In the introduction, I give a short summary of the rationale behind the scientific study and the institutional framework it was embedded in. In the methods, I describe my data and introduce the theoretical framework of Social Ecological Systems. I then reformulate my theoretical hypotheses to the specific situation of wild mammal conservation and describe the strategy used for the statistical analysis. In the results, I show the results of my hypotheses tests and discuss implications for the theoretical work on social dilemma, as well as for the conservation of wild mammals in the conclusion. This chapter mainly takes up a published study: L. Boesch, R. Mundry, H. S. Kühl and R. Berger, 2017, Wild mammals as economic goods and implications for their conservation, Ecology and Society, 22(4). Some parts were, however, adapted for the purpose of this work.

7.1 Introduction: observational study

7.1.1 Wild mammals as a natural resource and issues related to their conservation

Wildlife is an important natural resource for human societies (section 4.2). Wild mammals, as an integral part of wildlife, are also used by humans as a natural resource and can be seen as an economic good. Excludability and rivalry are the two fundamental properties of any economic good (table 2). Excludability refers to the restriction of access to the good, and rivalry refers to the divisibility of the consumption of the good among individuals (Musgrave and Musgrave 1989). According to these criteria, wild mammals can be classified as common goods in many regions of the world. Humans can gain economic value from wild mammals in three ways (Chardonnet et al. 2002). First, nutritious value is gained when humans exploit wild mammals in a direct consumptive way: wild mammals are an important source of meat for humans in many parts of the world, and demand for bushmeat has been identified as one factor driving wild mammals to extinction (Davies 2002; Milner-Gulland et al. 2003). Second, productive use value is gained when wild mammals are exploited in a direct nonconsumptive way. Examples for the productive use value of wild mammals are numerous, but trade certainly plays the most important role: wild mammals are an important source of income for humans in many parts of the world (Milner-Gulland et al. 2003), and the trade in wild mammals has been identified as a driver of the extinction of endangered wild mammal species (Madhusudan 2005; Milledge 2007; Nijman and Schepherd 2007; TRAFFIC 2008; Nijman 2010; Briceno-Linares et al. 2011). In the African context, the exploitation of wild mammals includes the whole range from rural consumption, based on subsistence, to purely commercial activities driven by the demand of international trade (Brashares et al. 2011). Third, even if they do not exploit wild mammals directly, humans can still gain indirect nonconsumptive use value from wild mammals. Examples of this value are bird-watching or safari tourism. Finally, wild mammals are an integral part of the ecosystem. Ecosystem functions in turn provide goods and services that are essential for the survival of people. This aspect is not commonly included in the economic value consideration as it is difficult to quantify (de Groot et al. 2002).

The properties inherent in common goods may lead to a social dilemma, where appropriators of the common good have the incentive to raise the exploitation of the common good without limit, thereby leading to its destruction (section 4.3.2). The assumption that the property of wild mammals as non-excludable can be altered has been the origin of deer parks in medieval Europe, where the king considered all deer as his private good (Birrell 1992). This assumption is one of the main paradigms of modern conservation policy, which has led to the implementation of strictly protected areas (Gardner et al. 2007), where wild mammals no longer represent an economic value. The success of protected areas in conserving wild mammal populations is, however, not guaranteed and depends on substantial efforts (Bruner et al. 2001; Craigie et al. 2010; Tranquilli et al. 2012; Tranquilli et al. 2014), thereby leading to the "mounting realization that protected areas are part of a complex social-ecological system characterized by flux, nonlinear relationships and unpredictable outcomes" (van Wilgen and Biggs 2011, p. 1179). Integrated conservation and development projects therefore suggest that the best way to protect wild mammals is to directly involve the local human population: through ownership, economic incentives, and participation, local people should benefit from conservation and support it (Campbell and Vainio-Mattila 2003). This approach is also termed "new conservation" and has been heavily criticized (Soulé 2013; Marvier and Kareiva 2014; Marvier 2014). A pragmatic approach to conservation therefore builds upon a flexible case-to-case approach, where the whole array of management tools are taken into consideration.

An understanding of wild mammal-human relationships and the consequences of human activities for the spatial distribution of animals is of major interest for conservation biology and policy because it allows understanding the relationships between the human population and wild mammals in an area of interest (Elith and Leathwick 2009; Iwamura et al. 2014; van Vliet et al. 2015). This is an important condition, first, for improving our understanding of social-ecological systems, and second, this understanding is essential for implementing viable conservation programs, since the fate of biodiversity, and especially wild mammals, is closely linked to human behaviour and activities (Chazdon et al. 2009; Brncic et al. 2015; Junker et al. 2015). Typically, the set of predictors for modelling species distribution does not include detailed socioeconomic information but only some measure of human population density as a proxy for human activity. Probably this is because spatial information about human population density is easily accessible and does not require the time-consuming collection of detailed spatial socioeconomic context information. However, this approach neglects the fact that some important characteristics of human populations are not represented by human density. For example, knowing that two areas have the same human population density does not tell us anything about the religious affiliation or the economic activities of the people living in those areas. Not taking account of those differences might lead to biased estimations. Analysing the relationship between wild mammals and humans within the framework of social-ecological systems can help determine the relevant set of predictors. Ostrom (2007; 2009) suggested a framework where social-ecological systems are made up of four subsystems: the resource system, the resource units, the users, and the governance systems. Although those subsystems are loosely separable, they interact to produce a common outcome at the social-ecological system level. When trying to model the relationship between different factors within a social-ecological system, the relevant factors from the four subsystems should therefore be determined and incorporated as predictors into the model. We used a region in the Republic of Guinea as an example to estimate the influence of humans on wild mammal abundance. We compared the predictive value of human population density and other socioeconomic factors on wild mammal abundance. We incorporated the concepts discussed so far into a social-ecological system framework, as suggested by Ostrom (2007; 2009), to derive the relevant factors for our model. This approach also allows to test predictions of Hobbes, Rousseau and Smith applied to the conservation of wild mammals. Finally, we consider how our socioeconomic approach could be used to increase our understanding of wild mammal-human relationships in other regions.

7.1.2 The offset project implemented by the Wild chimpanzee foundation in Guinea

The Republic of Guinea (figure 46 A), located in Western Africa, covers an area of 245,720 km2 (World Bank 2016*c*). Although its mammal fauna is not well-studied, Guinea is believed to have the highest diversity of large mammals in the West African forests on a species per area basis (Barnett and Prangley 1997). Results from a first nationwide chimpanzee survey, conducted from 1996 to 1997, suggested that Guinea was also home to about 18,000 chimpanzees (95% confidence limits: 8113–29,011), the largest countrywide population of chimpanzees in West Africa (Ham 1998). A second large-scale chimpanzee survey conducted by the Wild Chimpanzee Foundation (WCF) in 2012 confirmed such a large chimpanzee population (Regnaut and Boesch 2012). On the other hand, Guinea is one of the poorest and least developed countries in the world. In 2011, Guinea ranked 178 of 187 in the World Development Indicator (United Nations Development Programme 2016), with a yearly per capita income of US$447.8 and a life expectancy of 57 years (World Bank 2016*b*; World Bank 2016*d*). The Guinean economy relies on extractive activities. It has an important mining sector with potential access to one-third of the world's highest grade bauxite deposits, one untouched high-grade iron ore deposit, and gold, diamonds, platinum, cobalt, nickel, silver, uranium, lead, and zinc (Campbell and Clapp 1995). In 2011, Guinea had mineral rents worth 15.8% of its gross domestic product (GDP) and forest rents worth 13.4% of its GDP (World Bank 2016*e*; World Bank 2016*a*). While 35% of the Guinean population lived in urban areas in 2011 (World Bank 2016*g*), the rural population relies on ecosystem services for its survival (Laakso and Tyynela 2006) and practices a slash-and-burn agriculture. Since "the current level of extraction is low compared to the potential indicated by the resource value on the ground" (World Economic Forum 2011, p. 28), extractive economic activities are believed to further increase. Furthermore, population growth was continuously greater than 2% from 2004 to 2014 (World Bank 2016*f*). Past population growth led to a decrease in the fallow period from traditionally 17 years to 8 years (Sirois et al. 1998). Concerns are high that population and economic growth will have a negative effect on the Guinean wild mammal populations, if no appropriate measures are taken. In 2014, 15.4% of the world's terrestrial area was classified as protected area (Juffe-Bignoli et al. 2014). In Guinea, there were 124 resource management and protected areas covering 30% of the country's terrestrial area (Protected Planet 2016). Of these, 98 were classified forests (CFs). These are forests that have been classified by the Guinean state as being of national interest. The exploitation of environmental goods in CFs is regulated in a way as to find an equilibrium between the socioeconomic needs of the local population and the interests of conserving the environment (Ministère de l'agriculture et des ressources animales de la République de Guinée 1999). Only five Guinean protected areas (Kankan Faunal Reserve [IUCN category IV], Mont Nimba Strict Nature Reserve [IUCN category I], Badiar National Park [IUCN category II], Haut Niger National Park [IUCN category II], and Blanche Island Faunal Reserve [IUCN category IV]) were dedicated to the protection of biodiversity. These five protected areas cover 7050 km2 (2.9%) of Guinea's terrestrial area, including three of five Guinean ecoregions. Furthermore, not all globally threatened mammals that occur in Guinea are found in these five protected area. These findings highlight the need to increase the number of protected areas that are dedicated to the protection of biodiversity in Guinea (Brugiere and Kormos 2009). In an effort to create a new national park in the region, the WCF cooperates with the Guinean government, the International Finance Corporation (IFC), and the mining companies Compagnie des Bauxites de Guinée and Global Aluminum Corporation, in order to implement a biodiversity offset project in Guinea. The WCF is a nongovernmental organization with the mission "to enhance the survival of the remaining wild chimpanzee populations and their habitat, in West Africa" (Wild Chimpanzee Foundation 2018). The WCF offset project aims at achieving conservation outcomes from offset programs of the involved mining companies' activities, according to IFC standards (International Finance Corporation 2012), through the creation of a new national park in Guinea (Wild Chimpanzee Foundation 2015). The location of this future national park was selected according to abundance data based on the Guinean WCF Chimpanzee Inventory 2012, as well as feasibility criteria (Regnaut and Boesch 2012). The park is located close to the border of Mali, between the Labe-, the Mamou-, and the Faranah regions, and comprises an already existing network of CFs (figure 46 A).

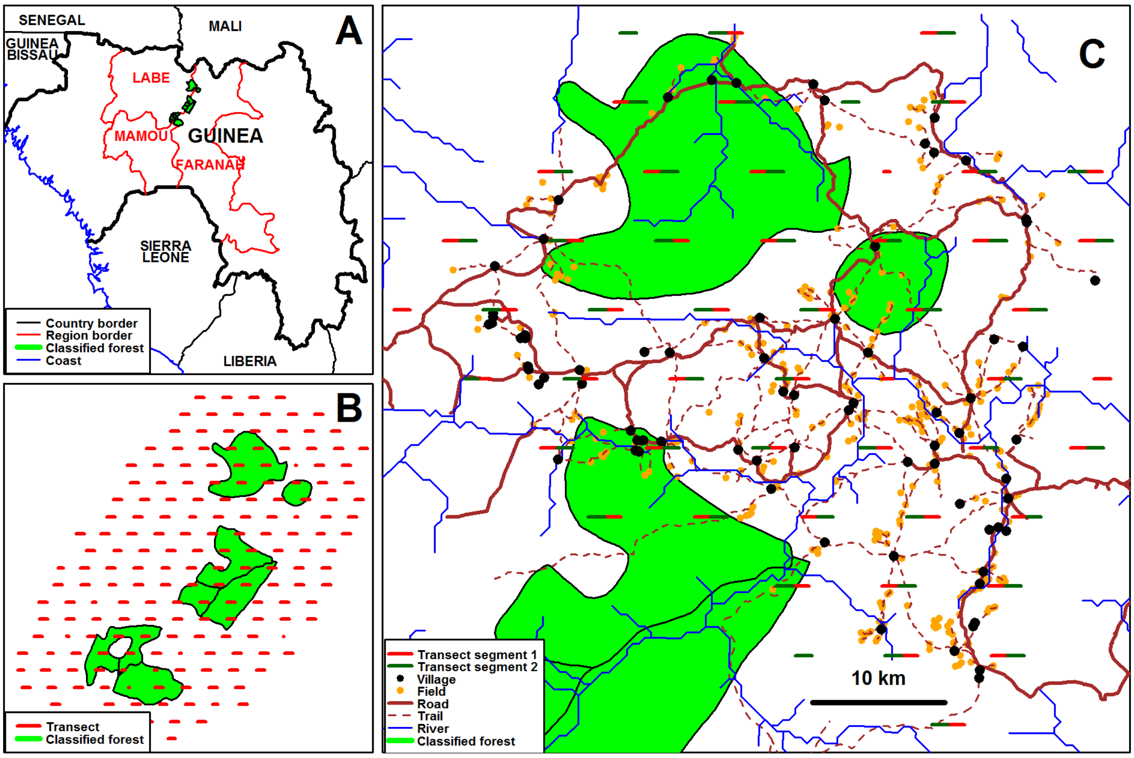

Figure 46: Guinea, study region and study area.
(A) Guinea and the broader study region. (B) Transects of the Wild Chimpanzee Foundation biomonitoring project located within a classified forests network in the study region. (C) Study area with the transect segments and the locations of the villages, fields, rivers, roads, and trails.

7.2 Methods: observational study

7.2.1 Study area, sampling, and field data collection

In 2013 and 2014, data on wild mammals and the human population were collected in the region where the WCF offset project is located to gain a better understanding of the wild mammals, the human population, and human activities in the region (chapter 6). From October 2013 to March 2014, two WCF biomonitoring teams recorded signs and sightings of wild mammals on 184 line transects according to IUCN standards (Kuehl et al. 2009), using a systematic design (systematically segmented track line sampling) and distance sampling methodology (Buckland et al. 2001; Thomas et al. 2010). Transect length was 2.5 km, and spacing between transects was 5.5 km. Total effort was 462.5 km (185 transects), covering 8153 km2. This was the WCF biomonitoring project area (figure 46 B). From April 2013 to June 2014, one sociological team, consisting of four people and headed by L. B., collected socioeconomic and infrastructure data in the same area. The sociological team focused its effort on a part of the WCF biomonitoring project area. This area is referred to as the study area, and all further details on data and results refer to it. The study area comprised 52 transects and 69 villages (figure 46 C). The transects were selected according to the following criteria: they had to be partly located either within a 5 km range of fields or villages, or they had to be within an area surrounded by villages. We conducted detailed face-to-face interviews with the household heads of the village population and, if necessary and feasible, several other members of the households. The interviews focused on demography, economic practices, values, and beliefs related to the environment (see questionnaire in the appendix). Furthermore, we took GPS track logs of the locations of the villages, their important fields, the trails, and the roads in the study area.

7.2.2 The theoretical model

Applying the basic concepts briefly described in the introduction to the situation in the study area enabled us to formulate hypotheses regarding the influence of the local human population on the wild mammals in the study area. Our underlying assumption was that the local population did not gain an indirect use value from wild mammals. This assumption was based on our knowledge of the situation on site. We considered only the value which the local population could deduce by exploiting wild mammals. Furthermore, we did not consider the relevance of wild mammals for other stakeholders or the ecosystem. Using the social-ecological system framework suggested by Ostrom (2007; 2009), we defined the situation and the relevant factors as follows. The outcome of interest was wild mammal abundance. The resource unit system was made up of mobile wild mammals. The resource system consisted of the habitat where the wild mammals live. We expected the suitability of the habitat for wild mammals to depend on the habitat type (Tews et al. 2004; Guisan and Thuiller 2005), its access to water (Western 1975; Redfern et al. 2003; DeGama-Blanchet and Fedigan 2006; Chammaillé-Jammes et al. 2007), its accessibility (Malcolm and Ray 2000; Develey and Stouffer 2001; Laurance et al. 2006), and its destruction rate (Tilmann et al. 1994; Pimm and Raven 2000). The user system was made up of the local population living in the study area. We expected the local population to use wild mammals as a source of meat for private consumption (Davies 2002; Milner-Gulland et al. 2003; Brashares et al. 2011) and a source of income (Milner-Gulland et al. 2003; Madhusudan 2005; Milledge 2007; Nijman and Schepherd 2007; TRAFFIC 2008; Nijman 2010; Briceno-Linares et al. 2011; Brashares et al. 2011). The dependency of the local population on wild mammals depends on viable alternatives (Bennett 2002; Milner-Gulland et al. 2003; Brashares et al. 2011; Junker et al. 2015), which are provided through access to the market, as well as fishing activities. Whether the population will use wild mammals is further influenced by normative prescriptions about the appropriateness of consuming specific kinds of wild animal meat (McDonald 1977; Balée 1985; Pezzuti et al. 2010; Read et al. 2010; Luzar et al. 2012). While the whole population uses wild mammals and can exploit them, only a fraction of the population consists of professional appropriators (hunters) who are specialized in harvesting wild mammals. They depend on the demand of the local population and the access to the market in order to be able to earn money. The hunters may have special normative prescriptions related to the killing of wild mammal species (McDonald 1977; Balée 1985; Pezzuti et al. 2010; Read et al. 2010), but we assumed that their hunting activities are based essentially on the demand from the local population and the market. The governance system is shaped by the limited influence of the central government, which is restricted to the CFs. Those are under government control, while the rest of the area is divided among the different village communities and is managed by them through customary rules (table 20).

7.2.3 Wildlife conservation from the perspective of Hobbes, Rousseau and Smith

Although it dos not seem obvious at first sight, the work of Hobbes, Rousseau and Smith (chapter 2) can help to gain insight about the way humans exploit wild mammals and about useful mechanisms for their conservation. In this section, predictions related to the effect of the human population on wild mammal abundance in the study area are elabourated.

Land ownership in the study area was determined according to customary and state law. Each village community owned a part of the area and the exploitation of wild mammals within these areas was regulated through customary rules. The CFs were owned by the state and the sustainable exploitation of wild mammals in the CFs was regulated through state law (Ministère de l'agriculture et des ressources animales de la République de Guinée 1999). Strictly speaking, the wild mammals in the study were therefore no common good any more: two of the main institutional solutions to the tragedy of the commons, the state property- and the communal property regimes were already implemented (section 4.3.2). While it generally seems that there was a broad consensus on the ownership of the land, some parts of the area were subject to conflicting land ownership claims (figure 47).

The empirical evidence regarding the success of the two types of property regimes in protecting wild mammals from overexploitation is contradicting (Bruner et al. 2001; Campbell and Vainio-Mattila 2003; Craigie et al. 2010; Tranquilli et al. 2012; Soulé 2013; Marvier 2014; Marvier and Kareiva 2014; Tranquilli et al. 2014; Jones et al. 2018). From a philosophical perspective, we find arguments supporting both regimes one over the other. Following Hobbes (section 2.1), the communal property regime should not be strong enough to solve the tragedy of the commons. Communal property means that all members of the community have at least some access to wild mammals and are not controlled by any external authority to restrict their use. This is due to the lack of the Leviathan, i.e. lack of a state authority (Hobbes 2012 [1651], p. 89). Therefore, selfish and greedy individuals can still overexploit wild mammals. This outcome can only be avoided with a Leviathan regulating its sustainable use in a state property regime. As a consequence, we would expect wild mammal abundance to be higher under state property regimes, than under communal property regimes. Following Rousseau (section 2.2), laws and rules only have a lasting influence on the behaviour of individuals if they coincide with their norms (Rousseau 1966 [1762], p. 90). This condition is more likely to be met in small communities, than in a large state. Therefore, the communal property regime should be more effective at exploiting wild mammals sustainably, than the state property regime. As a consequence, wild mammal abundance should be higher under communal property regimes than under state property regimes.

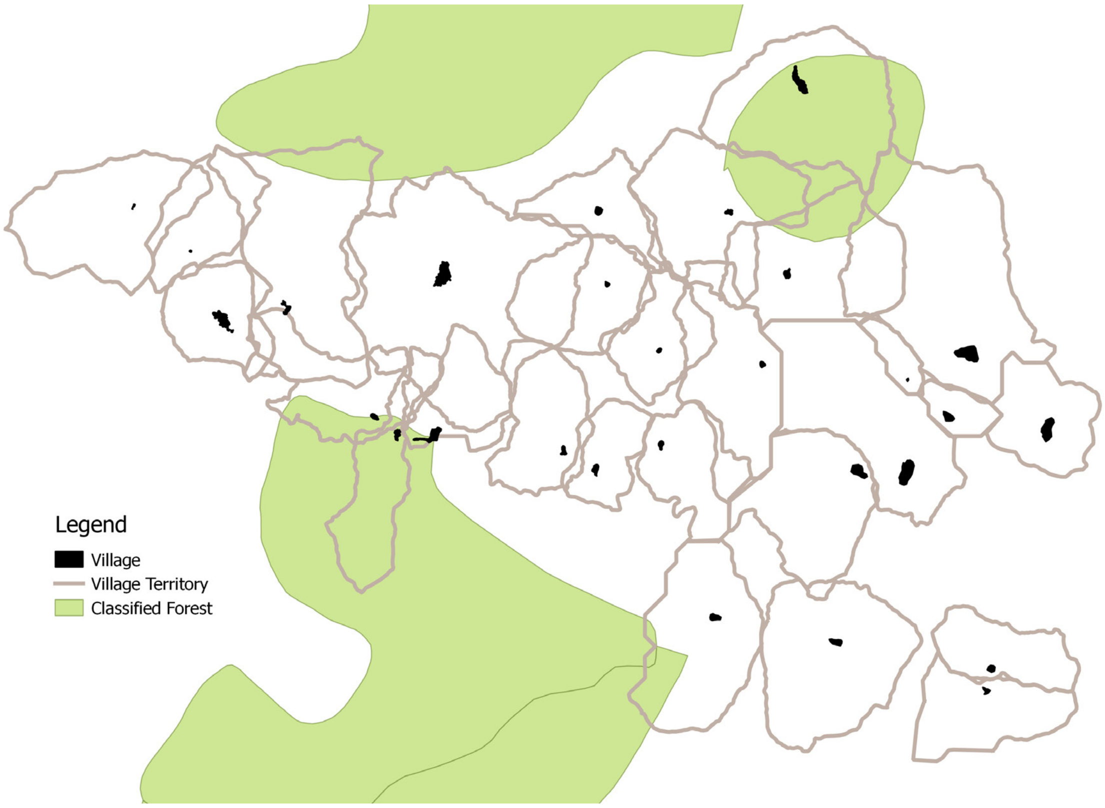

Figure 47: Land ownership in the study area.
The figure shows the 28 villages located in the centre of the study area (figure 46 C), the borders of their land and the CFs

In his work, Rousseau strongly argued for the necessity to govern with the help of normative rules (section 2.2). As a reminder, Binmore qualified Rousseau's project concerning the moral education of people as "brainwashing" (1994, p. 135). It follows that the most effective laws for the conservation of wild mammals should be laws coinciding perfectly with normative rules. The effectiveness of normative rules for the conservation of wild mammals has been shown in previous studies, where rules prohibiting the consumption of certain types of meat had a positive effect on the abundance of these animals (McDonald 1977; Balée 1985; Pezzuti et al. 2010; Read et al. 2010; Luzar et al. 2012). Similarly, we would expect wild mammals targeted by food taboos in the study area to be more abundant than wild mammals not targeted by such taboos.
In his work, Smith promoted an economic development of human societies with the goal to maximize the wealth and the freedom of humans, thereby naturally enforcing the natural rights of man. He believed that the means for this development would be the division of labour and the free market. By maximizing the extent of the free market, the wealth of societies and the freedom of individuals would be maximized (section 2.3). We have seen that increases in wealth come along with an increased exploitation of natural resources (section 4.1). As a consequence, we would expect the exploitation of natural resources to increase as the market extends. This is clearly in line of what Smith had in mind:

> "A particular country [...] may frequently not have capital sufficient both to improve and cultivate all its lands, to manufacture and prepare their whole rude produce for

> immediate use and consumption, and to transport the surplus part either of the rude or manufactured produce to those distant markets where it can be exchanged for something for which there is a demand at home." (Smith, 1993 [1776], p. 219)

Consequently, wild mammal abundance should decrease with increasing market extent (table 20).

Table 20: Predictions, mechanisms, variables, and sources of data.

Hypothesis	Theoretical mechanism	Variable and operationalization	Source of data
Smith: The higher the extent of the market, the lower the wild mammal abundance.	Wild mammals are an important source of income for people living in rural areas of economically developing countries when they dispose of the means to exploit them economically (Davies 2002; Milner-Gulland et al. 2003; Brashares et al. 2011). Humans can exploit wild mammals in a direct non-consumptive way if they are able to sell their products (Chardonnet et al. 2002). The opportunities of people to exploit wild mammals economically should increase with an expansion of the market, decreasing the wild mammal abundance.	Market extent: Mean monthly trips to markets of the village population; aggregated at transect segment level §.	Socioeconomic survey††; WCF transect data†.

Rousseau: The higher the number of people abiding to a food taboo targeting a specific wild mammal species, the higher the abundance of this specific wild mammal species.	Food taboos prohibit individuals to demand for the nutritious value of wild mammals targeted by the taboo. Food taboos reduce the exploitation of species targeted by the taboo (McDonald 1977; Balée 1985; Pezzuti et al. 2010; Read et al. 2010; Luzar et al. 2012,). Food taboos are prevalent in the population of the study area, and we expect species targeted by food taboos to be more abundant than species not targeted by food taboos.	Taboo influence: Number of household heads of a village abiding to a specific food taboo norm; aggregated at transect segment level §.	Socioeconomic survey††; WCF transect data†.
Hobbes: Wild mammal abundance is higher in CFs than in the rest of the study area	The property rights of land influences the access people have to the resources on the land (Hardin 1968; Musgrave and Musgrave 1989; Gardner et al. 1990; Ostrom 1990). The state property regime is one institutional solution to the overexploitation of resources (Feeny et al. 1990).The sustainable exploitation of wild mammals in CFs is controlled by the state (Ministère de l'agriculture et des ressources animales de la République de Guinée 1999) in the CFs. The state, as an external authority can enforce these rules, while on community land, overexploitation of wild mammals cannot be hindered.	Share classified forests: Proportion of transect segment located inside CFs.	World database on protected areas‡; WCF transect data†.

Rousseau: Wild mammal abundance is higher in areas under communal property regimes than in CFS	The property rights of land influences the access people have to the resources on the land (Hardin 1968; Musgrave and Musgrave 1989; Gardner et al. 1990; Ostrom 1990). The communal property regime is one institutional solution to the overexploitation of resources (Feeny et al. 1990). Rules only have a lasting effect when they coincide with the norms of the people. As this is more likely to be the case in small communities than in a large state, overexploitation of wild mammals is more likely to be avoided on communal land than in the CFs.	Share classified forests: Proportion of transect segment located inside CFs.	World database on protected areas‡; WCF transect data†.
Control			
C1) Supply of the local human population with fish.	Fish is an alternative source of animal proteins to wild mammals (Milner-Gulland et al. 2003; Junker et al. 2015).	Fish supply: Number of fishers living in a village; aggregated at transect segment level §.	Socioeconomic survey††; WCF transect data†.
C2) Hunting pressure.	Hunters are the professional appropriators of wild mammals and especially dependent on the exploitation of wild mammals for their survival (Hardin 1968; Gardner et al. 1990).	Hunting pressure: Number of hunters living in a village; aggregated at transect segment level §.	Socioeconomic survey††; WCF transect data†.

C3) Human population density.	Wild mammals are an important source of meat for people living in rural areas of economically developing countries (Davies 2002; Milner-Gulland et al. 2003; Brashares et al. 2011). Humans can use wild mammals as a source of food when they exploit them directly (they may also exploit them for fur, medicine, etc.) (Chardonnet et al. 2002). The people living in our study area belong to the category of people living in rural areas of economically developing countries.	Population density: Number of people living in a village; aggregated at transect segment level §.	Socioeconomic survey††; WCF transect data†.
C4) Habitat type.	Wild mammals need specific types of habitat to thrive and prosper (Tews et al. 2004; Guisan and Thuiller 2005).	NDVI¶: Calculated using satellite data of the study area. Vegetation characterizes the structure of the habitat (Tews et al. 2004) and NDVI values correlate with different habitat types (Holben 1986).	RapidEye satellite data#
C5) Habitat destruction.	The destruction of the habitat influences the distribution of wild mammals (Tilmann et al. 1994; Pimm and Raven 2000). Crop cultivation is the main habitat destructing activity in the study area and should therefore influence wild mammal abundance.	Distance to nearest field: Shortest Euclidian distance between transect segment mid-point and any field.	Track logs from socioeconomic survey††; WCF transect data†.

C6) Access to water.	Wild mammals need access to water to thrive and prosper (Western 1975; Redfern et al. 2003; DeGama-Blanchet and Fedigan 2006; Chammaillé-Jammes et al. 2007)	Distance to nearest river: Shortest Euclidian distance between transect segment mid-point and any river.	Spatial hydrology layer‖; WCF transect data†.
C7) Accessibility.	The access to wild mammals influences their abundance (Malcolm and Ray 2000; Develey and Stouffer 2001; Laurance et al. 2006). We expect the access to wild mammals to be easier in proximity to roads.	Distance to nearest road: Shortest Euclidian distance between transect segment mid-point and any road.	Track logs from socioeconomic survey††; WCF transect data†.

†) The transect data are available through the International Union for Conservation of Nature (IUCN) Species Survival Commision (SSC) A.P.E.S. Database (http://apes.eva.mpg.de). ‡) The world database on protected area is available through the IUCN and the United Nations Environment Project (UNEP) (www.protectedplanet.net). §) See text and figure 3 for the process of aggregation. ‖) The spatial hydrology layer was provided by the WCF. The layer represents the streams having water all year round in the study area. ¶) Normalized Differenced Vegetation Index #) Information on the level 3A products we used can be found on the following site: http://web-dev.rapideye.de/rapideye/all-products/ortho.htm ††) The survey was conducted for this study

7.2.4 Analytical methods

Processing of line transect data We aggregated the transect sighting raw data in the following way: first, transects longer than 1600 m were split into two equally long segments to account for potential local-scale variation in mammal distribution and the predictor variables (although all transects were designed with a length of 2500 m, it was not always feasible to pass through their entire length. This is why the mean length of the "empirical" transects was 2365 m and nine were shorter than 1600 m). Second, sighting types were classified as ephemeral (direct observation and vocalization) or long-lasting (faeces, trace, activity, and nest), and were summed up accordingly. Then, per species, we kept only the more common, ephemeral, or longlasting sightings, and finally considered only species with sightings that occurred on at least 10 transect segments (Brncic et al. 2015). This was our proxy for abundance. Finally, we further excluded species lacking information about home range sizes since we needed this information for the habitat type control variable (tables 20 and 21, figure 48).

Table 21: Raw sighting type records, by species and their respective aggregated abundance.

Species	Faeces (long lasting)	Trace (long lasting)	Nest (long lasting)	Observation (ephemeral)	Activity† (long lasting)	Vocalization (ephemeral)	Abundance
Cane rat (*Thryonomys gregorianus*)	9	3	0	0	0	0	Not included
African buffalo (*Syncerus caffer*)	10	0	0	0	0	0	Not included
Hippopotamus (*Hippopotamus amphibius*)	1	3	0	0	0	1	Not included
Otter (*Aonyx capensis or Hydrictis maculicollis*)	1	0	0	0	0	0	Not included
Red river hog *(Potamochoerus porcus*)	3	0	0	0	0	0	Not included
Green monkey (*Chlorocebus sabaeus*)	0	0	0	3	0	2	Not included
Mongoose‡ (*Herpestidae*)	0	1	0	1	0	0	Not included
Common genet (*Genetta genetta*)	14	0	0	0	0	0	14
African civet (*Civettictis civetta*)	25	0	0	1	0	0	25
Bushbuck (*Tragelaphus scriptus*)	20	8	0	1	0	0	28
Duiker (*Cephalophus spp.*)	28	1	0	0	0	0	29

Jackal (*Canis adustus*)	32	0	0	1	0	0	32
Crested porcupine (*Hystrix cristata*)	6	37	0	0	0	0	43
Patas monkey (*Erythrocebus patas*)	80	0	0	4	0	0	80
Scrub hare (*Lepus microtis*)	116	0	0	4	0	0	116
Guinea baboon (*Papio papio*)	125	104	0	5	0	8	229
Common wart hog (*Phacochoerus africanus*)	307	286	0	6	0	0	593
Chimpanzee (*Pan troglodytes*)	14	0	994	1	35	2	1043

†*Long-lasting signs of wild mammals others than faeces, traces, or nests, usually resulting from food activities.*
‡*Mongooses were not determined at the species or genus level; therefore, only the family name is given here.*

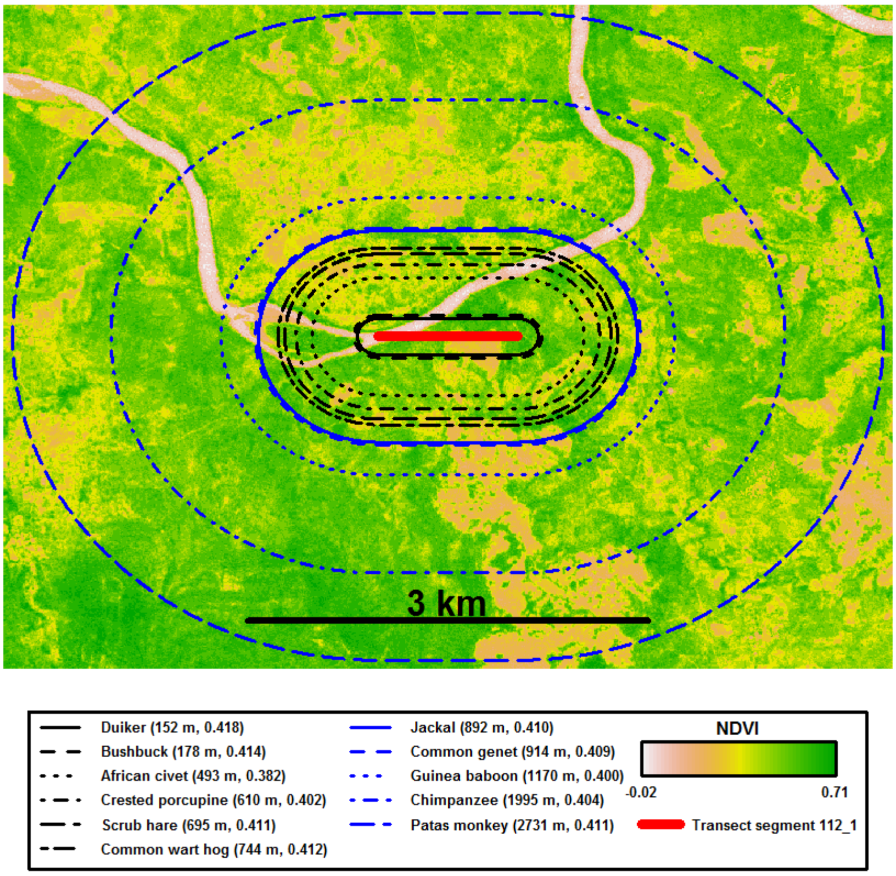

Figure 48: Pixel Normalized Differenced Vegetation Index (NDVI) values of a landscape surrounding an example transect segment (112_1) and the 11 home range polygons constructed around this transect segment.

The shortest distance from the polygon edge to the transect segment (this distance is the same for every location on the edge of the polygon) as well as the mean NDVI values of the pixels located within the home range polygons are shown in parentheses for each species. We obtained home range information from the following sources: duiker: Estes 1991; bushbuck: Estes 1991; African civet: Ayalew et al. 2013; porcupine: Mori et al. 2014; hare: Wildpro 2016; wart hog: Estes 1991; jackal: Estes 1991; common genet: Estes 1991; Guinea baboon: Patzelt 2013; chimpanzee: Estes 1991; patas monkey: PrimateInfo 2016.

Determination of predictor variables We interviewed 1389 households (86% of all village households) with a total of 10,463 individuals. We recorded the number of individuals living in households and summed all individuals of all households per village to derive village population sizes. Most villages had approximately 230 inhabitants, but there was a large variation in population size. In order to assess whether our village population sizes were trustworthy, we also counted the number of buildings in all villages and controlled whether the village population size correlated with the number of buildings in villages. The Pearson correlation between the number of buildings and the population sizes of the villages was 0.97, which suggested that the population size was indeed trustworthy. We measured the market integration of the village populations by recording monthly shopping trips of individuals and calculating the mean monthly trips to markets of each village population. The mean number of monthly trips to markets of the village populations ranged from 0 to 10.75. We recorded the number of hunters living in a village and summed them at the village level. Forty-three percent of all households possessed a hunting rifle; 17% of them hunted regularly. Overall, 15 households had commercial hunters, who hunted nearly every day. The most frequently hunted animals, in decreasing order, were scrub hare, duiker, cane rat, and bushbuck. An average hunter shot 1.56 duikers per month, whereas the best shot 20. Approximately 193 duikers were shot monthly by the people who were interviewed in the study area. We recorded the number of fishers living in a village and summed them at the village level. Eleven percent of all households fished regularly, and 45 households fished nearly every day. For each village, we recorded the number of household heads who abided to food taboo norms that forbid eating certain wild mammal species, and summed them at the village level. The population in the study area was strongly religious, and animistic beliefs survived side-by-side with the Muslim religion. Species targeted with food taboos were chimpanzees, common wart hogs, Guinea baboons, and patas monkeys. Household heads' food taboo abidance ranged from 0 to 100% per village (tables 20 and 22).

Table 22: Summary statistics of variables.

Variable	Mean	Standard deviation	Minimum	Maximum
Village: Population size	213	174	8	867
Transect segment: Population density	1667.194	720.520	354.100	3223.866
Village: Mean monthly trips to markets	3	2.9	0	10.7
Transect segment: Market integration	23.395	16.225	1.081	59.346
Village: Number of fishers	2.655	3.795	0	18
Transect segment: Fish supply	21.803	13.570	1.963	55.172
Village: Number of hunters	4.121	2.791	0	11
Transect segment: Hunting pressure	32.597	12.650	9.005	58.884
Village: Number of household heads not eating chimpanzees	11.034	10.299	0	44

Transect segment: Taboo influence	87.019	41.023	17.530	182.621
Village: Number of household heads not eating wart hogs	6.603	7.014	0	26
Transect segment: Taboo influence	52.080	24.458	10.551	113.196
Village: Number of household heads not eating Guinea baboons	6.414	7.260	0	28
Transect segment: Taboo influence	50.209	23.429	10.332	107.537
Village: Number of household heads not eating patas monkeys	6.414	7.260	0	28
Transect segment: Taboo influence	50.209	23.429	10.332	107.537
Transect segment: Share classified forest	0.22	0.39	0	1
Transect segment: Distance nearest road (in m)	2742	2146	6	9401
Transect segment: Distance nearest river (in m)	1979	1299	8	5020
Transect segment: Distance nearest field (in m)	2091	1525	93	6609
Transect segment: NDVI	0.50	0.08	0.18	0.69

Determination of control variables The studied human population practiced slash-and-burn crop cultivation. The most important crops were rice and peanut. Both were cultivated by approximately 95% of all households during the 2013 growing season. During this season, households harvested an average of 191 kg of rice, with a maximum of 3 tons, and an average of 602.6 kg of peanuts, with a maximum of 6 tons. Other important crops were manioc, millet, and beans. Human-wildlife conflicts were very common because wild mammals and humans competed for the crops in the fields. Ninety-five percent of all households were troubled by wild mammals in their fields, and they all took retaliatory measures when wild mammals entered their fields. We took crop cultivation as a proxy for habitat destruction, and computed the shortest Euclidian distance between transect segments' midpoints and any field. Access to water was calculated as the shortest Euclidian distance between transect segments' midpoints and any stream in the study area that had water year-round. Accessibility of the study area was very rudimentary; it was provided by a few dirt roads that were maintained by the local people, and rivers could be crossed only during the dry season (from November to June). We measured the accessibility of the transect segments as the shortest Euclidian distance between transect segments' midpoints and any road. Four CFs were located within the study area. For each transect segment, we determined its proportion that was located within a CF by using the World Database on Protected Areas layer (IUCN and UNEP 2016). On 1 and 2 December 2013, 13 RapidEye Level 3A tiles (Rapideye 2016) of the study area were acquired. We used those satellite images to calculate the Normalized Differenced Vegetation Index (NDVI). The NDVI has been successfully used to predict animal population size (Osborne et al. 2001; Oindo and Skidmore 2002; Zinner et al. 2002), and land cover types can consistently be stratified as a function of the NDVI (Holben 1986). We then extracted the mean NDVI within polygons around each transect. The shortest distance from each point on the edge of the polygons to the transect segment was equivalent to the home range radius for each species (table 20, table 22, figure 48).

Aggregation of predictor variables at transect segment levels All predictor variables were further aggregated at the transect segment level. For this process, we first computed the cost distance between all transect segment midpoints and all villages. The cost distance between two points is the path that links the two points with the least traveling effort. The effort was obtained by considering the slope and the distance between two points. We set the slope to 0 on terrain with a road or a trail, and otherwise set it to the steepness of the terrain. We used the costDistance function of the gdistance package in R (van Etten 2015; R Core Team 2016), a Shuttle Radar Topography Mission digital elevation model (Jarvis et al. 2008), our track logs of all roads, trails and villages, and the locations of the transect segments to compute the cost distance between all transect segments and villages. Our main assumption for the aggregation process, based on our experience in the field and other studies (N'Goran et al. 2012), was to define an activity radius of the local population of up to 25 km. This means we assumed that villagers living outside the 25 km radius of a transect segment had no influence on its wild mammals, and that the influence of villagers within the 25 km radius of a transect segment decreased with increasing cost distance to the transect segment. We constructed 25 km activity radii around all transect segment midpoints and selected all villages within the activity radii. The values of the predictor variables within the transect segment activity radii were then weighted with the respective inverse cost distance and then were summed up per transect (table 22, figure 49).

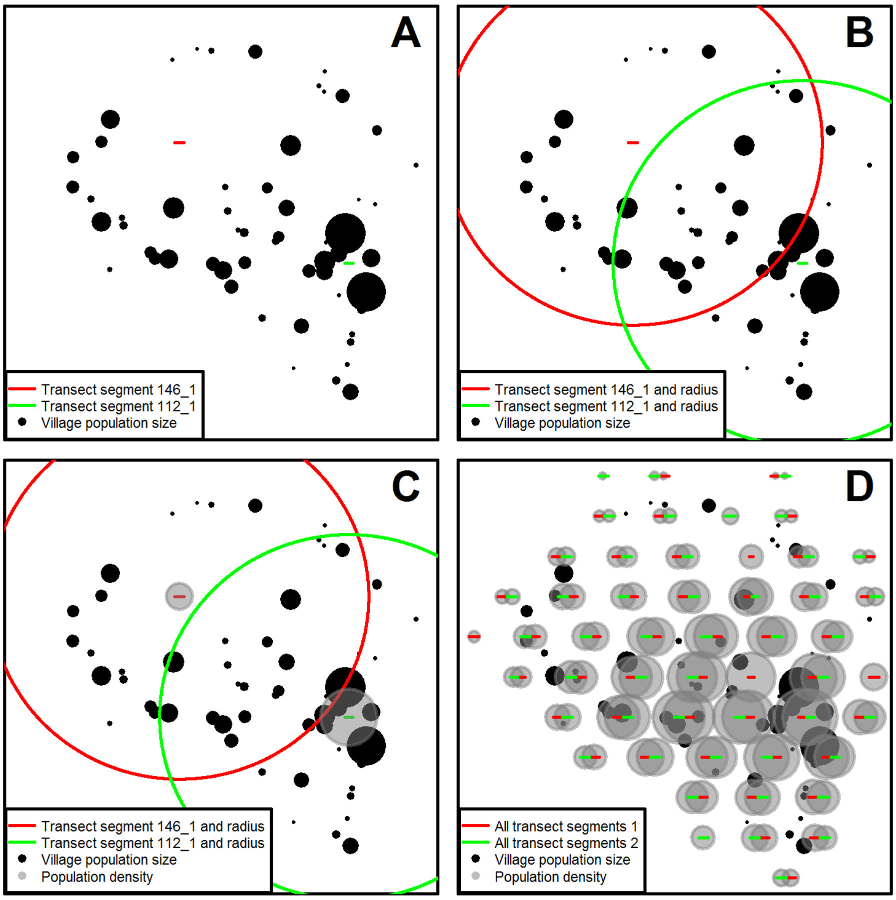

Figure 49: From village population size to transect segment population density.
(A) Population size is available only at the village level. The area of the black points shows the village population sizes. (B) Villages were assumed to have an influence on the respective transect segments when they fell within the respective 25 km action radius (red and green circle). (C) The population size figures of the villages that influenced the respective transect segments were weighted with the inverse cost distance to the respective transect segment and summed up, resulting in different population densities on the two transect segments, which are represented by the area of the grey points. (D) The result of the aggregation process of village population size, which resulted in population densities for each transect segment in the study area. We aggregated all predictor variables determined in villages in this way.

Model-building First, we identified all species with abundance data that followed approximately a Poisson distribution. This was the case for duiker, bushbuck, African civet, crested porcupine, scrub hare, common wart hog, jackal, common genet, Guinea baboon, and patas monkey. Chimpanzee abundance data, on the other hand, were highly overdispersed with an excess number of zeroes and some very high values. We built two data sets, the mixed species abundance data (938 cases) and the chimpanzee abundance data (97 cases). We used mixed effects Poisson regression models to estimate the influence of the human population on the mixed species abundance, and used zero inflated negative binomial regression models to estimate the influence of the human population on chimpanzee abundance (McCullagh and Nelder 1996; Baayen 2008). Because some of the correlations among predictors (population density, market integration, fish supply, hunting pressure, taboo influence) were very high (tables A2.1 and A2.2), we were not able to fit models that included all test and control predictors. Instead, we used multimodel inference (Burnham and Anderson 1998). Since the full model with all test and control predictors was characterized by large collinearity (maximum Variance Inflation Factor [VIF] 25.8) (Field 2005), we constructed the set of models in the following way: to begin with, we included a model that comprised the five control predictors only (share classified forests, distance nearest road, distance nearest river, distance nearest field, NDVI) and all models that included all five control predictors and one of the five test predictors (market integration, hunting pressure, fish provision, taboo influence, population density) at a time (six models for the mixed species abundance data and for the chimpanzee abundance data). The model that comprised the control predictors and population density corresponded to a standard ecological model. Since we were specifically interested in the combined effects of taboo influence, market integration, hunting pressure, fish provision, and population density, we added all models that contained combinations of these test predictors and all the control predictors with a maximum VIF 5 (eight additional models for the mixed species abundance data, leading to 14 models, and two additional models for the chimpanzee abundance data, leading to eight models). Since we were interested to know to what extent the control predictors contributed to mammal abundance, we added all the above models but without the control predictors to the set of models (14 additional models for the mixed species abundance data, leading to 28 models, and eight additional models for the chimpanzee abundance data, leading to 16 models). Note that this led to a model that comprised none of the test or control predictors. We controlled for varying transect segment length by including it (log transformed) as an offset term (McCullagh and Nelder 1996) into all models. The final model set for the chimpanzee abundance data comprised 16 models. For all models on the mixed species abundance data, we included an autocorrelation term as well as a random intercept of transect segment ID and random intercept of species (random slopes of the autocorrelation term within species and transect we kept in all models). Finally, we also replicated the entire set of 27 models (all models apart from the model that comprised only the intercept), and this time also included the random slopes of all predictors within species and added these models to the set. We included these models, since we were interested in whether species were affected differentially by the predictors, and we aimed at avoiding overconfident models (Barr et al. 2013). The final model set for the mixed species abundance data comprised 55 models (tables A3.1 and A3.2 for the full set of candidate models). All test and control predictors were transformed when necessary (i.e., to achieve approximately symmetrical distributions and to avoid influential cases) and then were standardized to a mean of zero and a standard deviation of 1 prior to estimation to achieve easier interpretable estimates (Schielzeth 2010). In order to control for autocorrelation (which was no issue for the chimpanzee abundance data), we first fitted a full model that included all test and control predictors, apart from taboo influence, and extracted the residuals from it. We then, separately for each data point, averaged the residuals of all other data points of the same respective species, whereby we weighted their contribution by their distance to the respective data point. By this we derived an "autocorrelation term" to be included in the full model. The function that determined the weights when averaging the residuals had the shape of a normal distribution with a mean of zero and a standard deviation determined such that the likelihood of the full model with the derived autocorrelation term included was maximized. This approach is similar to what was done in Fürtbauer et al. (2011). The 55 mixed effects Poisson regression models (table A3.1) on the mixed species abundance data were fitted using the glmer function of the lme4 package in R (Bates et al. 2015). The 16 zero inflated negative binomial regression models (table A3.2) on the chimpanzee abundance data were fitted using the zeroinfl function of the pscl package in R (Jackman 2015). For the zero inflated negative binomial regression models, we always included the same predictor and control predictors into the zero part as in the count part. We estimated VIF using the vif function from the car package in R (Fox and Weisberg 2011) The dispersion parameters of the mixed effects Poisson regression models ranged between 1.028 and 1.143. The dispersion parameter of the zero inflated negative binomial regression models ranged between 0.781 and 0.891. All Akaike information criterion (AIC) were calculated with the correction for sample size (AICc) (Burnham and Anderson 1998), and the AIC values for the mixed effects Poisson regression models we additionally corrected for overdispersion (QAICc) (Burnham and Anderson 1998). We centred our inference on delta AIC and the 95% best model confidence set based on Akaike weights (Burnham and Anderson 1998).

7.3 Results: observational study

7.3.1 Descriptive results

Wild mammal species abundance In total, 2303 sightings of 18 species were recorded in the study area. The most frequently recorded sighting type were chimpanzee nests, with 994 records, and the most frequently recorded species was the chimpanzee, with 1046 records. The least frequently recorded sighting type were vocalizations, with 13 records, and the least frequently recorded species was otter, with one record (table 21).

7.3.2 Results of statistical analysis

Mixed effects Poisson regression models on species abundance The 95% best model confidence set of our multimodel inference on mixed species abundance included 17 of 55 models (table 23). Fifteen of these models included random slopes. This indicates that it is important to account for variation between species in how the predictors influenced their abundance. Sixteen of the models from the confidence set comprised the control predictors. The model that comprised only control predictors was also included in the confidence set: with a delta AIC of 9.094 and an Akaike weight of 0.004, the support for this model was however meager. The fact that most models in the confidence set included the control predictors strongly supports the importance of environmental factors to wild mammal abundance.

Table 23: Result of multimodel inference on mixed effects Poisson regression on mixed species abundance (duiker, bushbuck, African civet, porcupine, hare, wart hog, jackal, common genet, Guinea baboon, and patas monkey) (AIC: Akaike information criterion; VIF: Variance Inflation Factor).

Model	Model rank	Confidence set	cum	AIC	Akaike weight	Delta AIC	Max. VIF
Hunting pressure+ Market integration+ Taboo influence+ control+RS	1	yes	0.372	3790.108	0.372	0	3.645
Market integration+ Taboo influence+ Population density+ control+RS	2	yes	0.596	3791.123	0.224	1.016	5.603
Market integration+ Taboo influence+ control+RS	3	yes	0.759	3791.753	0.163	1.645	1.972
Hunting pressure+ Market integration+ control+RS	4	yes	0.802	3794.458	0.042	4.35	3.622
Market integration+ control+RS	5	yes	0.843	3794.489	0.042	4.382	1.972
Market integration+ Population density+ control+RS	6	yes	0.884	3794.518	0.041	4.41	5.579
Taboo influence+ Population pressure+ control+RS	7	yes	0.899	3796.566	0.015	6.458	1.916
Population density+ control+RS	8	yes	0.909	3797.349	0.01	7.242	1.916
Hunting pressure+ Market integration+ Taboo influence+RS	9	yes	0.916	3798.063	0.007	7.955	2.897
Fish supply+ Taboo influence+ control+RS	10	yes	0.922	3798.366	0.006	8.258	1.935
Fish supply+ control+RS	11	yes	0.928	3798.398	0.006	8.29	1.935
Hunting pressure+ control+RS	12	yes	0.932	3799.162	0.004	9.054	1.961

Control+RS	13	yes	0.936	3799.202	0.004	9.094	1.609
Hunting pressure+ control	14	yes	0.939	3799.315	0.004	9.207	1.961
Hunting pressure+ Market integration+ control	15	yes	0.943	3799.326	0.004	9.218	3.622
Taboo influence+ control+RS	16	yes	0.947	3799.33	0.004	9.223	1.629
Hunting pressure+ Taboo influence+ control+RS	17	yes	0.951	3799.332	0.004	9.224	1.962
Hunting pressure+ Taboo influence+ control	18	no	0.954	3799.367	0.004	9.259	1.962
Population density+ Control	19	no	0.958	3799.37	0.004	9.263	1.916
Market integration+ Population density+ control	20	no	0.961	3799.381	0.004	9.273	5.579
Hunting pressure+ Market integration+ Taboo influence+ control	21	no	0.965	3799.389	0.004	9.282	3.645
Taboo influence+ Population pressure+ control	22	no	0.968	3799.43	0.004	9.322	1.916
Market integration+ Taboo influence+ Population density+ control	23	no	0.972	3799.447	0.003	9.339	5.603
Fish supply+ Taboo influence+ control	24	no	0.975	3799.461	0.003	9.353	1.935
control	25	no	0.979	3799.467	0.003	9.36	1.609
Market integration+ control	26	no	0.982	3799.468	0.003	9.36	1.972
Taboo influence+ control	27	no	0.986	3799.489	0.003	9.381	1.629
Fish supply+control	28	no	0.989	3799.509	0.003	9.401	1.935

Market integration+ Taboo influence+ control	29	no	0.992	3799.525	0.003	9.417	1.972
Market integration+ Taboo influence+ Population density+RS	30	no	0.995	3800.208	0.002	10.101	4.174
Hunting pressure+ Market integration+RS	31	no	0.996	3801.73	0.001	11.623	2.874
Market integration+ Taboo influence+RS	32	no	0.997	3801.973	0.001	11.865	1.067
Market integration+ Population density+RS	33	no	0.998	3802.451	0.001	12.344	4.15
Market integration+RS	34	no	0.998	3803.252	0.001	13.145	
Taboo influence+ Population pressure+ RS	35	no	0.998	3804.944	<0.001	14.836	1.065
Population density+RS	36	no	0.999	3805.327	<0.001	15.219	
Hunting pressure+ Market integration	37	no	0.999	3806.384	<0.001	16.277	2.874
Hunting pressure+ Market integration+ Taboo influence	38	no	0.999	3806.428	<0.001	16.32	2.897
Hunting pressure	39	no	0.999	3806.468	<0.001	16.361	
Hunting pressure+ Taboo influence	40	no	0.999	3806.45	<0.001	16.392	1.065
Hunting pressure+RS	41	no	0.999	3806.507	<0.001	16.4	
Hunting pressure+ Taboo influence+RS	42	no	0.999	3806.591	<0.001	16.483	1.065
Market integration+ Population density	43	no	0.999	3807.053	<0.001	16.945	4.15
Market integration+ Taboo influence+ Population density	44	no	0.999	3807.077	<0.001	16.969	4.174
Population density	45	no	1	3807.096	<0.001	16.988	

Taboo influence+ Population pressure	46	no	1	3807.129	<0.001	17.021	1.065
Fish supply+RS	47	no	1	3807.51	<0.001	17.402	
Fish supply+ Taboo influence+RS	48	no	1	3807.523	<0.001	17.415	1.073
Market integration+ Taboo influence	49	no	1	3807.924	<0.001	17.816	1.067
Market integration	50	no	1	3807.989	<0.001	17.881	
Fish supply+ Taboo influence	51	no	1	3808.214	<0.001	18.106	1.073
Fish supply	52	no	1	3808.353	<0.001	18.245	
Taboo influence	53	no	1	3808.434	<0.001	18.326	
Taboo influence+RS	54	no	1	3808.473	<0.001	18.365	
Intercept only	55	no	1	3809.319	<0.001	19.21	

Control predictors are share classified forests, distance nearest road, distance nearest river, distance nearest field, NDVI; and RS indicates that random slopes of all predictors within species were included in the model.

The best model had an Akaike weight of 0.372 and included hunting pressure, market integration, taboo influence, and the control predictors (table 24). In this model, the influence of the market integration varied between the species, having a negative effect on duiker, patas monkey, common genet, and common wart hog abundance, a positive effect on jackal, African civet, crested porcupine, and scrub hare abundance, and no clear influence on Guinea baboon or bushbuck abundance (figure 50). The model that included population density and the control predictors was also in the confidence set, but ranked only eight and had a delta AIC of 7.242 with an Akaike weight of 0.01 (table 25). The model averaged coefficients revealed that, across all models, taboo influence and distance to the nearest field had by far the strongest influence on species abundance. The stronger the taboo influence and the larger the distance to the nearest field, the larger the wild mammal species abundance. While the NDVI also had a positive influence on species abundance, the share classified forests, the population density, the hunting pressure, and the distance to the nearest river and road had a negative influence on wild mammal abundance. The influences of fish supply and market integration were very close to zero (figure 51).

Table 24: Result of the best model (mixed effects Poisson regression) on wild mammal abundance with market, hunting, and taboo influence, and the control predictors (NDVI: Normalized Differenced Vegetation Index).

Observations
938 abundance values

Random effects	N	Standard deviation	Chi²	P Value
Species intercept	10	0.839		
Transect intercept	98	0.507		
Species: Market integration‡		0.253	10.656	0.001
Species: Taboos†		0.079	0.048	0.826
Species: Hunting pressure‡		0.000	0.000	1.000
Species: NDVI†		0.136	0.466	0.495
Species: Distance next field‡		0.000	0.000	1.000
Species: Distance next river‡		0.000	0.000	1.000
Species: Distance next road‡		0.100	0.521	0.471
Species: Share classified forest†		0.000	0.000	1.000

Fixed effects		Estimate	Standard error	P Value
Intercept		-7.879	0.278	<0.001
Market integration‡		0.023	0.151	0.878
Taboo influence†		0.406	0.197	0.039
Hunting pressure‡		-0.203	0.137	0.140
NDVI†		0.073	0.081	0.365
Distance next field‡		0.214	0.087	0.014
Distance next river‡		-0.013	0.068	0.852
Distance next road‡		-0.027	0.092	0.765
Share classified forest†		-0.065	0.072	0.368

†) z-transformed ‡) square root and then z-transformed

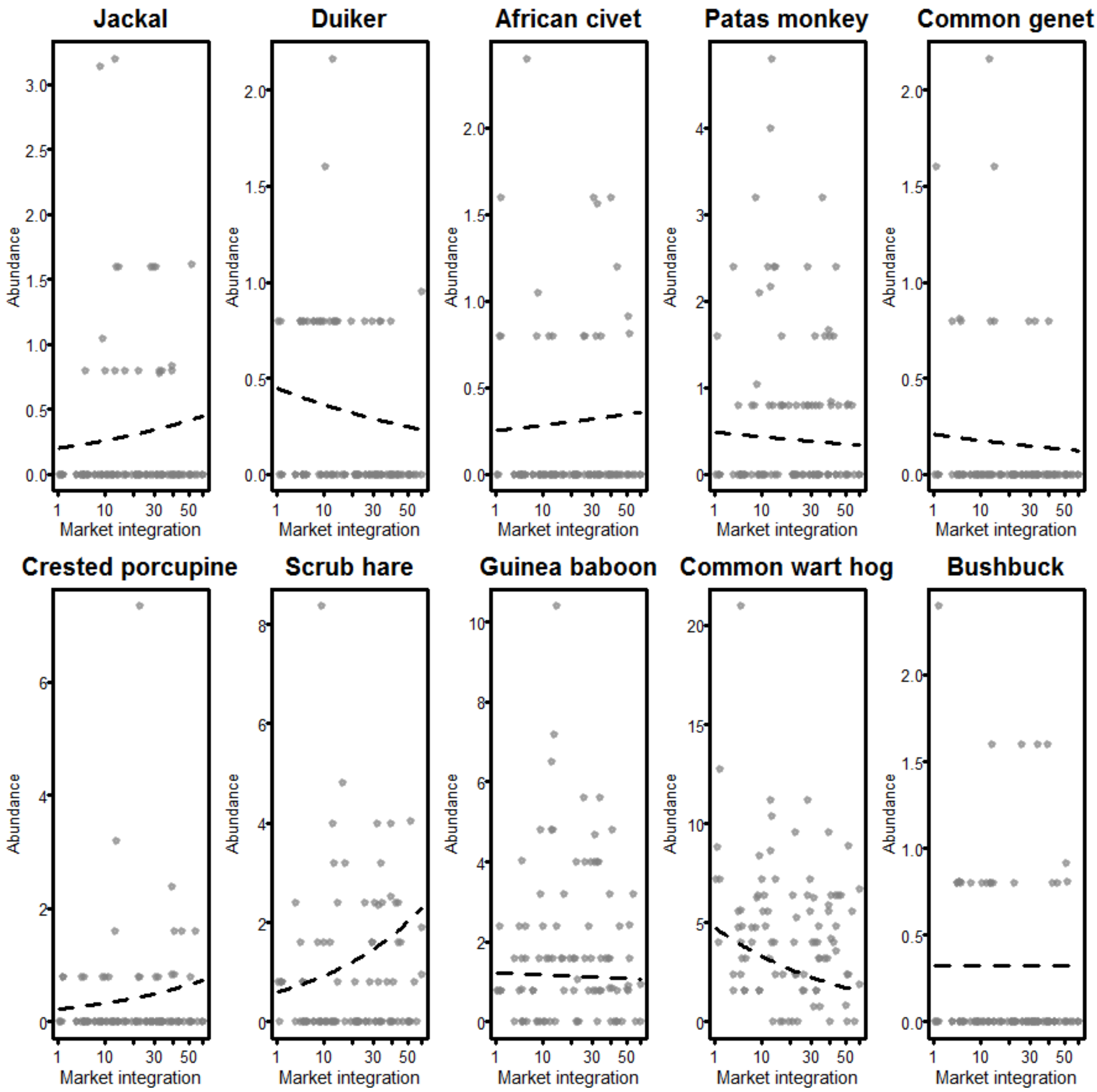

Figure 50: Influence of the market integration on wild mammal abundance.
Plots show the effect of market integration on species abundance for each individual species. Abundance refers to the number sightings per kilometre transect. Observed abundances are shown as points, and the estimated abundances are shown as dotted lines.

Table 25: Result of the mixed effects Poisson regression on wild mammal abundance with population density and the control predictors.

Observations
938 abundance values

Random effects	N	Standard deviation	Chi²	P Value
Species intercept	10	1.085		
Transect intercept	98	0.498		
Species: NDVI†		0.000	0.000	1.000
Species: Distance next field‡		0.000	0.000	1.000
Species: Distance next river‡		0.000	0.000	1.000
Species: Distance next road‡		0.089	0.367	0.545
Species: Share classified forest†		0.000	0.000	1.000
Species: Population density§		0.102	2.115	0.146

Fixed effects		Estimate	Standard error	P Value
Intercept		-7.852	0.352	<0.001
NDVI†		0.064	0.063	0.306
Distance next field‡		0.209	0.083	0.012
Distance next river‡		-0.013	0.067	0.846
Distance next road		-0.014	0.083	0.869
Share classified forest†		-0.069	0.067	0.297
Population density§		-0.013	0.079	0.866

†) z-transformed ‡) square root and then z-transformed §) square root transformed after subtraction of minimum and then z-transformed

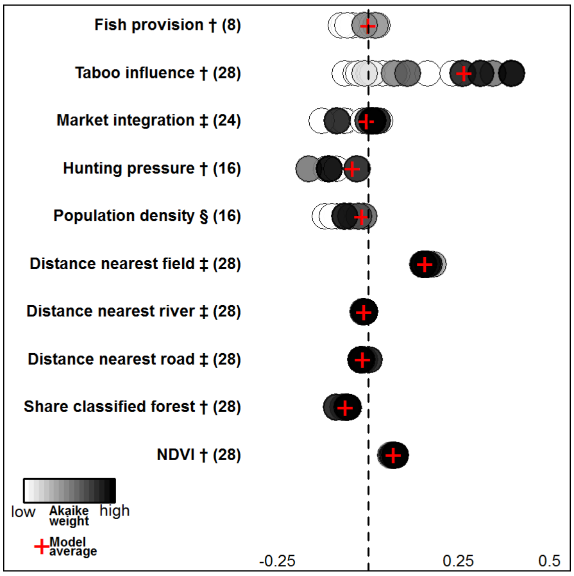

Figure 51: Coefficients of the fixed effects of the mixed effects Poisson regression models on mixed species abundance.
The values of the coefficients are shown on the x-axis, and the names of the predictors are shown on the y-axis. The number of times each predictor was included in a model is shown in parentheses behind the predictor name. The darker the coefficient, the higher the Akaike weight of the model it was taken from. All coefficients were standardized by the partial standard deviation of the respective predictors to be comparable across models and to allow for the deduction of meaningful model averaged coefficients (Cade 2015). (NDVI: Normalized Differenced Vegetation Index) †z-transformed; ‡ square root and then z-transformed; §square root transformed after subtraction of minimum and then z-transformed

Zero inflated negative binomial regression models on chimpanzee abundance The 95% best model confidence set of our multimodel inference on chimpanzee abundance included seven of 16 models (table 26). None of these models comprised control predictors, which suggests that environmental factors were not of primary importance in predicting chimpanzee abundance. The best model had an Akaike weight of 0.414 and was the model that included only market integration. The model that included population density alone was also in the confidence set. It had a delta AIC of 2.57 and an Akaike weight of 0.114. The model averaged coefficients of the count part of the zero inflated negative binomial models on chimpanzee abundance showed that, while market integration clearly had a negative influence on chimpanzee abundance, hunting pressure had a weak positive influence on chimpanzee abundance, and all other coefficients were close to zero (figure 52). The model averaged coefficients of the zero part of the zero inflated negative binomial models on chimpanzee abundance showed that the likelihood of no chimpanzee occurrence increased strongly with the market integration (figure 53). Our results revealed that including human socioeconomic factors other than human population density alone increased our capacity to model wild mammal abundance in our study area in Guinea. All human population factors that we considered in our analysis were deduced from the framework of wild mammals as economic goods. In the case of the analysis on mixed species abundance, the best model did not contain human population density at all, but was made up of taboo influence, market integration, hunting pressure, and the environmental control predictors. Chimpanzee abundance was best modelled by market integration alone.

Table 26: Result of multimodel inference on zero inflated negative binomial regression on the abundance of chimpanzees (AIC: Akaike information criterion; VIF: Variance Inflation Factor).

Model	Rank	Confidence set	AIC	delta AIC	Akaike weight	cum	max.VIF
Market integration	1	yes	525.519	0.000	0.414	0.414	
Taboo influence	2	yes	527.600	2.081	0.146	0.560	
Population density	3	yes	528.096	2.577	0.114	0.674	
Hunting pressure + Market integration	4	yes	528.220	2.702	0.107	0.781	2.793
Fish supply	5	yes	528.774	3.255	0.081	0.863	
Market integration + Population density	6	yes	529.476	3.957	0.057	0.92	4.101
Hunting pressure	7	yes	530.214	4.696	0.04	0.959	
Market integration + Control	8	no	531.878	6.359	0.017	0.977	1.931
Hunting pressure + Market integration + Control	9	no	534.143	8.624	0.006	0.982	3.569
1	10	no	534.304	8.785	0.005	0.987	
Market integration + Population density + Control	11	no	534.741	9.222	0.004	0.991	5.613
Fish supply + Control	12	no	535.622	10.103	0.003	0.994	1.910
Taboo influence + Control	13	no	535.685	10.167	0.003	0.997	1.976
Population density + Control	14	no	536.268	10.749	0.002	0.998	1.898
Control	15	no	537.899	12.380	0.001	0.999	1.606
Hunting pressure + Control	16	no	538.271	12.752	0.001	1.000	1.956

Control predictors are share classified forests, distance nearest road, distance nearest river, distance nearest field, and Normalized Differenced Vegetation Index.

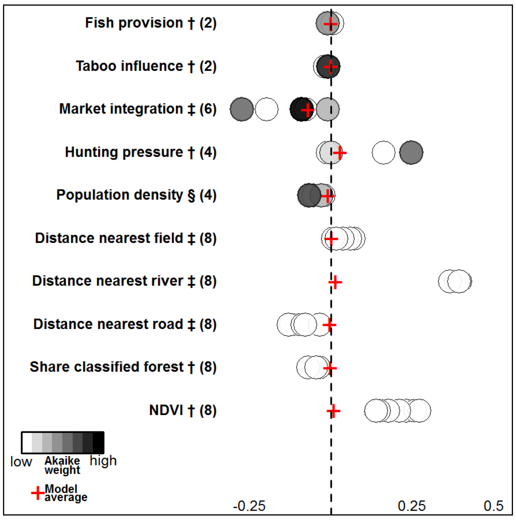

Figure 52: Coefficients of the count part of the zero inflated negative binomial regression models on chimpanzee abundance.

The values of the coefficients are shown on the x-axis, and the names of the predictors are shown on the y-axis. The number of times each predictor was included in a model is shown in parentheses behind the predictor name. The darker the coefficient, the higher the Akaike weight of the model it was taken from. All coefficients were standardized by the partial standard deviation of the respective predictors to be comparable across models and to allow for the deduction of meaningful model averaged coefficients (Cade 2015). (NDVI: Normalized Differenced Vegetation Index) †z-transformed; ‡square root and then z-transformed; §square root transformed after subtraction of minimum and then z-transformed

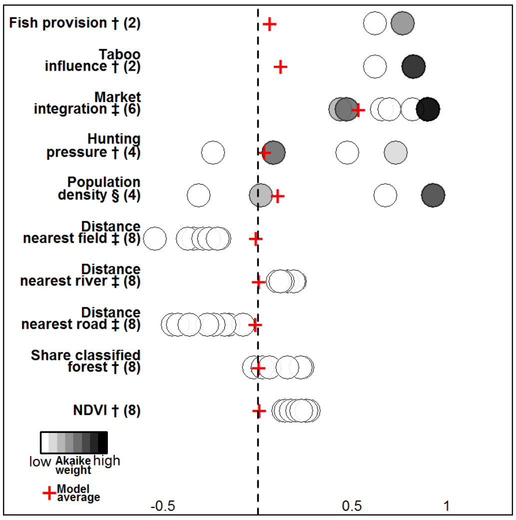

Figure 53: Coefficients of the zero part of the zero inflated negative binomial regression models on chimpanzee occurrence.

This part of the model estimates the probability of having zero in the response variable. The values of the coefficients are shown on the x-axis and the names of the predictors on the y-axis. The number of times each predictor was included in a model is shown in parentheses behind the predictor name. The darker the coefficient, the higher the Akaike weight of the model it was taken from.

All coefficients were standardized by the partial standard deviation of the respective predictors to be comparable across models and to allow for the deduction of meaningful model averaged coefficients (Cade 2015). (NDVI: Normalized Differenced Vegetation Index) †z-transformed; ‡ square root and then z-transformed; §square root transformed after subtraction of minimum and then z-transformed

7.4 Conclusion: observational study

7.4.1 Wildlife conservation from the perspective of Hobbes, Rousseau and Smith

Although the transect data revealed promising wild mammal abundance in the study area, our results point to serious issues for the WCF biodiversity offset project in the study region. These can all be linked to the works of Hobbes, Rousseau and Smith (chapter 2).

First, the CFs in the study area were not enhancing wild mammal abundance. Instead, they had a negative effect on wild mammal species abundance and did not influence chimpanzee abundance. This might be due to different reasons. For example, the knowledge of the classified forest boundaries was not widespread in the study area, and CF boundaries were not respected, as nine villages were being located right within them despite the law (figures 46 and 47). Furthermore, the success of protected areas in conserving wild mammals depends on considerable effort, especially in law enforcement (Bruner et al. 2001; Tranquilli et al. 2012; Tranquilli et al. 2014). Such effort is lacking in the study area. On the other hand, our results suggest that the village communities were more successful in controlling the overexploitation of wild mammals than the government was in the CFs. When the government does not sufficiently invest in monitoring and controlling its protected areas (as is the case in the example of the Island of Hidpaniola cited below), those areas might be considered as common ground by the communities surrounding them. The mechanism of the "tragedy of the commons" (Hardin 1968) then leads to overexploitation. Similar findings have been observed previously in other areas: converting communal property areas to a state property area in order to protect a resource can lead to a de facto open access area (Feeny et al. 1990). This indicates that protected areas without sufficient monitoring and controlling efforts are worse for the conservation of wild mammals than giving the land as property to the local communities (Coase 1960). Or vice versa, if areas with restricted access should remain an important element of conservation projects, the functional regulation and monitoring of restricted access to the area is essential for the protection of wild mammals. For our study area, this result supports the communal property- over the state property regime. Rousseau and his community approach seems to work better than the Hobbesian Leviathan in protecting wild mammals from overexploitation in the study area. Of course, it seems unfair to use Guinea, a "failed state" as an example for state interventions. Nevertheless, the idea that social order is only possible under the rule of a strong state, as proposed by Hobbes, is very popular and my results suggest that this is not true. Although our study was conducted in a very small area, the global pattern regarding the ability of states to enforce the protection of their protected areas goes in the same direction: worldwide, 57% of all protected areas are under intense human pressure. Even areas dedicated to the protection of biodiversity (IUCN I-IV) were under intense human pressure. In 55% of the protected areas designated prior to 1993, the human pressure increased until 2009 (Jones et al. 2018). Although increases in human pressure over such a long period of time might result from a wide range of different reasons, this result nevertheless highlights the inability, or at least the lack of effort, of the states in protecting their protected areas. As stated by Hobbes: "[...] no man obeys them, whom they think have no power to help, or hurt them." (Hobbes 2012 [1651], p. 64). For local people in the study area, this statement is certainly relevant. As the Guinean state is more or less absent in the study area, why should they respect its laws? The relevance of the power factor, which is clearly lacking in the study area, for the implementation of protected area becomes obvious when considering the fate of the island of Hispaniola. Hispaniola is divided into a green part (the Dominican Republic with 28% forest cover) and a brown part (Haiti with 1% forest cover). Although there are important geographic, climatic, historic and socioeconomic differences between both countries, the difference in the forest cover between the two countries is also the result of differences in the management of their protected areas. While the Dominican Republic used a top-down approach, including the extensive use of armed forces, to halt illegal human activities within its extensive network of protected areas (32% of the country's territory), Haiti did not intervene to protect its four national parks from human pressure (Diamond 2005).

Second, although the human population of the study area was poor and suffered from animal protein deficiency, some did not eat potential game (especially common wart hogs provide plenty of meat) because of religious beliefs. Food taboos had a positive effect on wild mammal species abundance in the study area. As suggested by other studies, our results support the notion that food taboos can work as resource management tools to protect wild mammal species (McDonald 1977; Balée 1985; Pezzuti et al. 2010; Read et al. 2010; Luzar et al. 2012). The option to appeal to such beliefs, in cooperation with local religious authorities, should seriously be considered. The notion that a moral norm is a good rule to govern, as suggested by Rousseau, is therefore supported by our analysis. The strength of such moral norms is especially highlighted by the fact that its abidance has a negative influence on the individual fitness: not eating a wart hog is nice for the wart hog, but from the perspective of a hungry human individual, it is counterproductive. In fact, moral norms can be so strong that they even may hinder the ability of societies to adapt to changes in their environment. For example, the Vikings were able to colonize Greenland for about 500 years. However, sometimes in the 1400s, their presence in Greenland vanished. One explanation for their failure is based on moral factors: "The Greenlanders' clinging to their European Christian image may have been a factor in their conservatism that I mentioned above: more European than Europeans themselves, and thereby culturally hampered in making the drastic lifestyle changes that could have helped them survive." (Diamond 2005, p. 247). First, although surrounded by fish and originating from a fish-eating culture, the Greenlanders developed a food taboo against fish. This seems especially misplaced when considering the abundance of fish in Greenland. Second, due to cultural preferences, the Greenlanders kept cattle. This practice was highly inefficient and inappropriate for the environment. As a consequence of not using the available resources, while practicing highly inefficient economic activities, the Greenlanders vanished (Diamond 2005).

Our results regarding chimpanzees are especially interesting because they suggest that in our study area, chimpanzee abundance was not obviously influenced by environmental factors but mainly by human population factors. Especially, the market integration had strong negative influence on chimpanzee abundance. The situation was similar for common wart hogs. Their abundance decreased strongly with increasing market integration. It seems that for species that lack a local demand due to moral food taboos, such as chimpanzees and common wart hogs, the market integration of the population compensates for this missing demand and puts pressure on these animals. This result supports the notion that market interactions erode moral values (Falk and Szech 2013). For other species, such as scrub hares, the same mechanism has however the opposite effect: their abundance increases with market integration. Probably, hunting scrub hare is substituted with buying cheap chicken, which is available only on the market. The simplistic view that increases in the market extent would lead to decreases in the overall wild mammal abundance, as we expected, does not hold in our study area. Our results reveal a more nuanced picture. The market extent does have an effect on wild mammals, but this effect varies between the species. As a consequence, a market approach to the conservation of wild mammals is not generally out of question. Instead, a consistent and thoughtful case-by-case approach is needed. In some cases, market mechanisms can support wild mammals' conservation, in others not. So overall, while the market integration provides alternative sources of income to the local population, it also provides additional incentives to exploit wild mammals. If, in the long run, the economic development and the market integration of the local population, which was very low, even for Guinean standards, should eventually catch up with the rest of the country, a strategy targeting this issue is necessary. A promising strategy for the WCF biodiversity offset might be to provide alternative sources of income for the local population. These alternatives should outweigh the benefits of exploiting wild mammals. Such a strategy is, however, unsustainable and risky: prices and economic incentives can change significantly from one day to the other, without announcement, rendering long term plans of action obsolete and ineffective (McCauley 2006).

7.4.2 Other findings

The local population of the study area relied on slash-and-burn cultivation for their subsistence agriculture. This practice has a detrimental influence on the environment, and the locations of the fields had a strong negative effect on wild mammal species abundance in the study area. It remains unclear whether this effect was due to habitat destruction or to conflicts with wild mammals that are attracted by field crops. In any case, long-term conservation planning in the area is constrained if the fields are relocated regularly. Protecting the crops without harming wild mammals, for example by erecting fences around the fields, might prove an efficient tool for wild mammal conservation in the study area (Rao and Tripathi 2016). Unlike Junker et al. (2015), we did not find an effect of fish availability on wild mammal abundance. This suggests that fish availability did not work as a substitute for wild mammal meat in the study area. One reason for this missing effect might be that the amount of fish provided in the study area is not sufficient to substitute bushmeat. Furthermore, the accessibility of the transects did not influence wild mammal abundance. This indicates that the few existing roads might not have affected the remoteness of the area and were used mainly by local people. The effect of hunting was ambiguous. On the one hand, wild mammal species abundance decreased with increasing hunting pressure. On the other hand, chimpanzee abundance increased with growing hunting pressure on other animal species. The reason for this difference might be that chimpanzees benefit from the decrease of other wild mammals, potential competitors, in areas with increased hunting pressure.

7.4.3 Outlook

Our results revealed that although environmental factors were important for understanding the abundance of wild mammal species in our study area, it was fundamental to also account for human population factors. In fact, only two of our environmental predictors (NDVI and distance to nearest river) were purely environmental. The other three (distance to nearest road, distance to nearest field, share classified forests) represented human factors. For the chimpanzees, the environmental control predictors did not influence their abundance at all. The crucial reason for considering factors other than human population density when estimating the effect of the human population on wild mammals consists not only of optimizing the goodness of fit, as it is shown in our multimodel inference analysis (tables 23 and 26). Rather, the main reason is to improve our understanding of the relationships between the human population and the wild mammals. This is best shown when comparing the best model (table 24) and the model of rank 8 (table 25) from our multimodel inference on the mixed species abundance (table 23). In the best model, wild mammal species abundance was a function of market integration, taboo influence, hunting pressure, and the control predictors. In the model of rank 8 (with a delta AIC of 7.24), wild mammal species abundance was a function of population density and the control predictors. The conclusions drawn from the two models differ substantially. When looking at the population density model (table 25), one would conclude that the human population had no influence on wild mammal abundance. But the best model, where human population density was replaced by hunting pressure, taboo influence, and market integration, showed a different picture (table 24 and figure 50): increasing taboo influence came along with increases in wild mammal abundance. Our analysis furthermore revealed that market integration negatively influenced the abundance of chimpanzees, duikers, patas monkeys, common genets, and common wart hogs, positively influenced the abundance of jackals, African civets, crested porcupines, and scrub hares, and had no obvious influence on the abundance of Guinea baboons and bushbucks. Therefore, when planning conservation activities in the area, market activities of the human population must be taken into account very carefully, avoiding negative effects (additional incentives to exploit wild mammals) and using positive ones (substitution of wild mammal products with products available on the market). Our results were expectable given that wild mammals and humans are part of a common social-ecological system and influence each other. The framework of wild mammals as economic goods within a social-ecological system is an appropriate tool to help detect important factors that drive the relationship between wild mammals and humans in a diverse range of settings.

Chapter 8

Experimental study: determinants of fair sharing

In this chapter, I combine my empirical data with experimental data from a common pool resource game which I conducted with the study population. This experiment allowed constructing a measure for fair allocations. My general theoretical hypotheses regarding factors influencing the fairness of natural resource allocations can therefore be reformulated in this context and put to an empirical test. In this context, fair allocations coincide with fair behaviour at the individual level. If all individuals behave in a fair way, the resulting allocation is fair. In the introduction, I discuss the importance of fairness for human societies and evolutionary mechanisms that favour the emergence of fairness in human societies. In the methods, I first discuss the experimental approach to the study of fairness in humans. Then, I describe the data and the theoretical model and predictions. Finally, I describe the strategy used for the statistical analysis of the data. In the results, I show the results of the test of my hypotheses and discuss the implications for the theoretical work on fairness in the conclusion. This chapter mainly takes up a manuscript which was accepted for publication by the journal *Human Nature* on March 21. 2019. Some parts were however adapted for the purpose of this work.

8.1 Introduction: experimental study

8.1.1 Theoretical introduction

Fairness is a normative concept, which is used to evaluate the distribution of a resource among individuals. The most common concepts of fairness are equity (fairness as the same ratio of input and output for everybody) and equality (fairness as the same share for everybody) (Berman et al. 1985). Fairness is an important characteristic of human societies because it is linked to the evolution of cooperation. As Brosnan and deWaal (2014, p. 1) note „Cooperation could not have evolved without mechanisms to ensure the sharing of payoffs."

Equal shares are omnipresent in nature, from the sex ratio of mammals to the division of a cake among a group of people (Skyrms 1994). Such fair shares do, however, not necessarily result from the human sense of fairness, but can also be the result of inequity aversion (IA). IA is a negative reaction to benefits characterized as being not equal. Disadvantageous IA occurs when the inequity is at the detriment of the actor. Advantageous IA occurs when the actor benefits from inequity. The capacity to compare one's benefits with others is the foundation for IA. Disadvantageous IA has been documented in controlled experiments in capuchin monkeys, macaques, chimpanzees, dogs, crows and humans. Those species protest and refuse a given reward when another individual receives a higher reward for the same task. In contrast to disadvantageous IA, advantageous IA occurs when the individual actually has an advantage. This behaviour has so far only been documented in humans and chimpanzees. High anticipatory capacities are necessary in order to be able to conduct the reasoning behind advantageous IA. Human fairness extends however further than IA. It is based on the notion that appropriate benefits apply to all individuals within the community. Abstraction at the community level, i.e. an understanding of the advantages of self-control when sharing resources and a precise language to exchange information about third parties, are necessary conditions for a notion of fairness to emerge within a population. Only the human species has built these capacities, due to its proportionally exceptional brain enlargement. However, the basic calculations and emotional reactions underlying the human sense of fairness seem to be rooted in the primate background of the human species (Brosnan and deWaal 2014).

8.1.2 Fairness in humans

In humans, fair sharing is a universally observed strategy applied in situations where resources are shared among individuals. Fair sharing is not only a Nash equilibrium among rational actors but also an evolutionary stable strategy (Rubinstein 1982; Skyrms 1994; André and Baumard 2011*b*; André and Baumard 2011*a*). The fact that fair sharing occurs is however intriguing, because it does not satisfy the short-term interests of parties involved in the distribution of resources (Brosnan and deWaal 2014; Debove et al. 2016). The interest in fairness has led to a great variety of research trying to explain how fairness could have evolved despite its costly short term effects. This research is interdisciplinary and the different theoretical models point to different mechanisms in order to explain the evolution of fairness. The different models, however, also frequently make use of different terminology, different definitions of fairness and refer to different time scales (Debove et al. 2016). Although all relevant theoretical models explaining the evolution of fairness make use of game theory (Debove et al. 2016), the underlying assumptions strongly differ, depending on the discipline. Orthodox game theory focuses on the payoff maximizing strategies in situations involving interactions between rational actors with full information and common knowledge. Evolutionary game theory, on the other hand, makes use of a "Darwinian Veil of Ignorance". In this context, no assumptions about rational, fully informed individuals, and common knowledge is needed. Strategies are successful when they maximize the fitness of individuals. The strategies played by the individuals are genetically encoded, so that individuals have no choice, and individual characteristics coincide with their strategy. The population consists of all individual strategies and the outcome of interest are dynamic changes in the composition of the population with the different strategies. Orthodox and evolutionary game theory can lead to strongly differing conclusions (Skyrms 2000).

8.1.3 Biological models of fairness

From a biological perspective, fairness in humans results from a sense of fairness which has evolved in human ancestors (Debove et al. 2016). Such a sense of fairness must therefore be genetically encoded and be the product of natural selection.

Natural selection Natural selection links the reproductive success (fitness) of individuals and the adaptation of populations to their environment. Heritable traits that increase the fitness of individuals are selected and accumulate, while heritable traits that decrease the fitness of individuals become less frequent in the population. Eventually, the better adapted individuals dominate the population, thereby altering its genetic pool (West and Gardner 2010). As equal sharing comes along with costs for the parties involved (a bigger share of the resource is always better), fairness can be described as a specific type of altruistic behaviour (Gintis et al. 2003; Tomasello and Vaish 2013). The theory of inclusive fitness determines necessary conditions for natural selection to favour altruism.

Fairness among related individuals Genes do not only spread directly from one individual to its own offspring (direct fitness), but also through the offspring of other individuals carrying the same genes (indirect fitness). The inclusive fitness is made up of these two components. When one individual, the actor, interacts with another individual, the recipient (both having a relatedness of r), and if the interaction between the two individuals comes at a cost, c for the actor, and a benefit, b for the recipient, natural selection favours altruism if $r*b-c>0$ (Hamilton's rule). By sticking to interactions with close kin having a common ancestor, one can maximize its indirect fitness. This mechanism, known as kinship selection, can lead to the evolution of altruism through natural selection: "[...] altruistic behaviors can be favored if the benefits are directed toward other individuals who share genes for altruism [...]" (West and Gardner 2010, p. 1341). Indirect fitness depends on the genetic relatedness between interacting individuals. This does not correspond necessarily to their kinship. A given set of genes responsible for a conspicuous phenotype of individuals in a population, the greenbeards, and using this information to discriminate between greenbeards and non-greenbeards by being altruistic only towards other greenbeards could be favoured by natural selection, even if the carriers were no kin. Thus, kinship selection and the greenbeard mechanism are two ways in which natural selection can favour the evolution of altruism within a population. Hamilton's rule is however not only about genetics (r), but also about the environment (b and c). The benefit cost ratio (b/c) is determined by the environment and strongly influences the outcome of natural selection: altruism becomes more competitive with increasing values of the b/c ratio. Genetics and the environment are not competing explanations, but always work side by side (West and Gardner 2010). In summary, indirect fitness can favour fairness, given the genetic relatedness between the individuals involved in the sharing of a resource is sufficiently high to compensate for the costs of fair sharing for the actors.

Fairness among unrelated individuals Fairness can also be favoured by natural selection if it leads to a comparative advantage in the direct fitness of individuals in a population. Natural selection works on the relative advantage of individuals in comparison with other individuals of the same population during their whole lifetime. Although single absolute benefits can be very high, in total, individuals with single high absolute benefits can still end badly compared to others. Furthermore, decisions to cooperate with others must be based on the entire history of interaction with the potential partners, and an evaluation of the effort versus payoff balance must be available to guide this decision. In this context, natural selection can favour fairness when it increases the benefits of cooperation for the individuals of a population (Brosnan and deWaal 2014). Sharing is therefore always the result of a prior interaction which generates an outcome among the actors involved in the interaction. This outcome then needs to be shared. The selective forces working on the evolution of strategies guiding the behaviour of the individuals involved in the sharing activity work in two directions: first, an individual has an advantage if he can get a big share of the resource, favouring selfish strategies; second, an individual has an advantage if he can attract partners to share with him, favouring generous strategies (André and Baumard 2011*a*). Depending on the bargaining power of the individuals sharing a resource, natural selection will favour certain types of strategies. When individuals sharing resources have the same bargaining power (this is a symmetric bargaining problem), fair sharing evolves as the only evolutionary stable strategy, because no individual needs to accept an unfavourable outcome, but is able to enforce a favourable one (Rubinstein 1982; Skyrms 1994). When the bargaining power of individuals sharing a resource is uneven (this is an asymmetric bargaining problem), the outcome is always in favour of the dominant individuals (the individuals with more bargaining power). This is due to the fact that the dominant individuals can impose their proposal to the subordinate individuals (the individuals with fewer bargaining power). In such situations, fairness cannot evolve (Nowak et al. 2000; Chiang 2008;André and Baumard 2011*b*; André and Baumard 2011*a*; Debove et al. 2015). Mechanisms that equalize the bargaining power between individuals in asymmetric bargaining problems can favour the evolution of fairness.

Free partner choice and outside options Free partner choice may change the bargaining power of the individuals sharing a resource, depending on their outside options. Outside options are the expected payoffs of individuals in the same time period if they refused to share the resource. If the subordinate individuals have better outside options than the dominant individuals, the bargaining power switches in favour of the subordinate individuals. In such situations, the outcomes favour the subordinate individuals, and fairness cannot evolve. If the dominant individuals have better outside options than the subordinate individuals, the outcomes are still in favour of the dominant individuals, leaving no room for fairness to evolve. Only when the dominant and subordinate individuals have the same outside options does free partner choice lead to the evolution of fair sharing (André and Baumard 2011*a*; Debove et al. 2015).

Free partner choice and reputation When individuals in a population have free partner choice, the possibility to build a reputation can lead to the evolution of fairness through natural selection. Individuals can build reputation when their behaviour in past sharing activities is known to other individuals when a new sharing opportunity emerges. In this case, the other individuals can choose whether to use this new opportunity based on the reputation. For dominant individuals, a negative reputation will have a negative impact on the number of occasions they can incite other individuals to share resources with them. This leads to a shift in bargaining power in favour of the subordinate individuals and may result in the evolution of fairness (Nowak et al. 2000).

Social fluidity Finally, social fluidity can also lead to the evolution of fairness in asymmetric bargaining problems. Social fluidity is given when individuals have the possibility to switch between dominant and subordinate positions when sharing resources. Even when individuals have fixed partners, changing roles allows for an equalization of bargaining power and the evolution of fairness in asymmetric bargaining problems: if the subordinate individuals would always refuse to interact with the dominant partner, no interaction and therefore no sharing, would occur. In order to be able to share a common resource, the dominant individuals have to restrict themselves and be more generous as if there was no switching of roles. This dynamic can lead to the evolution of fairness (André and Baumard 2011*b*).

Fairness and the market Free partner choice, social fluidity and reputation are especially pronounced characteristics of the human market economy. The human sense of fairness might therefore have been favoured by natural selection, because it optimizes human behaviour in an environment characterized by a market economy (Nowak et al. 2000; Chiang 2008;André and Baumard 2011*b*; André and Baumard 2011*a*; Debove et al. 2015).
The idea that participation in a market economy enhances fairness is in fact an old and widely accepted notion in economics. This proposition, known as the "doux-commerce thesis", was first postulated by Montesquieu in the 18th century. At that time, economists assumed that the emerging free market economy would create a new type of human being. This new human would be more reliable, honest, disciplined, and orderly than the human encountered in the pre-capitalist feudal epochs. Reliability, honesty, order, and discipline were considered as essential for the function of a market economy. With the continual expansion of the capitalist production mode, those mentalities would become more frequent in the overall population (Hirschman 1982). We have seen in section 2.3.3 that Adam Smith followed a similar line of argument.

Spite Finally, the power asymmetry between individuals in asymmetric bargaining problems can be overcome when the subordinate individuals have the opportunity to reject the offers of the dominant individuals. In contrast to free partner choice, the subordinate individuals do not have the opportunity to choose other individuals for an alternative interaction in such cases, but end up with nothing, just like the dominant individuals. Rejection of positive offers therefore comes at a cost for the rejecting individuals and is a form of costly punishment. Depending on the amount offered by the dominant individuals, the costs for such rejection might, however, differ between the individuals involved. When dominant individuals make selfish offers, the costs are higher for the dominant individuals than for the subordinate individuals, leading to comparative advantages for the rejecting individuals. When the dominant individuals make fair offers, rejecting those offers do not lead to comparative advantages for the rejecting individuals. When the dominant individuals make generous offers, rejecting these offers do even lead to advantages for the dominant individuals. The strategy of rejecting unfair offer leads to the evolution of fairness when the population size is small enough or when the individuals interact in clusters of limited size within the population (Huck and Oechssler 1999; Forber and Smead 2014).

8.1.4 Cultural Models of fairness

Cultural evolution describes a process whereby a population adapts to its environment through social (cultural) learning. While individual learning results from the interaction between an individual and his environment, social learning results from the interaction between different individuals of a population. The cognitive abilities necessary for social learning to emerge are transmission and preservation: the individuals of a population need first to transfer the relevant information from one brain to another (transmission), and second to keep the information (preservation) in order to be able to transfer those later. When fluctuations in the environment occur every tenth to hundredth generations, social learning can lead to an increased adaptation of the population. However, a population only made up of social learners has an average fitness equal to the average fitness of a population composed entirely of individual learners. Social learning only leads to a comparative increase in fitness, when it increases the output of individual learning, or when it leads to behaviour that no individual could acquire through individual learning over his entire lifetime. Cultural learning then is a type of social learning, where the information transferred between individuals has accumulated over generations. Although cultural variations are observed in different kinds of species, from birds to lizards, cultural learning is omnipresent in humans, and has so far only been observed to some limited extent in chimpanzees and birds. Cultural evolution can be modelled with the same tools as biological evolution, although there are two major differences: first, adaptation can occur during the lifetime of the individuals and is not necessarily observed intergenerationally; second, while genetic transmission is always preservative (the genes transmitted from one generation to the next should be preserved and only change by accident), cultural transmission is most of the time reconstructive: a specific strategy is not only blindly copied but also needs to be adapted to a new setting (Boyd and Richerson 1996; Henrich and McElreath 2003; Nowak and Sigmund 2004; Boyd et al. 2011; Claidière et al. 2014).

8.1.5 Gene-culture coevolution

In bargaining situations, fair sharing can evolve in a framework of cultural evolution through the same mechanisms that also favour the evolution of fair sharing through comparative advantages in the direct fitness of individuals (reputation, free partner choice, punishment). In fact, when analysing human behaviour, both genes and culture, as well as their interaction should be taken into account (Henrich and McElreath 2003).

8.2 Methods: experimental study

Empirical evidence related to fair behaviour is based to an important extent on labouratory game-theoretical experiments. Those experiments simulate different bargaining situations and compare the observed behaviour with theoretical predictions (Camerer 2003). So far, this experimental approach to symmetric bargaining problems has attracted little interest (Nydegger and Owen 1974;

Rubinstein 1982; Skyrms 1994). This might be due to the fact that the theory predicts fair sharing, which is indeed observed in such situations, which does not awake much interest in such symmetric bargaining situations.

8.2.1 Dictator and Ultimatum games as models of fairness

Interest in experimental approaches to asymmetric bargaining problems, on the other hand, has led to countless studies from different disciplines. In this case, the predictions differ strongly from the observed behaviour. The dictator game and the ultimatum game are the most prominent experiments conducted to investigate fair behaviour in asymmetric bargaining problems (Camerer 2003). In the dictator game, one player receives an amount of a resource and decides on how much to give to a second player. This game models the most asymmetric bargaining problem possible, because the second player has no bargaining power at all in this situation. Predictions for this game are clear: a first player is rational if he takes the whole amount for himself, leaving nothing to the second player. However, equal shares are frequently observed in dictator game experiments (Camerer 2003). In the ultimatum game, one player receives an amount of a resource and decides on how much to give to a second player. The second player then accepts the deal or not. If not, both players receive nothing. A rational actor will give the smallest possible positive amount and accept any positive amount. Since the first ultimatum game was presented in 1982, thousands of ultimatum game experiments have been published (Güth and Kocher 2014). The ultimatum game models an asymmetric bargaining problem in which the subordinate player still has some bargaining power. A review of the literature on ultimatum game experiments reveals that the mean offered share is wide above theoretically predicted shares and that positive amounts are frequently rejected (Oosterbeek et al. 2004; Güth and Kocher 2014). Furthermore, offered and rejected shares seem to vary with the cultural setting (Roth et al. 1991; Henrich 2000; Paciotti and Hadley 2003; Tracer 2003; Cronk 2007). The implications of the results from asymmetric bargaining experiments are highly contested with regard to content, as they are taken as a proof, either for selfish or prosocial human behaviour (Camerer 2003; Hagen and Hammerstein 2006). However, methodical issues related to labouratory experiments also challenge the external validity of those experiments (Levitt and List 2007). This challenge is further supported by the fact that those experiments are mainly conducted with Western, educated, industrialized, rich and democratic (WEIRD) people. However, WEIRD people represent one of the worst possible samples to make generalizations about the human species as a whole (Henrich et al. 2010a). Finally, also the reliability of those experiments is questioned: in cultural comparative studies, mostly samples on only one population per culture are taken, not enabling to control thoroughly for environmental differences (Oosterbeek et al. 2004; Lamba and Mace 2011). In the present study, the different aspects relevant to fairness discussed so far were put to an empirical test. We combined a socioeconomic survey with a field experiment (Gerber and Green 2012). The study was conducted in 37 mixed horticultural villages with varying population structures in Guinea. We used mixed effects regressions to analyse the data and test the predictive value of the different theoretical concepts on fair sharing.

8.2.2 Study population and design

Our study population lived in 37 villages of a remote rural area of Guinea, between the Labe and the Faranah regions. The villages had a population of between 45 and 908 inhabitants with a varying ethnic composition. The village population was mainly made up of the two main ethnic groups, Malinke and Fulbe, as well as a few foreigners, and other Guinean ethnic groups. People in the study area lived in a subsistence economy with animal keeping and slash-and-burn cultivation as primary income sources. They relied heavily on gathered forest products for energy and housing. However, some households also frequently visited markets and were well integrated in the broader Guinean market economy. Modern infrastructure and state institutions were absent in the area and the young population (median age: 14 years) was organized around kinship relations and traditional Islamic beliefs. Each village population was made up of between 2 and 16 extended families (kin groups) (figure 54, table 27).

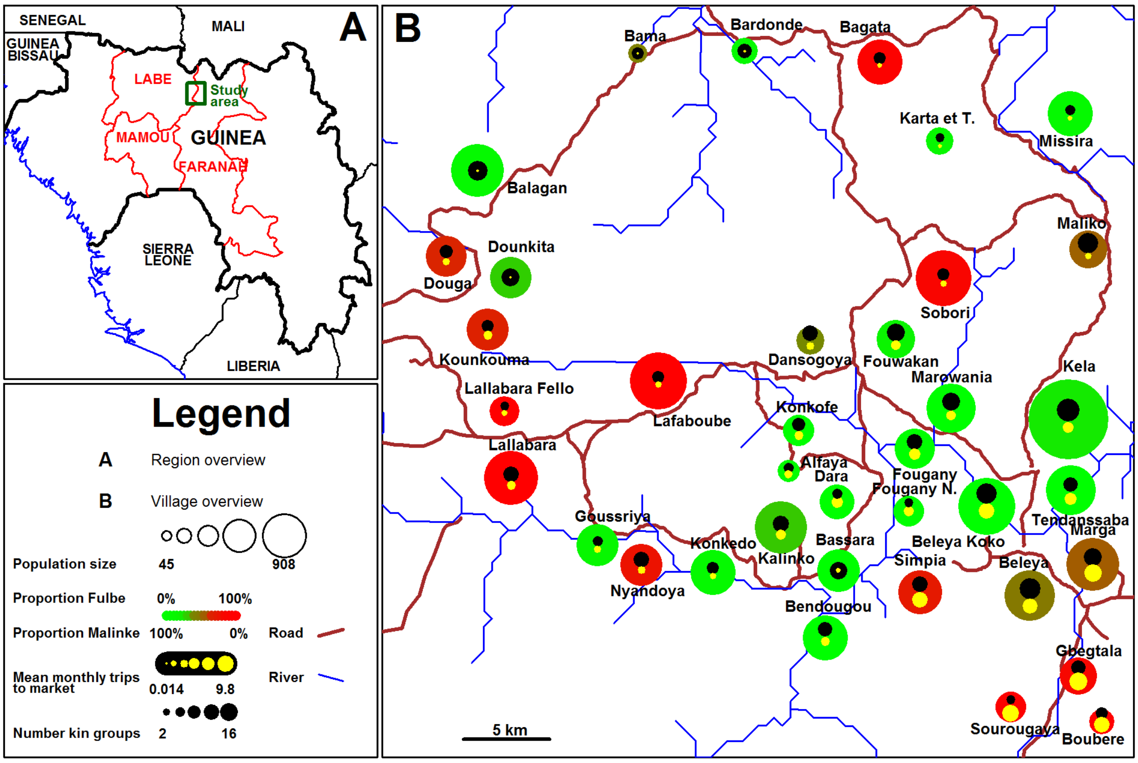

Figure 54: Map of the study area and its location within Guinea.
For the study area, the locations of the villages, their names, their population size, their market integration, the number of kin groups as well as the respective share of the two main ethnic groups are depicted. For illustrative purposes, if other ethnic groups than Malinke or Fulbe occurred in a village, they were included in the minority group of the village.

We conducted a socioeconomic survey in the study area, including questions about the demography, economic activities, as well as opinions and taboos concerning the environment from April 2013 to June 2014 (chapter 7, full questionnaire in A1). The surveys were conducted with the help of assistants, who mainly interpreted to the local languages. The assistants were residents of the capital of the country, Conakry, and had no links to the study population, which was known to everybody involved. The households taking part in the survey were promised a remuneration of 1 kilogram of salt. Salt is a valuable resource because it cannot be produced locally, can be stored and is essential for cooking. The salt was distributed in an experimental setting in which all surveyed households were entitled to participate. Each household had to choose one of its members to join our experiment. After having finished the survey in a village, we fixed a day when individuals could come to receive their salt. We put a bucket containing the exact amount of salt needed to compensate all entitled households of the village in a closed hut of the village. Then, subjects entered the hut one by one. They were told by the assistants that the salt in the bucket was intended for all households in the village having participated in the survey. They were instructed that they could take their share of salt, exactly 1 kilogram, with the measuring jug and put the salt in a black plastic bag provided to them. Such jugs and plastic bags are omnipresent in Guinea. Hence the amount taken was not obvious to the other inhabitants of the village. This was the case, as long as the subjects did not take more than about the double of the fair share of one kilogram, as the bag would have been quite bulky. When subjects took their share of salt in the presence of our assistants, the assistants did not interfere: the subjects took their share of salt in front of the assistants, put it in the black bag and left the hut. This was the control condition. We also implemented a treatment variation: after having explained the procedure to the subjects in the hut, the assistants left the hut. So the subjects of the treatment group took their share of salt alone in the hut. Subjects were allocated to the experimental groups randomly. The rationale behind our experimental variation was as follows: in the control group, due to the observability of behaviour, subjects had the opportunity to build a reputation. In the experimental group, this opportunity was missing. The bucket with the salt was weighed with a digital scale before the subjects entered the hut to take their share and after they left the hut with their share. We calculated the amount of salt taken by every subject by calculating the difference between these two weights. This procedure continued until the salt assigned to the entitled households of a village was entirely distributed. If some households were left without their share, because the other subjects had already taken all of it, the bucket was not refilled. In 5 villages (Balagan, Kela, Marga, Lafaboube, Sobori), the bucket was not big enough to hold the complete amount of salt for all subjects. In these villages, we filled as much salt into the bucket as possible, adding the missing salt later, after some subjects had already taken their share. The experiment was supervised by our Guinean assistants. Our experiment models a situation where a group of individuals shares a resource held in common. All subjects contributed to the production of the resource, the salt, by taking part in our survey. The situation had however the characteristic of an asymmetric bargaining problem. The first individual entering the hut had the most bargaining power. In principle, he could take the whole salt and leave the others without their share of salt. The bargaining power of individuals participating in our experiment decreased with their order of participation in the experiment and reached its lowest level with the last individual entering the hut. Our experiment is therefore a mixture of a common pool resource game (Rapoport 1988; Fischer et al. 2004; Ahn et al. 2011; Lamba and Mace 2011) and a sequential dictator game (Cason and Mui 1998; Diekman 2004). Our experiment was a covert field experiment, as the individuals taking part were not aware that it was an experiment (Gerber and Green 2012).

8.2.3 Predictions and variables

Fair sharing from the perspective of Hobbes, Rousseau and Smith In a strict sense, the situation modelled in our experiment was not a tragedy of the commons situation. Although the salt from our experiment was a common good to the subjects in the experiment, it was clear that the salt would be gone once the experiment was over. Subjects only had the possibility to use the salt once. Therefore, there were no collective costs occurring at the group level due to the use of the resource at the individual level (section 4.3.2). At the same time, our experimental design allowed for unequal allocations of the resource. Central parts of the works of Hobbes, Rousseau and Smith focused on the allocation of resources among individuals of a society (chapter 2). We can therefore apply the works of the three scholars to our experiment in order to deduce predictions about factors favouring a fair allocation of the resource.

In chapter 7, we showed that species targeted by a food taboo were more abundant than the other species. It follows that a moral norm can be used to govern the way how humans use a natural resource. This aspect of governance has been highlighted by Rousseau. In his work he argued that the capacity to govern with the use of moral norms depends to a big extent on the homogeneity of the society, with interest groups and other subgroups negatively affecting the moral integrity of a society (section 2.2). Consequently, the fairness of the allocation of the salt in our experiment should increase with the homogeneity of the village population. Rousseau's prediction related to the influence of ethnic homogeneity within a society is also supported by evolutionary theory. Human populations are frequently divided into ethnic groups with marked traits such as dress, style or speech. If humans have a predisposition to interact with people being similar to them, such ethnic markers can evolve through natural selection, because they facilitate coordination among individuals with the same markers. As a result, moral norms favouring group beneficial cooperation should be supported by ethnic markers, and individuals will cooperate only with other individuals carrying the same ethnic markers. The importance of ethnic markers for individual behaviour should be most important when populations are made up of different ethnic groups and at boundary regions, areas where the territories of different ethnic groups overlap (McElreath et al. 2003). The effect of ethnic markers on social norms is the result of a co-evolutionary process involving cultural as well as biological evolution (Henrich and McElreath 2003). Our study area is located at the edge of the Foutah Djallon, the heartland of the Fulbe, close to the Moyenne-Guinée, the traditional settlement area of the Malinke. Malinke and Fulbe speak different languages, have different conventions and distinct appearances. Ethnicity is a crucial social category in Guinea, where ethnic antagonism is pronounced (Groelsema 1998; Africa is a Country 2013). Ethnic markers were very pronounced in our study population and played an important role in the daily life of the individuals in the study area. Plenty of empirical evidence supports the hypothesis that ethnic homogeneity of a population positively influences prosociality (Alesina et al. 1999; Alesina and Ferrara 2000; Costa and Kahn 2003; Miguiel and Gugerty 2005; Newton and Delhey 2005; Pennant 2005; Anderson and Paskeviciute 2006; Leigh 2006; Habyarimana et al. 2007; Putnam 2007; Gustavsson and Jordahl 2008). On the other hand, Rousseau clearly also had income inequality in mind when he asserted the negative influence of interest groups on the normative integrity of a society. Interestingly, we are not aware of any study relating measures of income inequality with prosocial behaviour in experiments. Supporting evidence exists, however, for the effect of income inequality on prosociality in general (Anderson et al. 2008).

Unlike Rousseau, Smith conceptualized moral norms as a by-product of daily interactions (section 2.3). As a result, they cannot be manipulated and used as a tool to govern, as suggested by Rousseau. This does however not mean that Smith did not appreciate the importance of moral norms for human society. Fairness, for example, was conceived by Smith as the central moral norm to keep human egoism under control. He assumed that the gradual extension of the market economy within a society would coincide with the gradual assertion of a global sense of fairness among individuals within this society. Consequently, the fairness of the allocation of the salt in our experiment should increase with the extent of the market integration within a village population. Smith's prediction related to the positive influence of the market on fairness is supported by other theoretical- as well as empirical work. Good outside options for individuals of a population can favour the evolution of fairness through natural selection (André and Baumard 2011*a*; Debove et al. 2015). From this perspective, the emergence of the market economy, as one important outside option for individuals, leads to a co-evolutionary process where cultural evolution and natural evolution interact to create individuals adapted to a market economy, enforcing an even stronger market institution. It is, however, also conceivable that individuals adapt to the market economy solely through learning (Henrich et al. 2001; Henrich et al. 2010b). The positive effect of market integration on fair behaviour has been shown in previous studies (Henrich et al. 2001; Henrich et al. 2010b).

Furthermore, Smith was convinced that humans were striving for a positive judgment by others. This should be seen as one of the main motives of human behaviour. As a result, we would expect allocations of salt in our experiment to be fairer in the control condition with observation than in the treatment condition without observation. This prediction has also been postulated in the literature related to reputation. Reputation can favour the evolution of fair behaviour through natural selection (Nowak et al. 2000) or through learning (Chiang 2008). Individuals can, however, only build reputation if their past behaviour is known by potential interaction partners. Being observed by others allows individuals to build such a positive reputation by acting as normatively prescribed. Empirical evidence consistently supports the thesis that prosocial behaviour, especially helping strangers or donating to non-profit organizations, is elicited by the presence of observers (Satow 1975; Bull and Gibson-Robinson 1981; Kurzban 2001; Milinski et al. 2002; Soetevent 2005; Bereczkeit et al. 2007; Bereczkeit et al. 2010).

Contrary to Smith and Rousseau, Hobbes did not see a moral norm as strong enough to guide human behaviour. Although such norms could be useful, in the end, they were nothing more than empty words (chapter 2.1). As a consequence, the enforcement of a fair allocation in our experiment would only be possible through an external authority with absolute rights over the subjects. Obviously, we were not able to test this prediction in our experiment (tables 27 and 28).

Table 27: Summary statistics of the variables (the correlations among these variables are shown in table A4).

Variable	Mean	SD	Min.	Max.	Freq.
Kinship	0.404	0.197	0.119	0.943	
Ethnic homogeneity	0.847	0.175	0.475	1	
Market integration	2.934	2.707	0.014	9.804	
Population size	254.108	157.133	45.000	908.000	
Reputation					Reputation: 324 No Reputation: 305
Income inequality	0.443	0.060	0.320	0.600	
Sex					Male: 577 Female: 52
Age	44.420	15.989	3.000	86.000	
Ethnicity					Malinke: 398 Fulbe: 224 Other: 7
Income (yearly household income in €)	1056.480	1129.387	0.000	11,827.500	
Kg salt	11.516	5.822	2.000	28.840	

Control variables Since reputation was the only experimentally manipulated and randomized condition, we used a set of control variables to check for the robustness of our estimations. We controlled for the culture of subjects (Roth et al. 1991; Henrich 2000; Paciotti and Hadley 2003; Tracer 2003; Cronk 2007), the sex of subjects, the household income of subjects, the age of subjects, the amount of salt before subjects started the experiment, the kinship within the village (Morgan 1979; Silk 1980; Daly and Wilson 1988; Alvard 2003; Gintis et al. 2003; Gardner and West 2004; Madsen et al. 2007; Mulder 2007; Stewart-Williams 2008; West and Gardner 2010; Apicella et al. 2012; Tomasello and Vaish 2013; Hintze and Hertwig 2016), as well as village population size (Huck and Oechssler 1999; Stahl and Harvy 2006; Henrich et al. 2010b; Forber and Smead 2014), (tables 27 and 28).

Table 28: Predictions, theoretical mechanisms, and operationalization of all variables.

Variable name	Hypothesis	Mechanism	Operationalization
Predictors			
Income Inequality	Rousseau: Subject's fair behaviour in our experiment decreases with the income inequality of the village populations.	The normative integration of individuals within a society decreases with the number of interest groups in this society.	We built a Gini index for the village populations using information on household income, economic activities and economic assets with the INEQDECO module in STATA 13.1
Ethnic homogeneity	Rousseau: Subject's fair behaviour in our experiment increases with the ethnic homogeneity of the village populations.	The normative integration of a society increases with the homogeneity of the society.	Herfindahl index of all individual ethnic identities in a village (The Herfindahl index shows the probability to randomly select two individuals from the same ethnic group in the same village).
Market integration	Smith: Subject's fair behaviour in our experiment increases with the market integration of the village populations.	Market interactions of individuals correlate with their sense of fairness.	Mean monthly trips to markets of the village populations
Reputation	Smith: Subjects behaviour in the control condition, with observation, is fairer than in the experimental condition, without observation.	Humans strive for a positive judgment by others. Under observation, subjects should therefore behave more as morally prescribed than in anonymity.	Experimental treatment of observation.
Control			

Kinship		Kinship selection (West & Gardner 2010).	Herfindahl index of all family names in a village (The Herfindahl index shows the probability to randomly select two individuals with the same family name in the same village). Family names in villages of the study area should correlate with kinship (Cantrelle and Dupire 1964)
Population size		In populations with small size, spite can favour the evolution of fairness through natural selection (Huck & Hoechssler 1999, Forber & Smead 2014).	Number of individuals living in a village.
Sex		Sex of subjects could influence the behaviour in economic games.	We recorded the sex of subjects (male or female).
Age		Age of subjects could influence the behaviour in economic games.	We recorded the age of subject (in years).

Ethnicity		Previous studies have found an effect of ethnic identity on behaviour in economic games (Roth et al. 1991, Cronk 2007, Henrich 2000, Paciotti & Hadley 2003, Tracer 2003).	We recorded the ethnic identities of subjects (Malinke, Fulbe or others).
Income		Household income of subjects could influence the behaviour in economic games	We recorded household income, - economic activities and - economic assets in local currency to calculate a yearly household income in €
Kg salt		The bargaining power of individuals in our experiment depends on the amount of salt that is available	We recorded the amount of salt before subjects took part in the experiment

8.2.4 Data processing and operationalization of predictor variables

86% of all village households (1,389 households) participated in our survey and most of them took part in the experiment. Our experimental sample was a good representation of the village population: the Pearson's correlation coefficient between the sample size in our experiment and the respective village population size was 0.81. A total of 911.35 kilograms of salt was distributed to 881 individuals in 39 villages. Subjects for whom the amount of salt in the bucket was below 2 kilograms were not included in the analysis, because they had no opportunity of being distinctively selfish. We also excluded all subjects for whom we did not have all necessary information for the analysis. We furthermore excluded two villages from the analysis for which only two observations without missing values were left. This was a necessary step to guarantee that village sample sizes were large enough for the analysis. This left us with a total of 629 observations made in 37 villages. We used the data from our survey to generate the predictor and control variables.

Measure for fairness The response variable was subject's fair behaviour. It was common knowledge that all households participating in our experiment had made the same effort (participation in our survey) and would receive the same reward (1 kilogram of salt). The fair share in the experiment coincided therefore with the most common concepts of fairness (Berman et al. 1985). Besides, no participant in the experiment or in the survey complained about the amount of the remuneration. We assumed that 1 kilogram of salt was perceived by all participants as the fair and normatively prescribed share. We measured subject's fair behaviour by calculating the deviation of the amount of salt taken by subjects from the fair share of 1 kilogram. A deviation of 0 coincided with fair behaviour. The more the subjects deviated above 0, the more selfish they were, the more below 0, the more generous.

Measure for income inequality We first recorded all economic activities, economic assets and household incomes of all households in the villages. Then we valued these different income classes with market prices and finally calculated a Gini index for the village populations using this information with the INEQDECO module in STATA 13.1 (tables 28 and 27).

Measure for ethnic homogeneity We recorded the ethnic identities of the interviewees. We coded ethnicities different to "Malinke" or "Fulbe" as "other" and assigned the father's ethnicity to all children of the household. We measured the ethnic homogeneity of the village populations by calculating a Herfindahl index of ethnic identities of all individuals of the village populations. This measure shows the probability to randomly choose two subjects with the same ethnic identity in one village population (tables 28 and 27).

Measure for market integration We calculated the market integration of the village populations by recording the number of monthly trips to markets of all individuals of a village population and calculating the mean monthly trips to markets of the village population (tables 28 and 27).

Measure for reputation We measured reputation with our unobserved experimental treatment. Building a positive reputation was possible when our assistants observed the subjects in our experiment, the control group, while this opportunity was missing when the subjects were alone when taking their share of salt, the treatment group. This was the case in our treatment condition (tables 28 and 27).

8.2.5 Data Analysis

Using the lmer function of the lme4 package in R (Bates et al. 2015; R Core Team 2016), we ran a mixed-effects regression on the subject's deviation from the fair share, including all variables from table 27 as fixed effects, controlling for village differences with a village random intercept and random slopes for all variables varying within a village. This was our full model. To test the significance of our predictor variables as a whole, we compared the fit of the full model with that of a reduced model only comprising the control variables (Forstmeier and Schielzeth 2011) using the anova function in R. All predictor and control variables were transformed when necessary (i.e. to achieve approximately symmetrical distributions and to avoid influential cases) and then standardized to a mean of zero and a standard deviation of one prior to estimation to achieve easier interpretable estimates (Schielzeth 2010). We further transformed and standardized the response variable in order to meet model assumptions (Quinn and Keough 2002). We estimated random slopes for all fixed effects varying within villages. Such random slopes account for the possibility that the effect of a predictor varies among villages, and their inclusion is also important to keep type I error rates at the nominal level of 5% (Schielzeth and Forstmeier 2009; Barr et al. 2013). We checked whether multicollinearity was an issue in our estimation by running a multiple linear regression using all main terms from our full model and looking at the VIF values of this estimation using the vif function of the car package in R (A5) (Fox and Weisberg 2011). We also checked whether the random terms, as well as the residuals of our full model approximately followed a normal distribution (A6 - A13). We finally checked for constant variance of the residuals of our full model and run model stabilities on our full model (A14 - A16).

8.3 Results: experimental study

Subjects mean deviation from the fair share in our experiment was 44 grams and differed significantly from 0 (One-sample t-test, $t=9.366$, $df=628$, $p<0.001$). This suggests that the subjects in our experiment were selfish on average. The subjects' behaviour varied however strongly: while the most selfish subject took 1.222 kg more than the fair share, the most generous subject took 238 grams less than the fair share. There was also a significant variation in mean deviations between the villages (Kruskal wallis test, $chi^2=144.83$, $df=36$, $p<0.001$). Mean village deviations ranged from -130 to 142 grams (Figure 55). An important fraction of the subjects' mean deviation from the fair share and the village specific variation in mean deviations was accounted for by village effects and our predictor and control variables. In a first step, by modelling the subjects' deviation from the fair share as a function of normally distributed village specific means deviating from an overall mean (village random intercept), the subjects' mean deviation decreased to 27 grams and the range of the mean village deviations decreased to -109 to 90 grams. Additionally, adjusting for characteristics of the subjects (reputation, sex, age, ethnicity, income, kg salt) further decreased subjects' mean deviation to 18 grams and the range in the mean village deviations to -103 to 66 grams. Finally, by also adjusting for differences in village characteristics (kinship, ethnic homogeneity, market integration, population size and income inequality), the subjects' mean deviation slightly increased to 20 grams and the range in the mean village deviation further decreased to -2 to 41 grams (figure 55).

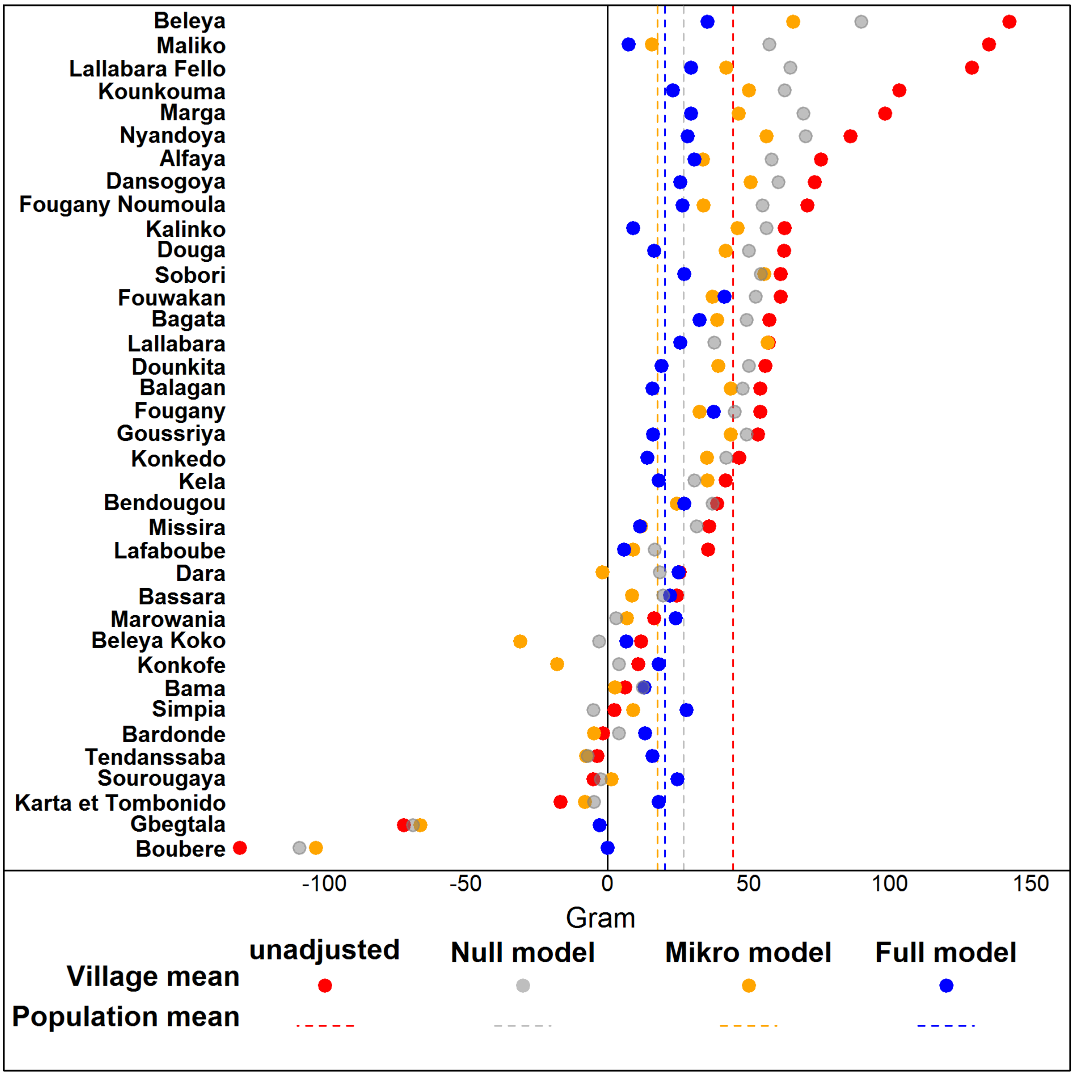

Figure 55: Mean deviations from the fair share for the different villages and the overall population. *The adjusted means shown are for the references of the respective regression models.*

Overall, our predictor variables (ethnic homogeneity, kinship, market integration, population size, reputation) clearly influenced subjects' fair behaviour in our experiment (AIC difference: -6.87, Chi² = 45.526, df = 6, p=<0.001). All village level variables were statistically significant: while kinship and population size had a negative effect on fair behaviour, ethnic homogeneity, income inequality and market integration had a positive effect on fair behaviour (table 29, figure 56). Although the overall effect of a lack of opportunity to build reputation on subjects' fair behaviour in our experiment was not statistically significant, we found a highly statistically significant variation of this effect between the villages: while in Tendanssaba, the unobserved subjects took on average 29 grams less than the observed subjects, this difference reached its maximum in Maliko, where the unobserved subjects took on average 107 grams more than the observed subjects. The effect of our treatment of no observation on the amount of salt taken by the subjects was negative in 13 villages. In the other 24 villages, the lacking opportunity for reputation building led to bigger (e.g.

Kounkoum, Marga, Maliko and more) or smaller (e.g. Alfaya, Dara, and more) increases in the amount of salt taken (table 29, figure 57). Overall, there was no significant effect of the household income on fair behaviour. However, there was a significant variation in the way the household income affected fair behaviour between the villages (table 29, A17). The same holds true for the effect of the amount of salt in the bucket on fair behaviour (table 29, A18). None of the estimates of sex, ethnicity and age were statistically significant at the 5% level of statistical significance.

Table 29: Full model. Result of the mixed effects regression on the subjects' fair behaviour.

Observations
629
Villages
37

Random intercept	Sd
Villages	0.058

Random slopes	Sd	Chi Square	Df	p value
No reputation	0.121	16.608	2.000	<0.001
Female	0.040	0.156	2.000	0.346
Malinke	0.000	0.000	2.000	0.500
Kg salt|	0.053	8.639	2.000	0.001
Age*	0.000	0.000	2.000	0.500
Income|	0.058	8.613	2.000	0.001

Fixed effects	Estimate	Standard error	Likelihood ratio test	p value
Intercept	-1.170	0.047		
Ethnic Homogeneity|	-0.082	0.020	13.079	<0.001
Kinship*	0.051	0.021	5.773	0.016
Gini*	-0.041	0.020	4.689	0.030
No reputation	0.052	0.029	3.038	0.081
Population size#	0.077	0.020	13.121	<0.001
Market Integration|	-0.065	0.018	11.183	0.001
Female	-0.018	0.042	0.183	0.669
Malinke	0.048	0.032	2.216	0.137
Income|	-0.005	0.015	0.100	0.751
Kg salt|	-0.023	0.014	2.506	0.113
Age*	0.019	0.011	2.749	0.097

**) z-transformed |) square root and then z-transformed #) log-transformed prior to z-transformation. Prior to estimation, we added 290 grams and log-transformed the subjects' deviation scores. Reference for "No reputation" is "reputation", for "female" is "male", for "Malinke" is "Fulbe". P-values for all terms were calculated following the approach proposed by Bolker et al. 2009.*

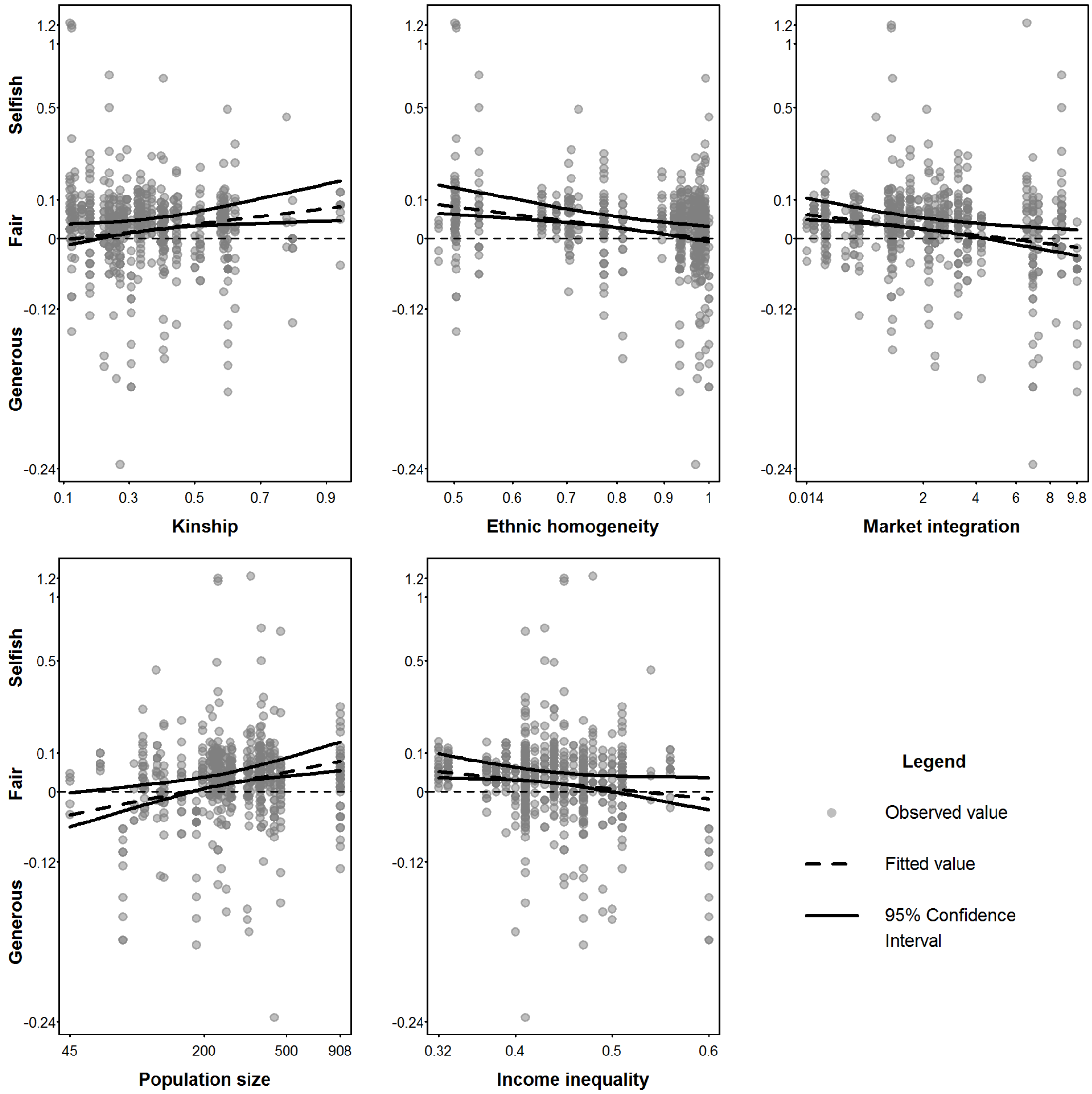

Figure 56: The influence of ethnic homogeneity, kinship, population size, market integration and income inequality on the subjects' fair behaviour.

The thin dashed line depicts the location of 0 on the y-axis across the range of the x-axis. The darker the observed value point, the more observations were made on the respective location. The fitted values were estimated for male Fulbe subjects in the condition with observation with all other variables being at their mean using the full model estimates (table 3). The 95% confidence intervals were estimated using a bootstrap procedure, provided by Roger Mundry (www.eva.mpg.de), on the full model.

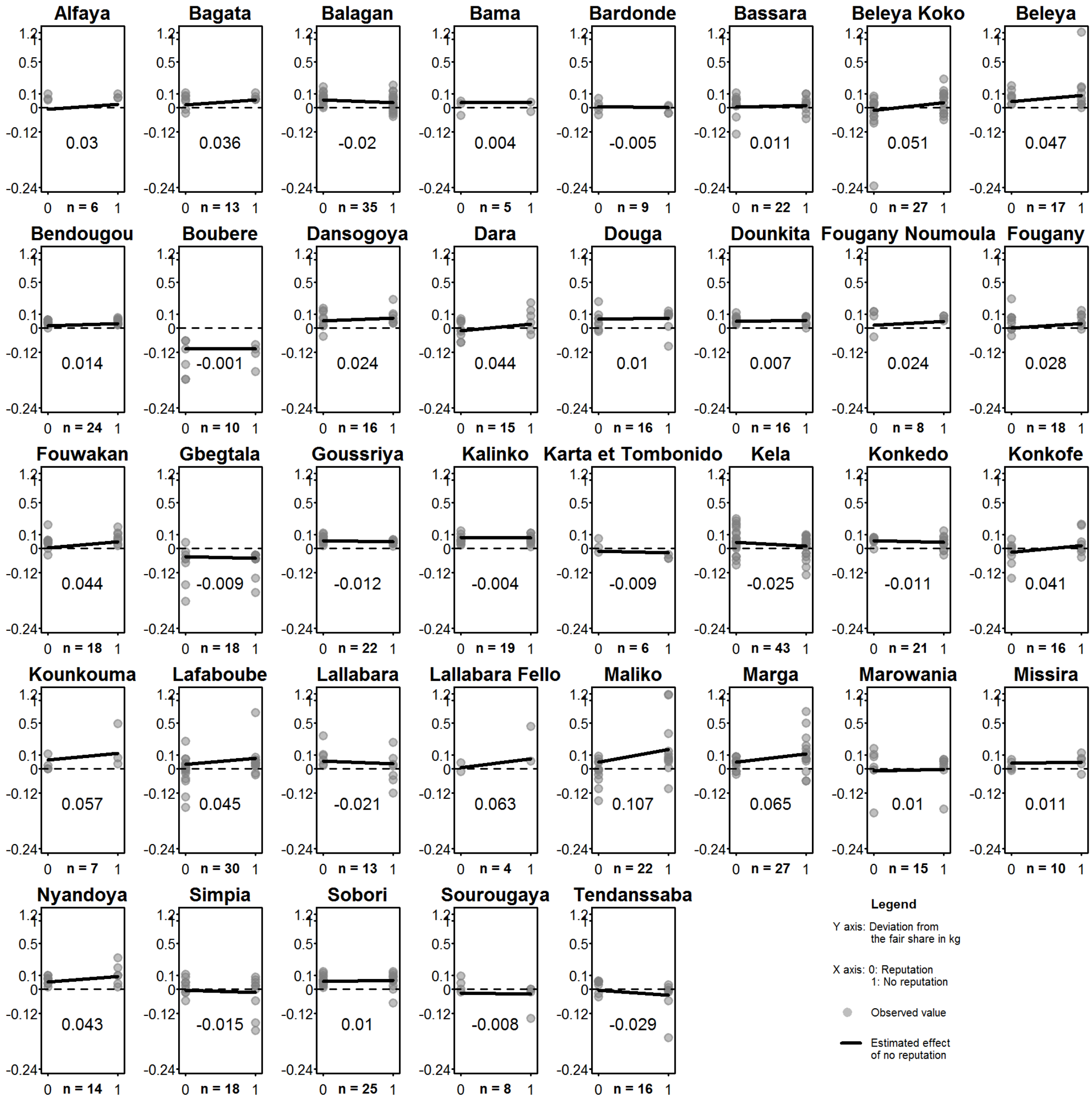

Figure 57: The influence of a lack of reputation building opportunity on the subjects' fair behaviour.

The name of the village is written in bold on top of the respective plot, and the sample size for every village is shown below the plot. The graph in the centre of the plot shows the estimated mean difference in the deviation from the fair share conditional on reputation (=0). The thin dashed line depicts the location of 0 on the y-axis across the range of the x-axis. The darker the observed value point, the more observations were made on the respective location. The estimated effect of a lack of reputation building opportunities on the subjects' fair behaviour in our experiment was calculated by subtracting the fitted value for male Malinke subjects in the control condition (with observation) from the fitted value for male Malinke subjects in the treatment condition (without observation) using the full model estimates. The village variables were set at their actual values and all the other variables at their mean.

8.4 Conclusion: experimental study

The results of our multivariate analysis revealed that the subjects' behaviour in our experiment on fair sharing was mainly driven by the characteristics of the village population they belonged to: first, a simple look at the data revealed an important variation in fair behaviour between the villages. However, we were able to explain an important portion of this village specific variation in the subjects' fair behaviour by controlling for the characteristics of the village populations (figure 55, table 29). Second, we also found an important variability between the villagers in the way they responded to our experimental stimulus of a lack of opportunity to build reputation, as well as to how the household income and the amount of salt influenced their behaviour in our experiment (table 29, figure 57, A17, A18). Third, the importance of the village population characteristics on the subjects' behaviour is further highlighted by the fact that all village level fixed effects were statistically significant in our analysis. In contrast, none of the individual level fixed effects was statistically significant (table 29). Unlike in previous studies (Roth et al. 1991; Henrich 2000; Paciotti and Hadley 2003; Tracer 2003; Cronk 2007), we did not find an effect of the subjects' ethnicity on fair behaviour in our experiment. We assume that this is due to the fact that, on the one hand, we intentionally sampled several villages containing different range of both main ethnic groups under study (figure 54, table 27). On the other hand, we also controlled for the population characteristics our subjects lived in (table 29). If we had only selected one Malinke and one Fulbe village for our experiment, like for example Boubere and Beleya Koko, not being able to properly control for the population characteristics, we would have found a highly significant effect of ethnicity on fair behaviour in our experiment. We would have concluded that Malinke subjects are much more selfish than Fulbe subjects (A19) and would have speculated about the reasons for this ethnic difference in fair behaviour. All these findings highlight the importance of sampling a multitude of populations of each cultural group and controlling for contextual factors when conducting cultural comparative studies (Oosterbeek et al. 2004; Lamba and Mace 2011).

8.4.1 Fair sharing from the perspective of Hobbes, Rousseau and Smith

First, subject's fair behaviour was positively influenced by the village's ethnic homogeneity. Predicted behaviour of subjects in our experiment was only fair in ethnically homogenous villages (table 29, figure 56). This result clearly supports Rousseau's prediction related to the homogeneity of a society and its normative integration. This result was also expected from an evolutionary point of view (McElreath et al. 2003) and aligns well with the existing empirical evidence regarding the influence of ethnic homogeneity on prosociality (Alesina et al. 1999; Alesina and Ferrara 2000; Costa and Kahn 2003; Miguiel and Gugerty 2005; Newton and Delhey 2005; Pennant 2005; Anderson and Paskeviciute 2006; Leigh 2006; Habyarimana et al. 2007; Putnam 2007; Gustavsson and Jordahl 2008). However, fair behaviour was also positively influenced by villages' income inequality. This result clearly contradicts Rousseau's prediction related to the negative effect of interest groups and the normative integration of a society. The result also contradicts a common perception seeing income inequality as highly problematic for human societies: "Ungleichheit hat desaströse Folgen" (Tagesspiegel 2016). It seems, therefore, that the stratification of a population into multiple subgroups has no general negative effect on the normative integration of the population, as postulated by Rousseau (section 2.2). The effect of the stratification on normative integration depends on the underlying stratification characteristics. In our study, ethnic stratification had a negative- and income stratification a positive influence on the normative integration of the population. A review of findings on the effect of population stratification on prosociality even suggests that the effect of population stratification on the normative integration may vary across time, place, and context:

> "A consistent finding in the literature on social capital is that not all forms of group heterogeneity are important determinants of the efficacy of collective action. For example, using the General Social Survey, Alesina and La Ferrara (2000) finds that participation in one or more voluntary membership organizations is negatively associated with metropolitan area income inequality, as well as racial and ethnic fragmentation, but not age fragmentation. Costa and Kahn (2003a,b) conduct a similar analysis using data from several surveys; they find that membership is negatively associated with metropolitan area income inequality, racial fragmentation and birthplace fragmentation; however, neither the magnitude nor significance of these measures is consistent across surveys. In a study of shirking within companies of the Union Army, Costa and Kahn (2003c) report desertions and other acts of cowardice are positively associated with group heterogeneity based on income, ethnicity, occupation or age, albeit not significantly so for income inequality. These findings suggest that not all forms of heterogeneity are salient for group cooperation in all times or places." (Anderson et al. 2008, pp. 1012-1013)

Third, the subjects' behaviour in our experiment became increasingly fair with an increasing market integration of the village populations (table 29, figure 56). This result clearly supports Smiths prediction related to the influence of market interactions and fairness. This result was also expected from an evolutionary point of view (André and Baumard 2011*a*; Debove et al. 2015) and corroborates the positive effect of market integration on fairness found in studies conducted across different human societies (Henrich et al. 2001; Henrich et al. 2010b).

Finally, our results also show that a missing opportunity to build reputation did not lead to a general increase in selfish behaviour in our experiment: in none of the villages was the difference between observed subjects and unobserved subjects statistically significant. This result is not consistent with Smith's assumption related to the motives of human behaviour and the broad literature presenting empirical evidence for a general increase in the subjects' prosociality elicited by the presence of observers (Satow 1975; Bull and Gibson-Robinson 1981; Kurzban 2001; Milinski et al. 2002; Soetevent 2005; Bereczkeit et al. 2007; Bereczkeit et al. 2010). Instead, the effect of a lack of opportunity to build a positive reputation on fair behaviour in our experiment differed significantly between the villages. We found the expected increase in selfish behaviour in two thirds of the villages (a few very high deviations from the fair share were observed in the condition without observation (up to 1.2 kg) and the village specific estimated mean deviations from the fair share in the condition without observation went up to 106 grams). However, our experimental treatment under the no-observation condition led in one third of the villages to a fairer behaviour, or even to generous behaviour (table 29, figure 57). We can only speculate about this finding. From a methodical perspective, our experimental stimulus may not have worked as expected in all villages. From a theoretical point of view, the villages where our experimental treatment worked as expected must have differed in some ways which we did not control for compared to the villages where the treatment did not work as expected. Relevant factors could have been the influence of the village chiefs' authority or the feeling of privacy within the village communities.

8.4.2 Other findings

As expected (Huck and Oechssler 1999; Forber and Smead 2014), the ability of villages to stabilize fair behaviour decreased with village population size. Predicted subjects' behaviour was only fair for population sizes below 200 individuals (table 29, figure 56). An intriguing aspect of our results is that the predicted positive effect of kinship on the subjects' fair behaviour was not confirmed. On the contrary, increasing kinship among individuals of a village population led to more selfish behaviour of the subjects in our experiment. Predicted behaviour was only fair in the village populations with the lowest kinship among individuals (table 29, figure 56). A theoretical explanation for this result can be found when looking at the reproductive behaviour of male lions. Male lions of a pride form coalitions to protect their territory and share the females. The reproductive success of the individual males of a coalition depend on the coalition size: while all male lions have the same reproductive success in small coalitions (2 individuals), at least one male fails to breed in larger coalitions. These males become breeding-helpers. Being a breeding helper is, however, only a successful strategy if it increases the reproductive success of close relatives. As high levels of kinship guarantee for this condition to be met, breeding helpers only occur in coalitions made up of relatives (Packer et al. 1991). The same mechanism may also explain the negative effect of kinship on fair sharing in our experiment: instead of restraining the selfishness of individuals through equal sharing, kinship allows for unequal sharing, because individuals are more likely to accept unequal shares at their expense if the beneficiary is a kin than if the beneficiary is unrelated.

A methodical explanation for the unexpected negative effect of kinship on fairness is based on the fact that we used a measure of kinship at the aggregate level of the village. For some individuals, this measure may be a better approximation than for others. The share of a subjects' kin group to the total village population is a more accurate measure for the individual relatedness of a subject to the rest of the village population. Including this measure as a predictor into the full model does, however, not change the result: the estimate for the share of a subjects' kin group is not significant and does not change the estimate related to kinship (table 29, A20). Another theoretical explanation for the negative effect of kinship on fairness could be redistribution. If this was the case, we would expect individuals of important kin groups to take more salt during the experiment and redistribute it to other kin after the experiment. As shown in A20, this was however not the case.

8.4.3 Implications

In our study, we were dealing with traditional, small-scale societies that are partly in transition to more complex and socially stratified societies. The different villages showed an important variation in population, as well as in individual characteristics, although they were all located in the same area (figure 54, table 27). Putting our results in a broader human context might help to understand their implication. Some scholars have argued that humans are a unique species, as their altruism is not primarily based on kinship. The evolution of fairness and cooperation in human large scale societies cannot be explained solely by genetic evolution, but is best accounted for with cultural evolution and gene-culture co-evolution. The empirical evidence for these claims is based to an important extent on behavioural experiments (Fehr and Fischbacher 2003; Gintis et al. 2003; Henrich et al. 2010a). As far as we know, these experiments do, however, not include measures of kinship to test predictions related to the effect of kinship on behaviour in experiments. In our experiment, we found a statistically significant effect of kinship on fair behaviour: kinship led, however, to an increase in selfish behaviour and not, as expected by us, to increased fair behaviour. This result indicates that kinship might in fact be a driver of the evolution of fairness and cooperation in human large scale societies: as long as human populations were mainly composed of kin, tolerance for unfair behaviour was pronounced and fairness norms likely not able to evolve. In such a setting, cooperative activities among unrelated individuals were probably rare, one had to reach out of his own group to encounter unrelated individuals, and cooperation was fostered by kinship. Only as soon as human populations started to be made up of important fractions of unrelated individuals (through migration, population mixing, population growth or other mechanisms), did fairness have a chance to evolve. In such populations, unequal shares resulting from cooperative activities among individuals cannot be sustained by kinship, and humans had to rely on other mechanisms to promote cooperation. This may have been the catalyst for the emergence of fairness and large-scale cooperation among humans.

Chapter 9

Conclusion

In my thesis work, I confronted empirical observations I made in two field studies in Guinea with theoretical predictions deduced from the works of Hobbes, Rousseau and Smith. In chapter 2, I summarized and discussed the works of Hobbes, Rousseau and Smith. The scholars followed a comparative approach, explaining differences between humans and human societies with institutional differences. These differences are related to the capacity of the societies to enforce social order. Hobbes argued that only an absolutist state, as found in European monarchies, is able to create the trust needed for any cooperative activity. This state is known as the Leviathan. Humans lacking such a state are distrustful, defecting, and not able to enforce social order. In comparison, absolute states are able to enforce social order and their people are trustful and cooperative. Rousseau, on the other hand, argued that the main reason for differences found in human societies was the level of dependence of people on each other. This dependency results from private property and the division of labour and cannot be reversed once those social institutions have been created. The more people depend on each other, the more they try to increase their position at the expense of others, and the more violent their conflicts become. This leads to enduring violent conflicts and threatens social order. The only solution to end this vicious cycle of violence is a state and government ruled by the general will of the people. In such a collectivist state, social order lasts as long as the moral values of the people coincide with the laws of the state. This is the case as long as the people are homogeneous and equal. Smith, finally, agreed that the division of labour was a key aspect of society, because it allows to generate surplus production. As long as the division of labour is coordinated through some authority, the people are however not free and society is constantly involved in violent conflicts, threatening social order. If the division of labour is however coordinated through the free market, this not only leads to the maximal amount of wealth, at the same time, the freedom of the people is guaranteed, and the social order secured by the invisible hand of the free market. Accordingly, the state, the private property, the moral values as well as the free market are the key social institutions needed to explain differences found between human societies and their capacity to enforce social order. These thoughts are highly relevant for sociology. However, what is entirely lacking in this short summary are the dogmatic and philosophical arguments used by the classical scholars to reach their conclusions. Not only are the works of the classical scholars not mutually compatible, differing fundamentally in some of their key assumptions, they are furthermore not suitable for a scientific investigation in their original form, since some of their key assumptions and arguments cannot be captured empirically. In chapter 3, I discussed how the works of the classical scholars can nevertheless be used as the fundament for a scientific investigation. By sticking to simple assumptions of rationality and renouncing to all the others, orthodox game theory allows incorporating the main concepts suggested by the three classical scholars in a common theoretical framework. Although this approach does not satisfy the philosophical depth and complexity of the arguments of the three scholars, it nevertheless allows analysing the problem of social order from a more general perspective. From this perspective, the problem of social order is a problem of rational cooperation. In most situations, the rationality of actors following their self interest will lead to an optimal outcome for all parties involved. In some cases, however, the outcome will be suboptimal. In these situations, which are known as social dilemma situations, the rationality of actors fails in providing the optimal outcome. The definition as well as key concepts suggested to overcome social dilemma can be linked to the works of Hobbes, Rousseau and Smith. The incorporation of key concepts of Hobbes, Rousseau, and Smith in the minimalistic game-theoretical framework is a first step towards a scientific investigation of the relevance of their thoughts, since it allows formulating hypotheses in a mutually compatible theoretical framework that can be captured empirically.

In chapter 4, I discussed one of the most important social dilemmas, which occurs when humans exploit natural resources. Rational actors using a resource held in common will inevitably overexploit this resource, putting their own existence at risk. This is known as the tragedy of the commons. The tragedy of the common is a fundamental problem of social order since natural resources are essential for the survival of humans and the functioning of societies. Not only does the overexploitation of a key natural resource lead to conflicts that may result in violence or even the collapse of society, natural resources are also intrinsically linked to the social order of a society due to their allocation. An allocation of natural resources that is perceived as unfair might trigger violent conflicts and put the social order of a society into question. Hobbes, Rousseau and Smith suggested different mechanisms favouring social order. Based on these mechanisms, I formulated hypotheses related to factors influencing the sustainable use and the fair allocation of natural resources. These hypotheses lay the theoretical foundation for my empirical work.

By confronting theoretical hypotheses with empirical observations, cumulative knowledge on causal laws determining the functioning of our world can be generated. In chapter 5, I discussed the methodical and philosophical foundation of causal inference. Based on Popper's falsificationism, the continual confrontation of logically sound theoretical hypotheses with empirical observation allows discerning good from bad theories. Theoretical hypotheses that are not confirmed by empirical observation are falsified and therefore dismissed. Theoretical hypotheses that are corroborated by empirical observation are temporally supported. After an empirical test, the theories are adapted and altered according to the actual standard and confronted with new empirical observation. The continual practice of this approach then leads to robust and meaningful theories about the world. The confrontation of theoretical hypotheses with empirical observation is based on statistical tools applied to data. The result of such a confrontation is however only meaningful if the data and the statistical tools used are appropriate.

Following the contemporary science of human nature approach, a sound empirical test of my theoretical hypotheses requires that the used data basis is derived from observations made on a non-WEIRD study population with substantial variation in socioeconomic, demographic, as well as cultural factors. In chapter 6, I described the field work I conducted to collect empirical observations on small-scale societies living in a remote area of Guinea and showing important variations in demographic, cultural, as well as socio-economic factors. My data basis therefore clearly meets the requirements. Although there are a large number of potential statistical tools available to conduct an empirical test of theoretical hypotheses, these differ in their ability to capture the dependencies present in the data and to provide reliable results. Based on a simulation study (section 5.4), I showed that the most universally applicable tool of statistical inference is the mixed effects regression model. The statistical inferences in my empirical studies in chapters 7 and 8 were therefore all based on mixed effects regression models. The use of such rigorous statistical analysis as well as such comprehensive data is only rarely found in the empirical literature on cooperation and fairness in humans. In the next section, I give a brief summary of the results of my empirical hypotheses tests.

9.1 Summary of findings

In my observational study (chapter 7), I estimated the influence which the local human population had on wild mammals in my study area in Guinea. Wild mammals were used as a natural resource by the human population in the study area: meat, fur, and pets were the main commodities obtained by exploiting wild mammals (chapter 6). Based on abundance figures of 11 large wild mammal species in the study area, and the survey data obtained by interviewing the local human population (chapter 6), I found clear evidence for a strong influence of the local human populations on wild mammals in the study area. First, wild mammals were more abundant in areas under communal property than in areas under state property. Second, wild mammal species targeted by food taboos were more abundant than other species that were not subject to any food taboos: their abundance increased with the share of the human population abiding to respective food taboos. Third, while the market integration did not affect wild mammal abundance on average, it had a a strong negative effect on some of the wild mammals, and a strong positive effect on others. These results clearly show that the works of Hobbes, Rousseau and Smith helped understanding the distribution of wild mammals in the study area. While Hobbes' prediction was falsified, Rousseau's predictions were supported and Smith's prediction was supported for some species, while falsified for others. Unfortunately, the private property regime was not implemented in the study area. For this reason, Smith's prediction related to the effect of the private property regime on resource exploitation could not be tested (table 30). The main finding of my study on the abundance of wild mammals was therefore that it is essential to additionally consider detailed socioeconomic factors, beside the usual environmental factors, when modelling the distribution of wild species.

In my experimental study (chapter 8), I conducted a field experiment where the participating subjects shared a natural resource held in common. By linking the experimental data with the survey data obtained by interviewing the subjects and the rest of the human population living in the same study area (chapter 6), I was able to identify drivers of fair sharing in my field experiment. I found that fair sharing was strongly influenced by the characteristics of the villages where the subjects lived, as well as by the experimental treatment of observability: first, the propensity for fair sharing increased with the market integration of the subjects' villages; second, the propensity for fair sharing increased with the ethnic homogeneity of the subjects' villages; third, the propensity for fair sharing increased with the income inequality of the subjects' villages; finally, although the observability of the subjects' behaviour during the experiment had no effect on fair sharing of the subjects on average, the propensity for fair sharing increased when subjects were observed in some villages and decreased in others. These results show that the works of Rousseau and Smith helped understanding the behaviour of subjects in my field experiment. While one of Rousseau's predictions was supported, the other was falsified. Similarly, while one of Smith's predictions was supported, the other was only supported for some villages and falsified for others. Unfortunately, I was not able to test any prediction based on Hobbes' work in my experimental study. Out of a total of 10 predictions, eight were put to an empirical test, four were supported, two were clearly falsified, and mitigated evidence was found for the remaining two (table 30).

Table 30: Result of the hypotheses-tests of Hobbes, Rousseau and Smith related to the use and the allocation of natural resources.

Scholar	Study	Prediction	Result
Hobbes	Natural resource use (chapter 7)	Leviathan: Sustainable natural resource use can only be implemented in a state property regimes	Falsified
Rousseau	Natural resource use (chapter 7)	General will: Sustainable natural resource use is best implemented in a communal property regime	Supported
Rousseau	Natural resource use (chapter 7)	General will: The sustainability of natural resource use increases with the salience of a moral rule regulating its offer or demand	Supported
Smith	Natural resource use (chapter 7)	Invisible hand: Natural resource use increases with the extent of the market	Ambiguous evidence. No overall market effect but effect varying depending on the resource
Smith	Natural resource use	Invisible hand: Natural resource use increases with the extent of the market	Not tested
Hobbes	Natural resource allocation	Leviathan: The fair allocation of natural resources is only possible under the auspice of a coercive authority opting for such an allocation	Not tested
Rousseau	Fair natural resource allocation (chapter8)	General will: The fairness of the allocation of a natural resource decreases with increasing income inequality of a society	Falsified
Rousseau	Fair natural resource allocation (chapter8)	General will: The fairness of the allocation of a natural resource increases with the ethnic homogeneity of a society	Supported
Smith	Fair natural resource allocation (chapter8)	Invisible hand: The fairness of the allocation of a natural resource increases with the extent of the market integration of a society	Supported
Smith	Fair natural resource allocation (chapter8)	Invisible hand: The fairness of the allocation of a natural resource increases with the transparency of the behavir of individuals responsible for the allocation of the resource	Ambiguous evidence. No overall effect of observation. Effect varies depending on the society

9.2 Incorporating the social environment when studying human behaviour

The results of my work clearly highlight the use of the works of Hobbes, Rousseau, and Smith in understanding drivers of human behaviour. I showed that the work of Hobbes, Rousseau, and Smith could be used to understand human behaviour in situations that were not conceived by the authors and in types of societies they did not know. They lacked all the investigative and analytical tools of contemporary science (chapter 5), but their work still allowed to deduce valuable predictions that proved to be true. Most importantly, they focused on social institutions (the state, the property, the social norms, and the market) to explain differences between humans. My results strongly support the idea that the social environment is essential to understand human behaviour. Without considering the social environment, we would have missed the most important aspects of the way the people in the study area used and shared natural resources (chapters 7 and 8). This puts in question pure labouratory approaches that deliberately fade out the social environment of the subjects. Instead, a cross-cultural, empirical and quantitative approach, intentionally including variations in the social environment within the study sample, should be followed when studying human behaviour. Such an approach has prominent advocates (section 5.1) and I believe to have successfully applied it in this work.

In some instances, however, the results of my studies did falsify predictions derived from the classical scholars. Interestingly, this was the case for the two predictions I assumed to be the most straightforward and widely accepted. First, wild mammals were less abundant in protected areas under state property regimes than in areas under communal property regimes. Following Hobbes, we would expect the opposite. In fact, in his influential article “The Tragedy of the Commons”, Hardin (1968) did not even consider the communal property regime as a solution to the tragedy of the commons (section 4.3.2). Some would rightly argue that the Guinean state is not a good example for Hobbes’s Leviathan. Therefore, they would argue, the hypothesis related to the effectivity of the state property regime in protecting wild mammals was not really tested. Accordingly, the people living in the study area are in a Hobbesian state of nature, characterized by the lack of an external state authority. Interestingly, they were nevertheless able to enforce a high level of social order, contradicting Hobbes’ assumption about humans and the state of nature. No matter from which perspective the matter is considered, Hobbes is wrong in this case.

Second, fairness increased with the income inequality of the villages. Following Rousseau, we would have expected the opposite. A short google search for “income inequality destroys society” reveals that this is indeed a widely held assumption. More research is needed to uncover the mechanisms responsible for these two intriguing findings. However, it may well be that the works of the classical scholars are to some extent outdated. Even if they were right at their time, when centralized states were rare and private property restricted to a few privileged people, society has changed a lot since the classical scholars wrote their works. Now, centralized states rule over the majority of humanity and private property has spread to some extent even to the poorest people. It is, therefore, likely that individual behaviour has evolved and adapted to these massive changes in the social environment. A social theory that builds upon the different dogmatic traditions established by Hobbes, Rousseau, and Smith, and follows an eclectic paradigm could be a first step towards updating obsolete assumptions and uncovering the true human nature. Considering the sharp ideological trenches between the different disciplines in the social sciences, building such a theory would be an extremely exhausting task: while economists largely follow the tradition of Smith (Ostry et al. 2016), other social scientists are mostly adepts of Rousseau's tradition (Pinker 2002; Duarte et al. 2015). So far, there has been no fruitful dialogue between the different dogmatic camps (Lindsay et al. 2018). Instead, they live side by side (Stern 2016). However, even if the different dogmatic camps cannot be reconciled, more dogmatic diversity within the social scientific disciplines, combined with a quantitative empirical approach to scientific investigations, would still improve the quality of the scientific output by reducing bias in general (Duarte et al. 2015).

9.3 Drivers of sustainable natural resource use

The results of my two empirical studies (chapter 7 and 8) revealed some interesting findings related to the question of how to reach sustainability in natural resources use. This question is of high relevance, considering its importance for the future well-being of humanity (chapter 4). First, it seems that a normative solution, combined with a communal property regime, could be a promising approach to reach sustainability targets. This follows from the positive effect of the food taboos and the communal property regimes on the abundance of wild mammals (table 30). Second, the applicability of such a normative approach is strongly influenced by the social environment. This follows from the substantial effects of the market integration, the ethnic homogeneity, the income inequality, the population size, and the kinship of the villages on fairness (figure 56). Finally, the market mechanism can help reaching sustainability targets by providing a substitute for a given natural resource. This follows from the effect of the market integration on the abundance of wild mammal species. For some species, the effect was positive, providing a substitute for the species products, decreasing the economic pressure on these species and increasing their abundance. For others, the effect was negative, providing additional incentives to exploit these species and thereby decreasing their abundance. The rest of the species were only marginally affected by the market integration (figure 50). On the small geographical and time scale of my empirical studies, these results clearly help understanding how humans use natural resources. This understanding can then be used to work out pragmatic and comprehensive strategies for the conservation of wild mammals in the study area. But can these findings in some ways help understanding and solving global environmental problems?

9.4 Species loss and global warming

In order to put my findings in a global context, I will focus on two major global environmental challenges. First, the living planet report 2016 revealed that overall vertebrate population abundance of wild species declined by 58% from 1970 to 2012 (Oerlemans 2016, p. 18). The decline in wild species was ongoing since then, with overall vertebrate population abundance of wild species declining by 60% from 1970 to 2014. The decline consisted of 89% for South and Central American animal species and 83% for freshwater species (Grooten and Almond 2018, p. 8). It is obvious that this ongoing decline will eventually lead to the loss of most wild species at some point in the future, with unpredictable negative consequences for human well-being.

Second, the Intergovernmental Panel on Climate Change (IPCC) published its report on Global Warming of 1.5 degree in October 2018. According to the IPCC, human activities (figure 58) have led to an increase in global average annual temperature by 1 degree above pre-industrial levels (Masson-Delmotte et al. 2018, p. 6).

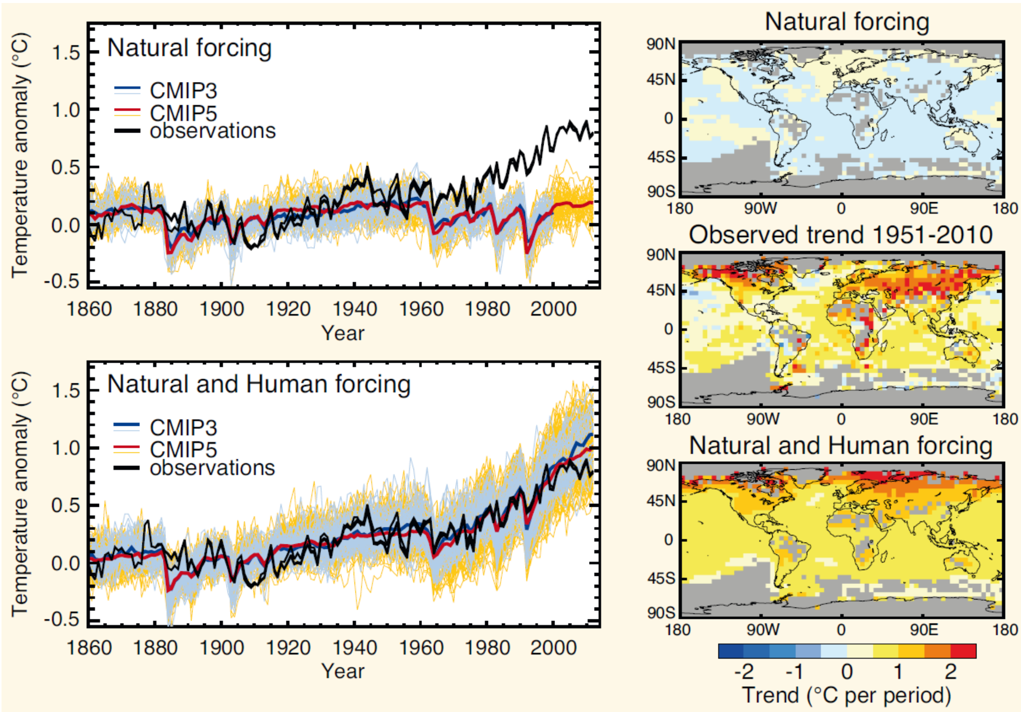

Figure 58: Pattern and explanation of climate change (the figure and the following legend are from Bindoff et al. 2013, p. 29).

(Left) Time series of global and annual-averaged surface temperature change from 1860 to 2010. The top left panel shows results from two ensemble of climate models driven with just natural forcings, shown as thin blue and yellow lines; ensemble average temperature changes are thick blue and red lines. Three different observed estimates are shown as black lines. The lower left panel shows simulations by the same models, but driven with both natural forcing and human-induced changes in greenhouse gases and aerosols. (Right) Spatial patterns of local surface temperature trends from 1951 to 2010. The upper panel shows the pattern of trends from a large ensemble of Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations driven with just natural forcings. The bottom panel shows trends from a corresponding ensemble of simulations driven with natural + human forcings. The middle panel shows the pattern of observed trends from the Hadley Centre/Climatic Research Unit gridded surface temperature data set 4 (HadCRUT4) during this period.

At current rate, global warming is expected to reach 1.5 degree between 2030 and 2052. Eventually, global warming will then reach levels of 2 degrees or more at some point of time if the current trend keeps going on. This will have consequences for human and natural systems. Climate-related risks will be lowest if the warming stays below 1.5 degree and highest if it reaches 2 degrees. Global warming above 2 degrees will lead to unpredictable outcomes. Climate-related risks include increases in the intensity and/or frequency of droughts, increases in the frequency of extreme heats, increases in the frequency of heavy precipitation and flood hazards, rising global sea level, loss and degradation of ecosystems and habitats, increases in forest fires, spread of invasive species, thawing of permafrost areas, loss of coastal resources, decrease in marine productivity, loss of marine and coastal ecosystems, loss of species, migration of species as well as melting and even loss of arctic ice cover (Masson-Delmotte et al. 2018, pp. 6-10). In summary, earth will become a much less pleasant place for humans, strongly affecting the well-being of humans and the functioning of human societies. According to the IPCC, these negative consequences can only be prevented if humans radically change their lifestyle:

> "Reaching and sustaining net zero global anthropogenic CO2 emissions and declining net non-CO2 radiative forcing would halt anthropogenic global warming on multi-decadal time scales (high confidence). The maximum temperature reached is then determined by cumulative net global anthropogenic CO2 emissions up to the time of net zero CO2 emissions (high confidence) and the level of non-CO2 radiative forcing in the decades prior to the time that maximum temperatures are reached (medium confidence). On longer time scales, sustained net negative global anthropogenic CO2 emissions and/ or further reductions in non-CO2 radiative forcing may still be required to prevent further warming due to Earth system feedbacks and to reverse ocean acidification (medium confidence) and will be required to minimize sea level rise (high confidence)." (Masson-Delmotte et al. 2018, p. 7)

9.5 CITES and EU ETS: solutions to global environmental problems

The fact that biodiversity loss and greenhouse gas emissions pose a serious threat to human well being has been widely acknowledged by the public opinion and the global political elite. As a result, institutional arrangements have been implemented to tackle these issues.

The Convention on International Trade in Endangered Species of Wild Fauna and Flaura (CITES), for example, was created in order to ensure the sustainability of international trade in wild flora and fauna (CITES 2018*d*). To reach this goal, member states of CITES are supposed to regulate their trade according to the guidelines defined in CITES. These guidelines regulate trade in wild species by first determining a threat level for each species. Species listed in appendix 1 are threatened with extinction. Their trade is allowed only under special circumstances. Species listed in appendix 2 are potentially threatened and trade should therefore be limited. Species listed in appendix 3 are protected in at least one member state. CITES supports the member states in regulating international trade in the protected species. International trade in species listed in CITES appendices relies on authorization given by CITES through a licensing system. All member states are responsible for the management and the enforcement of CITES (CITES 2018*b*). CITES entered into force in 1975 (CITES 2018*e*) and had 183 member states in November 2018 (CITES

2018*c*). While an average of 9 million whole organism equivalents (WOEs) were legally traded under CITES from 1975 to 1985, this figure went up to 100 million WOEs between 2005 and 2014. Overall, the trade shifted from a majority of products captured in the wild to a majority of products bred in captivity. 81.5% of transactions, products and quantities cited by the exporters matched with the products and quantities cited by the importers. In summary, although the trade in wild species products increased sharply since CITES entered into force, there was also a shift from wild- towards more captive sourced wildlife products (Harfoot et al. 2018, pp. 50-55). But what is the impact of CITES on the protection of wild species from threats occuring through global trade? Case studies can help finding an answer to this question. Pangolins had been classified in CITES appendix 2 from 1978 to 2000. During this period, trade in pangolins reported to CITES involved an annual average of about 23,418 animals. For the period between July 2000 and 2013, after pangolins were classified in CITES appendix 1, seizures in illegal trade amounted to an annual average of about 16,269 animals. Considering that these seizures only represent a small part of the illegal trade, the true extent of the illegal trade should be much larger (Challender et al. 2015, pp. 252-253). For pangolins, it seems that CITES did not succeed in limiting trade. Trade in pangolins simply shifted from a legal to an illegal sphere. A second case study focuses on the effect of CITES trade regulation on the exploitation of hammerhead sharks and whitetip sharks in India. These two species were listed in the CITES 2 appendix in September 2014 (Zacharia et al. 2017, p. iii). Indian landings of hammerhead sharks did not decrease substantially after their listings as CITES appendix 2 species. The same applies to whitetip sharks (Zacharia et al. 2017, pp. 20-27). In the case of these two shark species, CITES listing did not reduce their exploitation. Finally, let us look at the international trade in African grey parrots, a species listed in the CITES appendix 2 since June 1981 (CITES 2018*a*). The most important exporter of African grey parrots, the Democratic Republic of the Congo, exported 86,744 African grey parrots from 2005 to 2014. These were 26,744 more than permitted by the CITES (Poole and Shepherd 2017, p. 416). Even when export permits for vulnerable species are granted generously by considering the economic importance for the member states, members states can still exceed the quota without suffering any serious consequences. So what is the conclusion regarding CITES trade regulation now? Of course, it is not possible to know how the wildlife would have evolved without CITES. For some species, the situation would surely be worse now. However, on average, I would conclude that CITES failed so far in protecting wild species from the threats of international trade, because the legal trade increased since the implementation of CITES. Surley, trade in wildlife could also have increased due to increased wildlife abundance, but this it is highly unlikely.

The European Union Emissions Trading System (EU ETS) entered into force in 2005. The EU ETS is the main tool developed by the EU to combat climate change. It operates in 31 countries (Lichtenstein, Norway, Iceland plus all 28 EU countries), limits the emissions of more than 11,000 industrial plants and power stations as well as airlines operating within these countries, and covers about 45% of total EU's greenhouse gas emissions. The system works by defining a total amount of emissions allowed for the companies covered by the system. This is the cap. The cap is supposed to decrease over time. Companies receive or buy emission allowances and can trade these. At the end of each year, the emissions of a company are compared with their emission allowances. If the actual emissions surpass the emission allowances, heavy fines are imposed. Otherwise, the companies can keep their emission allowances for the future or sell them. The target set by the EU is to reduce EU emissions, compared to 2005, by 21% in 2020 and by 43% in 2030 (European Commission 2018). At first glance, the EU seems to have succeeded so far in reducing emissions. In 2016, the EU emissions declined by about 18% compared to 2005 (European Commission 2017, p. 4, own calculations). However, looking at the per capita emissions in the EU, we see that they only decreased marginally from 1990 to 2012 (European Commission 2017, p. 5). At the same time, global emissions even increased by 18% between 2005 and 2014 (Boden et al. 2017, own calculations). Considering that the EU ETS was primarily developed to combat global climate change, the figures cited suggest that it has failed so far.

9.6 Reasons for the failure of CITES and EU ETS

The broad literature on CITES and EU ETS discusses numerous reasons possibly responsible for the failure of CITES and EU ETS to reach their targets (Challender et al. 2015; Fan et al. 2017; Grosjean 2017; Harfoot et al. 2018; Naegele and Zaklan 2017; Poole and Shepherd 2017;Sommer and Hain 2017; Segura et al. 2018; Sills 2018). Here, I am going to apply the lessons learned from my field studies on these two cases.

Let us first look at the case of the EU ETS as a tool to combat human induced global warming. Human induced global warming results mainly from the consumption of fossil fuels and the cement production of all humans worldwide (Boden et al. 2017). Structurally, this is equivalent to the abundance of wild mammals in the study area in Guinea, which is negatively affected by the exploitative activities of all humans located within the borders of the study area (chapter 7). For illustrative purpose, let us focus on wart hogs. Wart hogs were targeted by food taboos in the study area. However, not all village communities did abide to wart hog food taboos (table 22). Food taboos succeeded in limiting the exploitation of wart hogs in the study area: their abundance increased with the share of the human population abiding to wart hog food taboos (figure 51). Obviously, food taboos limit the demand for wart hog products, since Muslims abiding to the food taboo do not eat pig meat. However, focusing on wart hog food taboos alone to decrease the exploitation of wart hogs in the entire study area is no promising strategy. What about the communities not abiding to wart hog food taboos? What if they keep on exploiting wart hogs at the usual levels, or even increase their consumption?

Similarly, the EU ETS reduces the demand for fossil fuels by defining a cap, which is decreasing over time, leading to a decreased consumption of fossil fuels within the EU. However, if the rest of the world continues with business as usual, or even increases its consumption of fossil fuels, the EU ETS will only have a limited impact on the global consumption of fossil fuels. Global problems ask for global solutions. However, no binding agreement to reduce emissions has been reached yet at the global level (Clémencon 2016, p. 4). One of the main reasons for this lack of global agreement on emission reduction at the global level is the human sense of fairness. Rich and developed countries are not ready to reduce their emissions, because they feel the suggested solutions come at their expense. Bargaining outcomes that are perceived as unfair run a risk of being undermined or broken and cause conflicts (Falk et al. 2003). President Trump made this clear when he declared his intention to withdraw from the not binding Paris agreement:

> "Not only does this deal subject our citizens to harsh economic restrictions, it fails to live up to our environmental ideals. As someone who cares deeply about the environment, which I do, I cannot in good conscience support a deal that punishes the United States - which is what it does - the world's leader in environmental protection, while imposing no meaningful obligations on the world's leading polluters. For example, under the agreement, China will be able to increase the emissions by a staggering number of years – 13. They can do whatever they want for 13 years. Not us. India makes its participation contingent on receiving billions and billions and billions of dollars in foreign aid from developed countries. There are many other examples but the bottom line is that the Paris Accord is very unfair at the highest level to the United States." (Climate Analytics 2017, p. 18)

Poor and undeveloped countries, on the other hand, feel that they have to pay for the mistakes of others. This view was well summarized by Robert Mugabe at the open summit of the Paris climate change talks: "Developed countries are being miserly [...] they burden us for cleaning up the mess they have created." (Reuters 2015). In my experimental study on fair sharing (chapter 8), I showed that some village communities were able to implement a fair outcome in a situation characterized by asymmetric bargaining power. This capacity depended on the social environment of individuals within the villages that can be conceived as human groups: under favourable conditions, the social environment supports cooperative social norms, self-sacrifice, and the equalizing of individual's baragaining power, leading to fair outcomes (chapter 8). The entire humanity, however, cannot be conceived as a group in the same way. This rules out that a fair agreement to reduce the global reduction of emissions can be reached based on the adaptive mechanisms that worked within the studied village populations.

CITES goes one step further than the EU ETS system. It acknowledges that a global threat needs a global solution and has convinced most of the countries in the world to join the club. Now, for simplicity, let us consider the 183 member states of CITES as the whole world population and the wild species as the resource. CITES aims at decreasing the exploitation of the resource by limiting its trade. Structurally, this situation is comparable to the village populations exploiting wild mammals within the study area in Guinea. Furthermore, let us consider the listing of one species in CITES appendix 1 as a form of taboo to trade the respective species. In my work, I showed that food taboos worked as a tool to decrease the exploitation of a species (figure 51). However, market mechanisms nevertheless still applied in the study area: while the abundance of wart hogs increased with the share of the population abiding to wart hog food taboos (food taboos decrease the local demand), at the same time, the abundance of wart hogs decreased with the market integration of the population (incentives to exploit wart hogs increase with the market driven demand) (figures 51 and 50). It seems that moral values and market incentives interact: "[...] market interaction displays a tendency to lower moral values [...]" (Falk and Szech 2013, p. 710).

Strictly speaking, when a new species is listed in CITES appendix 1, no new moral value is created. Instead, a new law enters into force. Unfortunately, market interactions also display a tendency to counteract the rule of laws. This is best exemplified with the failure of the global "war on drugs". Despite policies implementing severe and restrictive laws penalizing the production and the consumption of drugs over the last decades, the global area used to cultivate opium poppy doubled from 2006 to 2017, the global area used to cultivate coca bush increased by 76% from 2000 to 2013 (United Nations Office on Drugs and Crime 2018, p. 28) and the estimated number of users of illegal drugs reached its historical peak in 2016 with 275 million people (United Nations Office on Drugs and Crime 2018, p. 11). Normative and/or legal rules alone will always fail to decrease the exploitation of a resource, when not considering alternatives to satisfy the demand, or even means to decrease the demand for the resource in question: institutional limitations in exploitation (supply) will lead to higher prices if the demand persists. These higher prices will then lead to an increased supply on the black market. Criminal organizations will always find ways to supply the demand if the price is high enough. These remarks corroborate the findings of Challender et al 2015 for the failure of CITES to decrease the trade in pangolin products:

> "[...] CITES lacks a responsive mechanism through which to consider and act on these market dynamics. For instance, price data are not recorded in CITES. Although rising prices for pangolin products and suspected population declines were recorded in the RST process, this mechanism does not comprise an in-depth assessment of markets, and nor does it formulate interventions to address them, at least in demand terms. As Asian pangolins demonstrate, the remedial measures formulated for these species did nothing to address demand directly. However, these price trends are extremely worrying because where similar price increases have been observed for other rare species; they have been inversely correlated to population size" (Challender et al. 2015, p. 256).

According to the insights gained in my field work in Guinea, the failures of CITES and EU ETS to target the global environmental problems of species loss and global warming are basically threefold: first, global problems need global solutions, and humanity has not been able to agree on globally binding agreements; second, the inability to agree on globally binding agreements is due to the fact that the whole humanity does not function like a human group, blessed with means to foster prosociality and overcome social dilemma; third, the adaptations and measures necessary to tackle the issues of global warming and species loss would have serious effects on the supply and demand of crucial natural resources. All institutional solutions to the problems of species loss and global warming need to either find substitutes for the natural resources in question, or to reduce the demand for these resources. If not, any effort done in the right direction will be counteracted by the market mechanism. In summary, global environmental issues are true problems of social order and the institutional arrangements built to deal with these issues are not up to the job.

Chapter 10

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Bibliography

Africa is a Country (2013), 'Elections and ethnicity in guinea'.
URL: *http://africasacountry.com/2013/09/elections-and-ethnicity-in-guinea/*

Ahn, T. K., Ostrom, E. and Walker, J. (2011), 'Reprint of: A common-pool resource experiment with postgraduate subjects from 41 countries', *Ecological Economics* **70**, 1580–1589.

Alesina, A., Baqir, R. and Easterly, W. (1999), 'Public goods and ethnic divisions', *The Quarterly Journal of Economics* **114**(4), 1243–1284.

Alesina, A. and Ferrara, E. L. (2000), 'Participation in heterogeneous communities', *The Quarterly Journal of Economics* **115**(3), 847–904.

Alroy, J. (2001), 'A multispecies overkill simulation of the end-pleistocene megafaunal mass extinction', *Science* **292**(8), 1893–1896.

Alvard, M. S. (2003), 'Kinship, lineage, and an evolutionary perspective on cooperative hunting groups in indonesia', *Human Nature* **14**(2), 129–163.

Anderson, C. J. and Paskeviciute, A. (2006), 'How ethnic and linguistic heterogeneity influence the prospects for civil society: a comparative study of citizenship behavior', *Journal of Politics* **68**, 783–802.

Anderson, L. R., Mellor, J. M. and Milyo, J. (2008), 'Inequality and public good provision: An experimental analysis', *Journal of Socio-Economics* **37**, 1010–1028.

André, J. B. and Baumard, N. (2011*a*), 'The evolution of fairness in a biological market', *Evolution* **65**(5), 1447–1456.

André, J. B. and Baumard, N. (2011*b*), 'Social opportunities and the evolution of fairness', *Journal of Theoretical Biology* **289**, 128–135.

Apicella, C. L., Marlowe, F. W., Fowler, J. H. and Christakis, N. A. (2012), 'Social networks and cooperation in hunter-gatherers', *Nature* **481**, 497–502.

Axelrod, R. (1980), 'More effective choice in the prisoner's dilemma', *Journal of Conflict Resolution* **24**(3), 379–403.

Ayalew, B., Afework, B. and Balakrishnan, M. (2013), 'Home range and movement patterns of african civet civettictis civetta in wondo genet, ethiopia', *Small Carnivore Conservation* **48**, 83–86.

Baayen, R. H. (2008), *Analyzing linguistic data*, Cambridge University Press.

Baldassarri, D. and Grossman, G. (2011), 'Centralized sanctioning and legitimate authority promote cooperation in humans', *Proceedings of the National Academy of Sciences* **108**(27), 11023–11027.

Balée, W. (1985), 'Ka'apor ritual hunting', *Human Ecology* **4**, 485–510.

Banerjee, A. V. and Duflo, E. (2011), *Poor Economics a Radical Rethinking of the Way to Fight Global Poverty*, Public Affairs.

Barbier, E. B. (2005), 'Natural resource-based economic development in history', *World Economics* **6**(3), 103–152.

Barbier, E. B. (2011), *Scarcity and Frontiers: How Economies Have Developed Through Natural Resource Exploitation*, Cambridge University Press.

Barnett, A. A. and Prangley, M. L. (1997), 'Mammalogy in the republic of guinea: an overview of research from 1946 to 1996, a preliminary check-list and a summary of research recommendations for the future', *Mammal Review* **27**(3), 115–164.

Barnosky, A. D., Koch, P. L., Feranec, R. S., Wing, S. L. and Shabel, A. B. (2004), 'Assessing the causes of late pleisocene extinctions on the continents', *Science* **306**, 70–75.

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O. U., Swartz, B., Quental, T. B., Marshall, C., McGuire, J. L., Lindsey, E. L., Maguire, K. C., Mersey, B. and Ferrer, E. A. (2011), 'Has the earth's sixth mass extinction already arrived?', *Nature* **471**, 51–57.

Barr, D. J., Levy, R., Scheepers, C. and Tily, H. J. (2013), 'Random effects structure for confirmatory hypothesis testing: Keep it maximal', *Journal of Memory and Language* **68**, 255–278.

Bates, D., Mächler, M., Bolker, B. and Walker, S. (2015), 'Fitting linear mixed-effects models using lme4', *Journal of Statistical Software* **67**(1), 1–48.

Bendor, J. and Swistak, P. (2001), 'The evolution of norms', *American Journal of Sociology* **106**(6), 1493–1545.

Bennett, E. L. (2002), 'Is there a link between wild meat and food security?', *Conservation Biology* **16**(3), 590–592.

Bereczkeit, T., Birkas, B. and Kerekes, Z. (2007), 'Public charity offer as a proximate factor of evolved reputation-building strategy: an experimental analysis of a real-life situation', *Evolution and Human Behavior* **28**, 277–284.

Bereczkeit, T., Birkas, B. and Kerekes, Z. (2010), 'Altruism towards stragers in need: costly signaling in an industrial society', *Evolution and Human Behavior* **31**, 95–103.

Bergstrom, T. C. (2002), 'Evolution of social behavior: individual and group selection', *Journal of Economic Perspectives* **16**(2), 67–88.

Berkowitz, D. and Li, W. (2000), 'Tax rights in transition economies: a tragedy of the commons?', *Journal of Public Economics* **76**, 369–397.

Berman, J. J., Murphy-Berman, V. and Singh, P. (1985), 'Cross-cultural similarities and differences in perceptions of fairness', *Journal of Cross-Cultural Psychology* **16**(1), 55–67.

Bindoff, N. L., Stott, P. A., AchutaRao, K. M., Allen, M. R., Gillett, N., Gutzler, D., Hansingo, K., Hegerl, G., Hu, Y., Jain, S., Mokhov, I. I., Overland, J., Perlwitz, J., Sebbari, R. and Zhang, X. (2013), Detection and attribution of climate change: from global to regional, *in* T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley, eds, 'Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change', Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Binmore, K. (1994), *Playing fair: game theory and the social contract, volume 1*, Massachusetts Institute of Technology Press.

Birrell, J. (1992), 'Deer and deer farming in medieval england', *The Agricultural History Review* **40**(2), 112–126.

Black, D. (1948), 'On the rationale of group decision-making', *The Journal of Political Economy* **56**(1), 23–34.

Boden, T. A., Marland, G. and Andres, R. J. (2017), 'Global, regional, and national fossil-fuel co2 emissions'.

Bolker, B. (2007), *Ecological Models and Data in R*, Princeton University Press.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H. and White, J. S. S. (2009), 'Generalized linear mixed models: a practical guide for ecology and evolution', *Trends in Ecology & Evolution* **24**(3), 127–135.

Bothwell, L. E., Greene, J. A., Podolsky, S. H. and Jones, D. S. (2016), 'Assessing the gold standard - lessons from the history of rcts', *The New England Journal of Medicine* **374**(22), 2175–2181.

Boyd, R., Gintis, H. and Bowles, S. (2010), 'Coordinated punishment of defectors sustains cooperation and can proliferate when rare', *Science* **328**, 617–620.

Boyd, R. and Lorberbaum, J. P. (1987), 'No pure strategy is evolutionarily stable in the repeated prisoner's dilemma game', *Nature* **327**, 58–59.

Boyd, R. and Richerson, P. J. (1992), 'Punishment allows the evolution of cooperation (or anything else) in sizeable groups', *Ethology and Sociobiology* **13**, 171–195.

Boyd, R. and Richerson, P. J. (1996), 'Why culture is common, but cultural evolution is rare', *Proceedings of the British Academy* **88**, 77–93.

Boyd, R., Richerson, P. J. and Henrich, J. (2011), 'The cultural niche: Why social learning is essential for human adaptation', *Proceedings of the National Academy of Sciences* **108**(2), 10918–10925.

Brander, J. A. and Taylor, M. S. (1998), 'The simple economics of easter island: A ricardo-malthus model of renewable resource use', *The American Economic Review* **88**(1), 119–138.

Brashares, J. S., Golden, C. D., Weinbaum, K. Z., Barrett, C. B. and Okello, G. V. (2011), 'Economic and geographic drivers of wildlife consumption in rural africa', *Proceedings of the National Academy of Sciences of the United States of America* **108**(34), 13931–13936.

Breitburg, D., Levin, L. A., Oschlies, A., Grégoire, M., Chavez, F. P., Conley, D. J., Garçon, V., Gilbert, D., Gutiérrez, D., Isensee, K., Jacinto, G. S., Limburg, K. E., Montes, I., Naqvi, S. W. A., Pitcher, G. C., Rabalais, N. N., Roman, M. R., Rose, K. A., Seibel, B. A., Telszewski, M., Yasuhara, M. and Zhang, J. (2018), 'Declining oxygen in the global ocean and coastal waters', *Science* **359**(46), 1–11.

Briceno-Linares, J. M., Rodriguez, J. P., Rodriguez-Clark, K. M., Rojas-Suarez, F., Millan, P. A., Vittori, E. G. and Carrasco-Munoz, M. (2011), 'Adapting to changing poaching intensity of yellow-shouldered parrot (amazona barbadensis) nestlings in margarita island, venezuela', *Biological Conservation* **144**, 1188–1193.

Brncic, T., Amarasekaran, B., McKenna, A., Mundry, R. and Kühl, H. S. (2015), 'Large mammal diversity and their conservation in the human-dominated land-use mosaic of sierra leone', *Biodiversity and Conservation* **24**(10), 2417–2438.

Brosnan, S. F. and deWaal, F. B. M. (2014), 'Evolution of responses to (un)fairness', *Science* **346**(6207), 1–7.

Bruederl, J. and Ludwig, V. (2015), Fixed-effects panel regression, *in* H. Best and C. Wolf, eds, 'The SAGE Handbook of Regression Analysis and Causal Inference', SAGE Publications Ltd, London, chapter 15, pp. 327–357.

Brugiere, D. and Kormos, R. (2009), 'Review of the protected area network in guinea, west africa, and recommendations for new sites for biodiversity conservation', *Biodiversity and Conservation* **18**, 847–868.

Bruner, A. G., Gullison, R. E., Rice, R. E. and da Fonseca, G. A. B. (2001), 'Effectiveness of parks in protecting tropical biodiversity', *Science* **291**, 125–128.

Bryan, M. L. and Jenkins, S. P. (2016), 'Multilevel modelling of country effects: A cautionary tale', *European Sociological Review* **32**(1), 3–22.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2001), *Introduction to distance sampling estimating abundance of biological populations*, Oxford University Press.

Bull, R. and Gibson-Robinson, E. (1981), 'The influences of eye-gaze, style of dress, and locality on the amounts of money donated to a charity', *Human Relations* **34**(10), 895–905.

Bulmer, M. G. (1979), *Principles of statistics*, Dover Publications.

Bundesministerium fuer Umwelt, Naturschutz und nukleare Sicherheit (2018), 'Antwort der bundesregierung auf die kleine anfrage: Biodiversitaet in und an fluessen'.

Burnham, K. P. and Anderson, D. R. (1998), *Model Selection and Multimodel Inference*, Springer.

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Morcillo, M. H., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A., Tierney, M., Tyrrell, T. D., Vié, J.-C. and Watson, R. (2010), 'Global biodiversity: Indicators of recent declines', *Science* **328**, 1164–1168.

Cade, B. S. (2015), 'Model averaging and muddled multimodel inference', *Ecology* **96**(9), 2370–2382.

Camerer, C. (2003), *Behavioral game theory; experiments in strategic interaction*, Princeton University Press.

Campbell, B. and Clapp, J. (1995), 'Guinea's economic performance under structural adjustment: importance of mining and agriculture', *Journal of Modern African Studies* **33**(3), 425–449.

Campbell, L. M. and Vainio-Mattila, A. (2003), 'Participatory development and community-based conservation: opportunities missed for lessons learned?', *Human Ecology* **31**(3), 417–437.

Cantrelle, P. and Dupire, M. (1964), 'L'endogamie des peul du fouta-djallon', *Population* **3**, 529–558.

Cason, T. N. and Mui, V. L. (1998), 'Social influence in the sequential dictator game', *Journal of Mathematical Psychology* **42**, 248–265.

Challender, D. W. S., Harrop, S. R. and MacMillan, D. C. (2015), 'Understanding markets to conserve trade-threatened species in cites', *Biological Conservation* **187**, 249–259.

Chammaillé-Jammes, S., Valeix, M. and Fritz, H. (2007), 'Managing heterogeneity in elephant distribution: interactions between elephant population density and surface-water availability', *Journal of Applied Ecology* **44**(3), 625–633.

Chardonnet, P., des Clers, B., Fischer, J., Gerhold, R., Jori, F. and Lamarque, F. (2002), 'The value of wildlife', *Scientific and Technical Review of the Office International des Epizooties* **21**(1), 15–51.

Chaves, L. F. (2010), 'An entomologist guide to demystify pseudoreplication: Data analysis of field studies with design constraints', *Journal of Medical Entomology* **47**(3), 291–298.

Chazdon, R. L., Harvey, C. A., Komar, O., Griffith, D. M., Ferguson, B. G., Martínez-Ramos, M., Nigh, H. M. R., Sonto-Pinto, L., Breugel, M. V. and Philpott, S. M. (2009), 'Beyond reserves: a research agenda for conserving biodiversity in human-modified tropical landscapes', *Biotropica* **41**(2), 142–153.

Chiang, Y. S. (2008), 'Preferential association and the evolution of strategies in the ultimatum game', *Rationality and Society* **20**(2), 173–201.

CITES (2018*a*), 'Grey parrot'.
URL: *https://www.cites.org/eng/gallery/species/bird/grey$_p$arrot.html*

CITES (2018*b*), 'How cites works'.
URL: *https://www.cites.org/eng/disc/how.php*

CITES (2018*c*), 'List of parties to the convention'.
URL: *https://www.cites.org/eng/disc/parties/index.php*

CITES (2018*d*), 'Strategic vision'.
URL: *https://cites.org/eng/documents/Strategic$_v$ision*

CITES (2018*e*), 'What is cites'.
URL: *https://www.cites.org/eng/disc/parties/index.php*

Claidière, N., Scott-Phillips, T. C. and Sperber, D. (2014), 'How darwinian is cultural evolution', *Philosophical Transactions of the Royal Society B* **369**, 1–8.

Clark, K., Kay, S. and Sefton, M. (2001), 'When are nash equilibria self-enforcing? an experimental analysis', *International Journal of Game Theory* **29**, 495–515.

Climate Analytics (2017), 'Speech by president trump on the paris agreement'.
URL: *https://climateanalytics.org/media/fact$_c$heck$_t$rump$_p$a$_w$ithdrawal$_a$nnouncement.pdf*

Clémencon, R. (2016), 'The two sides of the paris climate agreement: Dismal failure or historic breakthrough?', *Journal of Environment & Development* **25**(1), 3–24.

Clutton-Brock, T. H. and Parker, G. A. (1995), 'Punishment in animal societies', *Nature* **373**, 209–216.

Coase, R. H. (1960), 'The problem of social cost', *Journal of Law & Economics* **3**, 1–44.

Cohen, J. E. (1995), 'Population growth and earth's human carrying capacity', *Science* **269**, 341–346.

Costa, D. L. and Kahn, M. E. (2003), 'Cowards and heroes: group loyalty in the american civil war', *The Quarterly Journal of Economics* **118**(2), 519–548.

Court, V. and Fizaine, F. (2017), 'Long-term estimates of the energy-return-on-investment (eroi) of coal, oil, and gas global productions', *Ecological Economics* **138**, 145–159.

Craigie, I. D., Bailiie, J. E. M., Balmford, A., Carbone, C., Collen, B., Green, R. E. and Hutton, J. M. (2010), 'Large mammal population declines in africa's protected areas.', *Biological Conservation* **143**, 2221–2228.

Cressey, D. (2016), 'The plastic ocean', *Nature* **536**, 263–265.

Cronk, L. (2007), 'The influence of cultural framing on play in the trust game: A maasai example', *Evolution and Human Behavior* **28**, 352–358.

Cully, M. (2014), 'The politics of antibiotics', *Nature* **509**, 16–17.

Daly, M. and Wilson, M. (1988), 'Evolutionary social psychology and family homicide', *Science* **242**(4878), 519–524.

Davies, G. (2002), 'Bushmeat and international development', *Conservation Biology* **16**(3), 587–589.

de Almeida, P. and Silva, P. D. (2009), 'The peak of oil production—timings and market recognition', *Energy Policy* **37**, 1267–1276.

de Groot, R. S., Wilson, M. A. and Boumans, R. M. J. (2002), 'A typology for the classification, description and valuation of ecosystem functions, goods and services', *Ecological Economics* **41**, 393–408.

de Quervain, D. J. F., Fischbacher, U., Treyer, V., Schellhammer, M., Schnyder, U., Buck, A. and Fehr, E. (2004), 'The neural basis of altruistic punishment', *Science* **305**.

Deaton, A. (2017), 'Understanding and misunderstanding randomized controlled trials'.
URL: *https://doi.org/10.1016/j.socscimed.2017.12.005*

Debove, S., André, J. B. and Baumard, N. (2015), 'Partner choice creates fairness in humans', *Proceedings of the Royal Society of London B* **282**, 1–7.

Debove, S., Baumard, N. and André, J. B. (2016), 'Models of the evolution of fairness in the ultimatum game: a review and classification', *Evolution and Human Behavior* **37**, 245–254.

DeGama-Blanchet, H. N. and Fedigan, L. M. (2006), The effects of forest fragment age, isolation, size, habitat type, and water availability on monkey density in a tropical dry forest, *in* A. Estrada, P. Garber, M. Pavelka and L. Luecke, eds, 'New perspectives in the study of Mesoamerican primates: distribution, ecology, behavior and conservation', Kluwer Academic/Plenium Publishers, New York, chapter 6, p. 165–188.

Develey, P. F. and Stouffer, P. C. (2001), 'Effects of roads on movements by understory birds in mixed-species flocks in central amazonian brazil', *Conservation Biology* **15**(5), 1416–1422.

Diamond, J. (2005), *Collapse: How Societies Choose to Fail or Succeed*, Penguin Books.

Diekman, A. (2004), ‘The power of reciprocity: Fairness, resiprocity, and stakes in variants of the dictator game’, *Journal of Conflict Resolution* **48**(4), 487–505.

Druckman, J. N., Green, D. P., Kuklinski, J. H. and Lupia, A. (2006), ‘The growth and development of experimental research in political science’, *American Political Science Review* **100**(4), 627–635.

Du, X. and Graedel, T. E. (2011), ‘Global in-use stocks of the rare earth elements: A first estimate’, *Environmental Science & Technology* **45**, 4096–4101.

Duarte, J. L., Crawford, J. T., Stern, C., Haidt, J., Jussim, L. and Tetlock, P. E. (2015), ‘Political diversity will improve social psychological science’, *Behavioral And Brain Science* pp. 1–58.

EBCC (2017), ‘Latest update of european wild bird indicators confirms continued decline of farmland birds’.
URL: *https://www.ebcc.info/index.php?ID=639*

Elias, N. (1997 [1939]), *Über den Prozeß der Zivilisation 2*, Suhrkamp Taschenbuch Verlag.

Elith, J. and Leathwick, J. R. (2009), ‘Species distribution models: ecological explanation and prediction across space and time’, *Annual Review of Ecology, Evolution, and Systematics* **40**(1), 677–697.

Ellis, D. P. (1971), ‘The hobbesian problem of order: a critical appraisal of the normative solution’, *American Sociological Review* **36**(4), 692–703.

Estes, R. D. (1991), *The behaviour guide to African mammals*, University of California Press.

European Commission (2017), ‘Two years after paris – progress towards meeting the eu’s climate commitments’.

European Commission (2018), ‘Eu emissions trading system (eu ets)’.
URL: *https://ec.europa.eu/clima/policies/ets$_e$n*

Falk, A., Fehr, E. and Fischbacher, U. (2003), ‘Reasons for conflict: Lessons from bargaining experiments’, *Journal of Institutional and Theoretical Economics* **159**, 171–187.

Falk, A. and Szech, N. (2013), ‘Morals and markets’, *Science* **340**, 707–711.

Fan, Y., Jia, J. J., Wang, X. and Xu, J. H. (2017), ‘What polica adjustments in the eu ets truly affected the carbon prices’, *Energy Policy* **103**, 145–164.

Farrington, D. P. and Welsh, B. C. (2005), ‘Randomized experiments in criminology: What have we learned in the last two decades’, *Journal of Experimental Criminology* **1**, 9–38.

Faysse, N. (2005), ‘Coping with the tragedy of the commons: Game structure and design of rules’, *Journal of Economic Surveys* **19**(2), 239–261.

Federal Ministry of Education and Research (2017), 'New sources of raw materials in nature'. **URL:** *http://www.research-in-germany.org/en/infoservice/newsletter/newsletter-2017/july-2017/new-sources-of-raw-materials-in-nature.htmlie=utf-8oe=utf-8client=firefox-b-ab*

Feeny, D., Berkes, F., McCay, B. J. and Acheson, J. M. (1990), 'The tragedy of the commons: Twenty-two years later', *Human Ecology* **18**(1), 1–19.

Fehr, E. and Fischbacher, U. (2003), 'The nature of human altruism', *Nature* **425**(6960), 785–791.

Fehr, E. and Fischbacher, U. (2004), 'Third-party punishment and social norms', *Evolution and Human Behavior* **25**, 63–87.

Fehr, E. and Gächter, S. (2000), 'Cooperation and punishment in public goods experiments', *The American Economic Review* **90**(4), 980–994.

Fehr, E. and Gächter, S. (2002), 'Altruistic punishment in humans', *Nature* **415**, 137–140.

Field, A. (2005), *Discovering statistics using SPSS*, Sage Publications.

Fischer, M. E., Irlenbusch, B. and Sadrieh, A. (2004), 'An intergenerational common pool resource experiment', *Journal of Environmental Economics and Management* **48**, 811–836.

Forber, P. and Smead, S. (2014), 'The evolution of fairness through spite', *Proceedings of the Royal Society of London B* **281**, 1–8.

Forstmeier, W. and Schielzeth, H. (2011), 'Cryptic multiple hypotheses testing in linear models: overestimated effect sizes and the winner's curse', *Behavioral Ecology and Sociobiology* **65**, 47–55.

Fox, J. and Petchey, O. L. (2010), 'Pubcreds: Fixing the peer review process by "privatizing" the reviewer commons', *Bulletin of the Ecological Society of America* **91**(2), 325–333.

Fox, J. and Weisberg, S. (2011), *An R companion to applied regression*, Sage Publications, Inc., Thousand Oaks.

Freedman, D. A. (2008), 'On regression adjustments to experimental data', *Advances in Applied Mathematics* **40**, 180–193.

Friedman, D. and Singh, N. (2001), 'Evolution and negative reciprocity'.

Fürtbauer, I., Mundry, R., Heistermann, M., Schülke, O. and Ostner, J. (2011), 'You mate, i mate: macaque females synchronize sex not cycles', *PLoS ONE* **6**(10).

Futurezone (2018), 'Space mining: 10.000 asteroiden im visier von bergbau-start-up'. **URL:** *https://futurezone.at/science/space-mining-10000-asteroiden-im-visier-vom-bergbau-start-up/400004264*

Gardner, A. and West, S. A. (2004), 'Cooperation and punishment, especially in humans', *The American Naturalist* **164**(6), 753–764.

Gardner, R., Ostrom, E. and Walker, J. M. (1990), 'The nature of common-pool resource problems', *Rationality and Society* **2**(3), 335–358.

Gardner, T. A., Caro, T., Fitzherbert, E. B., Banda, T. and Lalbhai, P. (2007), 'Conservation value of multiple-use areas in east africa', *Conservation Biology* **21**(6), 1516–1525.

Gerber, A. S. and Green, D. P. (2012), *Field Experiments: Design, Analysis and Interpretation*, Norton & Company.

Gersani, M., Brown, J. S., O'Brien, E. E., Maina, G. M. and Abramsky, Z. (2001), 'Tragedy of the commons as a result of root competition', *Journal of Ecology* **89**, 660–669.

Geyer, R., Jambeck, J. R. and Law, K. L. (2017), 'Production, use, and fate of all plastics ever made', *Science Advances* **3**, 1–5.

Gintis, H., Bowlers, S., Boyd, R. and Fehr, E. (2003), 'Explaining altruistic behavior in humans', *Evolution and Human Behavior* **24**, 153–172.

Glavic, P. and Lukman, R. (2007), 'Review of sustainability terms and their definitions', *Journal of Cleaner Production* **15**, 1875–1885.

Goldewijk, K. K., Beusen, A. and Janssen, P. (2010), 'Long-term dynamic modeling of global population and built-up area in a spatially explicit way: Hyde 3.1', *The Holocene* **20**(4), 565–573.

Goldewijk, K. K., Beusen, A., van Drecht, G. and de Vos, M. (2011), 'The hyde 3.1 spatially explicit database of human-induced gloabl land use change over the past 12.000 years', *Global Ecology and Biogeography* **20**, 73–86.

Groelsema, R. J. (1998), 'The dialectics of citizenship and ethnicity in guinea', *Africa Today* **45**(3/4), 411–421.

Grooten, M. and Almond, R. E. A. (2018), 'Living planet report 2018'.

Grosjean, G. (2017), 'Reforming the european union emissions trading system (eu ets): An institutional perspective'.

Grossman, J. and Mackenzie, F. J. (2005), 'The randomized controlled trial: gold standard, or merely standard?', *Perspectives in Biology and Medicine* **48**(4), 516–534.

Guisan, A. and Thuiller, W. (2005), 'Predicting species distribution: offering more than simple habitat models', *Ecology Letters* **8**, 993–1009.

Gustavsson, M. and Jordahl, H. (2008), 'Inequality and trust in sweden: Some inequalities are more harmful than others', *Journal of Public Economics* **92**, 348–365.

Güth, W. and Kocher, M. G. (2014), 'More than thirty years of ultimatum bargaining experiments: Motives, variations, and a survey of the recent literature', *Journal of Economic Behavior & Organization* **108**, 396–409.

Habyarimana, J., Humphreys, M., Posner, D. N. and Weinstein, J. M. (2007), 'Why does ethnic diversity undermine public goods provision', *American Political Science Reviews* **101**, 709–725.

Hagen, E. H. and Hammerstein, P. (2006), 'Game theory and human evolution: A critique of some recent interpretations of experimental games', *Theoretical Population Biology* **69**, 339–348.

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D. and de Kroon, H. (2017), 'More than 75 percent decline over 27 years in total flying insect biomass in protected areas', *PLoS ONE* **12**, 1–21.

Ham, R. (1998), 'Nationwide chimpanzee census and large mammal survey: Republic of guinea'.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O. and Townshend, J. R. G. (2013), 'High-resolution global maps of 21st-century forest cover change', *Science* **342**, 850–853.

Hardin, G. (1968), 'The tragedy of the commons', *Science* **162**(3859), 1243–1248.

Hardin, R. (1971), 'Collective action as an agreeable n-prisoners' dilemma', *Behavioral Sciences* **16**(5), 472–481.

Harfoot, M., Glaser, S. A. M., Tittensor, D. P., Britten, G. L., McLardy, C., Malsch, K. and Burgess, N. D. (2018), 'Unveiling the patterns and trends in 40 years of global trade in cites-listed wildlife', *Biological Conservation* **223**, 47–57.

Heckathorn, D. D. (1989), 'Collective action and the second-order free-rider problem', *Rationality and Society* **1**(1), 78–100.

Heckman, J. J. (2005), 'The scientific model of causality', *Sociological Methodology* **35**, 1–97.

Heilman, E. (2014), One weird trick to stop selfish miners: Fresh bitcoins, a solution for the honest miner, *in* R. Böhme, M. Brenner, T. Moore and M. Smith, eds, 'Financial Cryptography and Data Security. FC 2014. Lecture Notes in Computer Science, vol 8438', Springer, Berlin.

Henrich, J. (2000), 'Does culture matter in economic behavior?', *American Economic Review* **90**(4), 973–979.

Henrich, J. and Boyd, R. (2001), 'Why people punish defectors: Weak conformist transmission can stabilize costly enforcement of norms in cooperative dilemmas', *Journal of Theoretical Biology* **208**.

Henrich, J., Boyd, R., Bowles, S., Camerer, C., Fehr, E., Gintis, H. and McElreath, R. (2001), 'In search of homo economicus: Behavioral experiments in 15 small-scale societies', *The American Economic Review* **91**(2), 73–78.

Henrich, J., Ensminger, J., McElreath, R., Barr, A., Barrett, C., Bolyanatz, A., Cardena, J. C., Gurven, M., Gwako, E., Henrich, N., Lesorogol, C., Marlowe, F., Tracer, D. and Ziker, J. (2010b), 'Markets, religion, community size and the evolution of fairness and punishment', *Science* **327**, 1480–1484.

Henrich, J., Heine, S. J. and Norenzayan, A. (2010a), 'The weirdest people in the world', *Behavioral and Brain Sciences* **33**, 61–135.

Henrich, J. and McElreath, R. (2003), 'The evolution of cultural evolution', *Evolutionary Anthropology* **12**, 123–135.

Herley, C. and Florenico, D. (2008), A profitless endeavor: Phishing as tragedy of the commons, Association for Computing Machinery, Inc.

Hintze, A. and Hertwig, R. (2016), 'The evolution of generosity in the ultimatum game', *Scientific Reports* **6**, 1–7.

Hirsch, R. L. (2008), 'Mitigation of maximum world oil production: Shortage scenarios', *Energy Policy* **36**, 881–889.

Hirschleifer, D. and Rasmusen, E. (1989), 'Cooperation in a repeated prisoners' dilemma with ostracism', *Journal of Economic Behavior and Organization* **12**, 87–106.

Hirschman, A. O. (1982), 'Rival interpretations of market society: Civilizing, destructive, or feeble?', *Journal of Economic Literature* **20**(4), 1463–1484.

Hobbes, T. (2012 [1651]), *Leviathan*, Cambridge University Press.

Hochberg, M. E., Chase, J. M., Gotelli, N. J., Hastings, A. and Naeem, S. (2009), 'The tragedy of the reviewer commons', *Ecology Letters* **12**, 2–4.

Holben, B. N. (1986), 'Characteristics of maximum-value composite images from temporal avhrr data', *International Journal of Remote Sensing* **7**(11), 1417–1434.

Holland, P. W. (1986), 'Statistics and causal inference', *Journal of the American Statistical Association* **81**(396), 945–960.

Hollis, A. and Maybarduk, P. (2015), 'Antibiotic resistance is a tragedy of the commons that necessitates global cooperation', *The Journal of Law Medicine & Ethics* **43**, 33–37.

Homans, G. C. (1950), *The human group*, Harcourt, Brace and Company.

Höök, M. (2010), 'Coal and oil: The dark monarchs of global energy'.

Huck, S. and Oechssler, J. (1999), 'The indirect evolutionary approach to explaining fair allocations', *Games and Economic Behavior* **28**, 13–24.

Hume, D. (2007 [1748]), *An Enquiry Concerning Human Understanding and Other Writings*, Cambridge University Press.

Hurlbert, S. H. (1984), 'Pseudoreplication and the design of ecological field experiments', *Ecological Monographs* **54**(2), 187–211.

Hurtt, G. C., Frokling, S., Fearon, M. G., Moore, B., Shevliakova, E., Malyshev, S., Pacala, S. W. and Houghton, R. A. (2006), 'The underpinnings of land-use history: three centuries of global gridded land-use transitions, wood-harvest activity, and resulting secondary lands', *Global Change Biology* **12**, 1208–1229.

Hylander, L. D. and Meili, M. (2003), '500 years of mercury production: global annual inventory by region until 2000 and associated emissions', *The Science of the Total Environment* **304**, 13–27.

International Finance Corporation (2012), 'Performance standards on environmental and social sustainability'.

International Finance Corporation (2017), 'Press release 30/10/2017'.

IUCN and UNEP (2016), 'The world database on protected areas'.
URL: *http://www.protectedplanet.net*

Iwamura, T., Lambin, E. F., Silvius, K. M., Luzar, J. B. and Fragoso, J. M. V. (2014), 'Agent-based modeling of hunting and subsistence agriculture on indigenous lands: understanding interactions between social and ecological systems', *Environmental Modelling & Software* **58**, 109–127.

Jackman, S. (2015), 'pscl: classes and methods for r developed in the political science computational laboratory, stanford university. r package version 1.4.9.'.
URL: *http://pscl.stanford.edu/*

Jarvis, A., Nelson, H. I. R. A. and Guevara, E. (2008), 'Holefilled seamless srtm data v4'.
URL: *http://srtm.csi.cgiar.org*

Jones, K. J., Venter, O., Fuller, R. A., Allan, J. R., Maxwell, S. L., Negret, P. J. and Watson, J. E. M. (2018), 'One-third of global protected land is under intense human pressure', *Science* **360**, 788–791.

Juffe-Bignoli, D., Burgess, N. D., Bingham, H., Belle, E. M. S., de Lima, M. G., Deguignet, M., Bertzky, B., Milam, A. N., Martinez-Lopez, J., Lewis, E., Eassom, A., Wicander, S., Geldmann, J., van Soesbergen, A., Arnell, A. P., O'Connor, B., Park, S., Shi, Y. N., Danks, F. S., MacSharry, B. and Kingston, N. (2014), 'Protected planet report 2014'.

Junker, J., Boesch, C., Mundry, R., Stephens, C., Lormie, M., Tweh, C. and Kühl, H. S. (2015), 'Education and access to fish but not economic development predict chimpanzee and mammal occurrence in west africa', *Biological Conservation* **182**, 27–35.

Kahan, B. C., Jairath, V., Doré, C. J. and Morris, T. P. (2014), 'The risks and rewards of covariate adjustment in randomized trials: an assessment of 12 outcomes from 8 studies', *Trials* **15**(139), 1–7.

Kant, I. (1983), *Kritik der reinen Vernunft*, Wissenschaftliche Buchgesellschaft.

Koch, P. L. and Barnosky, A. D. (2006), 'Late quaternary extinctions: State of the debate', *Annual Review of Ecology, Evolution, and Systematics* **37**, 215–250.

Kohler, U. and Kreuter, F. (2012), *Datenanalyse mit Stata*, Oldenburg Wissenschaftsverlag GmbH.

Kollock, P. (1998), 'Social dilemmas; the anatomy of cooperation', *Annual Review of Sociology* **24**, 183–214.

Krugman, P. (1979), 'Trade, accumulation, and uneven development'.

Kuehl, H., Maisels, F., Ancrenaz, M. and Williamson, E. (2009), 'Lignes directrices pour de meilleures pratiques en matière d'inventaire et de suivi des populations de grands singes'.

Kurzban, R. (2001), 'The social psychophysics of cooperation: Nonverbal communication in a public goods game', *Journal of Nonverbal Behavior* **25**(4), 241–259.

Laakso, A. and Tyynela, T. (2006), 'Non-wood forest benefits and agroforestry practices in the fouta djallon highlands of guinea', *Nordic Journal of African Studies* **15**(4), 579–590.

Lamba, S. and Mace, R. (2011), 'Demography and ecology drive variation in cooperation across human populations', *Proceedings of the National Academy of Sciences* **108**(35), 14426–14430.

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V., McTeer, M. A., Murray, C. J. L., Ndahimananjara, J. D., Perera, F., Potočnik, J., Preker, A. S., Ramesh, J., Rockström, J., Salinas, C., Samson, L. D., Sandilya, K., Sly, P. D., Smith, K. R., Steiner, A., Stewart, R. B., Suk, W. A., van Schayck, O. C. P., Yadama, G. N., Yumkella, K. and Zhong, M. (2017), 'The lancet commission on pollution and health', *The Lancet* pp. 1–51.

Laurance, W. F., Croes, B. M., Tchignoumba, L., Lahm, S. A., Alonso, A., Lee, M. E., Campbell, P. and Ondzeano, C. (2006), 'Impacts of roads and hunting on central african rainforest mammals', *Conservation Biology* **20**(4), 1251–1261.

Leigh, A. (2006), 'Trust, inequality and ethnic heterogeneity', *Economic Record* **82**, 268–280.

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L. and Geschke, A. (2012), 'International trade drives biodiversity threats in developing nations', *Nature* **486**, 109–112.

Levitt, S. D. and List, J. A. (2007), 'What do laboratory experiments measuring social preferences reveal about the real world?', *The Journal of Economic Perspectives* **21**(2), 153–174.

Lewis, D. (1973), 'Causation', *The Journal of Philosophy* **70**(17), 556–567.

Lindsay, J., Boghossian, P. and Pluckrose, H. (2018), 'Project fact sheet'.
URL: *https://leiterreports.typepad.com/files/project-summary-and-fact-sheet.pdf*

Lomborg, B. (1996), 'Nucleus and shield: the evolution oc social structure in the iterated prisoner's dilemma', *American Sociological Association* **61**(2), 278–307.

Low, B. S. and Heinen, J. T. (1993), 'Population, resources, and environment: Implications of human behavioral ecology for conservation', *Population and Environment: A Journal of Interdisciplinary Studies* **15**(1), 7–41.

Luzar, J. B., Silvius, K. M. and Fragoso, J. M. V. (2012), 'Church affiliation and meat taboos in indigenous communities of guyanese amazonia', *Human Ecology* **40**(6), 833–845.

MacLean, R. C. (2008), 'The tragedy of the commons in microbial populations: insights from theoretical, comparative and experimental studies', *Heredity* **100**, 233–239.

Macy, M. W. and Flache, A. (2002), 'Learning dynamics in social dilemmas', *Proceedings of the National Academy of Sciences* **99**, 7229–7236.

Madhusudan, M. D. (2005), 'The global village: linkages between international coffee markets and grazing by livestock in a south indian wildlife reserve', *Conservation Biology* **19**(2), 411–420.

Madsen, E., Tunney, R. J., Fieldman, G., Plotkin, H. C., Dunbar, R. I. M., Richarson, J. M. and McFarland, D. (2007), 'Kinship and altruism: A cross-cultural experimental study', *Brithish Journal of Psychology* **98**(2), 339–359.

Mahdi, N. Q. (1986), 'Pukhtunwali: Ostracism and honor among the pathan hill tribes', *Ethology and Sociobiology* **7**, 295–304.

Malcolm, J. R. and Ray, J. C. (2000), 'Influence of timber extraction routes on central african small-mammal communities, forest structure, and tree diversity', *Conservation Biology* **14**(6), 1623–1638.

Marlowe, F. W. (2005), 'Hunter-gatherers and human evolution', *Evolutionary Anthropology* **14**, 54–67.

Marvier, M. (2014), 'New conservation is true conservation', *Conservation Biology* **28**, 1–3.

Marvier, M. and Kareiva, P. (2014), 'The evidence and values underlying "new conservation"', *Trends in Ecology & Evolution* **28**, 131–132.

Marwell, G. and Ames, R. E. (1981), 'Economists free ride, does anyone else? experiments on the provision of public goods, iv', *Journal of Public Economics* **15**, 295–310.

Masson-Delmotte, V., Zhai, P., Poertner, H. O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (2018), 'Global warming of 1.5°c: Summary for policymakers'.

McCauley, D. J. (2006), 'Selling out on nature', *Nature* **443**(7), 27–28.

McCullagh, P. and Nelder, J. A. (1996), *Generalized linear models*, Chapman and Hall.

McDonald, D. R. (1977), 'Food taboos: a primitive environmental protection agency (south america)', *Conservation Anthropos* **72**, 734–748.

McElreath, R., Boyd, R. and Richerson, P. J. (2003), 'Shared norms and the evolution of ethnic markers', *Current Anthropology* **44**(1), 122–130.

McElroy, F. W. (1967), 'A necessary and sufficient condition that ordinary least-square estimators be best linear unbiased', *Journal of the American Statistical Association* **62**(320), 1302–1304.

McGovern, F. E. (2002), 'The tragedy of the asbestos commons', *Virginia Law Review* **88**(8), 1721–1756.

Meadows, D., Randers, J. and Meadows, D. (2004), *Limits to Growth: The 30-Year Update*, Earthscan.

Micklin, P. (2007), 'The aral sea disaster', *Annual Review of Earth and Planetary Sciences* **35**, 47–72.

Miguiel, E. and Gugerty, M. K. (2005), 'Ethnic diversity, social sanctions, and public goods in kenya', *Journal of Public Economics* **89**, 2325–2368.

Milinski, M., Semmann, D. and Krambeck, H. J. (2002), 'Donors to charity gain in both indirect reciprocity and political reputation', *Proceedings of the Royal Society of London* **269**, 881–883.

Milledge, S. A. H. (2007), 'Illegal killing of african rhinos and horn trade, 2000–2005: the era of resurgent markets and emerging organized crime', *Pachyderm* **43**, 96–107.

Milner-Gulland, E. J., Bennett, E. L. and the SCB 2002 Annual meeting wild meat group (2003), 'Wild meat: the bigger picture', *Trends in Ecology & Evolution* **18**(7), 351–357.

Ministère de l'agriculture et des ressources animales de la République de Guinée (1999), 'Code forestier'.

Mohr, S. H., Mudd, G. M. and Giruco, D. (2012), 'Lithium resources and production: Critical assessment and global projections', *Minerals* **2**, 65–84.

Moorthy, K. S. (1985), 'Using game theory to model competition', *Journal of Marketing Research* **22**(3), 262–282.

Morgan, C. J. (1979), 'Eskimo hunting groups, social kinship, and the possibility of kin selection in humans', *Ethology and Sociobiology* **1**, 83–86.

Mori, E., Lovari, S., Sforzi, A., Romeao, G., Pisani, C., Massolo, A. and Fattorini, L. (2014), 'Patterns of spatial overlap in monogamous large rodent, the crested porcupine', *Behavioural Processes* **107**, 112–118.

Mudd, G. M. (2007), 'Global trends in gold mining: Towards quantifying environmental and resource sustainability', *Resources Policy* **32**, 42–56.

Mudd, G. M. (2010), 'Global trends and environmental issues in nickel mining: Sulfides versus laterites', *Ore Geology Review* **38**, 9–26.

Mudd, G. M. (2012), 'Sustainability reporting and the platinum group metals: A global mining industry leader?', *Platinum Metals Revue* **56**(1), 2–19.

Mudd, G. M., Weng, Z., Jowitt, S. M., Turnbull, I. D. and Graedel, T. E. (2013), 'Quantifying the recoverable resources of by-product metals: The case of cobalt', *Ore Geology Reviews* **55**, 87–98.

Mulder, M. B. (2007), 'Hamilton's rule and kin competition: the kipsigis case', *Evolution and Human Behavior* **28**, 299–312.

Mundry, R. (2017), From nonparametric tests to mixed models: a brief overview of statistical tools frequently used in comparative psychology, *in* J. call, G. M. Burghardt, I. M. Pepperberg, C. T. Snowdon and T. Zentall, eds, 'APA Handbook of Comparative Psychology: Volume 1. Basic Concepts, Methods, Neural Substrate, and Behavior', American Psychological Association, Washington, chapter 8, pp. 157–177.

Mundry, R. and Nunn, C. (2009), 'Stepwise model fitting and statistical inference: turning noise into signal pollution', *American Naturalist* **173**(1), 119–123.

Murphy, D. J. and Hall, C. A. S. (2011), 'Energy return on investment, peak oil, and the end of economic growth', *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES* **1219**, 52–72.

Musgrave, R. A. and Musgrave, P. B. (1989), *Public finance in theory and practice*, fifth edition edn, McGraw-Hill Book Company.

Myerson, R. B. (2004), *Game theory: analysis of conflict*, Harvard University Press.

Naegele, H. and Zaklan, A. (2017), 'Does the eu ets cause carbon leakage in european manufacturing?'.

Newton, K. and Delhey, J. (2005), 'Predicting cross-national levels of social trust: global pattern or nordic exceptionalism?', *European Sociological Review* **21**, 311–327.

N'Goran, P. K., Boesch, C., Mundry, R., N'Goran, E. K., Herbinger, I., Yapi, F. A. and Kühl, H. S. (2012), 'Hunting, law enforcement, and african primate conservation', *Conservation Biology* **26**(3), 565–571.

Nijman, V. (2010), 'An overview of international wildlife trade from southeast asia', *Conservation* **19**, 1101–1114.

Nijman, V. and Schepherd, C. R. (2007), 'Trade in non-native, cites-listed, wildlife in asia, as exemplified by the trade in freshwater turtles and tortoises (chelonidae) in thailand', *Contributions to Zoology* **76**(3), 207–212.

Nonnenmacher, G. (1989), *Die Ordnung der Gesellschaft*, VCH Verlagsgesellschaft mbH.

Nowak, M. A., Page, K. M. and Sigmund, K. (2000), 'Fairness versus reason in the ultimatum game', *Science* **289**(5485), 1773–1775.

Nowak, M. A. and Sigmund, K. (1993), ‘A strategy of win-stay, lose-shift that outperforms tit-for-tat in the prisoner’s dilemma game’, *Nature* **364**, 278–307.

Nowak, M. A. and Sigmund, K. (2004), ‘Evolutionary dynamics of biological games’, *Science* **303**(5659), 793–799.

Nydegger, R. V. and Owen, G. (1974), ‘Two-person bargaining: An experimental test of the nash axioms’, *International Journal of Game Theory* **3**(4), 239–249.

Oerlemans, N. (2016), ‘Living planet report 2016’.

Oindo, B. O. and Skidmore, A. K. (2002), ‘Interannual variability of ndvi and species richness in kenya’, *International Journal of Remote Sensing* **23**(2), 285–298.

Olson, M. (1971), *The logic of collective action*, Harvard University Press.

Oosterbeek, H., Sloof, R. and van de Kuilen, G. (2004), ‘Cultural differences in ultimatum game experiments: Evidence from a meta-analysis’, *Experimental Economics* **7**, 171–188.

Osborne, P. E., Alonso, J. C. and Bryant, R. G. (2001), ‘Modelling landscape-scale habitat use using gis and remote sensing: a case study with great bustards’, *Journal of Applied Ecology* **38**, 458–471.

Ostrom, E. (1990), *Governing the commons*, Cambridge University Press.

Ostrom, E. (2007), ‘A diagnostic approach for going beyond panaceas’, *Proceedings of the National Academy of Sciences of the United States of America* **104**(39), 15181–15187.

Ostrom, E. (2009), ‘A general framework for analyzing sustainability of social-ecological systems’, *Science* **325**, 419–422.

Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B. and Policansky, D. (1999), ‘Revisiting the commons: Local lessons, global challenges’, *Science* **284**(5412), 278–282.

Ostry, J. D., Loungani, P. and Furceri, D. (2016), ‘Neoliberalism: Oversold?’, *Finance & Development* pp. 38–41.

Pacheco, J. M., Santos, F. C., Souza, M. O. and Skyrms, B. (2009), ‘Evolutionary dynamics of collective action in n-person stag hunt dilemmas’, *Proceedings of the Royal Society* **276**, 315–321.

Paciotti, B. and Hadley, C. (2003), ‘The ultimatum game in southwestern tanzania: Ethnic variation and institutional scope’, *Current Anthropology* **44**(3), 427–432.

Packer, C., Gilbert, D. A., Pusey, A. E. and O’Brien, S. J. (1991), ‘A molecular genetic analysis of kinship and cooperation in african lions’, *Nature* **351**(6327), 562–565.

Pascual, U., Balvanera, P., Diaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Dessane, E. B., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S., Amankwah, E., Asah, S. T., Berry, P., Bilgin, A., Breslow, S. J., Bullock, C., Caceres, D., Daly-Hassen, H., Figueroa, E., Golden, C. D., Gomez-Baggethun, E., Gonzalez-Jimenez, D., Houdet, J., Keune, H., Kumar, R., Ma, K., May, P. H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B. B., van den Belt, M., Verma, M., Wickson, F. and Yagi, N. (2017), 'Valuing nature's contributions to people: the ipbes approach', *Current Opinion in Environmental Sustainability* **26**, 7–16.

Patzelt, A. (2013), 'The social system of guinea baboons (papio papio) with a focus on male–male relationships'.

Pennant, R. (2005), 'Diversity, trust and community participation in england. home office findings 253'.

Perc, M. and Szolnoki, A. (2010), 'Coevolutionary games-a mini review', *BioSystems* **99**, 109–125.

Pezzuti, J. C. B., Lima, J. P., Lima, D. F., da Silva, D. F. and Begossi, A. (2010), 'Uses and taboos of turtles and tortoises along rio negro, amazon basin', *Journal of Ethnobiology* **30**(1), 153–168.

Piketty, T. (2013), *Le capital au XXI siècle*, Editions du seuil.

Pimm, S. L. and Raven, P. (2000), 'Biodiversity: extinction by numbers', *Nature* **403**, 843–845.

Pinker, S. (2002), *The Blank Slate: The Modern Denial of Human Nature*, Penguin.

Poole, C. M. and Shepherd, C. R. (2017), 'Shades of grey: the legal trade in cites-listed birds in singapore, notably the globally threatened african grey parrot psittacus erithacus', *Oryx* **51**(3), 411–417.

Popper, K. (1935), *Logik der Forschung*, Springer-Verlag.

Prescott-Allen, C. and Prescott-Allen, R. (1986), *THe first resource*, World Wildlife Fund.

PrimateInfo (2016), 'Patas monkey erythrocebus patas'.
URL: *http://pin.primate.wisc.edu/factsheets/entry/patas$_m$onkey*

Prior, T., Giurco, D., Mudd, G., Mason, L. and Behrisch, J. (2012), 'Resource depletion, peak minerals and the implications for sustainable resource management', *Global Environmental Change* **22**, 577–587.

Protected Planet (2016), 'Guinea africa'.
URL: *https://www.protectedplanet.net/country/GN*

Putnam, R. D. (2007), 'E pluribus unum: Diversity and community in the twenty-first century the 2006 johan skytte prize lecture', *Scandinavian Political Studies* **30**(2), 137–174.

Quinn, G. and Keough, M. (2002), *Experimental Design and Data Analysis for Biologists*, Cambridge University Press.

R-Bloggers (2011), 'Maximum likelihood'.
URL: *https://www.r-bloggers.com/maximum-likelihood/*

R Core Team (2016), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria.
URL: *https://www.R-project.org/*

Rankin, D. J., Bargum, K. and Kokko, H. (2007), 'The tragedy of the commons in evolutionary biology', *TRENDS in Ecology and Evolution* **22**(12), 643–651.

Rao, V. V. and Tripathi, R. S. (2016), Vertebrate pests - issues and management strategies with relevance to wild boar (sus scrofa), *in* P. K. Agrawal, A. Verghese, S. R. Krishna and K. Subaharan, eds, 'Human animal conflict in agro-pastoral context: issues & policies', Indian Council of Agricultural Research, New Delhi, India, chapter 2, pp. 10–22.

Rapideye (2016), 'Ortho product (level 3a)'.
URL: *http://web-dev.rapideye.de/rapideye/all-products/ortho.htm*

Rapoport, A. (1988), 'Experiments with n-person social traps ii: tragedy of the commons', *Journal of Conflict Resolution* **32**(3), 473–488.

Rapoport, A. and Dale, P. (1966), 'Models for prisoner's dilemma', *Journal of Mathematical Psychology* **3**, 269–286.

Ratchford, M., Allgood, B. and Todd, P. (2013), 'La nature du crime'.

Read, J. M., Fragoso, J. M. V., Silvius, K. M., Luzar, J., Overman, H., Cummings, A., Giery, S. T. and de Oliveira, L. F. (2010), 'Space, place, and hunting patterns among indigenous peoples of the guyanese rupununi region', *Journal of Latin American Geography* **9**(3), 213–243.

Redfern, J. V., Grant, R., Biggs, H. and Getz, W. M. (2003), 'Surfacewater constraints on herbivore foraging in the kruger national park, south africa', *Ecology* **84**(8), 2092–2107.

Regnaut, S. and Boesch, C. (2012), 'Offset strategy for the guinean aluminia project'.

Reuters (2015), 'Highlights-world leaders open paris climate change talks'.
URL: *https://uk.reuters.com/article/climatechange-summit-highlights-idUKL1N13P0FE20151130*

Roth, A. E., Prasnikar, V., Okuno-Fujiwara, M. and Zamir, S. (1991), 'Bargaining and market behavior in jerusalem, ljubljana, pittsburgh and tokyo: An experimental study', *American Economic Review* **81**(5), 1068–1095.

Rousseau, J.-J. (1964 [1750]), *Oeuvres complètes III Du Contrat Social Écrits Politiques*, Gallimard.

Rousseau, J.-J. (1966 [1762]), *Du Contrat Social*, Garnier-Flammarion.

Rousseau, J.-J. (1977 [1754]), *Discours sur l'origine et les fondements de l'inégalité parmi les hommes*, Editions socialces.

Rubin, D. B. (1974), 'Estimating causal effects of treatments in randomized and nonrandomized studies', *Journal of Educational Psychology* **66**(5), 688–701.

Rubin, D. B. (2008), 'The design and analysis of gold standard randomized experiments', *Journal of the American Statistical Association* **103**(484), 1350–1356.

Rubinstein, A. (1982), 'Perfect equilibrium in a bargaining model', *Econometrica* **50**(1), 97–109.

Russel, B. (1915), *Our Knowledge of the External World*, The Open Court Publishing Company.

Russel, B. (2012), *Philosophie des Abendlandes*, Anaconda Verlag GmbH.

Saellh, D., Wachtmeister, H., Tang, X. and Hoek, M. (2015), 'Offshore oil: Investigating production parameters of fields of varying size, location and water depth', *Fuel* **139**, 430–440.

Samuelson, P. A. (1954), 'The pure theory of public expenditure', *The Review of Economics and Statistics* **36**(4), 387–389.

Satow, K. L. (1975), 'Social approval and helping', *Journal of Experimental Social Psychology* **11**, 501–509.

Schielzeth, H. (2010), 'Simple means to improve the interpretability of regression coefficients', *Methods in Ecology and Evolution* **1**, 103–113.

Schielzeth, H. and Forstmeier, W. (2009), 'Conclusions beyond support: overconfident estimates in mixed models', *Behavioral Ecology* **20**, 416–420.

Schmidt-Catran, A. W. and Fairbrother, M. (2016), 'The random effects in multilevel models: Getting them wrong and getting them right', *European Sociological Review* **32**(1), 23–38.

Schumpeter, J. A. (2012 [1911]), *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest and Buisness Cycle*, Transaction Publishers.

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., von Gunten, U. and Wehrli, B. (2010), 'Global water pollution and human health', *Annual Review of Environment and Resources* **35**, 109–136.

Segall, M. H., Dasen, P. R., Berry, J. W. and Poortinga, Y. H. (1999), *Human Behavior in Global Perspective: An Introduction to Cross-Cultural Psychology*, Allyn & Bacon.

Segura, S., Ferruz, L., Gargallo, P. and Salvador, M. (2018), 'Environmental versus economic performance in the eu ets from the point of view of policy makers: A statistical analysis based on copulas', *Journal of Cleaner Production* **176**, 1111–1132.

Seidl, I. and Tisdell, C. A. (1999), 'Carrying capacity reconsidered: from malthus' population theory to cultural carrying capacity', *Ecological Economics* **31**, 395–408.

Siebert, S., Kummu, M., Porkka, M., Doell, P., Ramankutty, N. and Scanlon, B. R. (2015), 'A global data set of the extent of irrigated land from 1900 to 2005', *Hydrology and Earth System Sciences* **19**, 1521–1545.

Silk, J. B. (1980), 'Adoption and kinship in oceania', *American Anthropologist* **82**(4), 799–820.

Sills, J. (2018), 'Ivory crisis: Growing no-trade consensus', *Science* **360**(6386), 276–277.

Sirois, M. C., Margolis, H. A. and Camiré, C. (1998), 'Influence of remnant trees on nutrients and fallow biomass in slash and burn agroecosystems in guinea', *Agroforestry Systems* **40**, 227–246.

Skyrms, B. (1994), 'Sex and justice', *The Journal of Philosophy* **91**(6), 305–320.

Skyrms, B. (2000), 'Game theory, rationality and evolution of the social contract', *Journal of Consciousness Studies* **7**(1-2), 269–284.

Skyrms, B. (2004), *The stag hunt and the evolution of social structure*, Cambridge University Press.

Smith, A. (1896 [1763]), *Lectures on justice, police, revenue and arms*, Clarendon Press.

Smith, A. (1986 [1759]), *The theory of moral sentiments*, Lincoln-Rembrandt Publishing.

Smith, A. (1993 [1776]), *An inquiry into the nature and causes of the wealth of nations*, Oxford University Press.

Smith, J. M. and Price, G. R. (1973), 'The logic of animal conflict', *Nature* **246**, 15–18.

Smith, M. (2002), 'The state of nature: The political philosophy of primitivism and the culture of contamination', *Environmental Values* **11**, 407–425.

Smith, V. L. (1975), 'The primitive hunter culture, pleistocene extinction, and the rise of agriculture', *Journal of Political Economy* **83**(4), 727–756.

Soetevent, A. R. (2005), 'Anonymity in giving in a natural context - a field experiment in 30 churches', *Journal of Public Economics* **89**, 2301–2323.

Sommer, B. and Hain, A. (2017), 'Europe as a green leader? a brief evaluation of both the european union's climate and energy policy and common agricultural policy', *Culture, Practice & Europeanization* **2**(2), 33–45.

Soulé, M. (2013), 'The "new conservation"', *Conservation Biology* **27**, 895–897.

Stahl, D. O. and Harvy, E. (2006), 'Other-regarding preferences: Egalitarian warm glow, empathy and group size', *Journal of Economic Behavior & Organization* **61**, 20–41.

Stavins, R. N. (2011), 'The problem of the commons: Still unsettled after 100 years', *American Economic Review* **101**, 81–108.

Stern, C. (2016), 'Undoing insularity: A small study of gender sociology's big problem', *Econ Journal Watch* **13**(3), 1–58.

Stewart-Williams, S. (2008), 'Altruism among kin vs. nonkin: effects of cost of help and reciprocal exchange', *Evolution and Human Behavior* **28**, 193–198.

Surovell, T., Waguespack, N. and Braningham, P. J. (2005), 'Global archeological evidence for proboscidean overkill', *Proceedings of the National Academy of Sciences* **102**(17), 215–250.

Tagesspiegel (2016), 'Ungleichheit hat desaströse folgen'.
URL: *https://www.tagesspiegel.de/politik/reichtum-und-verteilung-ungleichheit-hat-desastroese-folgen/13972784.html*

Taylor, P. D. and Jonker, L. B. (1978), 'Evolutionary stable strategies and game dynamics', *Mathematical Biosciences* **40**, 145–156.

TEEB (2018), 'Ecosystem services'.
URL: *http://www.teebweb.org/resources/ecosystem-services/*

TEEB for Business Coalition/Trucost (2013), 'Natural capital at risk: The top 100 externalities of business'.
URL: *http://naturalcapitalcoalition.org/wp-content/uploads/2016/07/Trucost-Nat-Cap-at-Risk-Final-Report-web.pdf*

Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M. C., Schwager, M. and Jeltsch, F. (2004), 'Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures', *Journal of Biogeography* **31**, 79–92.

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., Bishop, J. R. B., Marques, T. A. and Burnham, K. P. (2010), 'Distance software: design and analysis of distance sampling surveys for estimating population size', *Journal of Applied Ecology* **47**, 5–14.

Tilmann, D., May, R. M., Lehman, C. L. and Nowak, M. A. (1994), 'Habitat destruction and the extinction debt', *Nature* **371**, 65–66.

Tomasello, M. and Vaish, A. (2013), 'Origins of human cooperation and morality', *Annual Review of Psychology* **64**, 231–255.

Tracer, D. P. (2003), 'Selfishness and fairness in economic and evolutionary perspective: An experimental economic study in papua new guinea', *Current Anthropology* **44**(3), 432–438.

TRAFFIC (2008), 'What's driving the wildlife trade? a review of expert opinion on economic and social drivers of the wildlife trade and trade control efforts in cambodia, indonesia, lao pdr and vietnam'.

Tranquilli, S., Abedi-Lartey, M., Abernethy, K., Amsini, F., Asamoah, A., Balangtaa, C., Blake, S., Bouanga, E., Breuer, T., Brncic, T. M., Campbell, G., Chancellor, R., Chapman, C. A., Davenport, T. R. B., Dunn, A., Dupain, J., Ekobo, A., Eno-Nku, M., Etoga, G., Furuichi, T., Gatti, S., Ghiurghi, A., Hashimoto, C., Hart, J. A., Head, J., Hega, M., Herbinger, I., Hicks, T. C., Holbech, L. H., Huijbregts, B., Kuehl, H. S., Imong, I., Yeno, S. L., Linder, J., Marshall, P., Lero, P. M., Morgan, D., Mubalama, L., N'Goran, P. K., Nicholas, A., Nixon, S., Normand, E., Nziguyimpa, L., Nzooh-Dongmo, Z., Ofori-Amanfo, R., Ogunjemite, B. G., Petre, C.-A., Rainey, H. J., Regnaut, S., Robinson, O., Rundus, A., Sanz, C. M., Okon, D. T., Todd, A., Warren, Y. and Sommer, V. (2014), 'Protected areas in tropical africa: Assessing threats and conservation activities', *PLoS ONE* **9**(12).

Tranquilli, S., Abedi-Lartey, M., Amsini, F., Arranz, L., Asamoah, A., Babafemi, O., Barakabuye, N., Campbell, G., Chancellor, R., Davenport, T. R. B., Dunn, A., Dupain, J., Ellis, C., Etoga, G., Furuichi, T., Gatti, S., Ghiurghi, A., Greengrass, E., Hashimoto, C., Hart, J., Herbinger, I., Hicks, T. C., Holbech, L. H., Huijbregts, B., Imong, I., Kumpel, N., Maisels, F., Marshall, P., Nixon, S., Normand, E., Nziguyimpa, L., Nzooh-Dogmo, Z., TikuOkon, D., Plumptre, A., Rundus, A., Sunderland-Groves, J., Todd, A., Warren, Y., Mundry, R., Boesch, C. and Kuehl, H. (2012), 'Lack of conservation effort rapidly increases african great ape extinction risk', *Conservation Letters* **5**, 48–55.

United Nations Development Programme (2016), 'Human development index (hdi)'.
URL: *http://hdr.undp.org/en/content/human-development-index-hdi*

United Nations Office on Drugs and Crime (2018), 'World drug report 2018'.

Ushenko, A. P. (1942), 'The problem of causal inference', *Philosophy of Science* **9**(2), 132–138.

van Etten, J. (2015), 'gdistance: distances and routes on geographical grids. r package version 1.1-9'.
URL: *http://CRAN.Rproject.org/package=gdistance*

van Vliet, N., Fa, J. and Nasi, R. (2015), 'Managing hunting under uncertainty: from one-off ecological indicators to resilience approaches in assessing the sustainability of bushmeat hunting', *Ecology and Society* **20**(3).

van Wilgen, B. W. and Biggs, H. C. (2011), 'A critical assessment of adaptive ecosystem management in a large savanna protected area in south africa', *Biological Conservation* **144**, 1179–1187.

Voigt, M., Wich, S. A., Ancrenaz, M., Meijaard, E., Abram, N., Banes, G. L., Campbell-Smith, G., d'Arcy, L. J., Delgado, R. A., Erman, A., Gaveau, D., Goossens, B., Heinicke, S., Houghton, M., Husson, S. J., Leiman, A., Sanchez, K. L., Makinuddin, N., Marshall, A. J., Meididit, A. and Miettinen, J. (2018), 'Global demand fornatural resources eliminatedmore than 100,000 bornean orangutans', *Current Biology* **28**, 761–769.

Watson, J. E. M., Shanahan, D. F., Marco, M. D., Allan, J., Laurance, W. F., Sanderson, E. W., Mackey, B. and Venter, O. (2016), 'Catastrophic declines in wilderness areas undermine global environment targets', *Current Biology* **26**, 1–6.

Watson, R. A., Cheung, W. W. L., Anticamara, J. A., Sumaila, R. U., Zeller, D. and Pauly, D. (2013), 'Global marine yield halved as fishing intensity redoubles', *Fish and Fisheries* **14**, 493–503.

Webber, S. and Prouse, C. (2018), 'The new gold standard: The rise of randomized control trials and experimental development', *Economic Geography* **94**(2), 166–187.

West, A. S. and Gardner, A. (2010), 'Altruism, spite and greenbeards', *Science* **327**(5971), 1341–1344.

Western, D. (1975), 'Water availability and its influence on the structure and dynamics of a savannah large mammal community', *African Journal of Ecology* **13**(3-4), 265–286.

Wild Chimpanzee Foundation (2012), 'Etat de la biodiversité en guinée'.

Wild Chimpanzee Foundation (2014), 'Rapport annuel 2013', pp. 1–42.

Wild Chimpanzee Foundation (2015), 'Complementary primates study cbg expansion project'.

Wild Chimpanzee Foundation (2018), 'Wcf mission'.
URL: *http://www.wildchimps.org/index.html*

Wildpro (2016), 'Lepus saxatilis – scrub hare'.
URL: *http://wildpro.twycrosszoo.org/S/0MLagomorph/Leporidae/lepus/Lepus$_s$axatilis.htmSocial*

World Bank (2016*a*), 'Forest rents (% of gdp)'.
URL: *https://data.worldbank.org/indicator/NY.GDP.FRST.RT.ZS*

World Bank (2016*b*), 'Gdp per capita (current us $)'.
URL: *https://data.worldbank.org/indicator/NY.GDP.PCAP.CD*

World Bank (2016*c*), 'Land area (sq. km)'.
URL: *https://data.worldbank.org/indicator/AG.LND.TOTL.K2*

World Bank (2016*d*), 'Life expectancy at birth, total (years)'.
URL: *https://data.worldbank.org/indicator/SP.DYN.LE00.IN*

World Bank (2016*e*), 'Mineral rents (% of gdp)'.
URL: *https://data.worldbank.org/indicator/NY.GDP.MINR.RT.ZS*

World Bank (2016*f*), 'Population growth (annual %)'.
URL: *https://data.worldbank.org/indicator/SP.POP.GROW*

World Bank (2016*g*), 'Urban population (% of total)'.
URL: *https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS*

World Economic Forum (2011), 'Responsible mineral developmentinitiative'.

Yellishetty, M., Mudd, G. M. and Ranjith, P. G. (2011), 'The steel industry, abiotic resource depletion and life cycle assessment: a real or perceived issue?', *Journal of Cleaner Production* **19**, 78–90.

Zacharia, P. U., Kizhakudan, S. J., Sujitha, T., Manojkumar, P., Rekha, J. N., Najmudeen, T. M., Purushottama, G. B., Muktha, M., Swathipriyanka, S. D., Akhilesh, K. V. and Remya, L. (2017), *Non-Detriment Findings (NDF) for the export of Shark and Ray species listed in Appendix II of the CITES and harvested from Indian waters*, Central Marine Fisheries Research Institute.

Zinner, D., Peláez, F. and Torkler, F. (2002), 'Distribution and habitat of grivet monkeys (cercopithecus aethiops aethiops) in eastern and central eritrea', *African Journal of Ecology* **40**, 151–158.

Chapter 11

Appendix

Date:

Questionnaire

Village:________________________________ Foyer:________________________________

Père de famille:____

Nombre et âge des Femmes:____

Nombre et âge des fils:____

Nombre et âge des filles:____

Est-ce que des parents vivent dans le foyer (âge, sex)? ________________________________

____

1. Quel âge avez-vous? ____

2. Origine ethnique? ☐Fulbé ☐ Malinké ☐Soussou ☐ Forestiers ☐ Étranger: _____________

3. Ou êtes-vous né? ____

4. Combien d'années avez-vous vécu au village? _____________________________________

5. Combien de mois par an êtes-vous au village? _____________________________________

6. Combien de fois par mois allez-vous au marcher? __________________________________

7. Combien de fois par an allez-vous en ville? _______________________________________

8. Travaillez-vous pendant une période de l'année dans une autre région? ☐ Oui ☐ Non

Quel travail et région? ____

9. Est-ce que vous soutenez vôtre famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

10. Combien d'années êtes-vous allé à l'école? _____________________________________

11. Quelle école? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

12. Savez-vous lire? ☐ Oui ☐ Non

13. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Autre:_____________

14. Quelle profession exercez-vous? ☐ Agriculteur ☐ Éleveur☐ Forgeront ☐ Commerçant

☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Maçon

☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre: ___________________________

15. Quel est votre revenu mensuel? ____

16. Quels moyens de locomotion avez-vous? ____

17. Avez-vous fait des expériences avec des projets de développement/conservation?

☐ Oui ☐ Non Quels projets et quand? ____

FOYER SECTION CHAMPS

Date :
Heure:

1. Avez-vous des terres? ☐ Oui ☐ Non

Lieux (carré dans carte): ______________________________

2. Cultivez-vous des champs? ☐ Oui -> Si oui, question 3

☐ Non -> Si non, section jardin

3. Qui travail dans les champs ?

☐ Foyer (préciser) ______________________________

☐ Employé (préciser) ______________________________

4. Pratiquez-vous une culture sur brûlis? ☐ Oui ☐ Non

5. Est-ce que vous épargnez certains arbres pendant le défrichement? ☐ Oui ☐ Non

Si oui, lesquels? ______________________________

6. Est-ce que vous bloquez le feu ?

☐ Oui ☐ Non

7. Quel est votre rythme de culture et de jachère?

Culture: ______________________________

Jachère: ______________________________

8. Entretenez-vous des haies mortes, vives ou mixtes pour vos champs?

☐ Mortes ☐ Vives ☐ Mixtes ☐ Pas de haies

9. À quelle distance (km) du village vous éloignez-vous pour vos champs?

____

Tableau pour les champs

Plante	**Engrais**	**Grandeur** (largeur x longueur m)	**Lieux** *(Carré dans carte)*	**Unités récoltées** *(Dernière récolte)*	**Unités vendues** *(Dernière récolte)*	**Gain** *(Dernière récolte)*
Riz						
Haricot						
Manioc						
Fonio						
Arachide						
Patate						
Taro						
Mil						
Autre:						
Autre:						
Autre:						

FOYER SECTION JARDINS

Date :
Heure:

1. Cultivez-vous des Jardins? ☐ Oui -> Si oui, question 2
☐ Non -> Si non, section arbres fruitiers

2. Qui travail dans les jardins ?

☐ Foyer (préciser) ____________________

☐ Employé (préciser) ____________________

3. Entretenez-vous des haies mortes, vives ou mixtes pour vos jardins?

☐ Mortes ☐ Vives ☐ Mixtes ☐ Pas de haies

4. À quelle distance (km) du village vous éloignez-vous pour vos jardins? ____________

1. Position dans le foyer ____________________

2. Quel âge avez-vous ? ____________________

3. Sexe: ☐ Féminin ☐ Masculin

4. De quelle origine ethnique êtes-vous ? ☐ Fulbé ☐ Malinké ☐ Soussou ☐ Forestiers ☐ Étranger ______

5. Où êtes-vous né? ____________________

6. Combien d'années avez-vous vécu au village? ____________________

7. Combien de temps par an êtes-vous au village? ____________________

8. Combien de fois par mois allez-vous au marcher ?____________________

9. Combien de fois par ans allez-vous en ville ?____________________

10. Travaillez-vous pendant une période de l'année dans une autre région ? ☐ Oui ☐ Non

Quel travail? ____________________

11. Est-ce que vous soutenez la famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

12. Combien d'années êtes-vous allé à l'école? ____________________

13. Quelle école avez-vous fréquentée? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

14. Savez-vous lire? ☐ Oui ☐ Non

15. Combien d'enfants avez-vous? ____________________

16. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Aucune

17. Quelle profession exercez-vous ? ☐ Agriculteur ☐ Éleveur ☐ Forgeront ☐ Commerçant ☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Macon ☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre ____________

18. Quel est votre revenu mensuel? ____________________

19. Quels moyens de locomotion avez-vous ? ____________________

20. Avez-vous fait des expériences avec des projets de développement/conservation? ☐ Oui ☐ Non

Quels projets et quand ? ____________________

Tableau pour les jardins

Plante	**Engrais**	**Lieux** *(GPS track ou carte)*	**Unités récoltées** *(Dernière récolte)*	**Unités vendues** *(Dernière récolte)*	**Gain** *(Dernière récolte)*
Aubergine					
Oignon					
Tomate					
Gombo					
Chou					
Carotte					
Piment					
Ail					
Patate					
Autre:					
Autre:					

FOYER SECTION ARBRES FRUITIERS   Date :
Heure:

1. Cultivez-vous des arbres fruitiers?   ☐ Oui -> Si oui, question 2
☐ Non -> Si non, section animaux

2. Qui s'occupe des arbres fruitiers ?

☐ Foyer (préciser) ____________________

☐ Employé (préciser) ____________________

3. À quelle distance (km) du village vous éloignez-vous pour vos arbres fruitiers?

____

1. Position dans le foyer ____________________

2. Quel âge avez-vous ? ____________________

3. Sexe: ☐ Féminin ☐ Masculin

4. De quelle origine ethnique êtes-vous ? ☐ Fulbé ☐ Malinké ☐ Soussou ☐ Forestiers ☐ Étranger ______

5. Où êtes-vous né? ____________________

6. Combien d'années avez-vous vécu au village? ____________________

7. Combien de temps par an êtes-vous au village? ____________________

8. Combien de fois par mois allez-vous au marcher ?____________________

9. Combien de fois par ans allez-vous en ville ?____________________

10. Travaillez-vous pendant une période de l'année dans une autre région ? ☐ Oui ☐ Non

Quel travail? ____________________

11. Est-ce que vous soutenez la famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

12. Combien d'années êtes-vous allé à l'école? ____________________

13. Quelle école avez-vous fréquentée? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

14. Savez-vous lire? ☐ Oui ☐ Non

15. Combien d'enfants avez-vous? ____________________

16. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Aucune

17. Quelle profession exercez-vous ? ☐ Agriculteur ☐ Éleveur ☐ Forgeront ☐ Commerçant ☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Macon ☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre ____________

18. Quel est votre revenu mensuel? ____________________

19. Quels moyens de locomotion avez-vous ? ____________________

20. Avez-vous fait des expériences avec des projets de développement/conservation? ☐ Oui ☐ Non

Quels projets et quand ? ____________________

Tableau pour les arbres fruitiers

Plante	**Engrais**	**Nombre de Pieds**	**Lieux** *(Gps track ou carte)*	**Unités récoltées** *(Dernière récolte)*	**Unités vendues** *(Dernière récolte)*	**Gains** *(Dernière récolte)*
Manguier						
Bananier						
Oranger						
Avocatier						
Ananas						
Acajou						
Colatier						
Citronnier						
Papayer						
Autre:						
Autre:						

FOYER SECTION ANIMAUX DOMESTIQUES

Date :
Heure:

1. Avez-vous des animaux domestiques? ☐ Oui -> Si oui, question 2

☐ Non -> Si non, section pêche

2. Qui s'occupe des animaux?

☐ Foyer (préciser) ____________________

☐Employé (préciser) ____________________

3. À quelle distance (km) du village vous éloignez-vous pour vos animaux domestiques?

____

1. Position dans le foyer ____________________

2. Quel âge avez-vous ? ____________________

3. Sexe: ☐ Féminin ☐ Masculin

4. De quelle origine ethnique êtes-vous ? ☐ Fulbé ☐ Malinké ☐ Soussou ☐ Forestiers ☐ Étranger ______

5. Où êtes-vous né? ____________________

6. Combien d'années avez-vous vécu au village? ____________________

7. Combien de temps par an êtes-vous au village? ____________________

8. Combien de fois par mois allez-vous au marcher ?____________________

9. Combien de fois par ans allez-vous en ville ?____________________

10. Travaillez-vous pendant une période de l'année dans une autre région ? ☐ Oui ☐ Non

Quel travail? ____________________

11. Est-ce que vous soutenez la famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

12. Combien d'années êtes-vous allé à l'école? ____________________

13. Quelle école avez-vous fréquentée? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

14. Savez-vous lire? ☐ Oui ☐ Non

15. Combien d'enfants avez-vous? ____________________

16. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Aucune

17. Quelle profession exercez-vous ? ☐ Agriculteur ☐ Éleveur ☐ Forgeront ☐ Commerçant ☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Macon ☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre ____________

18. Quel est votre revenu mensuel? ____________________

19. Quels moyens de locomotion avez-vous ? ____________________

20. Avez-vous fait des expériences avec des projets de développement/conservation? ☐ Oui ☐ Non

Quels projets et quand ? ____________________

Tableaux pour les animaux domestiques

Animal	Nombre	Lieux *(Carré carte)*	Utilisation	Nombre Vendu *(Année dernière)*	Gain *(Année dernière)*
Poulet					
Cochon					
Cheval					
Âne					
Chèvre					
Mouton					
Escargot					
Vache					
Agouti					
Pigeon					
Ruche à miel					
Canard					
Autre:					
Autre:					

Utilisation: Production viande; Force de travail; Production produits laitiers; Valeur; Statut; Dots; Funérailles; Culte (Sacrifice); Commerce…

FOYER SECTION PÊCHE

Date :
Heure:

1. Est-ce que vous pêchez? ☐ Oui -> Si oui, question 2
☐ Non -> Si non, section chasse

2. Combien de fois par mois pêchez-vous?
____

-> ☐ Si plus de 4 fois, question 3 -> ☐ Si moins de 5 fois, section chasse

3. Qui s'occupe de la pêche?
☐ Foyer (préciser) ________________________________

☐ Employé (préciser) ________________________________

4. À quelle distance (km) du village vous éloignez-vous pour la pêche? __________

1. Position dans le foyer ________________________________

2. Quel âge avez-vous ? ________________________________

3. Sexe: ☐ Féminin ☐ Masculin

4. De quelle origine ethnique êtes-vous ? ☐ Fulbé ☐ Malinké ☐ Soussou ☐ Forestiers ☐ Étranger ______

5. Où êtes-vous né? ________________________________

6. Combien d'années avez-vous vécu au village? ________________________________

7. Combien de temps par an êtes-vous au village? ________________________________

8. Combien de fois par mois allez-vous au marcher ?________________________________

9. Combien de fois par ans allez-vous en ville ?________________________________

10. Travaillez-vous pendant une période de l'année dans une autre région ? ☐ Oui ☐ Non

Quel travail? ________________________________

11. Est-ce que vous soutenez la famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

12. Combien d'années êtes-vous allé à l'école? ________________________________

13. Quelle école avez-vous fréquentée? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

14. Savez-vous lire? ☐ Oui ☐ Non
15. Combien d'enfants avez-vous? ________________________________

16. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Aucune

17. Quelle profession exercez-vous ? ☐ Agriculteur ☐ Éleveur ☐ Forgeront ☐ Commerçant ☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Macon ☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre __________________

18. Quel est votre revenu mensuel? ________________________________

19. Quels moyens de locomotion avez-vous ? ________________________________

20. Avez-vous fait des expériences avec des projets de développement/conservation? ☐ Oui ☐ Non
Quels projets et quand ? ________________________________

Tableau pour la pêche

Poisson	**Lieux** (Rivière et carré carte)	**Technique**	**Quantité pêchée** *(par mois)*	**Quantité vendue** *(Par mois)*	**Gain** *(Par mois)*

Technique: Nasse; Filet; Pêche à la ligne; Poison; Barrage; Harpon…

FOYER SECTION CHASSE

Date :
Heure:

1. Est-ce que vous chassez? ☐ Oui -> Si oui, question 2
☐ Non -> Si non, section produits de brousse

2. Combien de fois par mois chassez-vous? ____

-> ☐ Si plus de 4 fois, question 3 -> ☐ Si moins de 5 fois, section produits de brousse

3. Qui s'occupe de la chasse?

☐ Foyer (préciser) ____

☐ Employé (préciser) ____

4. Avez-vous un fusil? ☐ Oui ☐ Non Combiens: ________________________________

5. Est-ce que vous louez un fusil? ☐ Oui ☐ Non Où:______________________________

6. Où vous ravitaillez-vous en munitions? ______________________________________

7. Quels animaux avez-vous déjà chassez (Montrer images)?

Numéro images:____

8. Quels animaux ne chassez-vous jamais (Montrer images)?

Numéro images:____

Pourquoi pas ? ____

____

____

____

____

9. Est-ce que vous faites des battues ? ☐ Oui ☐ Non Si oui, quels animaux (Montrer images)

Numéro images____

10. Où vendez-vous le gibier? ____

11. À quelle distance (km) du village vous éloigniez vous pour la chasse?

____

Tableau pour la chasse (Jusqu'à 10 proies importantes)

Animal	**Lieux** *(Carré carte)*	**Technique**	**Nombre Chassé** *(Par mois)*	**Nombre Vendu** *(Par mois)*	**Gain** *(Par mois)*

Technique: Piège; Enfume; Fusil; Arc; Chien…

FOYER SECTION PRODUITS DE LA BROUSSE Date :
Heure:

1. Est-ce que vous utilisez des produits de la brousse? (Miel, plantes…)

☐ Oui -> Si oui, question 2

☐ Non -> Si non, section soutient familial

2. Qui s'occupe de la récolte des produits de la brousse?

☐ Foyer (préciser) ______

☐ Employé (préciser) ______

3. À quelle distance du village (km) vous éloignez-vous pour la récolte des produits de brousse? ______

1. Position dans le foyer ______

2. Quel âge avez-vous ? ______

3. Sexe: ☐ Féminin ☐ Masculin

4. De quelle origine ethnique êtes-vous ? ☐ Fulbé ☐ Malinké ☐ Soussou ☐ Forestiers ☐ Étranger ______

5. Où êtes-vous né? ______

6. Combien d'années avez-vous vécu au village? ______

7. Combien de temps par an êtes-vous au village? ______

8. Combien de fois par mois allez-vous au marcher ?______

9. Combien de fois par ans allez-vous en ville ?______

10. Travaillez-vous pendant une période de l'année dans une autre région ? ☐ Oui ☐ Non

Quel travail? ______

11. Est-ce que vous soutenez la famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

12. Combien d'années êtes-vous allé à l'école? ______

13. Quelle école avez-vous fréquentée? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

14. Savez-vous lire? ☐ Oui ☐ Non

15. Combien d'enfants avez-vous? ______

16. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Aucune

17. Quelle profession exercez-vous ? ☐ Agriculteur ☐ Éleveur ☐ Forgeront ☐ Commerçant ☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Macon ☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre ______

18. Quel est votre revenu mensuel? ______

19. Quels moyens de locomotion avez-vous ? ______

20. Avez-vous fait des expériences avec des projets de développement/conservation ? ☐ Oui ☐ Non
Quels projets et quand ? ______

Tableau pour produits de brousse

Produit	**Lieux** *(carré carte)*	**Quantité collectée** *(dernière saison)*	**Quantitée vendue** *(dernière saison)*	**Gain** *(dernière saison)*
Miel				
Vitelaria Paradoxa				
Tamarindus Indica				
Datrium Microcarpum				
Lannea Acida				
Parkia Biglobosa				
Xyclopia Aethiopium				
Sorendia Juglandifolia				
Landolphia Heudelotii				
Carapa Prossera				
Combretum Micranthum				
Elaeis Guineensis				
Cola Cordifolia				
Syzygium Guineense				
Vitex Doniana				
Piliostigma Thonningii				
Adonsonia Digitata				
Annona Senegalensis				

Produit	**Lieux** *(carré carte)*	**Quantité collectée** *(dernière saison)*	**Quantité vendue** *(dernière saison)*	**Gain** *(dernière saison)*
Saba				
Raphia				
Ficus				
Dialium				
Afromommum				
Jetrofa				
Autre:				
Autre:				
Autre:				
Autre:				

FOYER SECTION SOUTIEN FAMILIAL

Date :
Heure:

1. Est-ce que le foyer reçoit du soutient de membre de l'extérieur?

☐ Oui -> Question 2

☐ Non -> Section individuelle

2. Combien de Membres soutiennent le foyer et quelle est leur fonction?

____

____

____

____

3. À quel montant par an s'élève ce soutient?

☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

1. Position dans le foyer ______________________________

2. Quel âge avez-vous ? ______________________________

3. Sexe: ☐ Féminin ☐ Masculin

4. De quelle origine ethnique êtes-vous ? ☐ Fulbé ☐ Malinké ☐ Soussou ☐ Forestiers ☐ Étranger ______

5. Où êtes-vous né? ______________________________

6. Combien d'années avez-vous vécu au village? ______________________________

7. Combien de temps par an êtes-vous au village? ______________________________

8. Combien de fois par mois allez-vous au marcher ?______________________________

9. Combien de fois par ans allez-vous en ville ?______________________________

10. Travaillez-vous pendant une période de l'année dans une autre région ? ☐ Oui ☐ Non
Quel travail? ______________________________

11. Est-ce que vous soutenez la famille économiquement grâce à ce travail? ☐ Oui ☐ Non

Si oui: ☐ 100- 500`000 ☐ 500'000-1'000'000 ☐ 1'000'000-3'000'000 ☐ Plus de 3'000'000

12. Combien d'années êtes-vous allé à l'école? ______________________________

13. Quelle école avez-vous fréquentée? ☐ De l'état ☐ Coranique ☐ Privée ☐ Missionnaire chrétien

14. Savez-vous lire? ______________________________

15. Combien d'enfants avez-vous? ______________________________

16. Quelle est votre religion? ☐ Musulman ☐ Chrétien ☐ Animiste ☐ Aucune

17. Quelle profession exercez-vous ? ☐ Agriculteur ☐ Éleveur ☐ Forgeront ☐ Commerçant ☐ Fonctionnaire ☐ Chasseur ☐ Pêcheur ☐ Religieux ☐ Salarié ☐ Menuisier ☐ Macon ☐ Tisseur ☐ Minier ☐ Teinturier ☐ Autre ___________________

18. Quel est votre revenu mensuel? ______________________________

19. Quels moyens de locomotion avez-vous ? ______________________________

20. Avez-vous fait des expériences avec des projets de développement/conservation? ☐ Oui ☐ Non

Quels projets et quand ? ______________________________

INDIVIDU SECTION CONFLITS AVEC DES ANIMAUX Date :
Nom: Heure:

1. Avez-vous peur de certains animaux? ☐ Oui ☐ Non

Lesquels? ____

2. Avez-vous déjà été attaqué par un animal? ☐ Oui ☐ Non

Lesquels? ____

3. Est-ce que vous vous sentez en concurrence avec des animaux pour certains produits ?

☐ Oui ☐ Non Si oui: Quels produits et animaux?

____

____

____

____

4. Les animaux sauvages vous causent-ils des désagréments dans le cadre de vos activités

☐ Oui ☐ Non Si oui, précisez le genre de désagréments subis et la fréquence:

____

____

____

____

5. Les animaux sauvages causent-ils des dégâts aux cultures du village? ☐ Oui ☐ Non

6. A quelles cultures les animaux s'attaquent-ils? (Quels animaux/quels cultures)

____

____

____

____

7. Que feriez-vous/ font les riverains quand les animaux (leur) causent des désagréments ?

☐ Les fait fuir ☐ Pose des pièges ☐ Les empoisonne ☐ Leur tire dessus ☐ Ne fait rien

☐ Les captures

8. Organise-t-on des battues dans votre zone ? ☐ Oui ☐ Non

9. Que fait-on des animaux piégés lors de ces battues ?

☐ On les tue ☐ On les mange ☐ On les attrape pour les vendre ☐ On les laisse s'enfuir

10. Pensez-vous que les riverains et les animaux peuvent cohabiter sans grands dommages ?

☐ Oui ☐ Non

INDIVIDU SECTION TABOU Date :
Nom: Heure:

1. Votre religion ou vos traditions donne-t-elle des enseignements pour l'attitude à avoir vis-à-vis des animaux sauvages en général? ☐Oui ☐ Non

Des chimpanzés? ☐ Oui ☐ Non

Si oui, précisez ____

____

____

____

____

2. Ces enseignements sont-ils toujours respectés ? ☐ Oui ☐ Non

3. Quelle est la loi concernant l'utilisation des animaux sauvages ? (différents animaux)

____

____

____

____

4. Pensez-vous que les animaux devraient être protégés par la loi Guinéenne ?

☐ Oui ☐ Non

Pourquoi ?____

____

____

____

____

5. Pensez-vous que les lois qui protègent les animaux sont efficacement appliquées ?

☐ Oui ☐ Non

6. Connaissez-vous des gens qui ont tué des chimpanzés ?

☐ Oui ☐ Non

7. Connaissez-vous des gens qui ont été punis par la loi pour avoir tué des chimpanzés ?

☐ Oui ☐ Non

Date

Impressions sur les réponses données

1. Est-ce que les personnes questionnées ont réfléchi avant de répondre?

☐ Très ☐ plutôt ☐ ni l`un ni l`autre ☐ plutôt pas ☐ pas du tout

2. Est-ce que les personnes étaient attentives?

☐ Très ☐ plutôt ☐ ni l`un ni l`autre ☐ plutôt pas ☐ pas du tout

3. Est-ce que les personnes étaient influencées dans leurs réponses par d'autres?

☐ Très ☐ plutôt ☐ ni l`un ni l`autre ☐ plutôt pas ☐ pas du tout

4. Est-ce que les personnes vous paraissaient sincères?

☐ Très ☐ plutôt ☐ ni l`un ni l`autre ☐ plutôt pas ☐ pas du tout

5. Est-ce que les réponses vous paraissent probables?

☐ Très ☐ plutôt ☐ ni l`un ni l`autre ☐ plutôt pas ☐ pas du tout

A2.1 Correlations among predictor and control variables for the data on duiker, bushbuck, african civet, porcupine, hare, wart hog, jackal, common genet, Guinea baboon and patas monkey

	Market integration	Hunting pressure	Population density	Distance nearest road	Fish provision	Taboo influence	Share classified forest	Distance nearest field	NDVI	Distance nearest river
Market integration	1	0.781	0.85	0.015	0.933	0.249	-0.236	-0.386	-0.066	-0.124
Hunting pressure	0.781	1	0.979	-0.128	0.917	0.247	-0.056	-0.414	-0.026	-0.168
Population density	0.85	0.979	1	-0.126	0.953	0.257	-0.105	-0.407	-0.034	-0.154
Distance nearest road	0.015	-0.128	-0.126	1	-0.012	-0.016	0.308	0.541	0.204	0.171
Fish provision	0.933	0.917	0.953	-0.012	1	0.261	-0.151	-0.374	-0.057	-0.177
Taboo influence	0.249	0.247	0.257	-0.016	0.261	1	-0.04	-0.103	0.006	-0.039
Share classified forest	-0.236	-0.056	-0.105	0.308	-0.151	-0.04	1	0.299	0.127	0.074
Distance nearest field	-0.386	-0.414	-0.407	0.541	-0.374	-0.103	0.299	1	0.11	0.327
NDVI	-0.066	-0.026	-0.034	0.204	-0.057	0.006	0.127	0.11	1	0.133
Distance nearest river	-0.124	-0.168	-0.154	0.171	-0.177	-0.039	0.074	0.327	0.133	1

A2.2 Correlations among predictor and control variables for the data on chimpanzee

	Market integration	Hunting pressure	Population density	Distance nearest road	Fish provision	Taboo influence	Share classified forest	Distance nearest field	NDVI	Distance nearest river
Market integration	1	0.777	0.848	0.004	0.933	0.91	-0.233	-0.363	-0.115	-0.112
Hunting pressure	0.777	1	0.979	-0.151	0.913	0.957	-0.042	-0.419	-0.027	-0.161
Population density	0.848	0.979	1	-0.146	0.951	0.983	-0.094	-0.405	-0.046	-0.145
Distance nearest road	0.004	-0.151	-0.146	1	-0.024	-0.091	0.286	0.543	0.165	0.16
Fisher	0.933	0.913	0.951	-0.024	1	0.98	-0.147	-0.359	-0.114	-0.165
Taboo influence	0.91	0.957	0.983	-0.091	0.98	1	-0.11	-0.402	-0.058	-0.146
Share classified forest	-0.233	-0.042	-0.094	0.286	-0.147	-0.11	1	0.266	0.127	0.067
Distance nearest field	-0.363	-0.419	-0.405	0.543	-0.359	-0.402	0.266	1	0.091	0.315
NDVI	-0.115	-0.027	-0.046	0.165	-0.114	-0.058	0.127	0.091	1	0.111
Distance nearest river	-0.112	-0.161	-0.145	0.16	-0.165	-0.146	0.067	0.315	0.111	1

A3.1 Model formulas of all mixed effects Poisson regression models in the model set used for the model selection analysis on mixed species abundance in R

1	abundance~z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
2	abundance~z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
3	abundance~z.hunter+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
4	abundance~z.fisher+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
5	abundance~z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
6	abundance~z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
7	abundance~z.fisher+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
8	abundance~z.hunter+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
9	abundance~z.hunter+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
10	abundance~z.sqrt.market+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
11	abundance~z.sqrt.market+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
12	abundance~z.taboo+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
13	abundance~z.hunter+z.sqrt.market+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
14	abundance~z.sqrt.market+z.taboo+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+ac.term||species)
15	abundance~z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term||species)
16	abundance~z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+

	z.percent.protected+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
17	abundance~z.hunter+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term||species)
18	abundance~z.fisher+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.fisher+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term||species)
19	abundance~z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term||species)
20	abundance~z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
21	abundance~z.fisher+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.fisher+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
22	abundance~z.hunter+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
23	abundance~z.hunter+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
24	abundance~z.sqrt.market+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
25	abundance~z.sqrt.market+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
26	abundance~z.taboo+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+ z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.taboo+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term||species)
27	abundance~z.hunter+z.sqrt.market+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.sqrt.market+z.taboo+z.ndvi+z.sqrt.dist.field+ z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+ac.term||species)
28	abundance~z.sqrt.market+z.taboo+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+ z.sqrt.dist.roads+z.percent.protected+ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.taboo+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+ z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+ac.term||species)
29	abundance~ac.term+offset(log(transect.length))+(1+ac.term||transect.ID)+(1+ac.term||species)
30	abundance~z.sqrt.market+ ac.term+offset(log(transect.length))+

	(1+ac.term‖transect.ID)+(1+ac.term‖species)
31	abundance~z.hunter+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
32	abundance~z.fisher+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
33	abundance~z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
34	abundance~z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
35	abundance~z.fisher+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
36	abundance~z.hunter+z.sqrt.market+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
37	abundance~z.hunter+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
38	abundance~z.sqrt.market+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
39	abundance~z.sqrt.market+z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
40	abundance~z.taboo+z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
41	abundance~z.hunter+z.sqrt.market+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
42	abundance~z.sqrt.market+z.taboo+z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+ac.term‖species)
43	abundance~z.sqrt.market+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+z.sqrt.market+ac.term‖species)
44	abundance~z.hunter+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+z.hunter+ac.term‖species)
45	abundance~z.fisher+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+z.fisher+ac.term‖species)
46	abundance~z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+z.taboo+ac.term‖species)
47	abundance~z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+z.tr.pop.size+ac.term‖species)
48	abundance~z.fisher+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term‖transect.ID)+(1+z.fisher+z.taboo+ac.term‖species)

49	abundance~z.hunter+z.sqrt.market+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.sqrt.market+ac.term||species)
50	abundance~z.hunter+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.taboo+ac.term||species)
51	abundance~z.sqrt.market+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.taboo+ac.term||species)
52	abundance~z.sqrt.market+z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.tr.pop.size+ac.term||species)
53	abundance~z.taboo+z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.taboo+z.tr.pop.size+ac.term||species)
54	abundance~z.hunter+z.sqrt.market+z.taboo+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.hunter+z.sqrt.market+z.taboo+ac.term||species)
55	abundance~z.sqrt.market+z.taboo+z.tr.pop.size+ ac.term+offset(log(transect.length))+ (1+ac.term||transect.ID)+(1+z.sqrt.market+z.taboo+z.tr.pop.size+ac.term||species)

A3.2 Model formulas of all zero inflated negative binomial regression models in the model set used for the model selection analysis on chimpanzee abundance in R

1	abundance~1+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
2	abundance~1+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
3	abundance~1+z.hunter+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.hunter+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
4	abundance~1+z.fisher+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.fisher+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
5	abundance~1+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.taboo+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
6	abundance~1+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
7	abundance~1+z.hunter+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.hunter+z.sqrt.market+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
8	abundance~1+z.sqrt.market+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(transect.length))|1+z.sqrt.market+z.tr.pop.size+z.ndvi+z.sqrt.dist.field+z.sqrt.dist.river+z.sqrt.dist.roads+z.percent.protected+offset(log(1/transect.length))
9	abundance~1+offset(log(transect.length))|1+offset(log(1/transect.length))
10	abundance~1+z.sqrt.market+offset(log(transect.length))|1+z.sqrt.market+offset(log(1/transect.length))
11	abundance~1+z.hunter+offset(log(transect.length))|1+z.hunter+offset(log(1/transect.length))
12	abundance~1+z.fisher+offset(log(transect.length))|1+z.fisher+offset(log(1/transect.length))
13	abundance~1+z.taboo+offset(log(transect.length))|1+z.taboo+offset(log(1/transect.length))
14	abundance~1+z.tr.pop.size+offset(log(transect.length))|1+z.tr.pop.size+offset(log(1/transect.length))
15	abundance~1+z.hunter+z.sqrt.market+offset(log(transect.length))|1+z.hunter+z.sqrt.market+offset(log(1/transect.length))
16	abundance~1+z.sqrt.market+z.tr.pop.size+offset(log(transect.length))|1+z.sqrt.market+z.tr.pop.size+offset(log(1/transect.length))

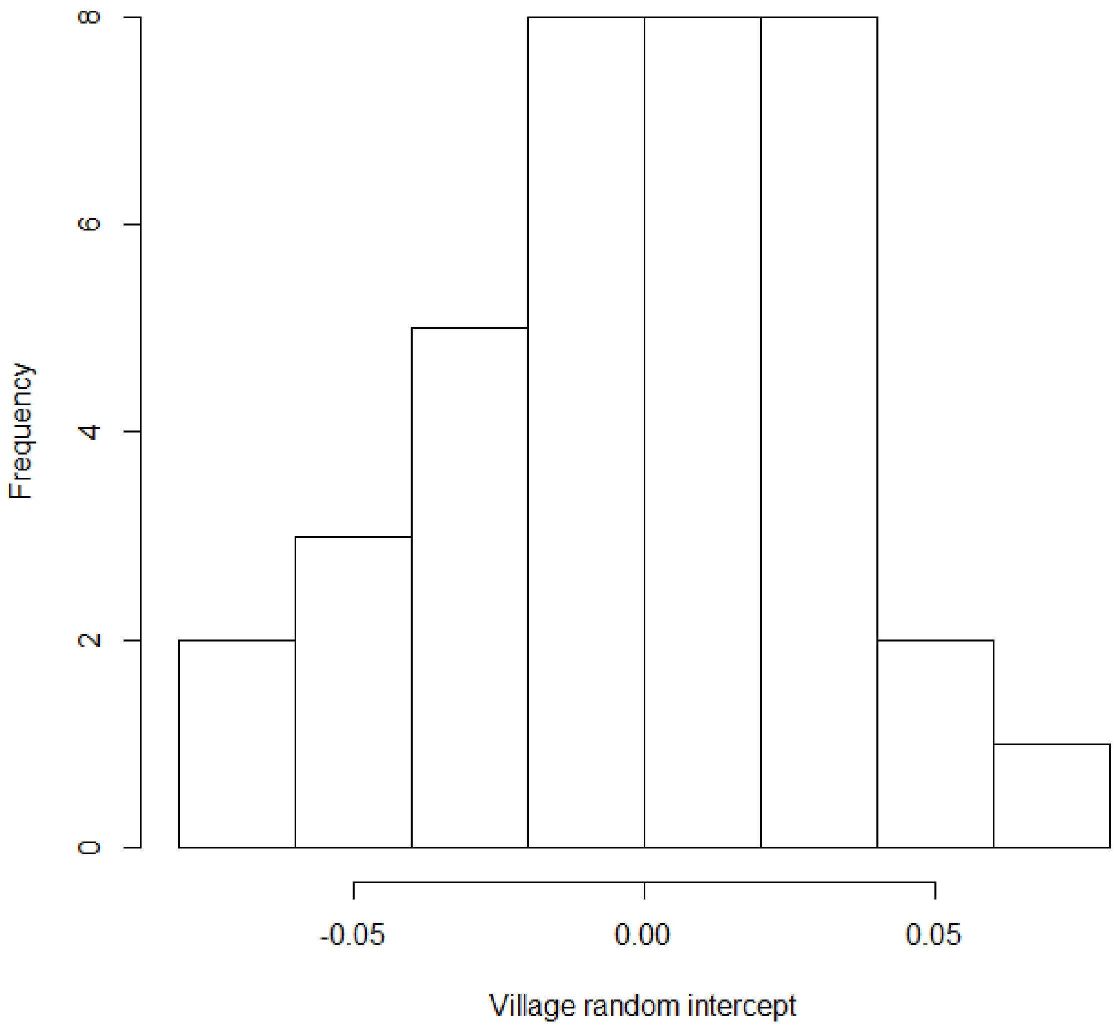
A4) Correlations among variables

	Ethnic homogeneity	Kinship	Income inequality	Reputation	Population size	Market integration	Sex	Ethnicity	Income	Kg salt	Age
Ethnic homogeneity	1	0.407	0.06	0.01	0.046	0.132	0.009	-0.148	-0.041	-0.053	-0.05
Kinship	0.407	1	0.164	0.002	0.377	0.003	0.008	0.199	-0.07	0.027	0.004
Income inequality	0.06	0.164	1	0.004	0.115	0.208	-0.05	-0.161	-0.016	-0.044	-0.09
Reputation	0.01	0.002	0.004	1	0.023	0.035	-0.01	-0.013	0.029	-0.008	-0.04
Population size	0.046	0.377	0.115	0.023	1	0.06	0.072	0.049	0.058	0.063	0.14
Market integration	0.132	0.003	0.208	0.035	0.06	1	-0	-0.189	0.097	0.007	-0.04
Sex	0.009	0.008	-0.05	-0.009	0.072	-0.002	1	0.023	0.131	0.066	0.357
Ethnicity	-0.148	0.199	-0.161	-0.013	0.049	-0.189	0.023	1	0.002	-0.021	-0.02
Income	-0.041	-0.07	-0.016	0.029	0.058	0.097	0.131	0.002	1	-0.013	0.149
Kg salt	-0.053	0.027	-0.044	-0.008	0.063	0.007	0.066	-0.021	-0.013	1	0.094
Age	-0.046	0.004	-0.085	-0.037	0.14	-0.041	0.357	-0.015	0.149	0.094	1

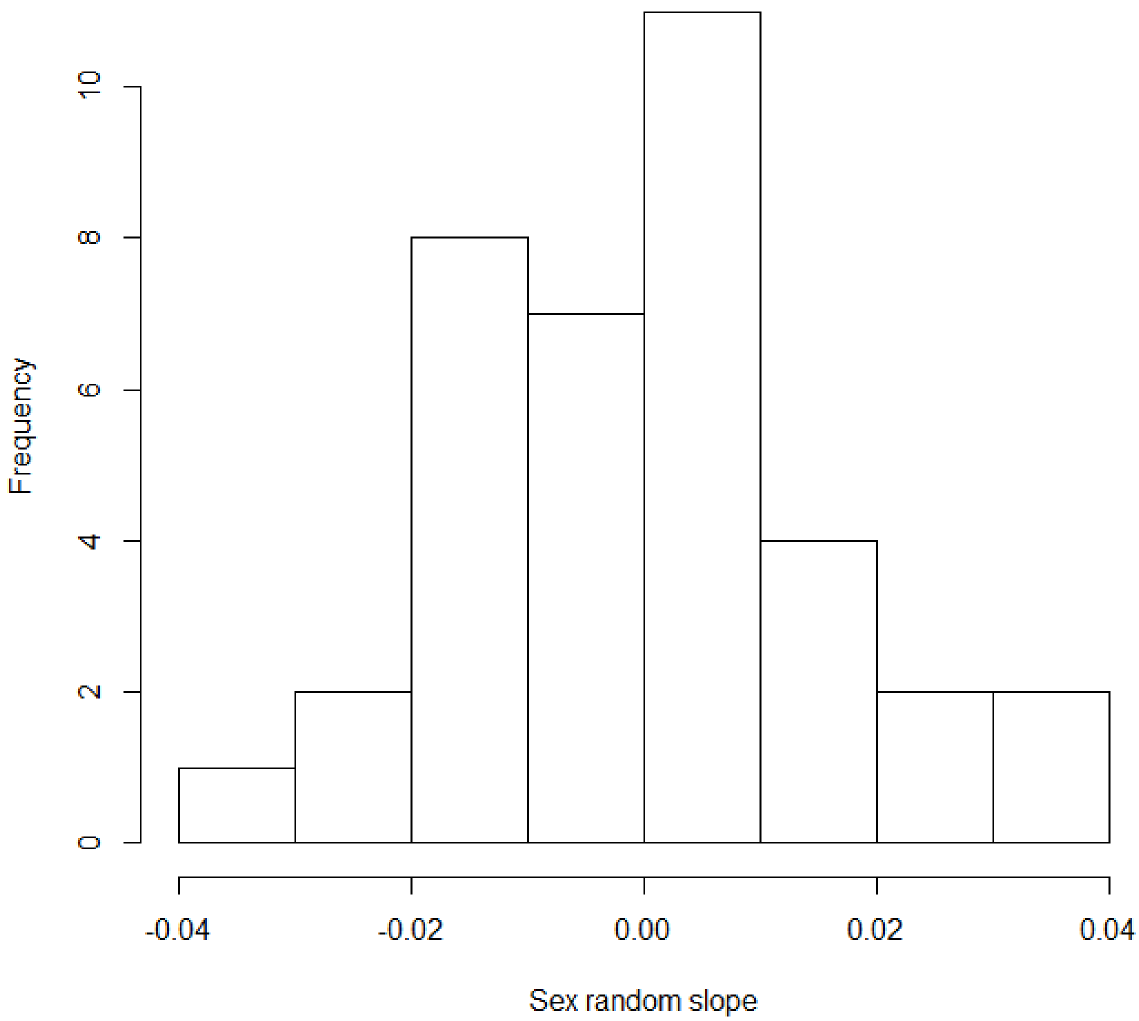
A5) VIF values of linear multiple regression with all terms from the full model.

Term	VIF
z.sqrt.HerfindahlEthnic	1.391
z.HerfindahlFamily	1.733
z.Gini	1.145
Anonymity	1.004
z.log.PopTotal	1.323
z.sqrt.MarketIntegration	1.105
Sex	1.166
Malinke	1.215
z.sqrt.incomeEU	1.073
z.sqrt.Kgstart	1.03
z.Age	1.204

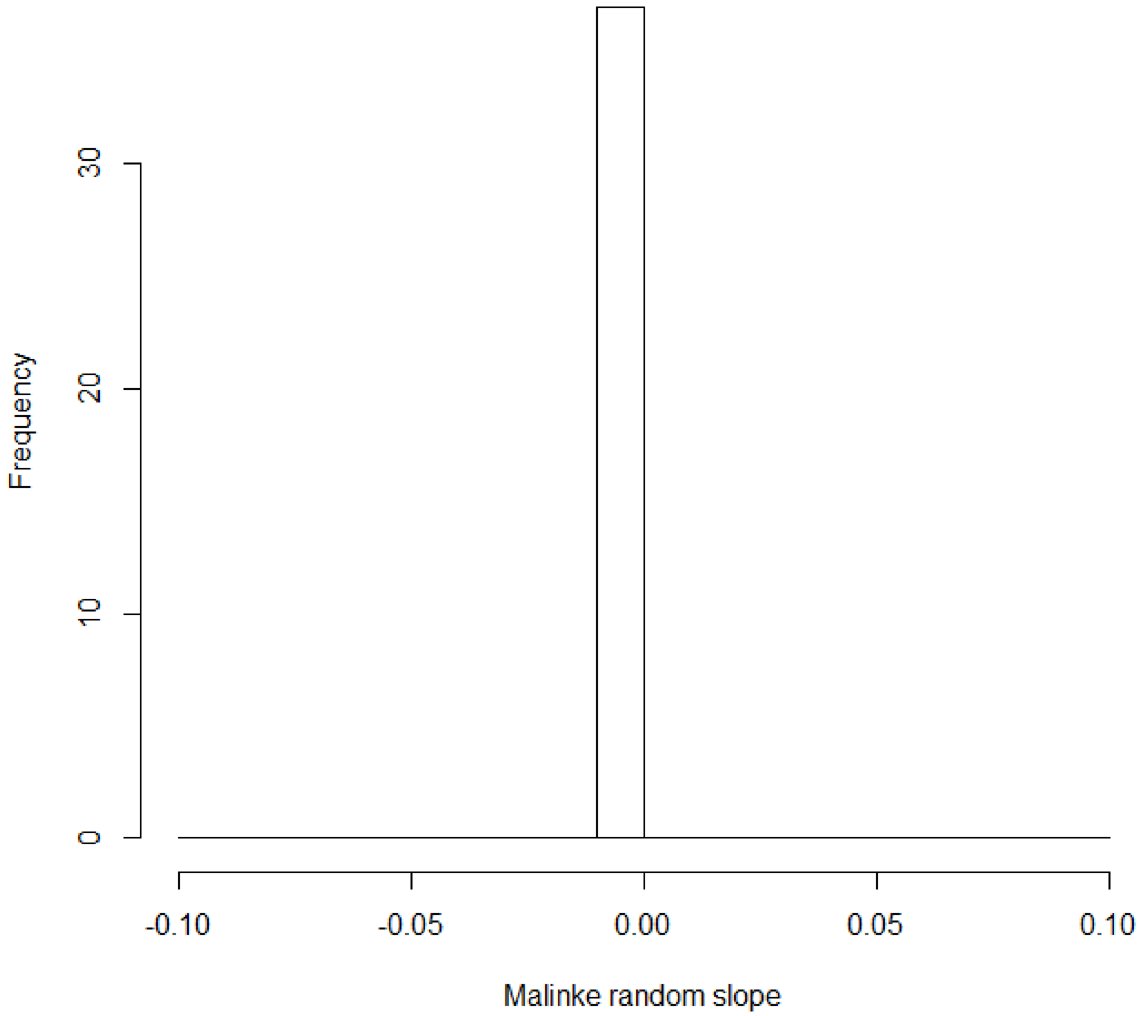
A6) Distribution of random intercepts from full model



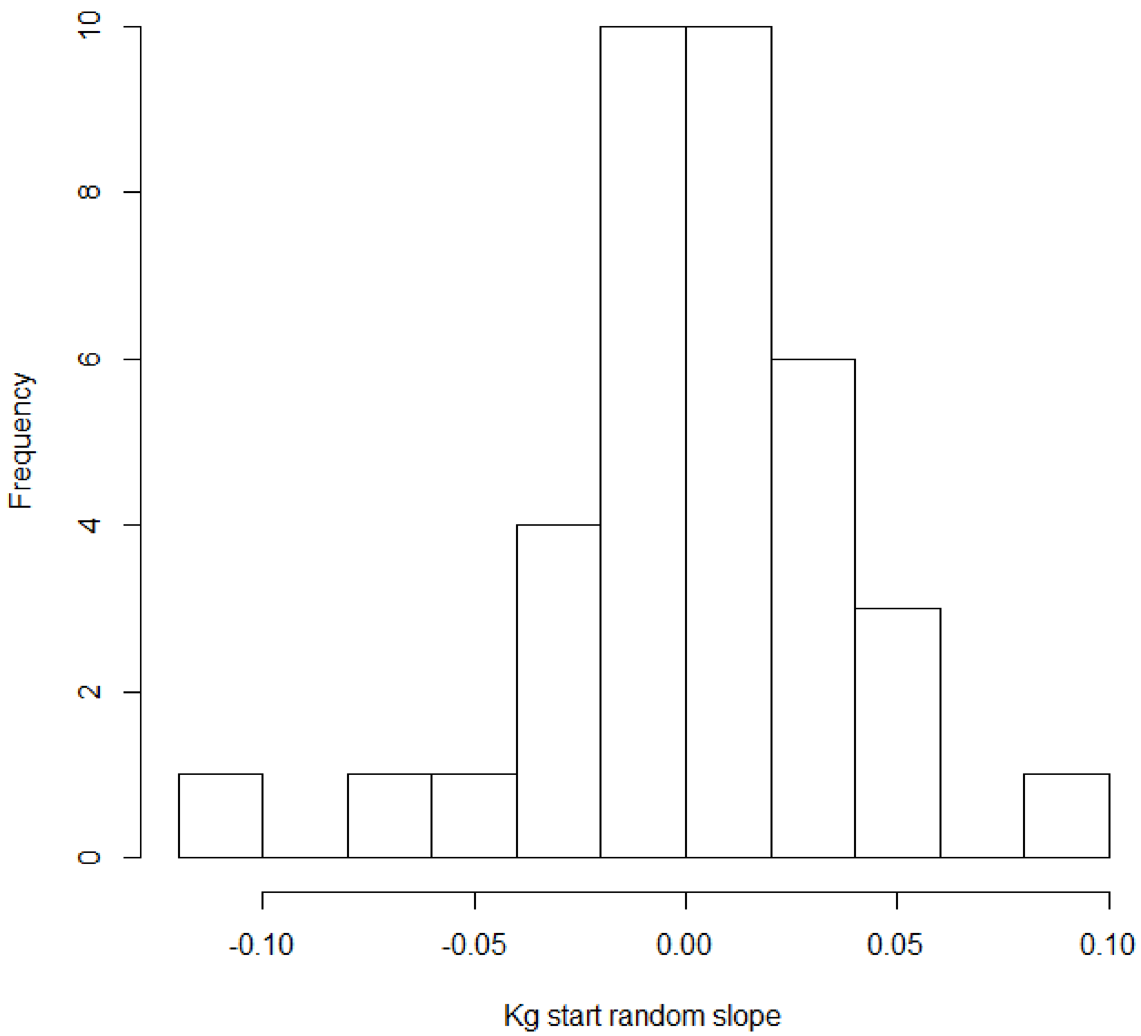
A7) Distribution of sex random slope from full model



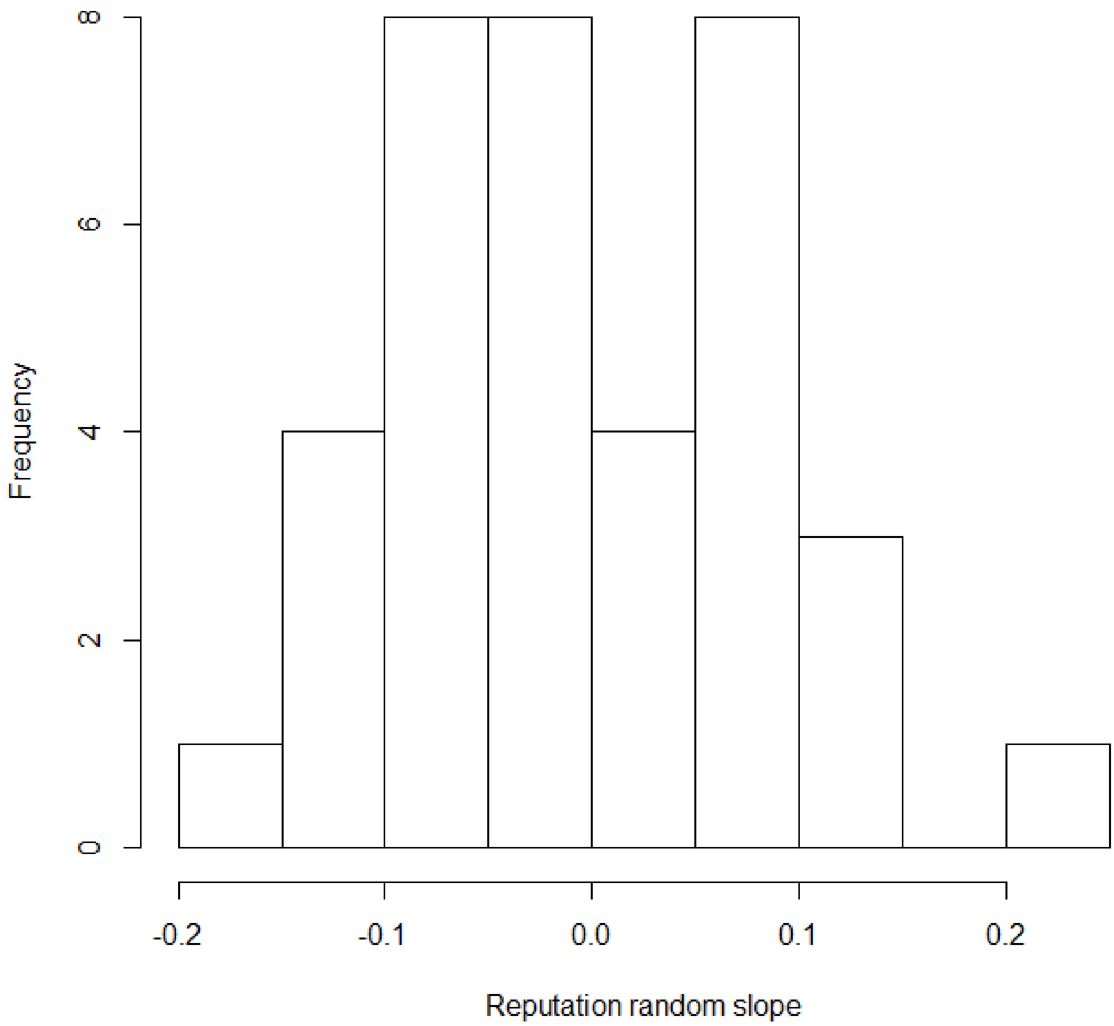
A8) Distribution of malinke random slope from full model



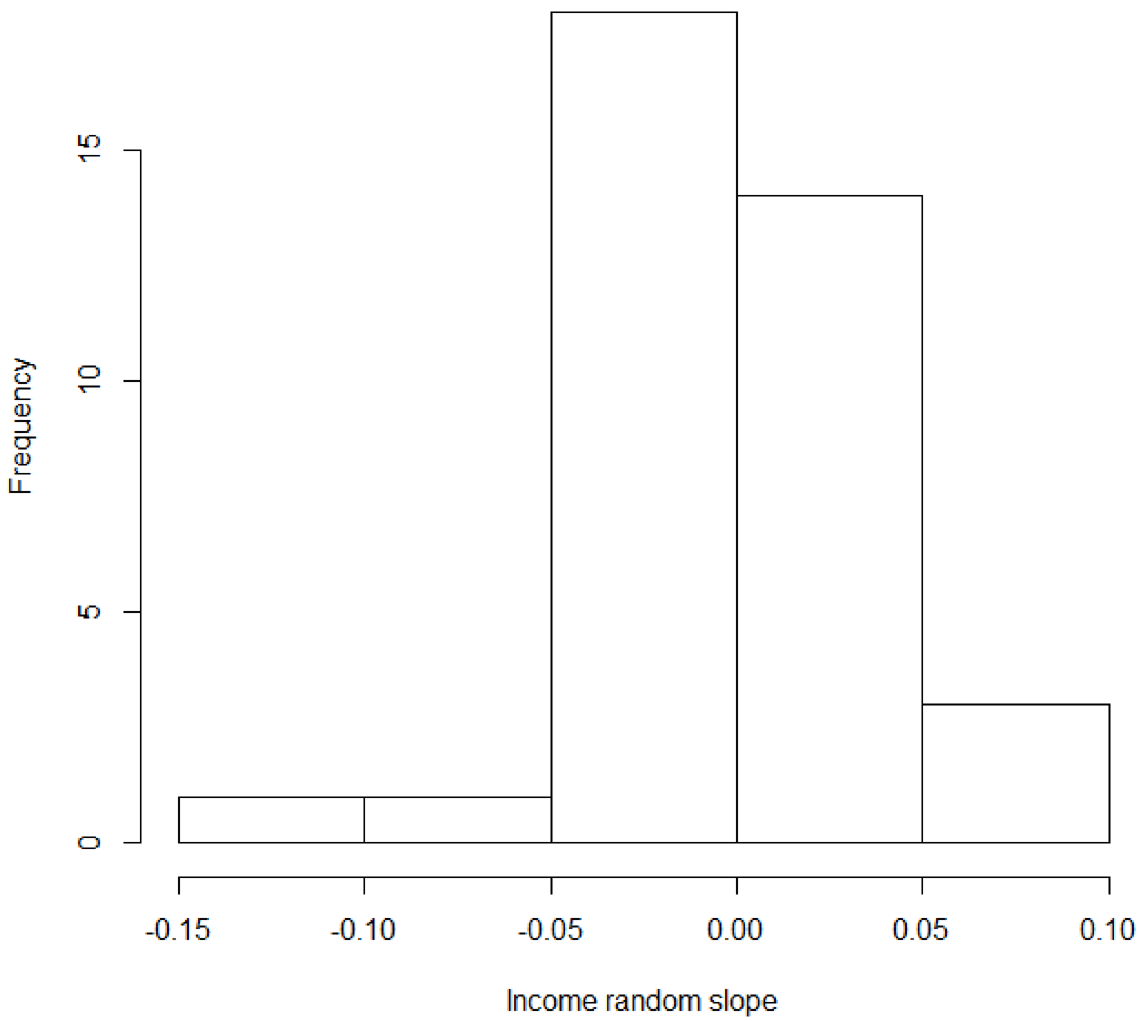
A9) Distribution of kg start random slope from full model



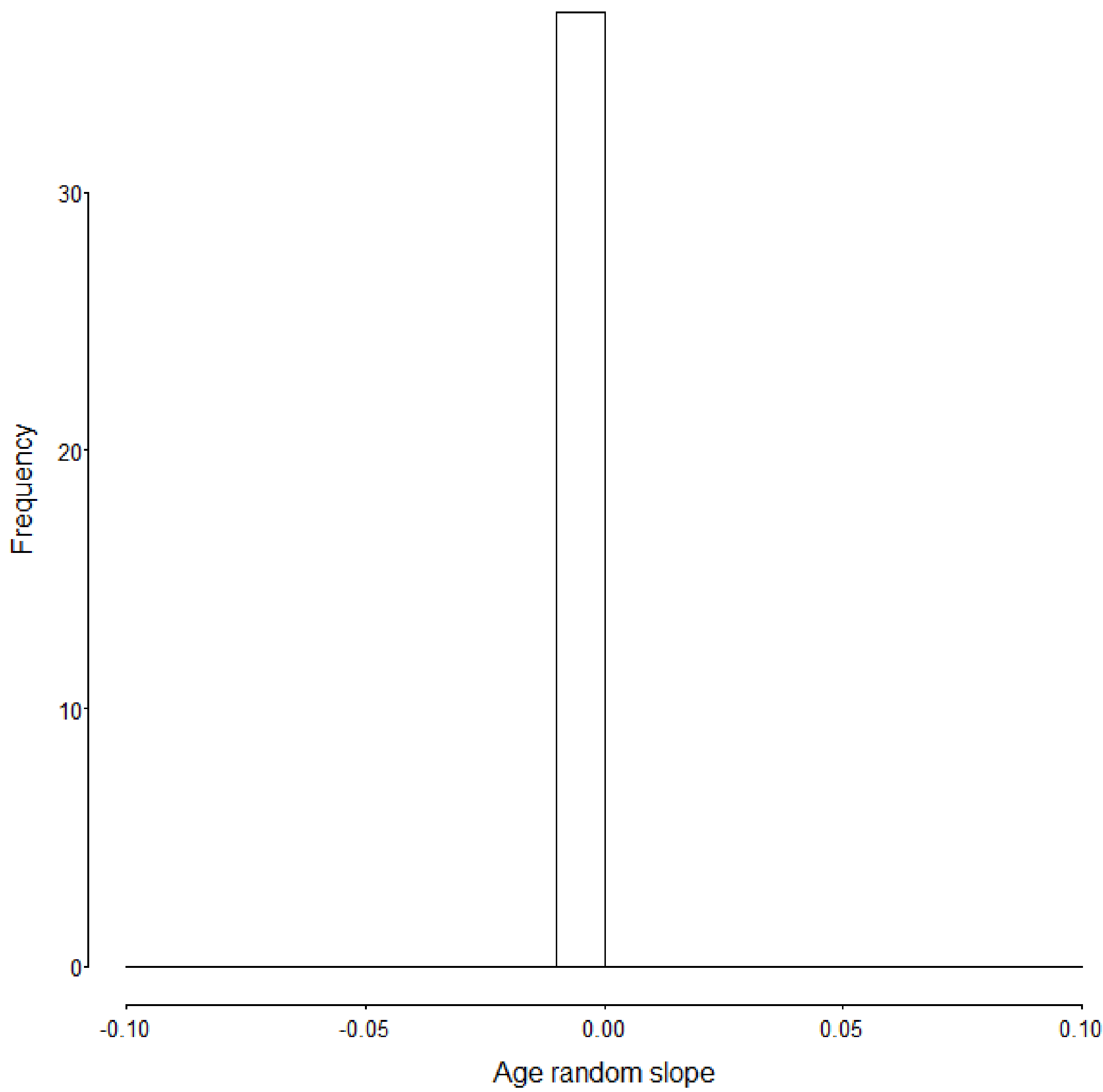
A10) Distribution of reputation random slope from full model



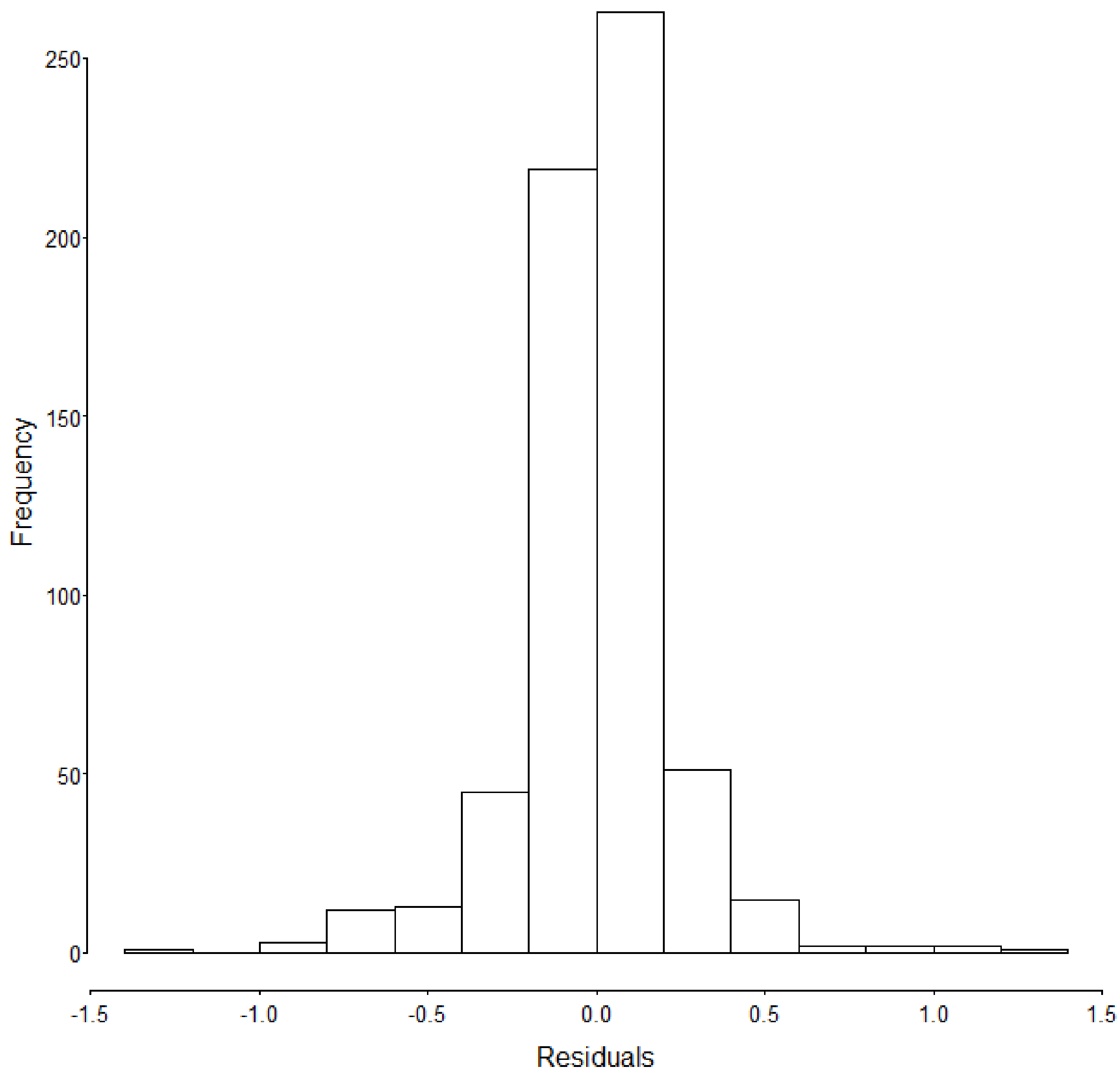
A11) Distribution of income random slope from full model



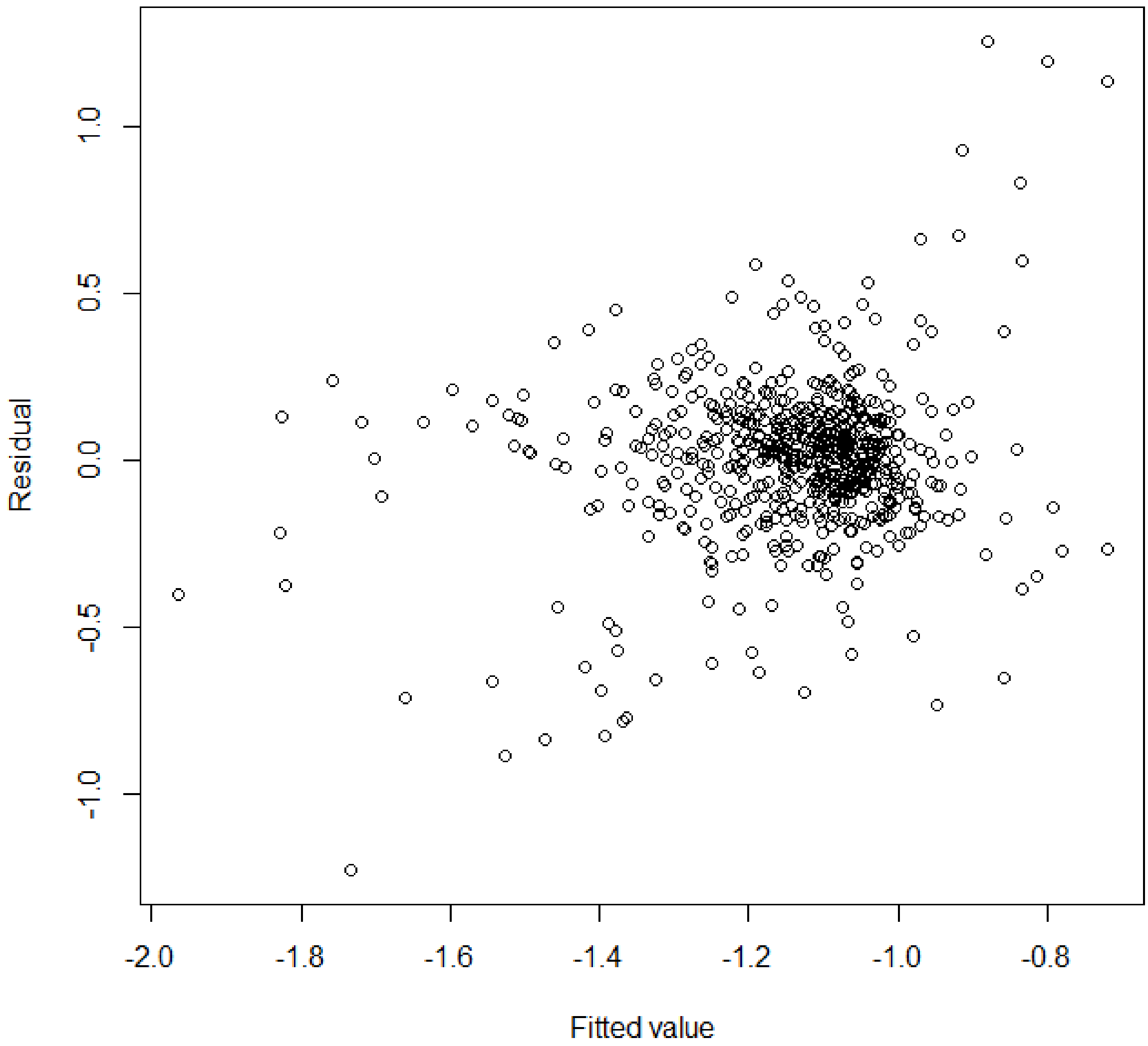
A12) Distribution of age random slope from full model



A13) Distribution of residuals from full model



A14) Fitted vs residuals plot from full model

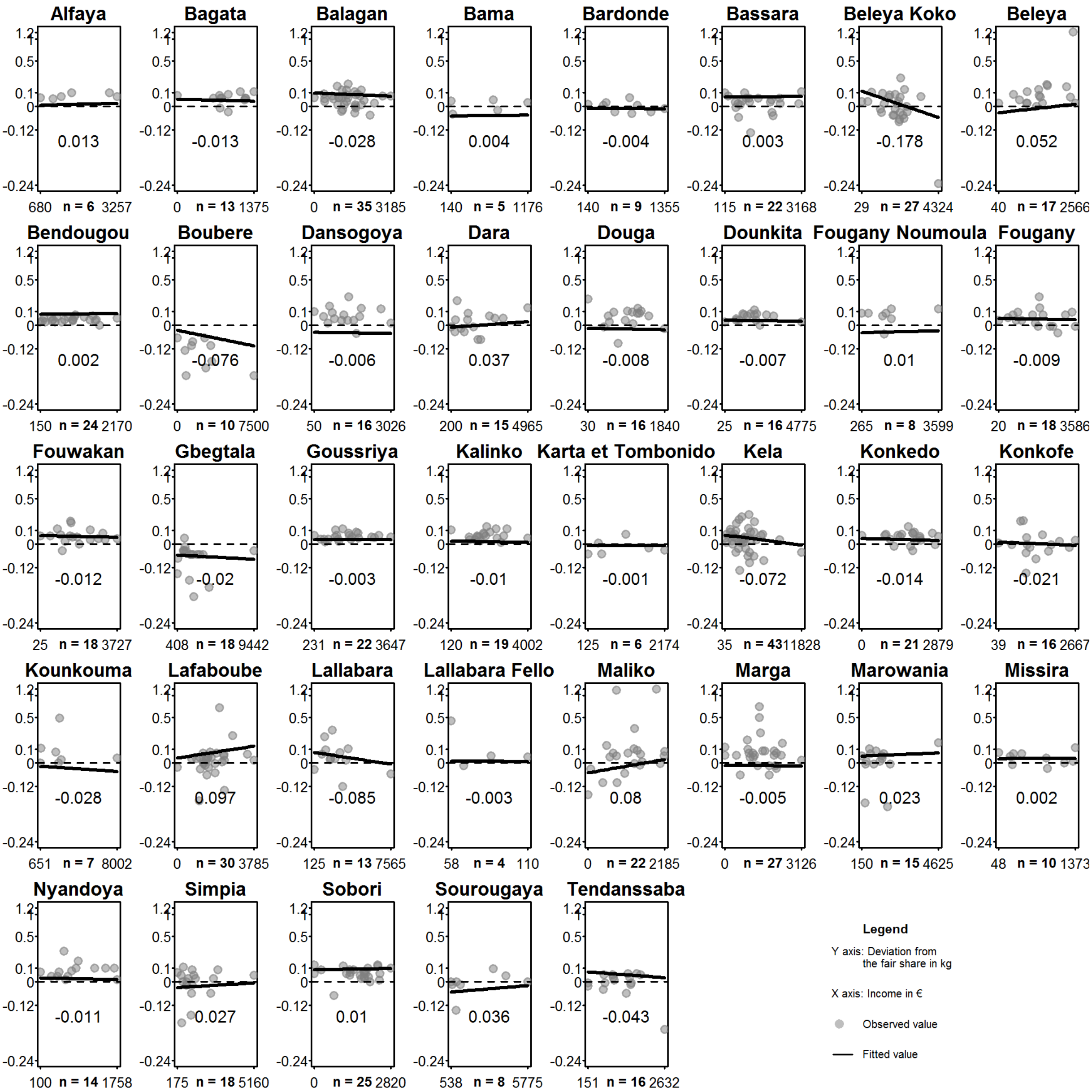


A15) Range of the estimates from the model stability analysis on the full model.
Here we checked for the influence of single villages on our estimates.

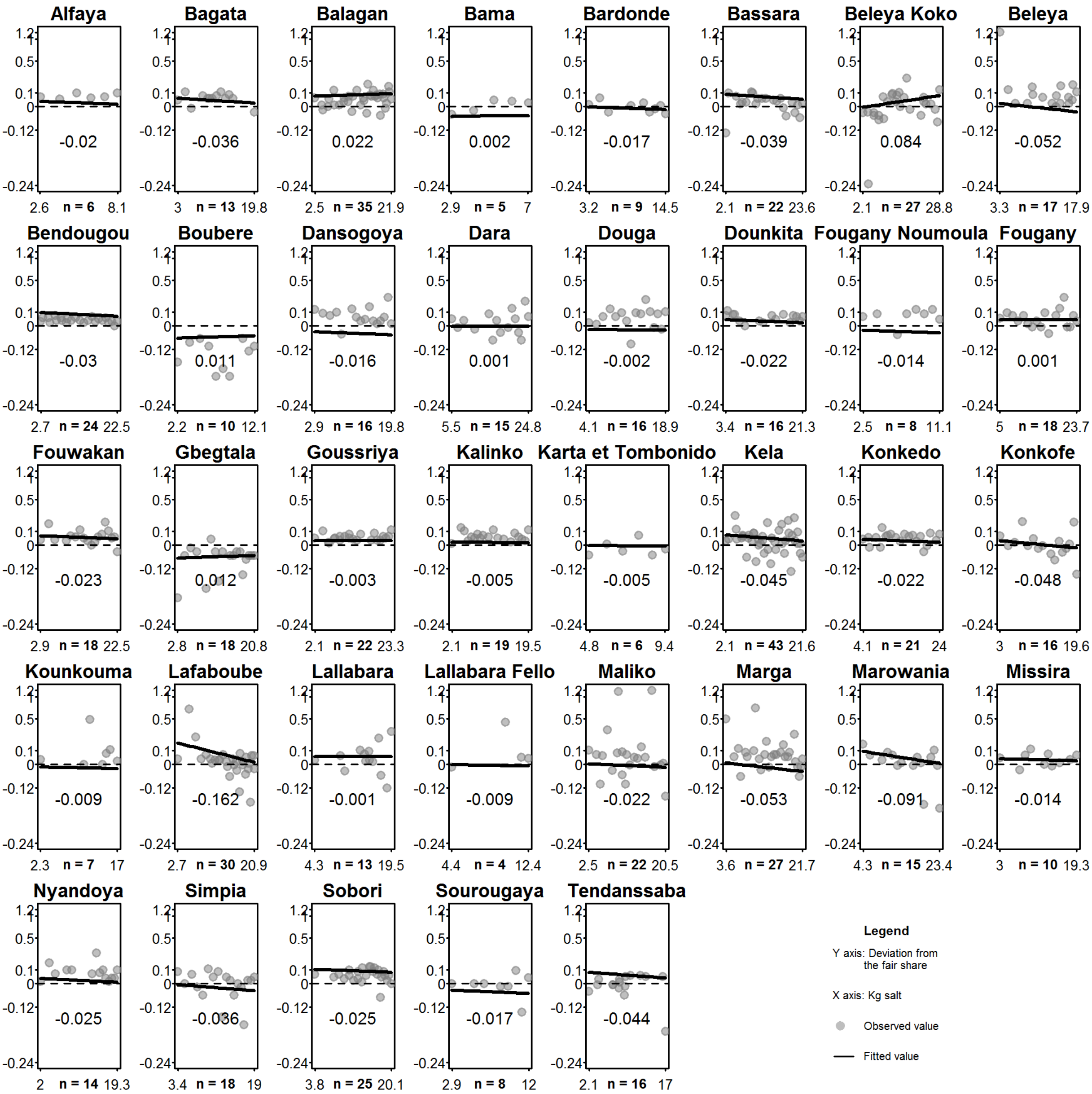
Term	Mimimum	Estimate	Maximum
Intercept	-1.206	-1.168	-1.141
z.sqrt.HerfindahlEthnic	-0.092	-0.082	-0.064
z.HerfindahlFamily	0.034	0.053	0.068
z.Gini	-0.053	-0.042	-0.023
Anonymity	0.033	0.051	0.06
z.log.PopTotal	0.054	0.079	0.093
z.sqrt.MarketIntegration	-0.074	-0.066	-0.047
Sex	-0.039	-0.018	0.009
malinke	0.024	0.046	0.066
z.sqrt.incomeEU	-0.012	-0.005	0.002
z.sqrt.Kgstart	-0.032	-0.024	-0.015
z.Age	0.015	0.019	0.024
(1|village)	0.045	0.075	0.086
(0+Anonymity|village)	0.111	0.127	0.131
(0+Sex|village)	0	0.045	0.066
(0+malinke|village)	0	0	0.034
(0+z.sqrt.Kgstart|village)	0.036	0.055	0.059
(0+z.Age|village)	0	0	0.017
(0+z.sqrt.incomeEU|village)	0.038	0.06	0.063

A16) Range of the estimates from the model stability analysis on the full model.
Here we checked for the influence of single subjects on our estimates.

Term	Mimimum	Estimate	Maximum
Intercept	-1.195	-1.168	-1.151
z.sqrt.HerfindahlEthnic	-0.087	-0.082	-0.074
z.HerfindahlFamily	0.049	0.053	0.058
z.Gini	-0.046	-0.042	-0.037
Anonymity	0.046	0.051	0.055
z.log.PopTotal	0.073	0.079	0.082
z.sqrt.MarketIntegration	-0.068	-0.066	-0.06
Sex	-0.032	-0.018	0.008
malinke	0.027	0.046	0.056
z.sqrt.incomeEU	-0.008	-0.005	0.001
z.sqrt.Kgstart	-0.028	-0.024	-0.02
z.Age	0.016	0.019	0.022
(1|village)	0.052	0.075	0.086
(0+Anonymity|village)	0.117	0.127	0.137
(0+Sex|village)	0	0.045	0.071
(0+malinke|village)	0	0	0.032
(0+z.sqrt.Kgstart|village)	0.044	0.055	0.058
(0+z.Age|village)	0	0	0.01
(0+z.sqrt.incomeEU|village)	0.037	0.06	0.065



A17) The effect of household income on the subject's fair behavior. The name of the village is written in bold on top of the respective plot and the sample size for every village is shown below the plot. The figure in the center of the plot shows the estimated mean difference in the deviation from the fair share between the richest and the poorest subjects in the village. The thin dashed line depicts the location of 0 on the y-axis across the range of the x-axis. The darker the observed value point, the more observations were made on the respective location. The fitted values were estimated for male Malinke subjects in the control condition with observation and with the village variables as well as the income at their actual values and the other variables at their mean using the full model estimates.



A18) The effect of the amount of salt in the bucket on the subject's fair behavior. The name of the village is written in bold on top of the respective plot and the sample size for every village is shown below the plot. The figure in the center of the plot shows the estimated mean difference in the deviation from the fair share between the subject with the most amount of salt in the bucket and the subject with the least amount of salt in the bucket in the village. The thin dashed line depicts the location of 0 on the y-axis across the range of the x-axis. The darker the observed value point, the more observations were made on the respective location. The fitted values were estimated for male Malinke subjects in the control condition with observationand with the village variables as well as the amount of salt at their actual values and the other variables at their mean using the full model estimates.

A 19) Result of the linear regression on the subject's fair behavior. In this case, we only included subjects from the villages of Boubere and Beleya Koko and did not control for the village population characteristics.

Number of observations				
37				
Adj. R^2				
0.52				
	Estimate	Standard Error	t value	p value
(Intercept)	-1.937	0.186	-10.424	<0.001
Sex	-0.011	0.169	-0.065	0.949
Ethnicity	0.583	0.146	3.978	<0.001
z.sqrt.incomeEU	-0.146	0.055	-2.68	0.012
z.sqrt.Kgstart	0.088	0.048	1.844	0.075
z.Age	-0.022	0.062	-0.358	0.723
Reputation	0.239	0.111	2.155	0.039

A20) Fixed effects of the full model additionally including the share of subject's kin group to the total population as an additional predictor

Fixed effects	Estimate	Standard error	Likelihood ratio test	p value
Intercept	-1.169	0.046		
Kinship*	0.059	0.022	6.851	0.009
Ethnic Homogeneity†	-0.080	0.020	12.524	<0.001
Reputation	0.052	0.029	3.108	0.078
Market Integration†	-0.066	0.018	11.198	<0.001
Population size‡	0.079	0.020	13.450	<0.001
Gini*	-0.041	0.018	4.654	0.031
Sex	-0.018	0.042	0.178	0.673
Ethnicity	0.046	0.032	2.027	0.154
Income†	-0.003	0.015	0.042	0.838
Kg salt†	-0.023	0.014	2.379	0.123
Age*	0.020	0.011	2.921	0.087
Share kin group†	-0.014	0.014	0.986	0.321

*) z-transformed †) square root and then z-transformed ‡) log-transformed prior to z-transformation. Prior to estimation, we added 290 grams and log-transformed the subject's deviation scores. Reference for "Reputation" is "reputation", for "Sex" is "male", for "Ethnicity" is "Fulbe". P-values for all terms were calculated following the approach proposed by Bolker et al. 2009.