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BEHAVIORS AND INCENTIVES UNDER SPATIAL EXTERNALITIES

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Abstract

Environmental Economics typically studies the problem of internalizing externalities using uniform (price or quantity) instruments. However, uniform regulations seem not well suited in heterogeneous contexts and when abatement efforts are complementary. This arises when farmers with neighboring plots make efforts to protect biodiversity (e.g. pollinators).

Incentive contracts are a potential useful instrument for regulating heterogeneous externalities. The theoretical literature on the subject shows that the scheme of optimal subsidies may be non-uniform when externalities are positive. Moreover, the optimal scheme is discriminatory when the efforts are complementary, in other words, two identical agents obtain differentiated subsidies. Two important aspects have received little attention in this literature: the role of private benefits and behavioral aspects.

This thesis contributes to the literature in analyzing the role of these two dimensions in the design of optimal contracts when agents generate heterogeneous externalities: **Chapter 2** investigates the role of private benefits in a model of contracting with externalities. We study the efficiency of the optimal contract outcome. We show that private benefits may lead the principal to induce efficient contributions. When reaching efficiency is not optimal, we characterize the structure of spatial effects that lead to inefficiency. Specifically, we show that the principal tends to induce agents characterized by high levels of private benefits and moderate levels of externalities to make inefficient contributions. In **Chapter 3**, we focus on the acceptability of the optimal contract with externalities using lab experiments. We study how subjects play a coordination game that is derived from the optimal solution of a model of contracting with heterogeneous externalities. This coordination game involves a trade-off between efficiency and equity in the sense that the most efficient equilibrium is the more unequal one. We find that subjects play the more unequal equilibrium more frequently. Using two treatments that differ in the level of equity at the efficient equilibrium, we find evidence which is consistent with subjects having social welfare motivations. Finally, **Chapter 4** analyzes the role of inequality-aversion preferences when the objective of the principal is to induce participation of two agents in a project. The agents generate positive externalities for each other when they both participate. We study the role of inequality aversion in this context and we find that advantageous inequality aversion has a first order effect: if the agents are not averse

to advantageous inequality, then the optimal contract does not depend on the agents' disadvantageous inequality aversion.

Résumé en français

L'Économie de l'environnement étudie la régulation des externalités en envisageant généralement des instruments uniformes, qu'il s'agisse de régulations par les prix ou par les quantités. Ces types d'instruments paraissent cependant peu adaptés à des environnements hétérogènes et lorsque les efforts d'abattement sont complémentaires, ce qui est le cas pour la protection de la biodiversité par les agriculteurs ayant des parcelles voisines (e.g. protection des pollinisateurs).

Les contrats incitatifs peuvent être un instrument pertinent pour réguler des externalités hétérogènes. La littérature théorique sur le sujet montre que le schéma de subventions optimales qui permet d'intégrer les externalités positives entre les agents n'est pas nécessairement uniforme et qu'elle est discriminatoire lorsque les efforts sont complémentaires : des agents identiques doivent recevoir des subventions différentes. Deux aspects importants ont été peu étudiés dans cette littérature : le rôle des bénéfices privés et les aspects comportementaux.

Cette thèse contribue à analyser le rôle de ces deux dimensions dans le design des contrats optimaux lorsque les agents génèrent des externalités hétérogènes : le **chapitre 2** étudie l'influence des effets spatiaux sur l'efficacité du contrat optimal. Nos résultats montrent que la prise en compte des bénéfices privés peut conduire à des situations efficaces. Plus important encore, on identifie le profil de l'agent pour lequel le principal préfère l'inciter à fournir un niveau de contribution inefficace. En effet, un agent caractérisé par des bénéfices privés élevés et des externalités modestes est susceptible de conduire à une situation inefficace. Dans le **chapitre 3**, on se focalise sur l'acceptabilité des contrats discriminants. À l'aide d'expériences de laboratoire, on analyse comment les sujets jouent un jeu de coordination qui correspond au choix d'accepter au non le contrat optimal. La particularité de ce jeu est que le résultat de la coordination nécessite un compromis entre efficacité et équité. En comparant deux jeux qui diffèrent sur le niveau d'égalité des paiements à l'équilibre, on montre que les sujets se coordonnent plus souvent sur le résultat efficace le plus inégalitaire. De plus, les comportements individuels observés sont cohérents avec une préférence pour le bien-être social. Enfin, le **chapitre 4** s'intéresse à l'impact des préférences pour l'égalité dans un contrat destiné à la réalisation d'un projet commun. En pratique, on introduit ces préférences, à savoir l'aversion à l'inégalité avantageuse et à l'inégalité désavantageuse, dans un modèle de contrat avec des externalités. On montre que l'aversion aux inégalités avantageuses joue un rôle fondamental

dans le contrat optimal. En l'absence de préférences pour ce type d'inégalité, le contrat optimal est indépendant des préférences des agents en matière d'inégalités désavantageuses.

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Chapter 1: General Introduction

The issues of providing the agents with the right incentives and achieving efficiency are at the core of the theory of incentives (See Bolton et al. (2005) for a review). Contracts are widely used in the economic context, especially when it comes to analyzing how to induce individuals to efficiently perform a costly action. In some cases contracts involve a single agents but in other situations contractual schemes may involve a group of individuals (Holmstrom, 1982; Mookherjee, 1984; Demski and Sappington, 1984). Such situations are particularly prevalent in the field of environmental economics (e.g, a group of landowners or forest owners is responsible for the provision of ecosystem services). Moreover, most studies on this topic consider that the output resulting from agents' action can be shared between the principal and the agents (the outcome is the provision of a private good). However, many interesting studies involve the provision of a collective good generating (positive) externalities among agents. For instance, the provision of environmental goods is an important problem.

Externalities are prevalent in many economic contexts involving a population of individuals providing contribution efforts. For instance, actions taken by individuals aimed at providing an environmental public good (ecosystem services for instance) often generate externalities for neighbors. This type of problem raises important question of how such externalities may impact the contract design and the outcome of the process.

The importance of introducing externalities into the economic analysis of a multi-agent contract design and of understanding its economic consequences has been acknowledges by several economists, including Grossman and Hart (1980); Gertner and Scharfstein (1991); Katz and Shapiro (1986b) and Bergstrom et al. (1986). To provide a few contribution, Katz and Shapiro (1986a) and Hart et al. (1990) study vertical contracting while Katz and Shapiro (1986b) analyze a framework characterized by the presence of network externalities in order to study the adoption of a new technology.[1] A unified model of contracting with externalities is provided by Segal (1999), who proposes a generic model describing a contractual relationship between a single principal and several agents. The action of each agent is assumed to induce externalities on the others. As a major

[1] Segal (1999); Segal and Whinston (2003) and Genicot and Ray (2006) provide a wide range of applications in the field of industrial organization. Helm and Wirl (2014) analyze problems in the context of international climate agreements for emission abatement, where asymmetric information between the parties and externalities between the principal and the agents are consistent. The role of asymmetric information is examined by Csorba (2008b,a) and Shi and Xing (2018)

contribution, this model allows to encompass many of the existing frameworks and thus provides quite generic results. This thesis is in line with this theoretical perspective.

The salient feature of the studies developed in this literature relies on the way the effect of externalities is modeled. Two mains types of externalities are considered:

- externalities are increasing (*Increasing externalities*), or
- externalities are decreasing (*Decreasing externalities*).

With increasing [decreasing] externalities, the externality imposed on an agent by increasing other agents' contribution is more [less] positive when he contributes more (Segal, 1999).[2] The direct implication of such distinction is that agents are more (less) eager to contribute when other agents contribute. In addition, when externalities are positive [negative], the externalities "gained" at higher contribution levels are larger (smaller) than at lower contribution levels. In this thesis, we focus on the case where externalities are increasing because most of the applications we have in mind relate to various environmental economics settings. This may involve a group of agricultural producers providing efforts aimed to conserve bees; Or forest owners providing efforts in order to mitigate windstorm damages on their parcels.

Another important feature of the literature on contracting with externalities may be categorized based on the following items:

- First, whether the principal can offer differentiated payments to agents or not.
- Second, whether the corresponding game setting corresponds to a situation where externalities affect the agents' outside options (i.e. reservation utilities) or not.

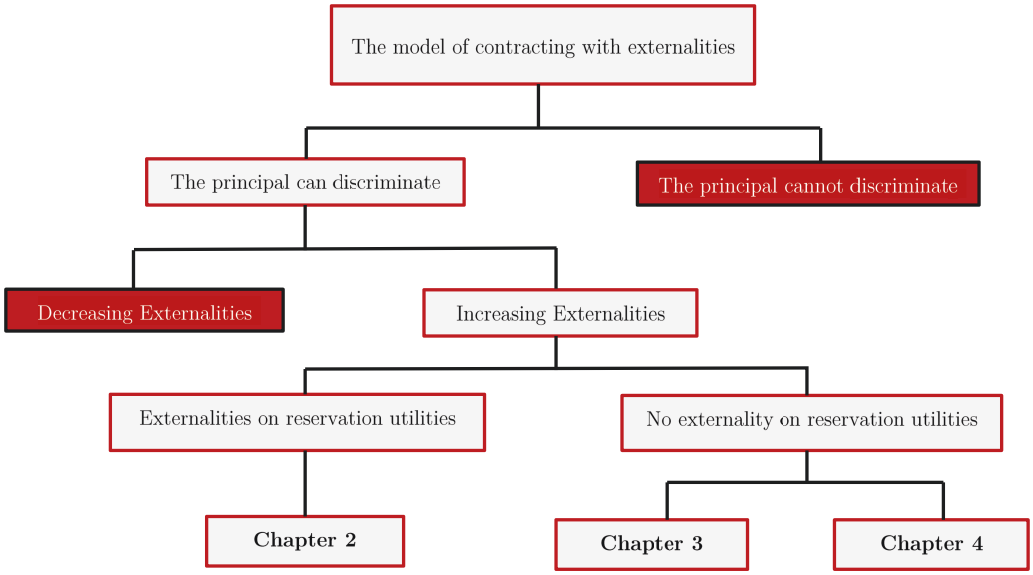
In this thesis, we mainly focus on the case where the principal is allowed to offer differentiated payments.[3] Regarding the assumption of the effect of externalities on reservation utilities, we provide contribution in both types of situation.

[2] More formally, externalities are (strictly) increasing [decreasing] if for all $i \in N$, $u_i(x_i, x_{-i})$ has (strictly) increasing differences in (x_i, x_{-i}) [in $(x_i, -x_{-i})$] in the sense of Topkis (1998). In this specification, x_i is the contribution of agent i while x_i refers to the contribution of other agents.

[3] The situations in which the principal cannot discriminate among agents is extensively discussed in Segal (2003).

This effect leads to have qualitative impact. For instance, Segal (1999) first provides results suggesting that the contract may lead to an inefficient outcome due to the effect of externalities on agents' outside options. Bloch and Gomes (2006) provide results suggesting that when externalities do not affect agents' outside options, an efficient equilibrium always exists. When externalities affect agents' outside options, games may have only inefficient equilibria. Möller (2007) and Münster and Reisinger (2015) find that simultaneous contracting —used in Segal (1999)— is efficient only when externalities on non-contracting agents tend to disappear with the number of contracting agents.

The following figure provides us with an overview of how this thesis fits into the literature on contracting with externalities.



More specifically, we rely on the assumption that externalities affect agents' outside options in **Chapter 2**. Second, **Chapter 3** and **Chapter 4** build on the assumption that externalities do not affect agents' outside options. More details about each chapter is provided below.

When externalities affect reservation utilities

Most of the existing literature concludes that contracts may lead to an inefficient outcome when externalities affect agents' outside options (Segal, 1999; Bloch and Gomes, 2006). However, it is important to note that these studies mostly ab-

stract from the potential existence of agents' private benefits. Many real-world applications suggest that such private benefits can arise in a multi-agent setting. For instance, agricultural producers providing efforts aimed at sustainably managing biodiversity are often the primary beneficiaries of their actions (See Balmford et al. (2002) for more details). Therefore, it is interesting to assess the effect of the existence of such private benefits. **Chapter 2** is an attempt to partially fill this gap. It aims at introducing such private benefits into a model of contracting with externalities.

We address the following questions: What are the relative impacts of private benefits and externalities on the optimal contract design? What are the characteristics of the individuals who drive the (in)efficiency of the contracting outcome? To analyze these issues, we introduce a theoretical model in which a single principal offers a contract to each member of a group. Each agent's contribution generates spatial effects in the group. The contract specifies that agents provide contribution efforts and receive rewards in return. Spatial effects are defined as follows. *Retention effects* refer to the private benefits generated by each contributor and *diffusion effects* to the additional benefits generated by each contribution effort on all the group's members except the contributor. The emphasis of this chapter is to study how the principal approaches the problem of the efficiency of the optimal contract when spatial effects are prevalent.

When externalities do not affect reservation utilities

As stated by Segal (1999) and Bloch and Gomes (2006), when externalities do not affect the agents' outside options, results suggest that contract may be socially efficient. It is important to note that the latter result relies on assumption that the principal can select his preferred equilibrium outcome, which means that there is no coordination issue in case of multiple equilibria. In contrast, when the principal does not have the possibility to select his preferred equilibrium, a few contributions suggest that coordination problems can emerge (Segal, 2003; Genicot and Ray, 2006; Winter, 2004). More precisely, researches in this context claim that the optimal contracts allow for the existence of at least two Nash equilibria in the game. Therefore, the implementation of a contractual approach raises an interesting issue, which is how to coordinate the agents to select the equilibrium that is the best for the principal.

Bernstein and Winter (2012) in the context of a voluntary participation game with heterogeneous externalities Winter (2004) in a more general setting, prescribe

the use of a discriminant contracting scheme. Specifically, they argue that a "Divide and Conquer" device may induce efficiency by allowing to implement the agents' contribution as a unique strict Nash equilibrium of the game. A Divide and Conquer contracting scheme proceeds as follows. First, the principal ranks the agents according to their "identity" in the group.[4] Then, according to the ranking, the principal offers to each agent a differentiated reward (where a higher ranked individual obtains a larger reward).

It has to be noticed that Bernstein and Winter (2012) assume that specific behavior in case on agent is indifferent between participating and not participating: in case of indifference, an agent is assumed to participate. This raises the question of whether agents actually follow such type of rule in practice.

Acceptability of discriminant contractual schemes

The role of discrimination is increasingly studied in the literature on contracting with externalities.[5] However, it is worth noting that "Divide and Conquer" contracting schemes lead to uneven distributions of agents' payoffs. In addition, as said previously, the efficiency of the "Divide and Conquer" contracting scheme relies on the assumption that agents are assumed to participate whenever they are indifferent between participating or not. Relaxing this assumption (which lacks behavioral foundations), the game considered may involve several equilibria where the most efficient one leads to the most unequal distribution of payoffs among the agents. Therefore, a potential problem of social acceptability may arise due to a potential trade-off between efficiency and equity. To the best of our knowledge, few studies have investigated the social acceptability of unequal distributions of payoffs in game settings[6] and none particularly in the context of discriminant

[4]The "identity" of an agent characterizes the agent who has the most influence in each bilateral relation inside the group (in terms of the externalities generated).

[5]See (Caillaud and Jullien, 2003; Che and Spier, 2008; Grossman and Hart, 1988; Innes and Sexton, 1994; Jullien, 2011; Katz and Shapiro, 1986a,b; Segal and Whinston, 2003; Posner et al., 2010) as well as Segal (2003) in a more general perspective.As studied before, Segal (2003); Winter (2004); Segal (2003) and Bernstein and Winter (2012) consider situations where externalities do not affect agents' reservation utilities and highlight the importance of discrimination for optimal contract design. Segal and Whinston (2003) consider the model introduced in Rasmusen et al. (1991) and find that discrimination allows the principal to internalize a part of the externalities that exist among the agents. Sakovics and Steiner (2012) focus on the identity of agents who should receive principal's offers in the situations where agents are heterogeneous. They argue that optimal incentives should target agents whose participation has a larger influence on the aggregate decision of participation, and also those who are relatively insensitive to variations in the aggregate action level.

[6]Devetag and Ortmann (2007) survey the literature on coordination games with Pareto ranked equilibria and provide insights about how coordination failure can happen in practice. Landeo and Spier (2009) analyze exclusive dealing contracts and claim that discrimination between agent can

contractual schemes. **Chapter 3** analyzes such efficiency-equity trade-off using laboratory experiments.

On the effect of social preferences on optimal contract design

The theory of contracting with externalities mostly rely on the assumption that individuals are self-interested. Evidence from a number of empirical studies suggest that individual behaviors may exhibit social consideration. Among other examples, inequality-aversion, social-welfare maximization, or reciprocity.[7] In particularly, several empirical studies provide evidence suggesting that inequality aversion affect the outcome of a contract (see Koszegi (2014) for a review). **Chapter 4** is an attempt to theoretically analyze the optimal contract design and outcome when inequality aversion preferences are taken into account in the basic model of contracting with externalities. We thus introduce inequality-aversion concerns in the spirit of Fehr and Schmidt (1999) into a model of contracting with heterogeneous externalities Bernstein and Winter (2012).

Chapter 4 is further motivated by the main result in Bernstein and Winter (2012) who show that optimal contract might induce differentiated payoffs when agents are assumed to be self-interested.

In this chapter, we address the following questions. First, how do inequality aversion preferences play upon the optimal outcome of a multi-agent contract when agents' actions generate (heterogeneous) externalities? Second, what is the outcome of a contractual approach when the principal takes into account both heterogeneous externalities and agents' heterogeneous preferences for unequal payoff distributions?

Overall, the present thesis provides three contributions lying at the intersection between the literature on contract with externalities and the literature on behavioral contract theory. **First**, it contributes to the literature on contracting with externalities by investigating how the joint presence of multilateral externalities and private benefits impacts the efficiency of the optimal contract outcome, and by characterizing the individual characteristics driving the inefficiency of the contract. **Second**, this thesis experimentally analyzes the acceptability of dif-

play an important role in reaching efficiency. Crawford et al. (2008) study the role of focal points (Schelling, 1960) in coordination games and show that payoff inequalities may cause coordination failure. López-Hoffman et al. (2010) follow the same line as in Crawford et al. (2008) and provide evidence suggesting that payoff equity acts as a major determinant for coordination success.

[7] See Charness and Rabin (2002); Loewenstein et al. (1989); Fehr and Schmidt (1999); Bolton and Ockenfels (2000); Rabin (1998) and Engelmann and Strobel (2004) for further details on individuals' social preferences.

ferentiated incentives, which might raise a potential tension between efficiency and equity when multiple equilibria arise. It contributes to the literature analyzing the issue of equilibrium selection. We provide evidence suggesting that more inequality results in higher coordination success. **Finally**, this thesis is related to the literature on behavioral contract theory by analyzing the role of inequality-aversion preferences in a situation where a principal wants to induce agents' participation, when individual participation generates externalities. It aims at understanding the impact of individuals' inequality aversion preferences on optimal contract design.

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Chapter 2: Contracting with Spatial effects

Abstract

This chapter is an attempt to study how the spatial characteristics (retention effects or diffusion effects) observed in certain public goods provision (environmental goods for instance), influence the efficiency of the contract outcome. Our theoretical results suggest that an optimal contracting scheme may be efficient when retention effects resulting from an agent's effort are sufficiently high. Moreover, our study helps to identify the agent that drives the potential inefficiency of an optimal contract approach. We show that an agent characterized by low retention effects and relatively high diffusion effects may lead to the inefficiency of the contracting outcome. This implies that bilateral contracts may not be the most appropriate instrument to solve the issues raised by spatial externalities.

Keywords

Contract, Spatial effects, Network externalities, Private benefit, Efficiency.

2.1 Introduction

In various economic activities, individuals' actions involve both private benefits and multilateral externalities within the group in which they belong. For instance, in the context of biodiversity conservation, a landowner who exerts efforts to protect bees creates private benefits since pollination can increase yield, and also externalities by allowing better pollination of neighboring parcels.[1] When creating a cross-border trans-boundary park, each action of an individual park manager creates both private benefits such as improving biodiversity in his own park and externalities by allowing species to move between the parks.[2] Therefore, the spatial effects, whether private benefits and externalities, are present in a number of economic situations involving multiple agents, which raises the question of how to design efficient incentives in such frameworks.

In the presence of spatial effects, the structure of the group becomes very quickly complex. Within a given group, the action of each individual generally has heterogeneous impacts on the payoff of the other individuals present in this group. An individual's action may have a more (less) significant impact on his own payoff through private benefits and/or a more (less) impact on the payoffs of others due to the externalities that he creates for his neighbors. Furthermore, the synergy between contributors and non-contributors can affect the individual's decision-making. Some of them may find it best not to provide contribution efforts and benefit from the efforts of others through the generated externalities. These lead us to wonder how the structure of the group influences the (in)efficiency of the contract. In other words, what are the characteristics of the group's individuals that may lead to the (in)efficiency of a contractual approach?

The most prominent papers on this topic mainly focus on the (in)efficiency of principal multi-agents contracting under the presence of multilateral externalities between the agents.[3] It is therefore interesting to note that these papers derive their conclusions for situations where the private benefits of the agents resulting from his effort contribution are not considered in the analysis. In addition, the previous studies investigate situations under which the agents' reservation util-

[1] For example, Maass et al. (2005) argues that the benefits of biodiversity conservation efforts along a border are totally heterogeneous. López-Hoffman et al. (2010) present a bunch of external effects when biodiversity conservation efforts are carried out around the state borders.

[2] See Busch (2008) for more details on the additional benefits generated by the creation of trans-boundary parks.

[3] Segal (1999); Katz and Shapiro (1986); Bergstrom et al. (1986); Hart et al. (1990); Genicot and Ray (2006) are some of the relevant papers that have examined the efficiency of contracts when there are externalities between agents.

ities either take externalities into account (See Segal (1999); Bloch and Gomes (2006)) or are not influenced by external effects (Bernstein and Winter, 2012; Sakovics and Steiner, 2012). In this chapter, besides the externalities, we allow for the existence of the agents private benefits in the group and consider the situation in which externalities are present on agents' reservation utilities. We address several issues that can not be explored in a simplified framework, such as the relative impacts of each type of spatial effect on the optimal contract and the determinants of the (in)efficiency of the contract.

This chapter's contribution is twofold. First, our finding suggests that the individual's private benefits play an important role on the efficiency of the contract. Most particularly, we show that higher private benefits may induce efficiency. Second, and most importantly, our analysis enables us to characterize the agents driving the inefficient contracting outcome. Specifically, an agent characterized by low private benefits and relatively high externalities is more likely to induce an inefficient contracting outcome.

Our analysis solves for the efficient contracting outcome, where efficiency refers to the situation under which a principal's contracting outcome corresponds to the first best, namely the socially optimal outcome.[4] It is an attempt to tackle the efficiency problem of the principal multi-agents contracting approach when agents are in a group with spatial effects among them. In our model, the agents provide private contribution efforts to enable the production of a public good. Formally, we analyze a theoretical model in which a single principal contracts with a group made up by several agents with spatial effects among them. The principal proposes a vector of incentives to the agents then the agents simultaneously decide whether to accept or to reject the principal's proposition. We define the spatial effects as follows. *Retention effects* refer to the private benefits generated by each contributor and *diffusion effects* to the additional benefits generated by each contribution effort on all the group's members except the contributor. Consequently, an agent who accepts his offer provides contribution efforts, generates both diffusion effects that benefit his neighbors and retention effects besides the transfer received from the principal. On the other hand, an agent who rejects his offer does not exert any effort, but still benefits from diffusion effects generated by the agents who have chosen to accept the contracts. In our model, we consider straightforward linear payoff functional forms that exhibit efforts' substitutability. Moreover, the principal offers only bilateral contracts as in Segal (1999), meaning

[4] Colyvan et al. (2011) analyze the game theoretical models related to the conservation of biodiversity using the same consideration as in this chapter.

that the incentive provided to each individual is not contingent on others' contribution efforts. The model allows to derive several comparative statics results on the effect of different model parameters on the relative efficiency of the contracting approach.

We begin the analysis with the case of homogeneous spatial effects. All agents have the same utility function. The only difference noted within this utility function relies on the variability of retention effects and diffusion effects. This means that the success of the project may depend on the variability of retention effects and diffusion effects, among other parameters of the model. In this setup, our analysis reveals that the parameters of the model, i.e. the weight that the principal awards to the success of the project, the number of agents constituting the group and most importantly the relative values of the spatial effects resulting from the agents' contribution efforts, shape the results. Our findings are threefold: firstly, when agents' retention effect levels are high, the contract is always socially efficient. Secondly, efficiency of the contract outcome is more easier to reach *(i)* when the importance of the project for the principal is sufficiently high, and *(iii)* when both retention effects and diffusion effects are relatively high. Finally, we find an unclear effect of the number of agents. The latter result implies that the characteristics of participating agents, in terms of spatial effects, are more important than their number.

In order to identify the characteristics of the agents that drive the inefficiency and those that favor the efficient contracting outcomes, we analyze the model under the assumption of heterogeneous spatial effects. Focusing on three-agent case, we find that the agent characterized by high retention effects drives the efficiency. Therefore, a principal offering optimal contract to such agent implements an efficient contribution level. Moreover, an agent characterized by low retention effects and relatively high diffusion effects is more likely to receive a contract inducing an inefficient outcome. This agent then drives the inefficiency of the contracting outcome. The latter finding implies that the agent who receives a relatively high amount of externalities while creating for himself a small amount of private benefits is more likely to be excluded from the group of potential contractors. In addition, we also find that the weight that the principal awards to the success of the project influences the result. With a larger weight making the efficiency outcome easier to reach.

This study builds on the literature on optimal targeting in a network.[5] Of clos-

[5] Allouch (2015); Demange (2017); Galeotti et al. (2017) analyze this problem but without taking into account the agents' participation constraint.

est relevance to our study is the literature on optimal targeting in a network with agents' participation constraints. Bernstein and Winter (2012) focus on participation game and analyze optimal full participation as a unique Nash equilibrium.[6] In their model, the participation decision of each agent induces externalities among other participating agents. They show that the optimal contract depends on the structure of the externalities; i.e. the extent to which the bilateral externalities are asymmetric. Thus, in each bilateral relation, the agent generating the highest externalities receives the more generous incentive. Along the same line, Sakovics and Steiner (2012) in analyzing the effect of strategic uncertainty on the agent's behavior when playing a coordination game induced by the presence of externalities, argue that the optimal incentives –the ones that, at a minimal cost, may induce a better coordination success– should target agents who impose high externalities on others and on whom others impose low externalities. With respect to this literature, we consider continuous efforts and account for the agents' private benefits in the model, then we derive results not only on full participation but also on the efficiency of the optimal contracting outcome from the social viewpoint. Furthermore, as in Sakovics and Steiner (2012) and unlike Bernstein and Winter (2012), our results suggest that the principal may target a subgroup of agents instead of all agents. Besides constrained budget for the principal, Belhaj and Deroïan (2018) also take into account agent's continuous efforts and private benefits for participating agents when analyzing the issue of contracting in a network. They find that the optimal contract – the contract that maximizes the principal's payoff – may target a subgroup of agents. They also argue that the optimal contract may exclude the most central agent from the targeted group. Our study differs on at least two aspects. First, while they focus on the structure of the optimal network – i.e. whether the principal targets the entire members of the group or a subset of that group –, we rather concentrate on the characteristics of the agents that drive the (in)efficiency of the contracting outcome from the social viewpoint. Second, by assuming a model in which non-contracting agents continue to exert efforts and interact with the contracting agents, they highlight the disciplinary role of the most central agent in the optimality of the contract. Unlike them, in our model, we consider that the non-contracting agent do not interact with contracting agents by exerting contribution efforts but only by receiving externalities from them. Our results suggest that the most central agent —the one who produces the greatest

[6] Feldman et al. (2009) analyze the effects of both side payments and principal's parallel projects. They find that with side payments the principal induces full participation as in without, especially when externalities are positive. Besides, under positive externalities, they show that it is optimal to bring all agents into a single project.

amount of spatial effects— always belongs to the targeted group.[7]

This study also relates to the literature on principal multi-agents contract efficiency problems (Holmstrom, 1982; Segal, 1999). Segal (1999) assumes that the principal can coordinate agents on his preferred equilibrium and shows that the contract may yield efficient outcome if the externalities do not influence the agents' reservation utilities. Segal (2003); Genicot and Ray (2006), in particular, extend the analysis of Segal (1999) under the case in which the principals is prohibited to choose his preferred equilibrium. They state that, with increasing externalities[8], the partial implementation contract causes coordination problems due to the presence of other equilibria[9]. It may also lead to an inefficiency from the social viewpoint. In this study, we allow a simple utility function that takes into account the heterogeneity of the spatial effects and consider that the externalities can exist on agents' reservation utility. Therefore, unlike the latter studies we provide results on the efficient contracting outcome and characterize it with respect to the spatial effects.

The rest of this chapter proceeds as follows. Section 4.2 presents the general version of the model. In section 2.3 we define the two benchmarks: the non-cooperative Nash equilibrium and the first best outcome, which is the social optimum result. We first analyze the homogeneous case of the model in section 2.4. This is followed by the analysis of the heterogeneous case in section 2.5. Section 4.4 concludes the study.

2.2 The model

We consider a model in which a single principal may provide incentive contracts to several agents in a situation where spatial effects exist among agents. The objective of the principal is to motivate the agents to exert private contribution efforts for the production of a public good. To be more specific, the contract stipulates that each agent performs a task (a contribution effort) and receives a reward from the principal in return. A crucial aspect of this model is that each agent who accepts his contracting offer generates private benefits, besides the

[7]This literature has also considered incomplete information about the structure of the network (Jadbabaie and Kakhbod, 2016; Csorba, 2008; Edmans et al., 2013). For instance, focusing on the optimality of the contract, Edmans et al. (2013) study contracting with agents subject to synergies and shows the importance of the total synergy on the level of optimal contribution effort.

[8]Segal (2003) proves that with decreasing externalities, unique implementation does not impose extra costs for the principal.

[9]Bland and Nikiforakis (2015) analyze the role of the sign of third-parties externalities on coordination problems but they abstract from the incentive issue.

externalities he produces for his neighbors. In this model, we use the term spatial effects to cover both multilateral externalities (diffusion effects) and private benefits (retention effects).

The timing of the contract consists of three stages: in the first stage, the principal offers bilateral contracts to the agents; in the second stage, each agent observes all the offers and the agents then simultaneously decide whether to accept or to reject their respective offer; in the final stage, the contracts are implemented, each agent exerts his contribution effort and receives a transfer corresponding to the effort he provided.

In this model, there is no asymmetry of information between the parties; that is to say that the efforts are observable and contractible by the principal, and that each agent can observe the offer made to him, the offers made to other agents and the set of decisions is a common knowledge.

We assume that the null contract, in which a null transfer is associated with a zero contribution, belongs to the set of contracts that can be proposed by the principal. Thus, an agent who chooses to reject his offer is assumed to accept the null contract. According to this setup, we focus on the notion of Subgame Perfect Nash Equilibrium. Specifically, we analyze the sub-game perfect Nash equilibrium which maximizes the principal's objective since then all contracts are accepted. In other words, we focus on the principal's preferred Nash equilibrium.

Formally, a contracts between the principal and the agents is a contribution-transfer pairs $(x_i,\ t_i)_{i\in N}$ such that $i \in N$ and $N = \{1, 2, ..., n\}$ be the set of agents. Any agent i may contribute $x_i \in [0, \bar{x}]$, such that $\bar{x}$ refers to the maximum contribution effort, and gets $t_i \in \mathbb{R}$ in return, namely the transfer offered by the principal, or selects the null contract $(0, 0)$.

In this model, spatial effects may appear whenever an agent accepts his contract offer. An agent who chooses to accept the principal's offer provides x_i contribution efforts, creates retention effects for himself, receives diffusion effects from his neighbors' efforts and, gets the payoff represented by the utility function $U_i(x)$. Therefore, the utility function of an agent depends on his own effort and the others' effort through the spatial effects net of the participation cost. Formally, the agents' utility function has the following specification

$$U_i(x) = \sum_{j\neq i} e_{ji}x_j + e_{ii}x_i + t_i - x_i,$$

or,

$$U_i(x) = \sum_j e_{ji} x_j + t_i - x_i, \qquad \text{with} \quad i, j \in N, \tag{2.1}$$

where the spatial effects are captured by the parameter e_{ji}. The interpretation of these parameters goes as follows: first, if $j \neq i$, then e_{ji} is said to be the agent i's *marginal benefit* from the diffusion effects provided by the contribution of agent j; second, if $i = j$, then the parameter e_{ii} refers to the *marginal benefit* from the retention effects which measures the private benefit that an agent creates for himself by choosing to participate. Notice that when there only exist diffusion effects, e.g. $e_{ii} = 0$, the model is a special case of the model of contracting with externalities analyzed in the seminal paper of Segal (1999). We additionally assume that the spatial effects are positive. In other words, the agents' contribution efforts are complementary.

Agent i's payoff when he decides to participate is, captured by the sum of his gain from the spatial effects $\sum_j e_{ji} x_j$ and the transfer t_i he receives from the principal net of the opportunity cost of participation (x_i). Furthermore, note that the utility function (2.1) specifies that the agent's participation cost is linear and the marginal costs are constant and normalized to one. Thereby, in this model, the heterogeneity only arises from the spatial effects.

When an agent rejects his potential contract, he rather gets his outside option; that is, his reservation utility. In this model, we assume that non-contracting agents still belong to the group, and, therefore, benefit from the diffusion effects provided by the contracting agents.[10] Formally, the specification of agent i's reservation utility is given by $R_i(x_{-i})$, which is solely a function of the diffusion effects provided by others.

$$R_i(x_{-i}) = \sum_{j \neq i} e_{ji} x_j \tag{2.2}$$

On the other hand, the principal's payoff function in case of agents' participation is represented by the following linear function

$$f(x) = \frac{a}{n} \sum_i \sum_j e_{ji} x_j - \sum_i t_i, \qquad \text{with} \quad i = j = 1, 2, \ldots, n \tag{2.3}$$

where the vector $x = (x_1, x_2, \ldots, x_n) \in [0, \bar{x}]^n$ represents the agents' contribution profile. The principal assigns a weight $a > 0$ to the success of the project that measures the importance of the project from her viewpoint. In this model, the

[10] In contrast with Belhaj and Deroïan (2018), here, the non contracting agents do not exert contribution efforts and by the same time cannot generate private benefits.

principal values the average contribution in the group (which justifies the presence of $\frac{1}{n}$). The marginal benefit of the project is captured by $\frac{a}{n}\sum_i \sum_j e_{ji}$ and the total cost of incentives is equal to $\sum_i t_i$. We simply consider that the principal's budget is not constrained. Therefore, the main objective of the principal is to maximize her payoff.

2.3 The Benchmarks

2.3.1 The game without the principal

In this part, we analyze the non-cooperative game outcome; that is, the vector of contribution profiles (denoted by x^{NE}) which corresponds to the outcome that emerges when the agents individually play the effort contribution game without intervention of the principal. In this instance, each agent maximizes his own payoff function, assuming that the other agents' contributions are given.

Since the functional form of the agents' utility are identical,[11] then the maximization program of agent i is given by

$$\max_{x_i} \quad e_{ii}\, x_i + \sum_{j\neq i} e_{ij}\, x_j - x_i$$

subject to

$$x_i \geq 0$$
$$\bar{x} - x_i \geq 0$$

Solving this program implies the following proposition 1.

Proposition 1. *In the presence of spatial effects, the optimal non-cooperative contribution profile corresponding to the vector* $x^{NE} = (x_1^{NE}, x_2^{NE}, \ldots x_n^{NE})$ *is obtained such that, (i) if* $e_{ii} > 1$, *then* $x_i^{NE} = \bar{x}$, *(ii) if, instead,* $e_{ii} < 1$, *then* $x_i^{NE} = 0$, *(iii) and, if* $e_{ii} = 1$, *then* $x_i^{NE} \in [0, \bar{x}]$

Proof. See appendix G.1. □

In cases (i) and (ii) of Proposition 1 the agents have dominant strategy. In addition, Proposition 1 states that, at the Nash equilibrium, the contribution decision of the agents depends only on the retention effects. The agents make their contribution decisions by comparing the marginal private return of their effort contribution with the marginal cost of contributing which is equal to 1 in this model. Thus, if for all agents the marginal private return exceeds the marginal

[11] Condition I in Segal (2003) holds. This condition states that agents are identical. Therefore, they have the same utility function form.

cost, then there is a unique contribution profile under which the Nash equilibrium of each agent corresponds to the maximum contribution. In the opposite case, the unique contribution profile becomes the situation where each agent Nash equilibrium contribution is the zero contribution. Moreover, it may exist cases in which some agents contribute the maximum while others do not contribute.

Notice that there exists a case in which any contribution profile can be a Nash equilibrium of the game. In the rest of the analysis, as in this part, we choose to exclude this degenerate solution since it does not provide additional insights. The Nash equilibrium outcome is thus unique, that is not always the case in Segal (2003); Genicot and Ray (2006). Therefore, we do not have coordination problems here.

In this analysis, the Nash equilibrium outcome will serve as a first benchmark in order to determine when intervention is needed.

2.3.2 The First-best contribution profile

The first best contribution profile maximizes the total surplus. In this model, the total surplus is defined as the joint net payoff of the parties (the principal and the set of agents) without contract. Let $W(x)$ denotes the total surplus, we have:

$$W(x) = (\frac{a}{n} + 1) \sum_i \sum_j e_{ji} x_i - \sum_i x_i \tag{2.4}$$

The central planner's objective is to find the optimal vector of contribution profile denoted $x^{FB} = (x_1^{FB}, x_2^{FB} ..., x_n^{FB})$ that maximizes $W(x)$. Formally, the central planner's program is given by

$$\max_{x^{FB}} \ (\tfrac{a}{n} + 1) \textstyle\sum_i \sum_j e_{ji} x_i - \sum_i x_i$$

subject to

$$x_i \geq 0$$
$$\bar{x} - x_i \geq 0$$

Proposition 2 characterizes the first best solution.

Proposition 2. *The first best contribution profile* $x^{FB} = (x_1^{FB}, x_2^{FB} ..., x_n^{FB})$ *is characterized as follows:*

(i) if agent i's utility function satisfies $(\frac{a}{n} + 1) \sum_j e_{ji} > 1$*, then his optimal contribution effort is given by* $x_i^{FB} = \bar{x}$*;*

(ii) if, instead, agent i's utility function satisfies $(\frac{a}{n} + 1) \sum_j e_{ji} < 1$*, then his first best contribution is given by* $x_i^{FB} = 0$*;*

(iii) finally, if agent i's utility function satisfies $(\frac{a}{n}+1)\sum_j e_{ji} = 1$, *then* $x_i^{FB} \in [0, \bar{x}]$ *represents his first best contribution.*

Proof. See appendix G.2. □

Proposition 2 states that the first best outcome depends on the characteristics of the agents, especially in terms of spatial effects. The contribution decision of an agent depends on whether the characteristics of that agent are such that the gross marginal benefits, captured by $(\frac{a}{n}+1)\sum_j e_{ji}$, are greater than the individual cost of participation or not. The gross marginal benefit is equal to the sum between the marginal benefit received by an agent $(\sum_j e_{ji})$ when he chooses to participate and the principal's valuation of the average marginal benefit obtained by that agent $(\frac{a}{n}(\sum_j e_{ji}))$. If the gross marginal benefit generated by an agent is greater (lower) than its individual marginal cost, then the society's welfare is higher when this agent contributes the maximal contribution level $(\bar{x})$ (the minimal contribution level (0)). However, if there is equality between the gross marginal benefit and the individual cost, any contribution between 0 and $\bar{x}$ can be the desired contribution for the society. The intuition behind this proposition is that the central planner only needs the contribution efforts of agents capable of doing so without ex-post loss.

For the rest of the analysis, we focus on two particular cases. In the first case, we study the efficiency of the optimal contract under the assumption of homogeneous spatial effects. In the second case, we rather assume heterogeneous spatial effects, and we characterize the type(s) of agents driving the (in)efficiency of the optimal contract in a three-agent case.

2.4 Contracting with homogeneous spatial effects

In this section, we first analyze the optimal contract when spatial effects are homogeneous between agents, and then we study its efficiency. Before doing so, let us rewrite the parties' payoffs, firstly defined in (2.3) and (2.1), by taking into account the homogeneity of the spatial effects. Formally, the principal's payoff function is specified by

$$f(x) = \frac{a}{n}(r + (n-1)d)(\sum_i x_i) - \sum_i t_i \tag{2.5}$$

while the payoff function of the agents is specified by

$$U_i(x) = rx_i + d(\sum_{j \neq i} x_j) - x_i + t_i \tag{2.6}$$

where, in both payoff functions, r and d refer to the agents' homogeneous retention effects and diffusion effects, respectively. Formally, $e_{ii} = r, \forall i$; $e_{ji} = e_{ki}, \forall i$ and $\forall j, k \neq i$ and $d = \sum_j e_j i, \forall i$. These payoff functions are considered in the rest of the analysis developed in this section.

let x^c be the vector of contribution profiles that maximizes the objective of the principal. Since, x^{FB} represents the first best, we define the contracts' efficiency as follows:

Definition 2.1. *The contracting outcome is said to be efficient if* $x^c = x^{FB}$.

Definition 2.1 indicates that efficiency is achieved when contracts can induce the first best solution.

We begin the analysis by establishing the conditions under which a contract can be used as an incentive scheme in such a model. The principal's use of contract is only possible under certain conditions. These are summarized in the following condition 1.

Condition 1. *In order to use a contract as an incentive scheme, the following conditions must hold for all agents:*

(A) $r < 1$;

(B) $(\frac{a}{n} + 1)(r + (n-1)d) > 1$.

Condition 1 indicates that a contract can be used only if the first best outcome does not coincide to the "*laisser-faire*" situation, which corresponds to the non-cooperative game outcome. This condition suggests that the individual agents are not willing to join the project (A); that is, they contribute the minimal level of effort (zero), while the central planner (the society) wishes them to contribute the maximal level $\bar{x}$ (B). Therefore, the use of a contracting scheme is justified in order to reconcile the individuals' objective with the central planner's objective.[12]

In the rest of this part's analysis, we will assume that the following assumption holds:

Assumption 1. *The first best solution is such that the characteristics of each agent satisfy* $(\frac{a}{n} + 1)(r + (n-1)d) > 1$.

[12] Since the first best corresponds to the maximum contribution, these conditions are set in such a way that the efficiency can not coincide with the situation where the agents do not contribute.

This implies that the first best outcome is unique and it corresponds to the situation under which all agents contribute the maximal level. This assumption is made because the case where efficiency corresponds to the non-contribution for all agents is not interesting.

2.4.1 Optimal contract

We examine the optimal bilateral contract in the case of homogeneous spatial effects, assuming that condition 1 holds.

The principal now seeks the agents contribution efforts that maximize her own payoff. She offers a menu of contracts to each agent, the menu being represented by the pair $(x_i^c,\ t_i^c)_{i\in N}$, subject to the agents' participation constraints.

Formally, the principal solves the following maximization program:

$$\begin{aligned} &\max_{x,t} \quad f(x) \\ \text{subject to} \quad & \\ & x_i \geq 0 \\ & \bar{x} - x_i \geq 0 \\ & U_i(x_i, x_{-i}) \geq R_i(x_{-i}) \end{aligned}$$

such that t denotes the optimal vector of transfers, x^c the optimal vector of contribution efforts, and $R_i(x_{-i}) = d(\sum_{j\neq i} x_j)$ is the agent i's reservation utility while $U_i(x_i, x_{-i}) \geq R_i(x_{-i})$ is its participation constraint. The principal then maximizes her payoff subject to the domain constraint and the agents' participation constraints.

The solution for this program is derived as follows: First, since the participation constraints are binding at the optimum, otherwise the principal can increase her payoff by saving on the transfers, then the expression of the transfer can be written as $t_i = (1-r)x_i$; second, plugging the expression of the transfers into the principal's program, we obtain the following simple problem.

$$\begin{aligned} &\max_x \quad \tfrac{a}{n}(r + (n-1)d)\textstyle\sum_i x_i - (1-r)\sum_i x_i \\ \text{subject to} \quad & \\ & x_i \geq 0 \\ & \bar{x} - x_i \geq 0 \end{aligned}$$

The principal then solves the simple problem in which she seeks the vector of optimal contribution efforts x^c that maximizes her payoff. Proposition 3 provides the characterization:

Proposition 3. *In the presence of homogeneous spatial effects among agents, the optimal contracts are given by* $(x_i^c,\ t_i^c)_{i\in N}$ *such that, if the agents' characteristics satisfy* $\frac{a}{n}(r+(n-1)d)+r>1$, *the principal offers them the contract* $(x_i^c,\ t_i^c)=(\bar{x},\ (1-r)\bar{x})$; *if, however, the agents' characteristics satisfy* $\frac{a}{n}(r+(n-1)d)+r<1$, *then they get the null contract* $(0,\ 0)$.

Proof. See appendix G.3. □

Proposition 3 indicates that the optimal contract is such that the agents contribute the maximum level $\bar{x}$ (the minimum level 0) if their characteristics allow a positive (negative) bilateral surplus in favor of the principal. This result implies that, at the margin, the benefit generated by the agent's contribution on behalf of the principal should cover the cost incurred by the agent. Otherwise, offering a contract to the agent becomes costly for the principal. Therefore, the principal only contracts with productive agents.

Proposition 3 also highlights the crucial role of the agents' characteristics, in terms of spatial effects, on the optimal contract. In fact, the principal's surplus increases with both the diffusion effects and the retention effects. Therefore, the principal should target the agents characterized by a high capacity to produce spatial effects. Moreover, this proposition also reveals that the principal's bilateral surplus increases as much as the project is important for the principal.

2.4.2 Efficiency of the optimal contract

Now, we characterize the situations in which the contract leads to efficiency. To do so, we ask the following question: under which conditions does the principal's optimal contract lead to an efficient outcome? In order to answer this question, we first figure out the contracting outcomes that allow reaching efficiency and then characterize it. We then discuss the efficiency of the contracting outcome with respect to the model parameters.

Analytical results

We know from Proposition 3 that the principal's offer induces a maximum contribution level from each agent if and only if the condition $\frac{a}{n}(r+(n-1)d)+r>1$ holds; i.e. the bilateral surplus of the principal is strictly positive. In other words, when the marginal benefit generated by a contract between the principal and an agent is above the marginal cost of that agent, then the principal offers him a contract that exhibits a maximal level of contribution.

Taking all the above conditions into account, proposition 4 characterizes the efficiency of the contract as a range values of retention effects.

Proposition 4. *The optimal contract is efficient if the agent's range of retention effects r is such that*

$$\frac{n - and + ad}{n + a} < r < 1$$

Proof. See appendix G.4. □

Proposition 4 indicates that the efficiency of the contract, expressed through a range of the retention effects, depends crucially on three parameters: *(i)* the valuation awarded to the project by the principal, a. *(ii)* the number of participating agents, n. *(iii)* the diffusion effects, d. One implication of proposition 4 is that a larger (smaller) range of retention effects may imply that the contract outcome is more (less) likely to be efficient.

In what follows, we study the influence of each parameter on the range of the retention effects separately, before discussing the relative impact of the spatial effects on the efficiency.

Regarding the condition in proposition 4, the retention effects belong to an interval which lower bound is a function of three parameters. We can immediately notice that when the retention effects are null, then the contract outcome is efficient if the diffusion effect is greater than the value $\frac{n}{(n-1)a}$, which is strictly positive since $n \geq 2$. Thus, the efficiency of the contracting outcome requires the presence of at least a certain amount of spatial effects from the agents.

Now, let us denote by $\underline{r}(a, n, d)$ the lower bound of the retention effect range values, such that

$$\underline{r}(a, n, d) = \frac{n - and + ad}{n + a}$$

We analyze the marginal effect of each parameter on the difference between the upper and lower bounds of the retention effects range values.

First, differentiating $\underline{r}(a, n, d)$ with respect to a, we obtain the following expression:

$$\frac{\partial \underline{r}}{\partial a} = -\frac{n(dn - d + 1)}{(n + a)^2} \tag{2.7}$$

Inspecting equation (2.7), the set of model parameters for which the efficiency of the contracts is obtained expands when the principal awards greater value to the project. In fact, in this model, since the principal contracts with at least 2 agents, then $\frac{\partial \underline{r}}{\partial a}$ is negative. This equation then reveals that a higher value of a leads to a larger set of parameters for which the outcome of the optimal contract

is efficient. Hence, contracting for a project with great importance allows reaching efficiency more easily.

Second, focusing now on the marginal impact of the number of participating agents we then obtain the following expression:

$$\frac{\partial \underline{r}}{\partial n} = -\frac{a(ad + d - 1)}{(n + a)^2} \tag{2.8}$$

Expression (2.8) highlights the presence of two different effects that are strongly influenced by the diffusion effects and the principal's value awarded to the project. (1) If $ad + d > 1$, the marginal effect of the number of participating agents on the lower bound of the retention effects is negative; this leads to expanding the range values of retention effects. The set of model parameters for which the efficiency of the contract outcome is obtained then expands due to a wider range of retention effects induced by a high number of participants if the diffusion effect is sufficiently high and/or the principal valuation of the project is sufficiently important. This result implies that the participating agents should produce sufficient level of diffusion effects in such a way that combined with the principal's valuation, they ensure a positive surplus for both the principal and the society. (2) If, in contrast, $ad + d < 1$, the marginal effect of a larger number of agents on the lower bound of retention effects is positive. As a result, the set of model parameter for which the efficiency of the contract outcome is obtained shrinks in the case of high number of participants. That is if the project matters less to the principal and its members cannot generate sufficiently high diffusion effects, then a high number of participants will not be beneficial for the society.

The direct implication of these latter results is that, rather than focusing on increasing the number of participants, the principal should target agents according to their capacity to generate spatial effects.

Finally, concerning the influence of the diffusion effects, differentiating $\underline{r}(a, n, d)$ with respect to d gives:

$$\frac{\partial \underline{r}}{\partial d} = \frac{-an + a}{n + a} \tag{2.9}$$

Expression (2.9) shows that the marginal effect of the diffusion effects on the lower bound of the retention effects ($\underline{r}(a, n, d)$) is always negative since the principal valuation of the project and the number of agents are strictly positive. This yields a larger range of retention effects values. Therefore, an increase in the magnitude of diffusion effects leads to a situation in which efficiency becomes easier to achieve. This confirms the importance of the diffusion effects in the efficiency

of the contracting outcome.

However, all of the above results are based on the marginal effects of each parameter (considered separately) on the magnitude of the range of retention effects values. These results, therefore, do not allow to identify the relative influence of both retention effects and diffusion effects on the efficiency of the contracting outcome.

Since it seems rather difficult to capture this relative effect analytically, we perform a graphical analysis. This new way of analyzing the problem makes it possible to simultaneously vary the two spatial effects and to discuss the influence of their interplay on the efficiency of the optimal contract.

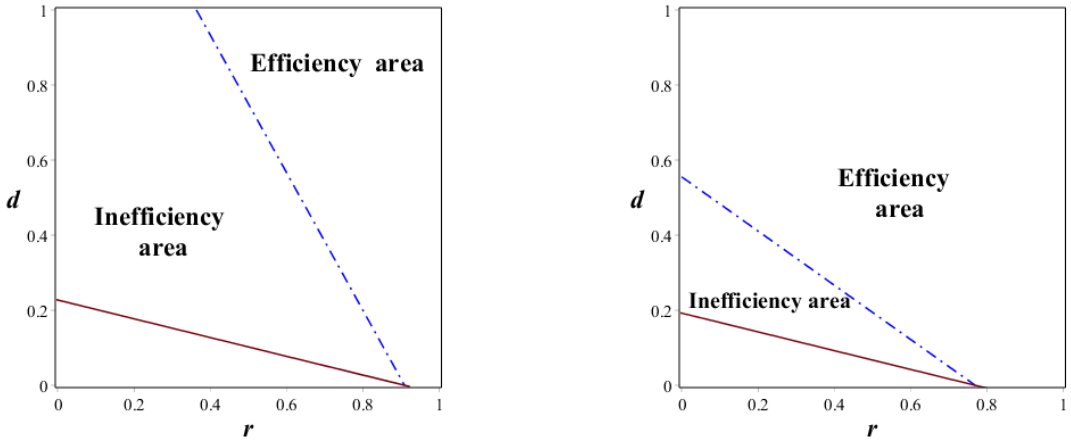
Graphical analysis

To develop the intuitions behind the results in proposition 4 we draw figures 2.1 and 2.2 delineating the areas of efficiency and inefficiency of the contract. These areas are induced by the pairs of retention-diffusion effect levels (r, d), for given values of a and n. In each figure, retention effects are reported on the horizontal axis (r) while diffusion effects are provided on the vertical axis (d). The dotted line refers to the lower bound of the efficiency area; that is the limit beyond which the principal offers a contract that results in a maximum contribution. Below the solid line, the social optimum outcome requires a zero contribution from all the agents, thus in this area there is no need for contract. Following the definition of efficiency (definition 2.1), this area characterizes an efficient situation. But, it is not attractive in our analysis.

Both figures suggest that a high-level of retention effects always yields an efficient contract outcome. The influence of the diffusion effects strongly depends on the number of participating agents and the principal's valuation of the project (a). This suggests that the effect of the retention effects is more detrimental than the one generated by the diffusion effects. Furthermore, inefficiency may be due to a low-level of retention effects and an intermediate value of the diffusion effects. Here again, the magnitude of the interval of the diffusion that leads to an inefficiency is strongly influenced by the number of participating agents and the principal's valuation. An increase in the number of participating agents enlarges the interval and also reduces the lower bound of that interval. The principal's valuation has the opposite effects.

In figure 2.1, we arbitrarily define the number of agents and vary the principal's valuation (a), from a low value (left) to a relatively high value (right). This variation has at least two impacts on the efficiency of the contracting outcome. First,

Figure 2.1: *Efficiency areas when n=5, a = 1/2 (left) and a = 3/2 (right).*



as we have shown in the analytical study, if the principal's valuation is large enough, then efficiency area increases making the efficiency of the contracting outcome more easier to achieve. Secondly, we can observe that an increase in the principal's valuation allows lower values of the retention effects to be part of the set of efficient contract outcomes, especially when the diffusion effects are large enough. The mechanism behind these results is that an increase in the principal's valuation leads to an increase in the principal's profit, all things being equal. Thus, providing incentives costs less ex-post for the principal. This induces the principal to offer incentives for even agents that have a lower capacity to generate spatial effects. As a result, an increase in the efficiency area appears due to a reduction of the inefficiency area.

Figure 2.2: *Efficiency areas when a = 1/2 , n = 2 (left) and n = 7 (right).*

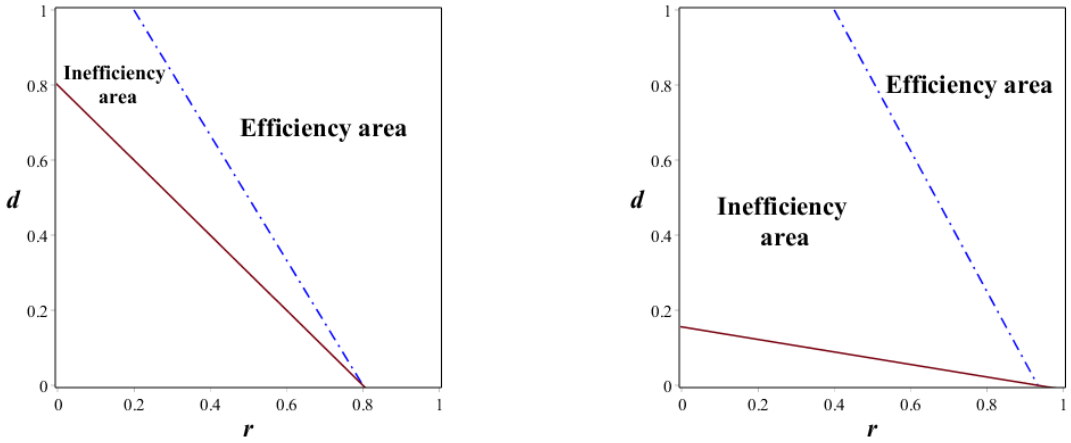


Figure 2.2, in contrast, pictures the efficiency and inefficiency areas when the principal's valuation is fixed. In this figure, we consider that the number of participating agents is either 2 (left) or 7 (right). We can observe two effects. First,

an increase in the number of participating agents raises the slope of the dotted line and shifts this line to the right, reducing the efficiency area. At the same time, it reduces the slope of the solid line, resulting in an increase of the inefficiency area. The second interpretation contrasts with that of the previous figure and relies on the fact that the increase in the number of participating agents excludes small values of retention effects from being part of the efficiency area.

In summary, the main insight we address from the observation of these figures is that efficiency of the contract outcome is more easier to achieve when the spatial effects' ratio ($\frac{\text{retention effects}}{\text{diffusion effets}}$) is high, i.e. when high value of retention effects is associated with a small value of diffusion effects. Furthermore, efficiency also holds both when the principal highly values the success of the project and the number of participating agents is sufficiently low.

2.5 Contracting with heterogeneous spatial effects

In this part, we first relax assumption 1 that stated that the first best corresponds to the maximum level of contribution for all agents. We then consider a three-agent case, where agents are denoted by i_1, i_2 and i_3. In addition, we assume that for two of them, let say agent i_1 and agent i_2, the socially optimal outcome corresponds to a maximum contribution level, and for the remaining one, agent i_3, the socially optimum outcome correspond to a zero contribution level. Formally, we have the following conditions for the three agents:

$$\begin{cases} (\frac{a}{3}+1)(\sum_j e_{ji_1}) > 1 \\ (\frac{a}{3}+1)(\sum_j e_{ji_2}) > 1 \\ (\frac{a}{3}+1)(\sum_i e_{ji_3}) < 1 \end{cases}$$

These conditions are equivalent to stating:

Assumption 2. *The first best solution is such that* $x^{FB} = (x_{i_1}^{FB}, x_{i_2}^{FB}, x_{i_3}^{FB})$ *where* $x_{i_1}^{FB} = \bar{x}$, $x_{i_2}^{FB} = \bar{x}$, $x_{i_3}^{FB} = 0$.

We arbitrarily chose to focus on this case for two reasons. First, we want to allow for heterogeneity among agents. Second, we aim at examining the role of agent specificities on the (in)efficiency of the contract outcome.

2.5.1 Optimal contract

Since the agents' participation constraints are binding at the optimum, in case of heterogeneous agents, the principal offers contracts that are the solutions of

the following program.

$$\max_{x_i} \quad \frac{a}{3} \sum_i \sum_j e_{ji} x_j + \sum_i e_{ii}\, x_i - \sum_i x_i$$

Subject to

$$x_i \geq 0$$
$$\bar{x} - x_i \geq 0$$

We obtain the following result:

Proposition 5. *Assume that the characteristics of agent i_1 satisfy $\frac{a}{3}(e_{i_1 i_1}+e_{i_1})+e_{i_1 i_1} > 1$ and the characteristics of both agents i_2 and i_3 satisfy $\frac{a}{3}(e_{i_2 i_2} + e_{i_2}) + e_{i_2 i_2} < 1$ and $\frac{a}{3}(e_{i_3 i_3} + e_{i_3}) + e_{i_3 i_3} < 1$, respectively. The optimal contract is such that, the principal offers the contract $(x_i^c,\ t_i^c) = (\bar{x},\ (1 - e_{ii})\bar{x})$ to agent i_1. In contrast, she offers the contract $(0,\ 0)$ to agents i_2 and i_3.*

Proof. See appendix G.5. □

Proposition 5 specifically indicates that the principal offers a null contract to agent i_2. Knowing that without incentive agent i_2 contributes the minimum level while the society wishes that he contributes the maximum level, contracting with this agent yields an inefficient outcome. This proposition implies that the characteristics of agent i_2 do not satisfy the objective required by the principal, that is the benefit provided by the contribution effort exerted by agent i_2 does not cover the reward procured for this contribution effort.

In the next part, we will focus on the characteristics of agent i_2. Most specifically, we will discuss his characteristics in terms of spatial effects.

2.5.2 (In)efficiency of the optimal contract

We know from Proposition 5 that the principal offers a null contract to i_3. The outcome induced by this contract is efficient in regards to the first best. The principal also offers a contract that induces agent i_1's to a maximal contribution level. This again yields an efficient outcome. Conversely, the principal offers an outcome inefficient contract to agent i_2. Therefore, in order to characterize the inefficiency of the contracting outcome, we particularly focus on the characteristics of agent i_2. The aim of this part is to analyze the specificity of agent i_2, in terms of retention effects ($e_{i_2 i_2}$) and diffusion effects ($e_{i_j i_2}, j = \{1, 3\}$), that makes him the driver of the inefficiency. We also discuss the characteristics of agent i_2 with respect to the characteristics of agents i_1 and i_3.

First of all, in order to get some insights, we analyze the characteristics of agent i_2 and compare it with the ones of agent i_1 and i_3. In doing so, we begin with the study of the characteristics of agent i_1 and agent i_3 in terms of retention and diffusion effects such that the contract outcomes are efficient. Then, we focus on the case of agent i_2 by highlighting the differences in this agent's characteristics —in terms of spatial effects— that drive the inefficiency.

Let us first assume that the diffusion effects received by each agent is denoted e_i such that $e_i = \sum_{j \neq i} e_{ji}$. That means that e_i is the sum of diffusion effects obtained by agent i.

Agent i_1. The characteristics of agent i_1 are formalized by the system $\mathcal{N}_1$, such that

$$\mathcal{N}_1 = \begin{cases} (\frac{a}{3} + 1)(e_{i_1 i_1} + e_{i_1}) > 1 \\ e_{i_1 i_1} < 1 \\ \frac{a}{3}(e_{i_1 i_1} + e_{i_1}) + e_{i_1 i_1} > 1 \end{cases}$$

Simplifying $\mathcal{N}_1$, we obtain

$$-\frac{ae_{i_1} - 3}{a+3} < e_{i_1 i_1} < 1 \qquad (2.10)$$

The outcome generated by agent i_1 is efficient from the social viewpoint. Expression (2.10) then indicates that the efficiency is present when agent i_1's retention effects is ranged between his marginal cost and a lower threshold value $\underline{r}_{i_1}$ such that $\underline{r}_{i_1} = -\frac{ae_{i_1} - 3}{a+3}$. $\underline{r}_{i_1}$ is a function of the principal's valuation of the project and the diffusion effects he received from the contribution of the other agents. Inspecting $\underline{r}_{i_1}$ yields the conclusion that increasing the diffusion effects benefiting the agent reduces the lower bound of the retention effects range. Hence, it enlarges the range values of the retention effects for agent i_1. Efficiency driven by agent i_1's contract outcome is therefore more easier to reach when this agent benefits from high levels of diffusion effects. Furthermore, an increase in the principal's valuation a has the same effect on the efficiency.

Agent i_3. The following system $\mathcal{N}_3$ characterizes agent i_3.

$$\mathcal{N}_3 = \begin{cases} (\frac{a}{3} + 1)(e_{i_3 i_3} + e_{i_3}) < 1 \\ e_{i_3 i_3} < 1 \\ \frac{a}{3}(e_{i_3 i_3} + e_{i_3}) + e_{i_3 i_3} < 1 \end{cases}$$

After simplification, we obtain

$$0 < e_{i_3 i_3} < -\frac{ae_{i_3}+3e_{i_3}-3}{a+3} \tag{2.11}$$

The outcome generated by agent i_3 is also efficient from the social viewpoint. Expression (2.11) shows that agent i_3 is such that the magnitude of the retention effect resulting from agent i_3's effort lies in between the minimum value (zero) and a maximum threshold $\overline{r}_{i_3}$ where $\overline{r}_{i_3} = -\frac{ae_{i_3}+3e_{i_3}-3}{a+3}$. This maximum threshold $\overline{r}_{i_3}$ is a function of both the principal's valuation and the diffusion effects he receives. Differentiating $\overline{r}_{i_3}$ with respect to a and e_{i_3} gives $-\frac{3}{(a+3)^2}$ and -1, respectively. Thus, an increase in the principal's valuation and/or the retention effects received by agent i_3 makes the efficiency less easier to reach since it reduces the range of agent i_3's retention effects. Moreover, it is worth noting that expression (2.11) exists only if $3 > (a+3)e_{i_3}$ since $e_{i_3 i_3} > 0$. This implies that agent i_3 is characterized by a relatively small value of diffusion effects. This relative value decreases as much as the principal's valuation (a) increases.

From the characteristics of agents i_1 and i_3 we derive that when the diffusion effects are sufficiently high, then efficiency of maximum contribution is more easier to achieve while the minimum contribution (zero contribution) becomes less easier to achieve.

Now, consider the case of the agent who drives the inefficiency, i.e. agent i_2. The characteristics of this agent are given by the following system λ_2.

$$\lambda_2 = \begin{cases} (\frac{a}{3}+1)(e_{i_2 i_2}+e_{i_2}) > 1 \\ e_{i_2 i_2} < 1 \\ \frac{a}{3}(e_{i_2 i_2}+e_{i_2}) + e_{i_2 i_2} < 1 \end{cases}$$

Simplifying λ_2, we obtain

$$-\frac{ae_{i_2}+3e_{i_2}-3}{a+3} < e_{i_2 i_2} < -\frac{ae_{i_2}-3}{a+3} \tag{2.12}$$

Inspecting expression (2.12), we can immediately remark that it is only satisfied, firstly, if $e_{i_2} < \frac{a}{3}$, meaning that e_{i_2} should be sufficiently small; secondly, if the diffusion e_{i_2} corresponds to an intermediate value which belongs to the interval $\left[\frac{3}{a+3}, \frac{3}{a}\right[$. Thus, any small value of retention effects $e_{i_2 i_2}$ may satisfy conditions in the expression (2.12) since $e_{i_2 i_2} < -\frac{ae_{i_2}-3}{a+3}$. In contrast, when $e_{i_2} < \frac{3}{a+3}$, then the lower bound in the expression (2.12) becomes strictly negative inducing that the condition in the expression (2.12) only holds when the retention effects are not too high but also not too small.

Expression (2.12) also shows that the contracting outcome is inefficient if agent

i_2's retention parameter belongs to the interval $[\underline{r}_{i_2}, \bar{r}_{i_2}]$, where the thresholds are $\underline{r}_{i_2} = -\frac{ae_{i_2}+3e_{i_2}-3}{a+3}$ and $\bar{r}_{i_2} = -\frac{ae_{i_2}-3}{a+3}$. Notice that these thresholds are function of the principal's weight awarded to the project and the diffusion effects received by agent i_2. Differentiating each threshold with respect to a gives $-\frac{3}{(a+3)^2}$ and $-\frac{3(e_{i_2}+1)}{a+3}$, respectively. Holding constant the value of the diffusion effects, the marginal effect of the principal's valuation leads to a decrease in the magnitude of the interval $[\underline{r}_{i_2}, \bar{r}_{i_2}]$. Hence, inefficiency driven by agent i_2 becomes less easier to achieve.

Our main result is presented in the following proposition 6.

Proposition 6. *If agent i_2 is characterized by a production of low retention effects and an intermediate value of diffusion effects that he receives from others, then the inefficiency of the optimal contracting outcome is less easier to reach.*

Proof. See appendix G.6. □

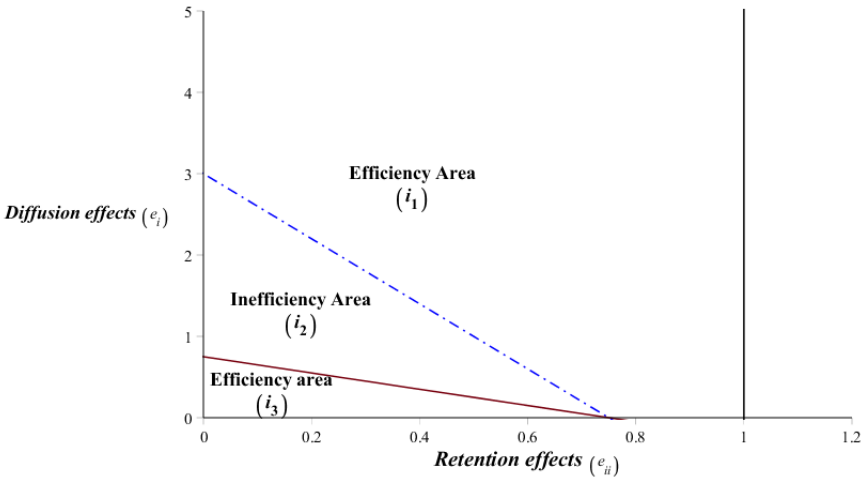
Proposition 6 indicates that contracting with agent i_2 does not make the principal's surplus positive. In other words, agent i_2 can not generate retention effect at a sufficient level and he also can not receive a sufficient compensation from the diffusion effects generated by agents i_1 and i_3. Therefore, the principal offers to agent i_2 an outcome inefficient contract in which a null transfer is associated with zero contribution. Indeed, providing an outcome efficient contract to agent i_2 is too costly for the principal.

Notice that in expression (2.12), the thresholds $\underline{r}_{i_2}$ and $\bar{r}_{i_2}$ have respectively the same slopes than the thresholds $\bar{r}_{i_3}$ and $\underline{r}_{i_1}$. This allows us to perform a graphical analysis and compare the characteristics of the three agents.

Before doing so, we arbitrarily set the value of a as equal to 1. We plot the results in figure 2.3, where we picture the joint influence of the retention effects and the sum of the diffusion effects on the (in)efficiency of the contract. Three areas, delineated by the dotted line and the solid line, characterize the three agents: the efficiency area of maximal level of contribution corresponds to agent i_1; the efficiency area of non-contribution corresponds to agent i_3; The inefficiency area corresponds to agent i_2.

Figure 2.3 provides three interesting messages. *(i)* The first one concerns the efficiency area (driven by agent i_1). We observe that the efficiency of the contracting outcome is more easier to achieve if this agent receives high level or diffusion effects and/or this agent is characterized by high levels of retention effects. When the retention effects are above a certain threshold (here $\simeq 0.8$ which is a high value since $e_{ii} < 1$), the contracting outcome is always efficient. This is the same when the diffusion effects are above a certain threshold (here, it is

Figure 2.3: *Efficiency -inefficiency- of the optimal contracts (a = 1)*



above 3). Hence, combining high values of spatial effect renders the efficiency more easier to achieve. *(ii)* The second message is about the inefficiency area (driven by agent i_2). The observation of figure 2.3 indicates that the inefficiency of the contract outcome is more easier to achieve when the retention effects are sufficiently small while the magnitude of diffusion effects is intermediate (neither too small nor too high). When the retention effects decrease, the inefficiency area grows, increasing the likelihood of the inefficiency. In the case depicted in Figure 3, it is when the magnitude of retention effects lies below the threshold value 0.8 while the magnitude of the diffusion effects lies in between 0.8 and 3. *(iii)* The final message refers to the efficiency area of non-contribution (driven by agent i_3). In this area, we can note that the efficiency of the contracting outcome is more easier to achieve when both the diffusion effects and the retention effects are sufficiently small. In fact, when the retention effects tend to zero while the diffusion effects are below 0.8, it becomes more easier to reach this efficiency area.

In summary, the examination of the heterogeneous case allows us to identify the profile of the agent that may drive the inefficiency of the contract outcome. Things that the homogeneous case did not allow. We claim that agents characterized by small retention effects and intermediate value of diffusion effects are more likely to receive contracts that induce inefficiency from the social viewpoint. It is the case when the ratio $\frac{\text{retention effects}}{\text{diffusion effects}}$ is relatively small. This implies that a bilateral contractual approach is not necessarily the good instrument to overcome inefficiency issue when it comes to provide collective public goods involving externalities between contributors.[13] The presence of heterogeneous effects not only

[13]Agglomeration bonuses (Parkhurst and Shogren, 2007; Parkhurst et al., 2002) and payments for environmental services (Pagiola and Platais, 2005; Wünscher et al., 2008; Wunder et al., 2008;

raises the question of using differentiated payments but highlights that even offering contracts to the entire population of involved parties may not be grounded in economic efficiency. Finally, agents that are characterized by high retention and diffusion effects are more likely to receive an outcome efficient contract.

2.6 Conclusion

This chapter focuses on the efficiency of the optimal contract with group of agents under the presence of spatial effects. This chapter also examines the impacts of individual spatial effects, both retention effects and diffusion effects, on the efficiency of the contract. We assume that non-contracting agents still belong to the group and benefit from diffusion effects created by contracting agents. These are fundamental aspects of the model lead to interesting insights.

First, we consider a situation in which the spatial effects are homogeneous between the agents. In this instance, we find that the contracting outcome is inefficient when both the retention effects and the diffusion effects are small. Moreover, we find the effect of the number of participating agents is ambiguous. The number of participating agents positively influences the efficiency when the concerned agent(s) receive(s) a sufficient level of diffusion effects. Otherwise, the number of participating has a decreasing effect on the likelihood of reaching the efficiency outcome.

Secondly, we allow for heterogeneous agents. According to a three-agent case, we draw two important lessons: first, high retention effects combined with high diffusion effects may ensure efficiency of the contracts; secondarily, inefficiency may be due to the presence of low retention effects and an intermediate value of diffusion effects. Moreover, moving from homogeneous to heterogeneous agents helps us to identify which characteristics drive the inefficiency of the contractual approach. Heterogeneous analysis allows to screen agents according to their performance in terms of spatial effects, i.e. the retention effects they create and the diffusion effects they receive from others.

The results presented in this chapter can have important implications. They put in light the necessity to target agents based more on the spatial effects they provide than their number. Furthermore, in terms of public policy, rather than targeting incentives on agents creating a wide array of externalities, our results

Engel et al., 2008) are such examples of contracts designed for environments characterized by the presence of heterogeneous spatial effects. The efficiency of these contracts are importantly debated in environmental economics fields.

suggest that it may be preferable to target agents characterized by a sufficient level of retention effects, especially when the diffusion effects is not high enough. The fact that ongoing interventions such as Payments for Ecosystem services or Agri-environment programs may be ineffective could be related to the fact that they miss the right target.

We are aware that this study involves some limitations. We note in particular the specification of the payoff functions. In fact, we consider simple linear functions in our model. This leads us to explore only corner solutions that are easy to further interpret. Therefore, it may be interesting to generalize this model by considering more elaborate functional forms.

It would also be interesting to consider a lab experiment as a follow-up analysis. Indeed, we believe that analyzing the contract in the presence of spatial effects between the agents may reveal important individual motivations that can further explains (in)efficiency of the contracting outcome besides the level of spatial effects.

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Chapter 3: Does Equity Induce Inefficiency? An Experiment on Coordination

Abstract

In this chapter, we use a laboratory experiment to analyze the relationship between equity and coordination success in a game with Pareto-ranked equilibria. Equity is decreased by increasing the coordination payoffs of some subjects while the coordination payoffs of others remain unchanged. Theoretically, in this setting, difference aversion may lead to a positive relationship between equity and coordination success, while social efficiency motivations leads to a negative relationship. Using a within-subject experimental design, we find that less equity unambiguously yields a higher level of coordination success. Furthermore, this result holds *even for subjects whose payoffs remain unchanged*. Our results suggest that social efficiency motivations drive the negative relationship between equity and coordination success found in this experiment. Moreover, our data highlight that the order of treatment matters. Groups facing over time a reduction in inequalities reach the efficient outcome more often, over the entire experiment, compared to groups facing over time an increase in inequalities. This study thus contributes to the debate on the efficiency-equity trade-off and provides evidence on the effect of variations in inequalities on the resulting efficiency of collective decisions.

Keywords

Coordination game, equity, efficiency, difference aversion, social efficiency motivation.

3.1 Introduction

Equity often plays a crucial role in the acceptability of economic decisions, raising the issue of the tension between efficiency and equity considerations (Okun, 1975).[1] The potential existence and difficulty to overcome the conflict between efficiency and equity is met in various settings such as the design of salary structures in organizations (Lazear, 1989), instruments and mechanisms designed to overcome social dilemmas (e.g. see Gangadharan et al., 2017) or development policy issues (Bardhan, 1996). At the same time, coordination between economic agents in markets, contracts, firms, governments and organizations is a necessary condition to reach efficiency in most economic activities.

To improve our understanding of the importance of the equity efficiency tradeoff, it is thus crucial to investigate how it comes forward in coordination problems. In other words, does equity affect efficiency through its influence on the agents' ability to coordinate? Does the prospect of unevenly distributed larger coordination gains decrease or increase the frequency at which agents coordinate efficiently? What kind of motivations drive the agents' behavior in such situation? In this chapter, we present the results of a laboratory experiment to address these questions.

We study the link between equity and efficiency using a laboratory experimental coordination game with Pareto ranked equilibria. Equity is decreased by increasing the coordination payoffs of some subjects while the coordination payoffs of others remain unchanged. Theoretically, in this setting, difference aversion (see Fehr and Schmidt, 1999) may lead to a positive relationship between equity and coordination success, while social efficiency motivations (see Charness and Rabin, 2002) lead to a negative relationship. Using a within-subject experimental design, we find that less equity in coordination payoffs unambiguously increases coordination success. Moreover, this result holds even for subjects who were assigned the least favorable role and whose payoffs were not affected by the decrease in equity. These results suggest that social efficiency motivations drive the negative relationship between equity and coordination success. Moreover, our data suggest that the order of treatment matters. Groups facing first the treatment with high inequality in coordination payoffs, then the treatment with low inequality in coordination payoffs, reach the Pareto dominant equilibrium more often in both treatments compared to groups playing first the treatment with low

[1] See also Browning and Johnson (1984).

inequality in coordination payoffs, then the treatment with high inequality in coordination payoffs. We suggest that this order effect may be consistent with the assumption that subjects assess the level of strategic risk based on their past experience.

This chapter contributes to two strands of the literature. The first contribution is related to the experimental works analyzing the existence and magnitude of the trade-off between efficiency and equity motives. A notable part of this literature focuses on dictator games and similar settings (see Charness and Rabin, 2002).[2] Few other works consider more elaborate settings such as gift exchange or ultimatum games (Charness and Haruvy, 2002), bargaining problems (see Isoni et al., 2014 , or Galeotti et al., 2018), and public good contribution games (see Gangadharan et al., 2017 or Balafoutas et al., 2013). We complement this literature by providing conclusive experimental evidence on this trade-off in another complex setting involving interactions between agents, that is, coordination situations. Our results suggest that efficiency motives, rather than equity considerations, drive the behavior of the subjects.

The second contribution is related to the literature on coordination games, which has mostly abstracted from considerations of the trade-off between efficiency and equity concerns. More specifically, the literature on the effect of payoff asymmetry on coordination success in Pareto ranked coordination games is relatively scarce.[3] A strand of the literature focuses on the relationship between payoffs heterogeneity and coordination in Battle of the sexes experimental games, i.e coordination games with no Pareto dominant equilibrium. Crawford et al. (2008) show that introducing a small degree of heterogeneity in a symmetric Battle of the sexes game has a negative effect on coordination. However, this pattern reverses when payoff asymmetry becomes sufficiently large.[4] Another strand of the literature analyzes coordination problems in games with Pareto ranked equilibria (e.g. see Brandts and Cooper, 2006 and Goeree and Holt, 2005), but related contributions abstract from the effect of a change in payoff heterogeneity.[5] As

[2]For other works related to this type of game see Engelmann and Strobel, 2004, Bolton and Ockenfels, 2006 or Fehr et al., 2006.

[3]The research agenda dealing with the analysis of factors that may affect agents' abilities to coordinate is of course quite broad, as illustrated by the analysis of the effect of subjects' background provided in Jackson et al. (2014).

[4]Parravano and Poulsen (2015) analyze the role of stake size on coordination frequency on the label salient strategy in symmetric and asymmetric coordination games with no Pareto dominant equilibrium.

[5]Devetag and Ortmann (2007) provide a survey of the literature on coordination failures in order-statistics and Stag Hunt games. Lòpez-pèrez et al. (2015) focus on the relative performance of a proposed equity-related selection criterion in several 2×2 coordination games.

in the present chapter, Chmura et al. (2005) analyze coordination games with a Pareto dominant equilibrium and focus on variations in the subjects' payoffs (at this equilibrium).[6] They argue that the existence of beliefs about other subjects' difference aversion is consistent with the observed subjects' behaviors. Their results are however difficult to interpret since they use a between-subject setting with a relatively small number of subjects per treatment[7] and then they cannot distinguish between the effect of subjects' heterogeneity (in terms of preferences, behavior, etc.) and the effect of the various treatments. By contrast, we use a within-subject setting in order to control for subjects and group characteristics that may influence subjects' play, and we show that subjects' behaviors are consistent with social efficiency motivations and not with difference aversion.[8] As in the present chapter, Goerg et al. (2010) provide experimental results based on a theoretical model in which differentiated incentives are optimal.[9] They show that the optimal differentiated incentives outperform non optimal equal incentives in terms of coordination success.[10] They find that the subjects' decisions are highly sensitive to their own payoff but largely insensitive to the payoffs of the other subjects. Their experiment is not designed to analyze the role of social efficiency motivations, since they keep the sum of the individual rewards constant across the treatments. In the present chapter, the sum of the payoffs changes from one treatment to the other while the payoff of one of the players is kept constant across the treatments. This design enables us to test the hypothesis that this player gives weight to the payoffs of the other subjects in the same group, and thus that coordination may be facilitated when the payoffs of some players are larger, even if the payoffs are more unequal.

We present the results from an experiment where groups of three subjects play a coordination game based on the optimal solution to a club good production problem analyzed in Bernstein and Winter (2012).[11] The game admits multiple

[6] They focus on games with two players and two strategies.

[7] They implemented a quite large number of different treatments (seven) and the number of participant was almost identical as ours (280 and 270 respectively). Since their games involve two subjects each, they ended up with 20 subjects (i.e. observations) per treatment.

[8] This is not to say that subjects are not averse to differences. However, our results suggest that the effect of difference aversion preferences is weaker than the effect of preferences for social efficiency.

[9] Their experiment is based on Winter (2004) while ours is based on Bernstein and Winter (2012).

[10] In the present chapter, we compare the two optimal reward schemes of two different games.

[11] There are multiple examples of multilateral coordination problems in practice, which may induce additional issues compared to bilateral situations due to the increase in the complexity of the interactions. It is thus both interesting and important to provide experimental evidence about the likelihood of coordination success in multilateral situations.

Nash equilibria (thus raising coordination issues) that are Pareto ranked, and the efficient outcome is unique and is always an equilibrium outcome. The game has another interesting property for our purpose: the efficient outcome is such that the players' payoffs are always heterogeneous. We take advantage of this property and implement two treatments, one treatment in which the differences between the players' payoffs are almost equal at the efficient outcome, and a second treatment in which one of the subjects' payoffs remain unchanged while the other two subjects in the group earn a substantively higher payoff at the efficient outcome. Each of the 90 groups of three subjects repeatedly (10 rounds) plays the two treatments (in different orders).[12]

Our first main result is that groups reached the efficient outcome more often in the treatment with high inequality in coordination payoffs than in the treatment with low inequality in coordination payoffs. Our second main result is that, at the individual level, subjects choose to play the strategy that corresponds to the efficient outcome more often in the treatment with high inequality in coordination payoffs, *even if their situation remains unchanged between the two treatments* (while the two other subjects in their group get higher payoffs at the efficient outcome). To provide these results, we take advantage of the panel structure of our data that allows us to control for effects that are due to groups/individuals and time. These two results suggest that subjects have social preferences consistent with social efficiency motivations rather than with difference aversion. A third important result is that groups facing over time a reduction in inequalities reach the efficient outcome more often, over the entire experiment, compared to groups facing over time an increase in inequalities. Specifically, groups that first play the treatment with high inequality in coordination payoffs coordinate on the efficient outcome more frequently. This suggests that the equity-efficiency trade-off is affected differently depending on whether coordination gains decrease or increase.

The rest of the chapter is organized as follows. Section 3.2 introduces the games that are used in the experiment. In Section 3.3 we describe the experimental design and procedures. In Section 3.4 we present descriptive statistics and our main results. Section 4.4 concludes.

[12] We do not allow subjects to communicate since the effect of communication is not the focus of our analysis. Regarding this aspect, we refer to Charness (2000), Clark et al. (2001) and Manzini et al. (2009) for some related works.

3.2 Theory and qualitative hypotheses

In this section, we describe the games used in our experiment and we provide various qualitative predictions.

3.2.1 The experimental games

We now introduce the games that are used in the different treatments of the experiment. We choose payoff structures that are consistent with a class of problems analyzed in Bernstein and Winter (2012), who study the decision of group members to participate in a collective activity generating positive externalities to participants. Indeed, this class of problems is prevalent in economics, as it relates to situations where a club good is provided, and the induced game structure is often characterized by coordination issues due to the existence of strategic complementarity between the group members' individual choice of actions. Indeed, the game admits multiple Nash equilibria (thus raising coordination issues) that are Pareto ranked, and the efficient outcome is always an equilibrium. Moreover, the setting of this analysis allows one to introduce heterogeneous benefits from coordination: these benefits may be member-specific. This is an important feature in order to consider issues raised by inequality in payoffs.

The game structure of the experiment is as follows. We consider a group of three agents where each agent is randomly assigned a role, namely A, B, or C.[13] Each agent's decision is binary: choose 0 or choose 1.[14] All agents decide simultaneously. We consider two cases, one where there is a high degree of inequality in payoffs, which corresponds to Table 3.1, and one where there is a low degree of inequality in payoffs, which corresponds to Table 3.2.

We now explain how the two tables are obtained by relying on the setting introduced in Bernstein and Winter (2012). The game setting considered in Bernstein and Winter (2012) corresponds to a participation problem, where each agent decides to participate in a joint project or not. Participation results in positive externalities for participating members, and the bilateral externalities between the agents can be characterized by the following matrix:

[13] We consider groups of three agents when designing the experiment, as there was an initial risk that players assigned role C may consistently choose to not participate.

[14] In the context of the analysis provided in Bernstein and Winter (2012) choosing 0 would mean that the agent does not participate to the joint project, while choosing 1 would mean that the agent participates.

Table 3.1: *Payoff matrix faced by each individual subject*

	Combinations	Payoffs		
	(A, B, C)	*A*	*B*	*C*
1	(0, 0, 0)	60	60	60
2	(1, 0, 0)	60	60	60
3	(0, 1, 0)	60	29	60
4	(0, 0, 1)	60	60	10
5	(1, 1, 0)	90	60	60
6	(1, 0, 1)	81	60	32
7	(0, 1, 1)	60	56	38
8	(1, 1, 1)	111	87	60

Notes: (A, B, C) means that the first index is for agent A, the second for agent B and the last one for agent C. Line 5, instance means that (1, 1, 0) combination is reached, thus A gets 90, B gets 60 and C gets 60.

Table 3.2: *Payoff matrix faced by each subject*

	Combinations	Payoffs		
	(A, B, C)	*A*	*B*	*C*
1	(0, 0, 0)	60	60	60
2	(1, 0, 0)	60	60	60
3	(0, 1, 0)	60	29	60
4	(0, 0, 1)	60	60	10
5	(1, 1, 0)	61	60	60
6	(1, 0, 1)	61	60	32
7	(0, 1, 1)	60	30	38
8	(1, 1, 1)	62	61	60

Notes: (A, B, C) means that the first index is for agent A, the second for agent B and the last one for agent C. Line 5, instance means that (1, 1, 0) combination is reached, thus A gets 61, B gets 60 and C gets 60.

$$w = \begin{pmatrix} w_A(A) & w_A(B) & w_A(C) \\ w_B(A) & w_B(B) & w_B(C) \\ w_C(A) & w_C(B) & w_C(C) \end{pmatrix} \tag{3.1}$$

where $w_i(j)$ denotes the added benefit for agent i when participating jointly with agent j. Since an agent does not gain additional benefit from own participation $w_i(i) = 0$ is satisfied. Agent i's benefit from participating with a set of players M is $\sum_{j \in M} w_i(j)$. If an agent decides to not participate then he gets a payoff of c, which corresponds to the outside option.

We choose values for the externalities such that when all the players choose to participate, the differences between the players' payoffs are very small in the low inequality case and relatively large in the high inequality case. In the high

inequality case, the matrix specifying the externalities is

$$w_h = \begin{pmatrix} 0 & 30 & 21 \\ 31 & 0 & 27 \\ 22 & 28 & 0 \end{pmatrix} \tag{3.2}$$

while in the low inequality case, the matrix is

$$w_l = \begin{pmatrix} 0 & 1 & 1 \\ 31 & 0 & 1 \\ 22 & 28 & 0 \end{pmatrix} \tag{3.3}$$

The value of the outside option is $c = 60$ for both cases.

In order to ensure that participation of all members is an equilibrium outcome of the participation game, Bernstein and Winter (2012) characterize an appropriate incentive structure $v = (v_A, v_B, v_C)$ such that agent i gets payoff v_i if he participates and 0 if he does not participate. The resulting participation game is such that, if M denotes the set of agents who decide to participate, then agent $i \in M$ obtains $v_i + \sum_{j \in M} w_i(j)$, and each agent who does not participate gets the outside option c.

We choose parameter values to ensure that the incentive structure is identical in our two cases.[15] Specifically, this incentive structure is given by $(v_A, v_B, v_C) = (c, \quad c - w_B(A), \quad c - w_C(A) - w_C(B)) = (60, 29, 10)$. Now it remains to compute the payoffs derived from the different vectors of agents' decisions in the resulting participation game.

We provide the computations for the "High ineq." treatment. First, the vector of decisions $(0, 0, 0)$ corresponds to a payoff vector $(c, c, c) = (60, 60, 60)$.

Secondly, consider the case where only one agent participates. If agent A decides to participate while agents B and C do not, the corresponding payoff vector is $(c+0, c, c) = (60, 60, 60)$. If agent B decides to participate while the other agents do not, then one obtains $(c, c-w_B(A), c) = (60, 29, 60)$. If agent C decides to participate while the other agents do not, then one obtains $(c, c, c-w_C(A)-w_C(B)) = (60, 60, 10)$.

Now consider that only two agents decide to participate. If agents A and B are

[15] As such the efficient outcome is always an equilibrium of the induced coordination game, and the change in payoffs resulting from incentives does not drive differences from one treatment to the other, since this change is the same for both cases.

the only participating members, then one obtains $(c+w_A(B), c-w_B(A)+w_B(A), c) = (90, 60, 60)$. Similarly, we obtain that decision vector $(1, 0, 1)$ corresponds to payoff vector $(c + w_A(C), c, c - w_C(A) - w_C(B) + w_C(A)) = (81, 60, 32)$, while decision vector $(0, 1, 1)$ corresponds to payoff vector $(c, c-w_B(A)+w_B(C), c-w_C(A)-w_C(B)+w_C(B)) = (60, 56, 38)$.

Finally, if all agents decide to participate, the decision vector is given by $(1, 1, 1)$ and the resulting payoff vector is $(c + w_A(B) + w_A(C), c - w_B(A) + w_B(A) + w_B(C), c - w_C(A) - w_C(B) + w_C(A) + w_C(B)) = (111, 87, 60)$.

Collecting all payoff vectors, we obtain Table 3.1 corresponding to the high inequality case (Table 3.2 that corresponds to the "Low ineq." treatment is computed in a similar way).

This game structure is such that (i) the efficient outcome is always part of the equilibrium set (ii) the benefits from coordination increase from one case to the other (iii) the coordination payoffs of two agents increase (namely, the agents who are assigned roles A and B), while the coordination payoff of one agent is unaffected (namely, the agent who is assigned role C).

An important feature is that the set of Nash equilibria is identical in both cases. Specifically, decision vectors $(0, 0, 0)$, $(1, 0, 0)$, $(1, 1, 0)$ and $(1, 1, 1)$ constitute the set of Nash equilibria. One can notice that, as mentioned previously, this set can be Pareto ranked. Decision vectors $(0, 0, 0)$ and $(1, 0, 0)$ yield lower payoffs for all group members compared to $(1, 1, 0)$, and this equilibrium is Pareto dominated by $(1, 1, 1)$. Vector $(1, 1, 1)$ is the unique Pareto efficient outcome of the game.

3.2.2 Qualitative predictions

There are at least two strategic and behavioral aspects that are not accounted for in Bernstein and Winter (2012) that may play an important role in our laboratory experiment.

First, inspecting the payoff matrices suggests that strategic risk may play an important role in the way subjects play the game. We will be more specific about this below. Second, subjects may have social preferences. The two main broad categories of social preferences models are "difference aversion" and "social welfare". Specifically, we here consider cases where agents may be difference-averse (à la Fehr and Schmidt 1999) or have social efficiency considerations (a special case of the model introduced in Charness and Rabin 2002).

We now develop three sets of predictions based on these alternative assumptions. We first provide predictions assuming that subjects take strategic risk into

account and have standard preferences. We then make predictions assuming that subjects are averse to payoff differences. We finally provide predictions assuming that subjects are motivated by the possibility to increase social efficiency.

In order to derive predictions in the case of strategic risk, we make the following weak assumptions. We say that subject with role $i = A, B, C$ is "more likely to participate in the high inequality treatment than in the low inequality" if the difference between his expected utility when she participates and when she does not is larger in the high inequality treatment than in the low inequality treatment. In the case of difference aversion and social efficiency motivation, we make the following weak assumption. We assume that the probability that a subject chooses to participate (i.e. to choose 1) is an increasing function of the difference between the utility she gets when she chooses to participate and when she does not for all possible configurations of the other group members' choices. Formally, we say that subject with role $i = A, B, C$ is "more likely to participate in the high inequality treatment than in the low inequality" if

Pr(agent i chooses 1|treatment=High ineq.) $>$ Pr(agent i chooses 1|treatment=Low ineq.).

The probability function is defined as follows:

$$Pr(\text{Subject } i \text{ chooses } 1|\text{treatment=T}) = F_i(u_i^T(1,1,1) - u_i^T(0,1,1), u_i^T(1,1,0) - u_i^T(0,1,0), u_i^T(1,0,1) - u_i^T(0,0,1), u_i^T(1,0,0) - u_i^T(0,0,0)),$$

where u_i^T denotes subject's $i = A, B, C$'s payoff in treatment T = High ineq., Low ineq., and F_i a strictly increasing function in all its arguments.

A1. ***Strategic risk:*** Assume that the subjects have standard preferences and that they take strategic risk into account. Specifically, we here assume that each agent is uncertain about the choices of the other members of the group: as such, he assumes that any given member will choose 0 with probability $p \in]0, 1[$. Each agent can then compute the expected payoff resulting from choosing 1 and compare it to the expected payoff when choosing 0. An agent's incentive to prefer 1 over 0 is then given by the difference in expected payoffs. So, in this first case, an agent's utility function is given by the expected payoffs. We have the following predictions:

Proposition 7. *If there is some strategic risk and each subject assumes that any*

other given subject of her group will choose 0 with probability $p \in]0,1[$ *then we have the following conclusions:*

- *Role-A and role-B subjects are more likely to participate in the high inequality treatment than in the low inequality treatment;*
- *Role-C subject's likelihood to participate is not influenced by whether the high or the low inequality treatment is considered.*

All proofs are relegated in Appendix H.1.

If agents are sensitive to some strategic risk, the predictions highlight that one might expect subjects to exhibit different behaviors according to their respective roles in the group. Specifically, one might expect differences between role-A and role-B subjects on one side, and role-C subjects on the other side. Role-A subjects are clearly more likely to participate in the high inequality treatment as choosing to participate remains a dominant strategy while individual stakes are getting higher at the same time. Regarding role-B subjects, while choosing 0 yields the same expected payoffs in both treatments, expected payoffs when choosing to participate increase when moving from the low inequality to the high inequality treatment. Indeed, payoffs strictly increase in two cases, which correspond to the participation of role-A group member. As a result, the difference in expected payoffs increases when moving from the low inequality to the high inequality treatment. Finally, role-C subjects' expected payoffs corresponding to each choice of strategy remain unaffected when moving from the low inequality to the high inequality treatment.

If one interprets these results in relative terms, then they might suggest that coordination success should be more likely in the high inequality treatment: role-A and role-B subjects are more likely to participate, while role-C subjects' behavior should remain pretty much the same.

A2. ***Difference aversion:*** Now, assume that players have some aversion to differences between subjects' payoffs (Fehr and Schmidt, 1999). So, for any $i = A, B, C$, agent i's utility function is

$$U_i = x_i - \frac{a_i}{2}\sum_{j\neq i}\max\{x_j - x_i, 0\} - \frac{\beta_i}{2}\sum_{j\neq i}\max\{x_i - x_j, 0\}$$

where x_i denotes agent i's own material payoff, while $a_i \geq 0$ denotes this agent's disadvantageous inequality aversion parameter, and $\beta_i \geq 0$ denotes this agent's advantageous inequality aversion parameter. It is usually assumed that $a_i \geq \beta_i$ and $1 \geq \beta_i$ are satisfied. We obtain:

Proposition 8. *If the subjects have inequality aversion preferences, we have the following conclusions:*

- *Role-A subject is more likely to participate in the "High inequality" than in the "Low inequality" treatment;*
- *Role-B subject may be more or less likely to participate in either treatment;*
- *Role-C subject is less likely to participate in the "High inequality" than in the "Low inequality" treatment.*

All proofs are relegated in Appendix H.1.

The case of difference-averse preferences yields contrasted predictions: one should expect role-A subjects and role-C subjects to have opposite behavioral patterns, while role-B subjects' adjustment may be ambiguous. Intuitively, regarding role-A subjects, even though differences between group members' payoffs tend to increase when moving from the low inequality to the high inequality treatment (which makes role-A subjects less likely to participate), material payoffs of role-A subjects tend to increase as well (which makes role-A subjects more likely to participate). This second effect is actually dominant (because $\beta_i \leq 1$), and role-A subjects are more likely to participate in the high inequality treatment. By contrast, role-C subjects' material payoffs remain unaffected when moving from one treatment to the other, while differences between group members' payoffs tend to increase when moving from the low inequality to the high inequality treatment (which makes role-C subjects less likely to participate). Overall, role-C subjects are less likely to participate in the high inequality treatment. Finally, the case of role-B subjects is ambiguous, as the effect resulting from changes in material payoffs is not as clear-cut as for role-A subjects. Indeed, role-B subject's payoffs depend on their advantageous inequality aversion parameter a_i (as for role-A subjects) and also on their advantageous inequality aversion parameter β_i (differently from role-A subjects).

These predictions on individual strategies imply in turn that the overall impact on coordination success should be ambiguous when moving from one treatment to the other, as role-A and role-C subjects have always opposite patterns.[16]

A3. ***Social efficiency motivation:*** Last, assume that the subjects put some

[16] If one assumes that the chances of coordination success are higher if all group members have lower incentives to deviate, these are related to the difference between a subject's payoff when deviating and the one corresponding to $(1, 1, 1)$, for all roles.

weight on social efficiency. That is, role-i agent's utility function looks like:[17]

$$U_i = \gamma_i x_i + (1 - \gamma_i) \sum_{l=A,B,C} x_l = x_i + (1 - \gamma_i) \sum_{l \neq i} x_l$$

where $\gamma_i \in]0, 1]$ denotes the weight put on the payoffs of the other members of the group. We have the following result:

Proposition 9. *If the subject have some social efficiency motivation, all subjects (role-A, role-B and role-C) are more likely to participate in the high inequality treatment than in the low inequality treatment.*

All proofs are relegated in Appendix H.1.

From an individual point of view, the conclusion is non-ambiguous: intuitively, as overall stakes are getting higher when moving from the low inequality to the high inequality treatment, individuals who are motivated to some extent by social efficiency considerations should participate more in the high inequality treatment. This conclusion yields in turn a clear prediction on the chances of coordination success: coordination success is more likely in the high inequality treatment than in the low inequality treatment.

These three sets of predictions will allow us to discriminate between these three kinds of social preferences (none, difference aversion and social efficiency motivations).

3.3 Experimental design and procedures

The experiment was conducted using the Experimental Economics Laboratory (*laboratoire Montpellierain d'économie experimentale*, LEEM), at the University of Montpellier (France). We ran 16 sessions with 15 or 18 participants each (a total of 270 subjects). We used the Online Recruitment Software for Economic Experiments (ORSEE) (Greiner, 2015) to recruit subjects and the Z-Tree software to program and conduct the experiment (Fischbacher, 2007). Average earnings were around 14 € net of show up fees.[18] Each session lasted about one hour.

Upon arrival in the experimental room, each subject were asked to sit in front of an individual desk computer. Instructions (see Appendix H.5) were circulated and read aloud by the experimenter before each game. Participant subjects were

[17] This utility function corresponds to the one introduced in Charness and Rabin (2002) on page 852 without the Rawlsian component, i.e. $\delta = 0$.

[18] Show up fees were 6 € for participants coming from outside the University of Montpellier and 2 € for the students from the University of Montpellier.

requested to make their decision without any form of communication. Participants were informed that they would be paid according to the outcome generated by one randomly chosen treatment out of two. They would be paid for sure the earnings corresponding to the outcome of the first period plus the earnings corresponding to the outcome of one randomly selected period between the nine remaining periods. We expect that subjects thus played very carefully in the first period in each treatment. For our baseline results we use data on all the periods and we provide results using data on the first periods only as a robustness check.

Participant subjects were informed that, before the experiment, their computer were randomly matched into groups of three. In each group, subjects were randomly assigned a role, that can be either role A, role B or role C. Each role corresponds to a specific column in each payoff matrix. Subject were told that the payoffs are in experimental currency (ECU) and that their gains will be converted into euros using the exchange rate of 1 € ≃ 11 ECUs.[19]

An experimental session consisted of two treatments, three additional modules, and a short socio-demographic characteristics survey. Table 3 summarizes the experimental design. Treatments and modules are exhibited in block one and two, respectively. Block one refers to the two treatments played in a specific (random) order: around half of the groups played the two treatment according to order 1 (High inequality then Low inequality), and the other groups played the two treatments according to order 2 (Low inequality then High inequality). As a consequence, each group played the two treatments according to one of the two orders. Block two refers to the three additional modules.

Table 3.3: *Orders in the experiments*

	Block 1		Block 2			Survey
Order 1 (Decreasing ineq.)	*High ineq.*	*Low ineq.*	*MD*	*Ult*	*HL*	yes
Order 2 (Increasing ineq.)	*Low ineq.*	*High ineq.*	*MD*	*Ult*	*HL*	yes

Let us first describe the content of Block 1. For each of the two treatments, participant subjects were invited to play 10 rounds. Each round was split into two stages:

1. **Decision:** Subjects first get the common knowledge payoff matrix from Table 3.1 or 3.2, then they decided whether to play 0 (we call this choice non participation) or 1 (we will call this choice participation). We used neutral

[19] Using ECU allows to provide simple forms of payoffs (avoiding decimal numbers).

terminology in the instructions in order to avoid framing effects,[20] that may bias subjects' decisions.

2. **Payoffs:** Once the subjects' decisions were completed, a group outcome was reached and displayed to each group member. Subjects then receive payoffs that are equivalent to the one indicated by the reached combination outcome.

Now let us describe the content of block 2, i.e the three additional modules. Subjects first played a modified dictator game. Then subjects played an ultimatum game.[21] Finally, they played a multiple price-list lottery game. The modified dictator game allows us to estimate individuals' degrees of aversion toward advantageous inequality (Blanco et al., 2011) as well as a proxy for subjects' altruism. The ultimatum game allows us to estimate subjects' degrees of aversion toward disadvantageous inequality (Blanco et al., 2011), and the multiple price-list lottery game allows us to estimate a measure of their risk aversion (Holt and Laury, 2002). Further details concerning these modules and the estimates of subjects' preferences can be found in Appendix H.3.

Last, subjects were asked to fill a short socio-economic survey including information on their age and gender. Summary statistics of our sample can be found in Appendix H.3 (Table H.1).

Before going further, let us discuss two important choices we made in this experiment.

First, we use a within setting for analysis purposes (each group plays the two treatments). A within setting allows for within group and within individual comparison as it allows us to control for group and individual invariant characteristics and makes a more powerful statistical analysis possible. This type of design increases the number of independent observations and by the same vein the precision of the statistical tests (e.g. see Charness et al., 2012). However, we have to deal with the possibility that order effects are present,[22] that is, subjects might be sensitive to the given order of the treatments. Confounding variables can then interfere with the effect of the treatment and bias the results of the experiment. We follow Budescu and Weiss (1987) to control for order effects. They suggest counterbalancing the treatments among the sessions. In practice, groups receive a randomly given order of the treatments before each session. In this experiment, since we had only two treatments, counterbalancing was quite simple. Block 1 in

[20] See Kahneman and Tversky (1979) or Druckman (2001) for more details on this topic.
[21] See Güth et al. (1982), Camerer and Thaler (1995), and Thaler (1988).
[22] See Schuman et al. (1981) for further details about order-effects in experiments.

Table 3.3 is build to counterbalance the orders: each group either began by playing the “High ineq." treatment and then played the “Low ineq." treatment, which we refer to as the decreasing inequality order (Order 1) or it began by playing the “Low ineq." treatment and then played the “High ineq." treatment, which we refer to as the increasing inequality order (Order 2).

Second, we use a partner setting. Indeed, groups were formed and roles were assigned at the beginning of the experiment and they remained unchanged during all the experiment. This setting may generate reputations effects within groups and these effects evolve from one period to the following (e.g. see Andreoni et al., 2008). We use two different strategies to take these effects into account. First, we employ the following straightforward method. The total payoff of a subject (for Block 1) was computed as follows: select one of the two treatments randomly and take the sum of the payoff of the first period plus the payoff of one randomly selected period out of the nine remaining periods. Thus, we expect that the subjects focused on the first periods of each treatment like in a single-shot game. In our analysis, we provide results when using all the periods and when using the sub-sample of the first periods only. Notice that these random payments also allow us to eliminate wealth accumulation effects (Samuelson, 1963; Rabin, 2000).[23] Second, when we consider all the periods in our regressions, we cluster the standard errors at the group level in order to correct autocorrelation that can be due to reputation effects or other phenomena that generate correlation between different periods.

3.4 Results

3.4.1 Data and descriptive statistics

Our sample is based on observations of decisions made by 90 groups (composed of three subjects), among which 46 played with order 1 and 44 played with order 2. Our data consists of 5400 individual decisions and 1800 group outcomes.

Table 3.4 provides descriptive statistics on the frequency of the various outcomes. Groups reached the efficient outcome (i.e. they played (1, 1, 1)) 20.5% of the time. The outcome corresponds to another Nash equilibria 42% of the times. They played the Nash equilibrium in which none of the players choose to participate (i.e. they played (0,0,0)) 10% of the time, the Nash equilibrium in which only player A participates (i.e. they played (1,0,0)) 14.5% of the times, and the

[23] See also Heinemann (2008) for more details on how to measure wealth effects.

Nash equilibrium in which subjects A and B participate but not C (i.e. they played (1,1,0)) 17% of the time.

Table 3.4 also provides descriptive statistics on individual participation. Subjects chose to participate 52% of the time. Subjects A's participation frequency is 86%, which seems quite low given that choosing 1 is a dominant strategy for these subjects. Subjects B chose to participate almost half less often (44%) and subjects C chose to participate 26% of the time.

Table 3.4: *Descriptive statistics: outcome*

Variable	Mean	Std. Dev.	Min.	Max.	N
Group level					
Group coord. (1, 1, 1)	0.205	0.404	0	1	1800
Nash Eq. (0, 0, 0)	0.101	0.302	0	1	1800
Nash Eq. (1, 0, 0)	0.145	0.165	0	0.333	1800
Nash Eq. (1, 1, 0)	0.173	0.292	0	0.667	1800
Individual level					
Indiv. participation	0.523	0.500	0	1	5400
Subj. A participation	0.863	0.344	0	1	1800
Subj. B participation	0.443	0.497	0	1	1800
Subj. C participation	0.262	0.440	0	1	1800

Notes: The sample consists of 270 subjects, 90 groups playing 2 treatments with 10 repetitions each.

Individual characteristics from the survey (age, gender) and estimated by using the three modules (risk aversion, inequality aversion and altruism) are presented in Appendix H.3 (Table H.1).

3.4.2 The effect of inequality on coordination

In order to study how inequality affects individual participation decisions and coordination, we compare the two treatments using two different strategies. First, we perform a between-subject analysis using the first ten periods only. Second, we take advantage of the within-subject design and use a difference-in-difference estimation strategy that controls for individual characteristics, as well as sequence and order effects.

Between groups/subjects analysis

We first focus on the first ten periods to perform a between-subject analysis, i.e we compare the data from the High inequality treatment for groups (and individuals) playing the High inequality treatment first (Order 1) with the data from the Low inequality treatment for groups (and individuals) playing the Low inequality treatment first (Order 2).

Table 3.5 summarizes the results. Column (1) provides the frequency of occurrence of the various Nash equilibria in the two treatments. In columns (2) and (3), we provide the average value of the outcome (at the group or at the individual level) for the Low inequality treatment and the High inequality treatment, respectively. In column (4), we provide the results of non parametric tests (Wilcoxon rank-sum tests) of equality of the distributions of the frequency of occurrence of a Nash equilibrium or of individual participation in each treatment (we report the z-score and the p-value between brackets).

Table 3.5: *Between groups/subjects analysis*

	(1) **Mean**	(2) **Low ineq.**	(3) **High ineq.**	(4) **Wilcoxon rank sum stat.**	(5) **[p-value]**
Group level					
Group coord.	0.200	0.114	0.285	-6.400***	[0.000]
Nash Eq. (1, 1, 0)	0.170	0.153	0.187	-1.749*	[0.080]
Nash Eq. (1, 0, 0)	0.142	0.164	0.121	3.876***	[0.000]
Nash Eq. (0, 0, 0)	0.119	0.166	0.072	4.379***	[0.000]
Individual level					
Indiv. participation	0.522	0.472	0.572	-7.274***	[0.000]
Subj. A participation	0.863	0.837	0.889	-3.156***	[0.002]
Subj. B participation	0.443	0.369	0.516	-6.261***	[0.000]
Subj. C participation	0.260	0.212	0.310	-4.771***	[0.000]

Notes: z is the z-score of a Wilcoxon rank-sum test of equality of the distributions. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

The results are as follows. Groups achieved coordination on the Pareto dominant equilibrium 11% of the time in the Low inequality treatment and 28% of the time in the High inequality treatment and the difference is statistically significant. The Nash equilibrium in which subjects A and B participate and subject C does not participate was significantly (at the 10% level) more frequent in the High inequality treatment than in the Low inequality treatment (15% in the Low inequality treatment versus 19% in the High inequality treatment). The Nash equilibrium in which subject A is the only one to participate was significantly more frequent in the Low inequality treatment than in the High inequality treatment (16% versus 12%), and the Nash equilibrium in which none of the subjects participate was more frequent in the Low inequality treatment (17%) than in the High inequality treatment (7%). The largest difference between the two treatments is for the equilibrium in which all the subjects participate. This result suggests that coordination on the Pareto dominant equilibrium is facilitated in the High inequality treatment.

The results on individual participation decisions are striking. The High in-

equality treatment induces an additional 10 percentage points in the participation rate compared to the Low inequality treatment, which corresponds to a 20% increase compared to the participation rate in the Low inequality treatment (47%). For each role, participation is significantly larger in the High inequality treatment than in the Low inequality treatment. Role-A subjects' participation rate is 5 percentage points larger in the High inequality treatment than in the Low inequality treatment (it corresponds to a 4% increase). The difference is modest but statistically significant. For role-B subjects, the difference between the two treatments is both large and significant. The participation rate is 15 percentage points larger in the High inequality treatment than in the Low inequality treatment (and it corresponds to a 40% increase). More strikingly, the difference between the two treatments is also large (and significant) for role-C subjects. Their participation rate is 10 percentage points larger in the High inequality treatment than in the Low inequality treatment (and it corresponds to a 48% increase).

Figure 3.1 (group level) and Figure 3.2 (individual level) provide time series for group coordination on the Pareto dominant equilibrium and individual participation decision (for each role). We plot a time series for each treatment.

Figure 3.1: *Frequency of coordination per period for each treatment*

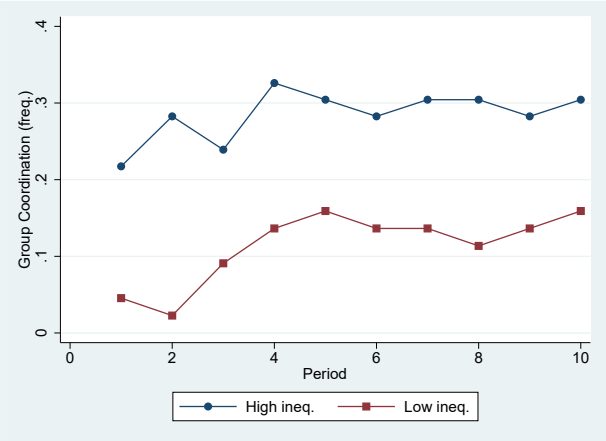
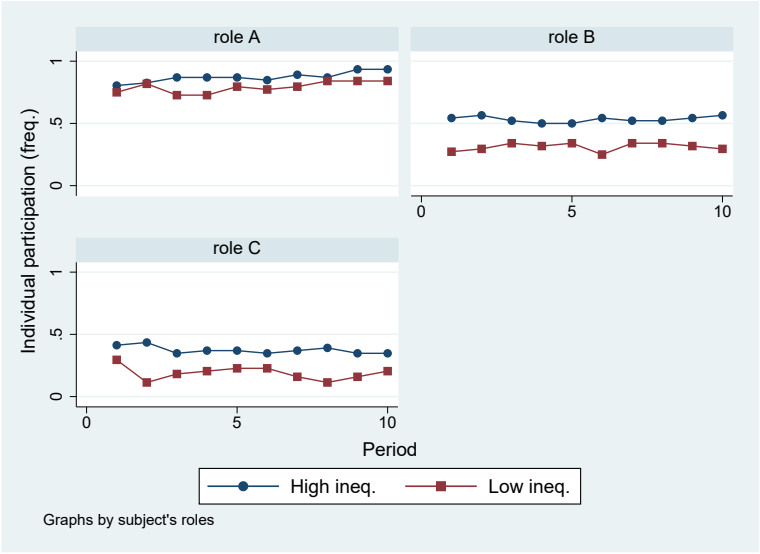


Figure 3.1 (group level) highlights that the frequency of coordination is higher in the High inequality treatment than in the Low inequality treatment in each period. The difference is remarkably stable between periods: the average difference is 17 percentage points and the standard deviation of the difference is small (0.04). The difference between the treatments in the first period - for which the subjects knew they will get payments for sure - is also 17 percentage points.

Figure 3.2 (individual level) highlights that the participation rate is higher in the High inequality treatment than in the Low inequality treatment in each period for each role. As for the frequency of group coordination, the difference between

Figure 3.2: *Frequency of coordination per period for each treatment*



the two treatments is remarkably stable between periods.

These results are conclusive thanks to our qualitative predictions (section 3.2.2). Among the three models (strategic risk, difference aversion, social efficiency motivation), only the "social efficiency motivation" model is consistent with all the results found in this section.

Difference-in-difference estimation

In this section, we take advantage of the structure of our data in order to control for individual characteristics as well as sequence and order effects. We use panel regressions estimates of a linear probability model that links the treatments and group coordination success or individual participation decisions.

We first perform an analysis at the group-period level (see Figure H.1 in Appendix H.2 for time series of group coordination success). The right hand side variable is High ineq., a dummy which is 1 if the group plays the High inequality game and 0 if the group plays the Low inequality game in the current period. The outcome variable is a dummy variable which is 1 if the group achieves coordination on the Pareto dominant equilibrium in the current period and 0 otherwise. In order to control for period and group characteristics and to be able to interpret the analysis as a difference-in-difference, we include both period and group fixed effects. Notice that order effects are controlled for by the group fixed effects, since each group played the two treatments according to one of the two orders (as explained in Section 3.3). Also notice that since each group is formed once and the subjects are matched for the 20 periods, there may be autocorrelation in the error

term. We thus cluster the standard errors at the group level.

Table 3.6 provides the results. Column (1) shows that the likelihood that a group achieves coordination is significantly higher in the High inequality treatment. The increase is as high as 9.7 percentage points compared to the Low inequality treatment. In column (2) we only include the first periods and the result is very similar.

These results are clear-cut. However, in order to discriminate between the three models that we consider (strategic risk, difference aversion, social efficiency motivation), we go one step further and study individual participation decisions.

Table 3.6: *Inequality and group coordination (fixed effects)*

	Dependent variable: Group Coordination	
	(1)	(2)
	All periods	First periods only
High ineq.	0.0969***	0.0998**
	(0.035)	(0.039)
Model	LPM	LPM
Group FE	YES	YES
Period FE	YES	YES
Obs.	1,800	180
Nb of groups	90	90
R^2	0.589	0.699

Notes: *** significant at 1% level, ** significant at 5% level, * significant at 10% level. High ineq. is the outcome of the dummy for treatment when it is equal to 1. Coordination equals 1 when groups select the most efficient Nash equilibria. LPM stands for Linear Probability Model. Reported standard errors are clustered at the group level.

We ask whether subjects with role A, B and C are more likely to participate when inequality is low or high. In other words, we analyze the effect of the High inequality treatment - compared to the Low inequality treatment - for each role A, B and C.

We answer this question using panel regressions of a linear probability model that links the treatments and individual participation decisions. The analysis is performed at the individual-period level. The outcome variable is a dummy variable which is 1 if the individual decides to participate (i.e. chooses 1) in the current period and 0 otherwise (i.e. if she chooses 0). In order to control for period and individual characteristics and to be able to interpret the analysis as a difference-in-difference, we include both period and individual fixed effects. As for the group level estimates, we cluster the standard errors at the group level.

The results are provided in Table 3.7. In columns (1) and (2) we use the full

sample that includes the subjects for each role. In columns (3) to (5), we consider the sub-samples that include subjects with role A, role B or role C only. In column (1), we find that the likelihood that a subject participates is 9.9 percentage points higher in the High inequality treatment than in the Low inequality treatment and that this effect is significant. In column (2) we use interaction variables in order to separate the effect of the treatments for each role A, B and C. We find that the likelihood that subjects with role A, B and C participate is higher in the High inequality treatment.[24] The likelihood that subjects with role A, role B, and role C participate is respectively 5, 15, and 10 percentage points higher in the High inequality treatment than in the Low inequality treatment (and all these effects are significant). In columns (3) to (5), i.e. when we consider each role separately, we find very similar results to those from column (2).

Table 3.7: *Inequality and individual decision (fixed effects)*

	Dependent variable: Participation decision				
	(1) Full sample	(2) Full sample	(3) Role A	(4) Role B	(5) Role C
High ineq.	0.099***				
	(0.028)				
High ineq. × subject A		0.052**	0.052**		
		(0.024)	(0.023)		
High ineq. × subject B		0.147***		0.148***	
		(0.046)		(0.046)	
High ineq. × subject C		0.099***			0.098***
		(0.036)			(0.035)
Model	LPM	LPM	LPM	LPM	LPM
Indiv. FE	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes
Obs.	5,400	5,400	1,800	1,800	1,800
Nb of subjects	270	270	90	90	90
R^2	0.59	0.59	0.33	0.43	0.37

Notes: *** significant at 1% level, ** significant at 5% level, * significant at 10% level. High ineq. is the outcome of the dummy for treatment when it is equal to 1. Participation decision equals 1 when subjects select "participation". × indicates interaction variable. LPM stands for Linear Probability Model. Reported standard errors are clustered at the group level.

The results at the group and individual level are very similar to those obtained in the between groups/subjects analysis in Section 3.4.2. They show that the positive effect of inequality on coordination success is sustained by all the subjects, independently of their role. The fact that subjects with role C are more likely to participate under the High inequality treatment is not consistent with the

[24] We reject the equality of the three coefficients at the 10% significance level.

strategic risk model or the difference aversion model considered in Section 3.2.2. This is however consistent with social efficiency motivation models that predict the qualitative results of the present section.

We cannot rule out that other models could explain these results. We can, however, argue that it is difficult to find other models that predict that all the subjects are more likely to participate in the High inequality treatment.

One may find alternative explanations for the case of subjects with role A. One may think that status seeking can explain why subjects with role A participate more in the High inequality treatment. However, status seeking cannot explain why subjects with role C –for which none of the payoffs is changed between the two treatments– participate more in the High inequality treatment.

In order to provide some direct evidence on the link between individual preferences and participation decision, we use estimated measures of individual preferences that can be obtained from the three modules that were played after the two treatments (see the description of Block 2 in Section 3.3) and the survey.

We can then include interaction variables in our regressions in order to test whether the effect of the treatment is larger or smaller depending on whether the individual is averse to disadvantageous or advantageous inequality, altruistic or not, more or less risk averse. However, we do not find evidence of such heterogeneous treatment effects. We relegate the description of this analysis to Appendix H.3 (Table H.2).

In order to test whether individual preferences played a role in the subjects' decisions, we also estimated the same models as in Table 3.7 without individual fixed effects in order to include individual preferences measures (see Table H.3 in Appendix H.3). We do not find evidence of an effect of the individual measures except of risk aversion on the individual decision to participate. Risk aversion has a negative effect on the likelihood to participate. This is consistent with the assumption that subjects take strategic risk into account.

3.4.3 Increasing versus decreasing inequality

While we control for order effects in our main results, it is interesting to investigate whether there was a difference in the frequency of coordination depending on the order of the treatments.

To derive a first comparison of the two orders, we plot one graph for each treatment in Figure 3.3. The left hand side plot represents the average frequency of coordination by period in the Low inequality treatment for each order. The

right hand side plot represents the average frequency of coordination by period in the High inequality treatment for each order. For almost all periods, the average frequency of coordination is larger for decreasing inequality (order 1) than for the increasing inequality order (order 2).

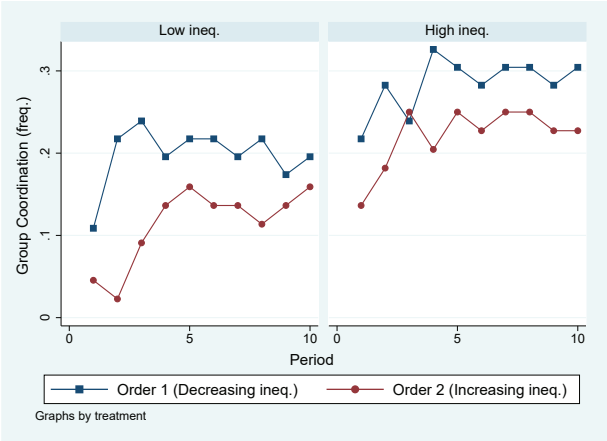


Figure 3.3: *Order comparison by treatment*

In order to provide more detailed information on the effect of the order of the treatments, we derive comparisons at the group and individual level between the effect of the High inequality treatment when it is played first (order 1) and when it is played second (order 2), and comparisons between the effect of the Low inequality treatment when it is played first (order 2) and when it is played second (order 1). Table 3.8 provides the results. Column (1) and (2) provide the average frequency of coordination success or individual participation for the Decreasing inequality order (order 1) and for the Increasing inequality order (order 2), respectively. Column (3) provides the result of a Wilcoxon rank sum test of equality of the distributions and column (4) provides the p-value.

Table 3.8: *Between groups/subjects analysis of order effects*

	(1) **Dec. ineq. (order 1)**	(2) **Inc. ineq. (order 2)**	(3) **Wilcoxon rank sum stat.**	(4) **[p-value]**
Group coordination				
High ineq. treatment	0.285	0.220	2.217**	[0.027]
Low ineq. treatment	0.198	0.114	3.471***	[0.000]
Individual participation				
High ineq. treatment	0.593	0.551	2.204**	[0.028]
Low ineq. treatment	0.514	0.430	4.379***	[0.000]

Notes: z is the z-score of a Wilcoxon rank-sum test of equality of the distributions. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

Table 3.8 shows that groups that played the treatments in the Decreasing inequality order (order 1) reach the Pareto dominant equilibrium more often than

the groups that played the treatment in the Increasing inequality order (order 2), and this holds for both the High inequality treatment phase (28.5% of the time in order 1 versus 22% of the time in order 2) and the Low inequality treatment phase (20% of coordination success in order 1 versus 11% in order 2) and the differences are statistically significant. These two results confirm the observation obtained using Figure 3.3 that the participation frequency is larger under the Decreasing inequality order than under the Increasing inequality order.

We find similar results as regards individual participation. Subjects who played the treatments in the Decreasing inequality order (order 1) participate more often than the subjects that played the treatment in the Increasing inequality order (order 2), and this holds for both the High inequality treatment phase (59% of the time in order 1 versus 55% of the time in order 2) and the Low inequality treatment phase (51% of coordination success in order 1 versus 43% in order 2) and the differences are statistically significant.

These results suggest that the order of treatments matters. Subjects who belong to groups facing over time a reduction in inequalities participate more often and then reach the efficient outcome more often, over the entire experiment, compared to subjects who belong to groups facing over time an increase in inequalities.[25]

We conjecture that this order effect might be due to the fact that subjects assess the level of strategic risk based on their past experience. Let us elaborate on this point. In light of the results from the previous sections, we know that the likelihood of coordination success is larger in the High inequality treatment than in the Low inequality treatment (see Section 3.4.2). The results obtained thanks to individual preference measures suggest that strategic risk plays a role in the way subjects make their choices in the experiment (see Table H.3 in Appendix H.3). Using these results, we believe that the order effect may be explained as follows. Assume that the subjects assess the magnitude of strategic risk based on their past experience of coordination success. In the decreasing inequality order, the participation rate is large in the first - high inequality treatment- phase (59%). In the second -low inequality treatment - phase, the participation rate is 8 percentage point lower. It is however still relatively high. This observation is consistent with the conjecture that the subjects estimate - based on the observation of a high participation rate in the first phase - that the strategic risk will remain relatively

[25]Another possible interpretation is that the frequency of coordination converges to a specific value (slightly above 0.20) independently of the order of the treatments. It is however difficult to find an explanation for the latter interpretation.

low and then they continue to participate quite frequently. By contrast, in the increasing inequality order, the participation rate is relatively low in the first - low inequality treatment- phase (43%). In the second -high inequality treatment- phase, the participation rate is 12 percentage points larger. It is however not as large as the participation rate in the high inequality treatment for the decreasing inequality order. This observation is consistent with the conjecture that the subjects estimate - based on the observation of a low participation rate in the first phase - that the strategic risk will remain relatively high and then they still choose to not participate quite frequently.

3.5 Conclusion

Coordination is often required to reach an efficient outcome, and the trade-off between efficiency and equity in coordination problems is a question that has surprisingly received little attention.

In this chapter, we report the results from an experiment where the subjects face a coordination problem and we compare a situation in which the coordination payoffs are close to equal with a situation in which some of the subjects' coordination payoffs are increased.

We show that groups reach the efficient outcome more frequently in the second case, and that subjects play the strategy that corresponds to this outcome more frequently even when their individual payoffs are unchanged. This suggests that subjects are motivated by social efficiency rather than by difference aversion considerations. We control for order effects that seem to exist in this setting. Thus, decreasing inequality and the coordination payoffs of some of the subjects (in other words, facing the High inequality treatment first) facilitates coordination compared to increasing inequality and the coordination payoffs of these subjects (facing the Low inequality treatment first). This order effect seems to be consistent with the assumption that subjects assess the level of strategic risk based on their past experience.

Our results first suggest that larger levels of welfare for some but not all increases coordination success and, second, that increasing the levels of welfare of some but not all through time decreases coordination success. Specifically, a larger surplus tends to facilitate the emergence of an efficient outcome, even if inequality levels are higher. Yet, this does not mean that one should necessarily make the size of the “pie" larger over time if inequalities simultaneously increase. The final results suggest that situations where groups of agents face over time

a reduction in inequalities facilitate coordination, compared to situations where groups face over time an increase in inequalities.

Thus, this study both contributes to the debate on the efficiency-equity trade-off and provides evidence on the effect of variations in inequalities on the resulting efficiency of collective decisions. Obviously, more work is needed to develop our understanding of this complex problem.

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Chapter 4: Contracting with Externalities and Fairness Preferences

Abstract

We analyze the optimal contract designed to induce inequality averse agents to participate in a joint project when individual participation generates positive externalities for other participants. We initially check that a principal offering a contract optimally designed for self-interested agents would not induce full participation of inequality-averse individuals. The characterization of the optimal contract then raises important insights. First, aversion to advantageous inequality has a first order effect. Specifically, when agents are not averse to such inequality, the optimal contract is the same as when they have standard (selfish) preferences. Moreover, if agents have homogeneous preferences, the optimal contract under symmetric externalities does not depend on the disadvantageous inequality aversion parameter. Second, the optimal contract exhibits notable qualitative differences when agents are heterogeneous, and both forms of aversion to inequality are complementary: the optimal scheme depends on disadvantageous inequality aversion only if agents are averse to advantageous inequality. Finally, we characterize the conditions under which the advantaged agent (the agent whose payoff is largest under the optimal contract) receives a larger reward than the disadvantaged agents, and discuss whether the optimal contract results in more or less inequality (compared to the standard case).

Keywords

Contract theory, Externalities, Inequality aversion, discrimination.

4.1 Introduction

Empirical evidence suggest that social preferences may matter for incentive design (Fehr and Fischbacher, 2002; Fehr et al., 2007). For instance, fairness may affect the provision of incentives in settings such as gift exchange (Fehr et al., 1993) or principal-agent relationships (Fehr et al., 2007).[1] A theoretical literature has emerged about the issues driven by behavioral features on contract design (see Koszegi (2014) for a review). However, there exist only a few studies focusing on the effect of fairness in multi-agent settings.[2] The aim of this contribution is to partially fill this gap by analyzing the optimal contract designed to induce inequality averse agents to participate in a joint project, when individual participation generates (positive) externalities for other participants.

We consider a set of agents who may choose to participate in a joint project, when an agent's participation generates externalities that benefit other participants only. Agents' preferences are assumed to exhibit fairness considerations: each agent may care for the material payoffs of the other agents. We follow Fehr and Schmidt (1999) and assume that agents are averse to inequalities. In line with the literature (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) we consider aversions to both disadvantageous (envy) and advantageous (guiltiness) inequalities. A principal's goal is to induce the participation of all agents (full participation) at least cost: we thus consider a contracting model under potentially heterogeneous externalities as in Bernstein and Winter (2012).[3] The timing of the process is as follows. First, the principal offers a contract, which consists in a menu of monetary rewards (one for each agent). Second, the agents play the induced participation game where they simultaneously decide whether to accept their own offer (and thus choose to participate) or to reject it (and decide to not participate). Finally, agents' payoffs are implemented.

The analysis focuses on the optimal contract design in such a setting: specifically, the focus is on the least-cost contract inducing full participation as a Nash equilibrium of the induced participation game (*partial implementation contract*).[4] We provide several important insights. We initially check that a principal offering

[1] See Fehr et al. (2007) for more details about the performances of bonus contracts.

[2] The contribution by Fehr et al. (2007) introduces fairness considerations within a principal-agent relationship when there is a single agent.

[3] We follow this contribution by restricting attention to bilateral contracting.

[4] As in most of the literature on contracting under externalities, we implicitly assume that coordination is not an issue: if multiple equilibria arise as a result of the contract, we assume that the principal can implement his preferred outcome.

a contract optimally designed for self-interested agents would not induce full participation of inequality-averse individuals as a Nash equilibrium.[5] We then focus on the two-agent case in order to analytically characterize the optimal contract, which exhibits interesting properties. First, aversion to advantageous inequality has a first order effect. Specifically, when agents are not averse to such inequality, the optimal contract is the same as when they have standard (selfish) preferences. The intuition of this result is as follows. The optimal contract ensures that each agent receives a reward that makes him indifferent between participating (when the other agent participates) and not participating. Since agents have the same opportunity cost, they receive the same material payoff, which equals the opportunity cost. Moreover, there is no other contract that induces full participation at a lower cost to the principal. Indeed, if the principal provides a lower reward to one of the agents, then this agent's utility is lower than the opportunity cost when all agents participate. If this agent deviates and does not participate, then he gets his outside option while the participating agent does not benefit from any positive externality and his material payoff is then lower than the opportunity cost. The deviating agent's utility is not affected by the inequality between the two agents, because he is precisely the one with the largest material payoff. Hence this agent's utility equals the opportunity cost, which is larger than his payoff when the two agents participate.

We further elaborate on the first-order importance of aversion to advantageous inequality: when agents have homogeneous preferences, the optimal contract under symmetric externalities does not depend on the disadvantageous inequality aversion parameter. A second important conclusion is that the optimal contract exhibits notable qualitative differences when agents are heterogeneous, and both forms of aversion to inequality are complementary. Indeed, the optimal scheme depends on disadvantageous inequality aversion only if agents are averse to advantageous inequality. Finally, we characterize the conditions under which the advantaged agent (the agent whose payoff is largest under the optimal contract) receives a larger reward than the disadvantaged agents, and discuss whether the optimal contract results in more or less inequality compared to the standard case.

This contribution relates to the literature considering a relationship between a single principal and a set of agents (Holmstrom, 1982; Mookherjee, 1984; Demski and Sappington, 1984) when the agents' individual decisions may generate exter-

[5] Here, we consider *full implementation contract* which refers to the situation in which the contracting scheme leads to the participation of all agents as a unique Nash. Note that before being a full implementation, a contract must be a partial implementation.

nalities on others (Segal, 1999, 2003; Segal and Whinston, 2003). This is a broad and important topic with many real-world applications. For instance, this is relevant in settings such as the provision of environmental collective goods, Payments for Environmental Services (Wunder, 2005; Engel et al., 2008)[6] involve a regulatory institution and farmers or forest owners.[7] In such settings agents' actions generate potential externalities: a farmer exerting conservation efforts to promote biodiversity generates positive externalities on neighboring parcels (Maass et al., 2005). Most of the literature mentioned above abstracts from the effect of fairness considerations on contract design.

The present contribution relates also to the literature on behavioral contract theory.[8] Specifically, this study relates to the literature focusing on optimal contracting with multiple inequality averse agents (Englmaier and Wambach, 2010; Rey-Biel, 2008; Demougin et al., 2006).[9] Very few papers consider a principal - multiple agent relationship under the presence of inequality aversion preferences. We can quote Goel and Thakor (2006) who analyze such a type of problems when agents envy each other: The focus is on contracts inducing surplus sharing in the case of homogeneous agents. By contrast with our contribution, issues raised by the presence of externalities generated by agents, by the different types of aversion to inequalities, and the effects raised by heterogeneous fundamentals, are abstracted from.[10]

Another part of the literature provides results related to team based incentives (Bartling and Von Siemens, 2011, 2010; Rey-Biel, 2008; Itoh, 2004). The general focus of these studies is on how the principal tailors agents' incentives to account for agents' preferences by offering more equitable contracts or team-based incentive schemes. They differ notably from the present contribution in terms of the setting considered and the research questions. First, we do not focus on team based incentives (output sharing) but rather on bilateral contracting in a collective good setting under positive externalities, where differentiated incentives are optimal. Second, we highlight the qualitative differences driven by heterogeneity in agents' social preferences and in the generated externalities.

The remainder of the contribution is organized as follows. Section 4.2 intro-

[6] See also Banerjee et al. (2017); Lawley and Yang (2015).

[7] See Farley and Costanza (2010) for further details on payments for environmental services.

[8] See Koszegi (2014); DellaVigna (2009); Rabin (1998) for extended reviews.

[9] Englmaier and Wambach (2010) consider the effect of inequality aversion on contract design in a single principal - single agent setting when the agent cares for the principal's material payoffs.

[10] Gürtler and Gürtler (2012) analyze the effect of inequality aversion on individuals' behavior in a quite general setting. Yet, the focus is on the externalities resulting from such preferences in an homogeneous population setting.

duces the model. In Section 4.3 we highlight how the neglect of inequality aversion yields a sub-optimal contract, then characterize the optimal contract and analyze the importance of each type of aversion to inequality for contract design. Section 4.4 concludes.

4.2 The model

A single principal (she) offers incentives to several agents in order to bring them into a common project where its success depends on the participation decision of all agents. The agents then choose whether to participate or not in the project. An agent (he) who chooses to participate creates positive externalities exclusively for the other participating agents. In contrast, an agent who chooses to abstain gets his outside option. The crucial aspect of this model is that agents are both self-centered, i.e. they care about their material payoff, and they are concerned about the distribution of payoffs within the group to which they belong. More specifically, the agents are inequality averse. In terms of material payoffs, this means that they dislike neither earning less (*envy*) nor earning more (*guilty*) than their neighbors.

The bilateral contractual approach between the principal and the agents proceeds in three stages. In the first stage, the principal designs and proposes a publicly observable contracting scheme –a vector of rewards– to the agents. In the second stage, the agents observe the principal's proposition and they simultaneously decide whether to accept or to reject their respective offer. In the final stage, the contract is executed and the externalities are either produced or not depending on the participation decision of all agents.

The objective of the principal is to minimize the total cost of incentives in implementing the participation of all the agents. Formally, a contacting scheme is represented by the vector of rewards $v = (v_1, v_2, .., v_n)$ such that each agent $i = \{1, 2, .., n\}$ receives a strictly positive reward v_i if he chooses to participate or $v_i = 0$ if he chooses to reject the principal's offer. In this model, we assume that the principal is able to discriminate between the agents. Discrimination in this context relies on the situation where the principal offers differentiated rewards to the agents in order to motivate their participation decisions, even though agents are identical.[11]

Once the principal proposes v, agents then play a participation game in which they have two strategies. Each agent can either choose to participate by accepting

[11] We rely on the same definition of the discrimination as in Segal (2003).

his offer or to abstain by rejecting it. A participation decision by each agent generates externalities for the others participating agents in the group. Agents are therefore linked by the externalities they creates for each other in the group. $e_i(j)$ denotes each bilateral relation between two agents. It measures the revenue from the externalities generated by agent j on behalf of agent i when they jointly participate in the project. We assume that agents do not get additional benefits from their own participation decision. This means that $e_i(i) = 0$.

Moreover, the agents in this model dislike inequalities in their material payoffs. We model their preferences in the spirit of Fehr and Schmidt (1999)[12]. Agents then derive their utility from their own material payoff which increases with the number of participating agents through the externalities, and they also suffer from a disutility caused by the potential differences on agents' material payoffs. More precisely, they dislike both being ahead (advantageous inequality aversion) or behind (disadvantageous inequality aversion). Let $(s_1, .., s_n)$ be the strategy profile of the group, with $s_i = p$ means that agent i chooses to participate, and $s_i = np$ means that i chooses to not participate. The utility function of an agent i is given by the following expression (4.1).

$$U_i(s_1, .., s_n) = \pi_i - \frac{1}{n-1} a_i \sum_{j \neq i} \max\{\pi_j - \pi_i; 0\} - \frac{1}{n-1} \beta_i \sum_{j \neq i} \max\{\pi_i - \pi_j; 0\} \qquad 4.1$$

where the parameters a_i and β_i capture disadvantageous and advantageous inequality aversion, respectively. π_i refers to agent i's material payoff. When agent i chooses to participate, he obtains a material payoff π_i such that $\pi_i = \upsilon_i + \sum_{j \in P} e_i(j)$, where P represents the set of participating agents and $\pi_i = c$ if agent i abstains . The material payoff of agent i is then equal to the sum of the reward he receives from the principal and the sum of the additional revenues generated by the externalities. The direct implication is that, with positive externalities, an increase in the number of participating agent results in an increase in agent i's material payoff.

We make the following assumptions on agents' parameters.

$$A_1 : \quad a_i \geq 0, \ \beta_i \geq 0$$
$$A_2 : \quad \beta_i < 1$$

Assumptions A_1 states that the agents are at worst self-centered with strictly

[12] Fehr and Schmidt (1999) was the pioneer proposing such function in order to capture agent's inequality aversion preferences.

self-centered agent corresponding to the agent who has null preferences for inequality aversion. This assumption rules out agents who enjoy being better off –i.e. like being ahead– as well as worse off –i.e. like being behind– than others. Assumption A_2 indicates that agents are not willing to overpay money to reduce advantageous inequality.

In this model, we consider that the non-participating agents do not receive externalities from participating agents. Moreover, we consider that when an agent rejects his offer, he still has preferences for inequality aversion and thus compares his material opportunity cost with the material payoff of others. In this instance, the reservation utility of agent i is given by R_i which depends on his material opportunity cost c (the same for all the agents) and the material payoffs of the $j \neq i$ participating agents. If $s_i = np$; that is agent i abstains, his utility is given by:

$$R_i(s_1, .., s_n) = c - \frac{1}{n-1} a_i \sum_{j \neq i} \max\{\pi_j - c; 0\} - \frac{1}{n-1} \beta_i \sum_{j \neq i} \max\{c - \pi_j; 0\} \quad (4.2)$$

where π_j is the material payoff of agent $j \neq i$. An agent thus chooses to participate whenever his utility from participating is at least as high as his reservation utility. In other words, an agent participates when the principal's offer satisfies his participation constraint.

In this model, coordination may be a problem owed to the multiplicity of equilibria. Following Bernstein and Winter (2012) we define two important notions: the *full implementation* and the *partial implementation*. We rely on partial implementation whenever the contracting scheme allows the participation of all agents but not necessarily as a unique Nash equilibrium. In contrast, Full implementation refers to the situation in which the contracting scheme leads to the participation of all agents as a unique Nash. By definition, partial implementation is the least-cost one but it can possibly lead to a coordination problem in the participation game.

4.3 Contracting under inequality aversion and externalities

In this section, we aim at analyzing the contract in the presence of inequality aversion and heterogeneous externalities. In doing so, we proceeds as follows. First, we examine the efficiency of a contracting outcome when the contract offer

does not take into account agents' inequality aversion preferences when those preferences actually exist. In other words, we examine whether the full participation is still a unique Nash equilibrium[13] of the participation game in a situation where a principal ignores agents' concern for an equal distribution of payoffs when those concerns actually exist. The aim of this focus is to identify whether considering inequality aversion are important in the context of contracting with multilateral externalities. In the second part, we rely on a two-agent case to define the optimal contract that takes into account agents' preferences for unequal distribution of material payoffs.

4.3.1 The role of disadvantageous inequality aversion

Bernstein and Winter (2012) state that the optimal contract may lead to full participation of agents as a unique Nash equilibrium (*full implementation contract*) if it is given by the vector v such that $v = (c,\ \ c - e_{i_2}(i_1), \ldots, c - \sum_{k=1}^{n-1} e_{i_n}(i_k))$, according to the ranking $\rho = (i_1, i_2, \ldots, i_n)$. With this offer, agent i_1 gets his outside option c which makes his participation decision dominant[14]. Then knowing that agent i_1 participates, agent i_2 gets $c - e_{i_2}(i_1)$. This offer makes his participation decision dominant too. And so on until agent n who gets the offer $c - \sum_{k=1}^{n-1} e_{i_n}(i_k))$ knowing that the $n-1$ agents that precede him in the ranking participate. Agent n then becomes indifferent between participating or not, he participates. Notice that, if the $n-1$ agents participate, then agent n's payoff corresponds exactly to his outside option c. This manner of implementing the participation of all agents makes the contract to follow the *Divide and Conquer* strategy. As the consequence, the outcome are unevenly distributed among agents, inducing inequality.

The aim of this part is to study the efficiency of Bernstein and Winter (2012)'s contracting scheme when the principal faces inequality averse agents. In particular, focusing on the presence of multilateral externalities, Bernstein and Winter (2012)[15] argue that Divide and Conquer contracting scheme may allow to implement the full participation of agents as a unique Nash equilibrium of the participation game. In this part, we consider that the agents facing such a Divide and Conquer offer have inequality aversion preferences. Now it comes at examining the efficiency of such Divide and Conquer contracting scheme; i.e. to study

[13] This refers to the result of the standard preferences Bernstein and Winter (2012)

[14] To be more precise, the participation decision becomes weakly dominant since the agent is indifferent between participating and not. However, we consider that an agent chooses the participation decision if he is indifferent.

[15] Segal (2003); Winter (2004) also analyze the efficiency of Divide and Conquer contracting scheme.

whether they allow the participation of all agents or not.

Offering the latter Divide and Conquer contracting scheme to inequality averse agents, we obtain the following result.

Proposition 10. *The optimal contracting scheme that induces full participation as a unique Nash equilibrium for agents with standard (selfish) preferences does not induce full participation of disadvantageous inequality averse agents.*

Proof. See appendix I.1. □

Proposition 10 indicates that when agents are inequality averse, the full participation can not be implemented by the use of Divide and Conquer contracting scheme intended for self-centered agents. This contracting offer is then inefficient since it fails to allow reaching the full participation of the agents. The intuition behind this result is straightforward. Since divide and conquer contracting scheme leads to a difference in agents' payoffs, then, in case of participation, each agent see his utility decrease when suffering from that inequality in payoffs. Each agent following another one in the ranking is affected by such a decrease in the utility. Consider the agent ranked in the last position–he earns his outside option when he participates–. Therefore, his loss of utility is greater because he follows $n-1$ agents that strictly earn more than him. This induces an important reduction on his utility. At the same time, his reservation utility decreases but slightly compared to when he participates. In fact, when he abstains, the agent that precedes him in the ranking occupies the last position and therefore earns his outside option. Hence, this agent suffers from inequality imposed by $n-2$ agent rather than $n-1$ when participated. His participation constraint is then violated, making the abstention strategy strictly dominant for him. It is worth noting that the agent ranked in the first position always participates. The reason is that when taking his decision, this agent consider that other agents abstain –He considers himself as being alone– (Divide and Conquer strategy). Thus, his preferences for inequalities does not impact his decision. Hence, the reservation utility of that agent remains unchanged as well as his utility (same as in the standard theory). He participates since he is still indifferent between participating or not.

The result in Proposition 10 implies that the principal should pay a careful attention to the agents' preferences for inequality aversion in their material payoffs when designing the contract offer. The object of the next section is to examine the contract when it takes into account the agents' preferences for inequality aversion.

4.3.2 The optimal partial implementation contract

We now turn to the analysis of the contract when agents' preferences inequality aversion are taken into account. To do so, we rely on a simple framework where the principal offers rewards to two inequality averse agents, say agent 1 and agent 2. We focus on the two-agent case to simply identify the impacts of introducing inequality aversion preferences in the model of contract with externalities. We focus here on partial implementation, i.e. the principal's objective is to implement the least-cost contract which induces full participation as a Nash equilibrium of the participation game.

Before analyzing the optimal contract, let us restate the utility function of an inequality averse agent in the two-agent case. When both agents choose to participate, then we obtain the following expression.

$$U_i(x) = \pi_i(x) - a_i \max\{\pi_j(x) - \pi_i(x); 0\} - \beta_i \max\{\pi_i(x) - \pi_j(x); 0\},$$

where $\pi_i(x) = v_i + e_i(j)$ and $\pi_j(x) = v_j + e_j(i)$ if the two agents choose to participate ($x = (p, p)$), $\pi_i(x) = c$ and $\pi_j(x) = v_j$ if agent i does not participate while j participates, and $\pi_1(x) = \pi_2(x) = c$ if none of the two agents participate. Here again, we rely on the same assumptions as in the multi-agent case. Hence,

$$\begin{aligned} A_1 : &\quad a_i \geq 0,\ \beta_i \geq 0 \\ A_2 : &\quad \beta_i < 1 \end{aligned}$$

Disadvantageous inequality aversion

In this section, we assume that the two agents are averse to disadvantageous inequalities but not to advantageous inequality. In this case, we obtain the following result:

Proposition 11. *When the agents are not averse to advantageous inequality, the optimal contract is the same as when they have standard (selfish) preferences.*

Formally, we have the following. When $\beta_1 = \beta_2 = 0$, the optimal partial implementation contract is such that:

$$\begin{aligned} v_1 &= c - e_1(2) \\ v_2 &= c - e_2(1). \end{aligned}$$

Proof. See appendix I.2. □

This result is striking. When the agents are averse to disadvantageous inequality but not to advantageous inequality, the optimal partial implementation contract does not depend on the agents' inequality aversion. While surprising, this result is in fact quite intuitive. Indeed, assuming that the other agent participates, each agent receives a reward that makes him indifferent between participating and not participating. If the two agents participate, they receive the same material payoff $\pi_1^* = \pi_2^* = c$. If an agent deviates, then he gets his outside option while the participating agent does not benefit from any positive externality and then the material payoff of the latter is lower than c. The agent who deviates does not suffer from the inequality between the two agents because he is advantaged. Hence the utility of this agent is c, which is larger than his payoff when the two agents participate.

The intuition of this result also suggests that when the agents are averse to both disadvantageous and advantageous inequality, the optimal partial implementation contract might depend on the agents' inequality aversion.

Both disadvantageous and advantageous inequality aversion

In this section, we consider the case of two agents who are averse to both disadvantageous and advantageous inequality. We first deal with the case in which the two agents are symmetric (same externality levels and same preferences) and then we analyse the case in which the agents are asymmetric (heterogeneous externalities and heterogeneous inequality aversion).

We further highlight the first-order importance of aversion to advantageous inequality. Specifically, we have the following property:

Proposition 12. *When the agents have homogenous disadvantageous and advantageous inequality aversion preferences and when the externalities are symmetric, their reward does not depend on their aversion to disadvantageous inequality.*

Formally, we have the following. Assume that $e_1(2) = e_2(1) = e$, $a_1 = a_2 = a$ *and* $\beta_1 = \beta_2 = \beta$. *Then the optimal partial implementation contract is unique and such that:*

$$v_1^* = v_2^* = c - e - \frac{\beta}{1-\beta}e.$$

Proof. See appendix I.2. □

When the agents have homogenous preferences, are averse to both types of inequality, and the externalities are symmetric, the optimal partial implementation contract is still independent of the agents' aversion to disadvantageous inequality. The reason is similar to the case where the two agents are not symmetric but

they have no aversion to advantageous inequality. Indeed, when the two agents participate, they obtain the same material payoff, $c - \frac{\beta}{1-\beta}e$, because they are symmetric. Thus, the utility levels of the agents do not depend on inequality aversion in this situation. If an agent deviates and chooses not to participate, his material payoff is c, which is larger than the material payoff of the other agent, which is $c - e - \frac{\beta}{1-\beta}e$. Thus, the utility of the deviating agent does not depend on his disadvantageous inequality aversion in this situation. All in all, assuming that the other agent participates, the choice between participating and not participating does not depend on disadvantageous inequality aversion.

Another interesting feature of the optimal contract is that the rewards are lower than in the case where the agents are only averse to disadvantageous inequality (in this latter case, the reward the agents get is $v_1^* = v_2^* = c - e$ if they are symmetric, see Proposition 2). The reason is as follows. As explained above, when the two agents participate, they obtain the same reward, and then their utility does not depend on their aversion to inequality. If an agent deviates from this situation, his material payoff is larger than the material payoff of the other agent, and then he suffers from advantageous inequality. Thus, an agent who is averse to advantageous inequality has larger incentives to participate than an agent who does not. As a consequence, the principal chooses to give a smaller reward to the two agents in the case where they are averse to inequality compared to the case where they are not.

We now consider the more general case in which the externalities and the agents' inequality aversion may be heterogeneous, in other words $e_1(2)$ is not necessarily equal to $e_2(1)$, β_1 is not necessarily equal to β_2, and a_1 is not necessarily equal to a_2. In this situation, we obtain the following result:

Proposition 13. *When the agents are heterogeneous, the optimal contract depends on disadvantageous inequality aversion only if the agents are averse to advantageous inequality.*

Formally, we have the following. Assume, without loss of generality, that $\frac{\beta_1}{1-\beta_1}e_2(1) \leq \frac{\beta_2}{1-\beta_2}e_1(2)$. *The optimal partial implementation contract is unique, such that* $\pi_1^* \geq \pi_2^*$ *and characterized by:*

$$v_1^* = c - e_1(2) - \frac{\beta_1}{1-\beta_1}e_2(1)$$
$$v_2^* = c - e_2(1) - \frac{(a_2+\beta_2)\beta_1}{(1+a_2)(1-\beta_1)}e_2(1) - \frac{\beta_2}{1+a_2}e_1(2).$$

Proof. See appendix I.2. □

This result is strikingly different from the case where the agents' preferences

are homogenous. Indeed, considering the agent who receives the smallest material payoff, his disadvantageous inequality aversion parameter affects his reward. Indeed, when the two agents participate, agent 1 is advantaged and then agent 2 suffers from disadvantageous inequality. When one of the agent deviates, he obtains a material payoff that is larger than the other agent, as in the case where the agents have no aversion to advantageous inequality or when they are symmetric. This explain why (only) the reward of agent 2 depends on his own disadvatageous inequality aversion parameter.

Also notice that the effect of a_2 on the second agent's reward (v_2^*) is positive:

$$\frac{v_2^*}{\partial a_2} = \left[\frac{\beta_2}{1-\beta_2}e_1(2) - \frac{\beta_1}{1-\beta_1}e_2(1\right]\frac{1-\beta_2}{(1+a_2)^2} \geq 0. \tag{4.3}$$

Intuitively, assuming the first agent participates, as the disadvantageous inequality aversion parameter increases, the second agent's utility tends to decrease if he chooses to participate while it is not affected if he chooses to not participate. As a result, the principal will tend to increase this agent's reward in order to ensure his participation.

Moreover, an agent is more likely to be advantaged (i.e. to obtain the largest material payoff) if he generates less externalities and his aversion to advantageous inequality is lower than the other agent.

Using Proposition 13, we obtain the following result:

Corollary 1. *Assume, without loss of generality, that* $\frac{\beta_1}{1-\beta_1}e_2(1) \leq \frac{\beta_2}{1-\beta_2}e_1(2)$. *The advantaged agent (i.e. agent 1, who gets a larger material payoff) receives a larger reward than the disadvantaged agent (agent 2) if and only if the following condition holds:*

$$\frac{1+a_2}{1-\beta_2}\left[e_1(2) - e_2(1)\right] \leq \frac{\beta_2}{1-\beta_2}e_1(2) - \frac{\beta_1}{1-\beta_1}e_2(1)$$

Proof. See appendix I.3. □

When the two agents have homogenous preferences, the Corollary implies that, if $e_2(1) \leq e_1(2)$ then agent 1 is advantaged but he receives a smaller reward than agent 2. In other words, if the agents have homogenous preferences, the agent who benefits from a larger externality is advantaged but the principal gives him a smaller reward. Another implication of the Corollary is that, if $e_2(1) \geq e_1(2)$, then the advantaged agent (agent 1) receives the largest reward.

4.4 Conclusion

This contribution analyzes the optimal contract designed to induce inequality averse agents to participate in a joint project, when individual participation generates (positive) externalities for other participants.

Focusing on the least-cost contract inducing full participation as a Nash equilibrium of the induced participation game, we provide several important insights. First, the neglect of agents' aversion to inequalities yields a sub optimal contract. Second, aversion to advantageous inequality has a first order effect on the optimal contract design. Specifically, when agents are not averse to such inequality, the optimal contract is the same as when they have standard (selfish) preferences. Moreover, when agents have homogeneous preferences, the optimal contract under symmetric externalities does not depend on the disadvantageous inequality aversion parameter. Third, the optimal contract exhibits notable qualitative differences when agents are heterogeneous, and both forms of aversion to inequality are complementary. Specifically, the optimal scheme depends on disadvantageous inequality aversion only if agents are averse to advantageous inequality. Finally, we discuss whether inequity aversion results in less inequality.

There are several natural avenues for further research, we briefly discuss only a couple of them. First, it is worth noting that the optimal partial implementation contract may induce coordination problems, as non participation of all agents may also be a Nash equilibrium of the induced game. In other words, it is implicitly assumed that, if such multiplicity of equilibria arises, there exists an external mechanism that allows the principal to choose his preferred equilibrium outcome. A natural next step of the analysis would consist in analyzing the unique implementation contract, which would induce at least cost full participation as the *unique* Nash equilibrium of the induced participation game. This may provide interesting insights about whether the implicit assumption on coordination issues is innocuous or not.

Another possibility would be to test the performance of the optimal contract in the laboratory: would this theoretically optimal scheme perform well? Would it be socially acceptable or would other behavioral features influence its performance? These and related questions would further our understanding of this important type of problem.

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Chapter 5: General Conclusion

The literature on contracting with externalities has provided several findings on the optimal contract design. Understanding how other potentially relevant characteristics of a principal-multi-agent setting, such as spatial effects, i.e. private benefits and externalities, or behavioral aspects related to individual preferences, affect the design and/or the acceptability of the optimal contract is an important step in order to advance beyond the current state of the art in this interesting line of research. This thesis is an attempt to make such a contribution. It analyzes the impact of spatial effects (**Chapter 2**) and of agents' behavioral concerns (**Chapter 3** and **Chapter 4**) on the optimal contract design and acceptability.

In **Chapter 2** we analyze the impact of spatial effects on how the principal tackles the problem of contract design. Our analysis shows that efficient outcomes can possibly arise, and we also provide a characterization of the agents' characteristics that drive the inefficiency of the contracting outcome. Contracting with agents characterized by a high level of private benefits and a moderate level of benefits generated by externalities makes the inefficiency of the contracting outcome more likely. The analysis in this chapter reveals that a bilateral contractual approach is not always an appropriate instrument to overcome inefficiency issues when it comes to providing collective goods involving externalities among contributors.

Some extensions need to be considered for future research related to this topic. First, it may be interesting to extend the model by considering other functional forms of the agents' payoffs. Indeed, here we consider simple linear functions, which yields corner solutions that are easy to further interpret. Second, it would also be interesting to analyze the performance of the optimal contract in a laboratory setting. This may reveal individual motivations that may further explain the (in)efficiency of the contracting outcome besides the spatial effects.

Chapter 3 focuses on the acceptability of the differentiated contractual schemes. Indeed, Bernstein and Winter (2012) theoretically show that a principal willing to implement the participation of all agents should rely on a Divide and Conquer contracting scheme, which has the appealing property to induce the participation of all agents as a unique strict Nash equilibrium. However, this relies on the assumption that agents choose to participate if they are indifferent between participating and not participating. This assumption does not have proper foundation,

and without it there might be coordination issues due to existing several equilibria in the participation game played by agents. Moreover, there is a potential trade-off between efficiency and equity. In this game, the most efficient equilibrium being also the most unequal (in terms of payoff distribution) and the least efficient equilibrium being the most inequitable. The aim of chapter 3 is to examine how agents deal with this trade-off. To do so, we rely on laboratory experiments with two treatments differing in their levels of inequality at the efficient outcome. We find that subjects coordinate on the most unequal equilibrium more often, even though only some of them receive an extra gain at the efficient outcome. Our setup also provides evidence suggesting that subjects may be motivated about social efficiency maximization.

More work is needed on this topic. It would be interesting to get additional insights to develop our understanding of how subjects play such a complex game. In addition, investigating the effects of the number of subjects in the group may improve the knowledge gathered in this type of problem.

As Chapter 3 suggests that social preferences may affect the outcome of contractual schemes in our setting, we take a step and introduce inequality aversion preferences into the model of contracting with heterogeneous externalities. **Chapter 4** focuses on the impact of agents' inequality aversion preferences on the optimal design of contracting with externalities. The choice of inequality aversion as agents' social preference was initially motivated by the outcome of the Divide and Conquer contract scheme, which involves differences in agents' payoffs. Thus, we consider inequality averse agents receiving incentive contracts in a context where each agent's action generates externalities on others. We find that advantageous inequality has a first order effect. When agents are not averse to such inequalities, the optimal contract is similar to the one when agents have standard preferences. We also find that the optimal contract depends on disadvantageous inequality aversion only if agents are averse to advantageous inequality.

There are natural avenues for future research. In particular, an while we empirically assume that coordination is not an issue if multiple equilibria arise, it would be interesting to characterize the least-cost contract inducing participation of all agents as a unique Nash equilibrium. Another aim would be to extend the model into more agents and seek more theoretical predictions. It would also be interesting to run laboratory experiments in order to identify other behavioral considerations that play a role in the performance of the schemes considered.

Appendices

Appendix A: Résumé de la thèse

L'Économie de l'environnement étudie la régulation des externalités en envisageant généralement des instruments uniformes, qu'il s'agisse de régulations par les prix ou par les quantités. Ces types d'instruments paraissent cependant peu adaptés à des environnements hétérogènes et lorsque les efforts d'abattement sont complémentaires, ce qui est le cas pour la protection de la biodiversité par les agriculteurs ayant des parcelles voisines (e.g. protection des pollinisateurs).

Les contrats incitatifs peuvent être un instrument pertinent pour réguler des externalités hétérogènes. La littérature théorique sur le sujet montre que le schéma de subventions optimales qui permet d'intégrer les externalités positives entre les agents n'est pas nécessairement uniforme et qu'elle est discriminatoire lorsque les efforts sont complémentaires : des agents identiques doivent recevoir des subventions différentes. Deux aspects importants ont été peu étudiés dans cette littérature : le rôle des bénéfices privés et les aspects comportementaux.

Cette thèse contribue à analyser le rôle de ces deux dimensions dans le design des contrats optimaux lorsque les agents génèrent des externalités hétérogènes : le **chapitre 2** étudie l'influence des effets spatiaux sur l'efficacité du contrat optimal. Nos résultats montrent que la prise en compte des bénéfices privés peut conduire à des situations efficaces. Plus important encore, on identifie le profil de l'agent pour lequel le principal préfère l'inciter à fournir un niveau de contribution inefficace. En effet, un agent caractérisé par des bénéfices privés élevés et des externalités modestes est susceptible de conduire à une situation inefficace. Dans le **chapitre 3**, on se focalise sur l'acceptabilité des contrats discriminants. À l'aide d'expériences de laboratoire, on analyse comment les sujets jouent un jeu de coordination qui correspond au choix d'accepter au non le contrat optimal. La particularité de ce jeu est que le résultat de la coordination nécessite un compromis entre efficacité et équité. En comparant deux jeux qui diffèrent sur le niveau d'égalité des paiements à l'équilibre, on montre que les sujets se coordonnent plus souvent sur le résultat efficace le plus inégalitaire. De plus, les comportements individuels observés sont cohérents avec une préférence pour le bien-être social. Enfin, le **chapitre 4** s'intéresse à l'impact des préférences pour l'égalité dans un contrat destiné à la réalisation d'un projet commun. En pratique, on introduit ces préférences, à savoir l'aversion à l'inégalité avantageuse et à l'inégalité désavantageuse, dans un modèle de contrat avec des externalités.

On montre que l'aversion aux inégalités avantageuses joue un rôle fondamental dans le contrat optimal. En l'absence de préférences pour ce type d'inégalité, le contrat optimal est indépendant des préférences des agents en matière d'inégalités désavantageuses.

Appendix B: Introduction Générale

Quel type d'incitation peut permettre d'atteindre un résultat efficace ? Cette question est au cœur de la théorie des contrats (voir Bolton et al. (2005)). Les instruments contractuels sont largement utilisés en économie, notamment quand il s'agit d'étudier comment inciter à la réalisation d'une tâche coûteuse de manière efficace. En pratique, ces contrats mettent en relation un principal et un agent, mais ils peuvent également mettre en relation un principal et un groupe formé par plusieurs agents (Holmstrom, 1982; Mookherjee, 1984; Demski and Sappington, 1984). Dans le cas où un contrat met en relation un principal et plusieurs agents, ce qui est particulièrement fréquent dans le domaine de l'économie de l'environnement. On peut par exemple citer le cas des contrats pour de la production de service écosystémiques qui relève de l'effort fourni par un groupe constitué d'agriculteurs ou de propriétaires forestiers. De plus, la plupart des études publiées dans le domaine des contrats se concentrent sur la manière dont les intervenants dans le contrat se partagent le résultat du contrat (le bien en question est donc un bien privé). Cependant, de nombreuses autres études s'intéressent à la fourniture des biens collectifs qui génèrent des externalités (positives) entre les agents. La fourniture de biens environnementaux est en l'occurrence un problème important qui rentre dans ce cadre.

Dans le domaine de l'économie, lorsque des individus membres d'un groupe doivent contribuer à la production d'un bien, la plupart du temps, des externalités sont créées. C'est le cas notamment des efforts mis en œuvre dans la production d'un bien publique environnemental (par exemple les services écosystémiques), qui très souvent, génèrent des externalités pour les voisins. Dès lors, une question très importante est soulvée, à savoir : comment la présence de telles externalités peut influencer le design ainsi que le résultat d'une approche contractuelle?

Plusieurs spécialistes ont reconnu l'importance de la prise en compte les externalités dans l'analyse économique des contrats impliquant plusieurs agents afin d'en comprendre leurs conséquences économiques (Grossman and Hart, 1980; Gertner and Scharfstein, 1991; Katz and Shapiro, 1986b; Bergstrom et al., 1986). Pour en citer quelques études, Katz and Shapiro (1986a) et Hart et al. (1990) étudient les relations verticales; Katz and Shapiro (1986b) analysent les externalités de réseaux dans un contexte d'adoption de nouvelle technologie.[1] A la suite

[1] Segal (1999); Segal and Whinston (2003) et Genicot and Ray (2006) donnent également plusieurs applications dans le domaine de l'organisation industrielle. Helm and Wirl (2014) analysent les problèmes liés au contexte des accords internationaux sur le climat avec de l'asymétrie informationnelle entre les intervenants et la présence d'externalités. Le rôle de l'asymétrie

de ces études, un modèle unifié de contrat avec des externalités est proposé par Segal (1999). Il s'agit d'un modèle qui décrit une relation entre un principal et plusieurs agents lorsque les actions des agents crées des externalités pour les autres agents. l'intérêt de ce modèle est qu'il permet de prendre en compte de nombreux cas d'études existants et de fournir des résultats assez génériques. Cette thèse s'inscrit dans la perspective théorique du modèle de contrat avec des externalités à la Segal (1999).

La littérature sur les contrats en présence d'externalités comporte deux aspects importants. Un premier aspect important dans les études développées dans cette littérature est la manière dont les externalités sont modélisées. Ces modèles considèrent deux types d'externalités:

- Les externalités croissantes, et
- les externalités décroissantes.

Avec des externalités croissantes [décroissantes], l'externalité reçue par un agent lorsque les autres augmentent leur niveau d'effort est plus [moins] grande quand cette agent contribue également.[2] Une telle distinction implique que les agents sont plus (moins) désireux de fournir un effort lorsque les autres fournissent un effort. De plus, quand les externalités sont positives (négatives), une contribution élevée procure un niveau de paiement plus élevé (faible) qu'une contribution faible. Dans cette thèse, on s'intéresse principalement à l'analyse des cadres caractérisés par des externalités croissantes. On se focalise sur ces situations pour des raisons de cohérence avec les applications qui nous intéressent, à savoir celles de l'économie de l'environnement (production de services écosystémiques). Plus concrètement, il peut s'agir des agriculteurs qui font des efforts pour la protection des abeilles, ou des propriétaires forestiers qui font des efforts pour atténuer les dommages qui peuvent être générés par les tempêtes sur leurs parcelles.

Le second aspect important dans la littérature sur les contrats en présence d'externalités peut être présenté sur la base de deux catégories :

- D'abord, la possibilité pour le principal de proposer, ou de ne pas proposer, des incitations conduisant à des paiements différenciés pour les agents.

d'information est étudié par Csorba (2008b,a) et Shi and Xing (2018)

[2] voir Segal (2003) pour une définition plus formelle.

- Ensuite, le contexte du jeu correspond à une situation où les externalités produites affectent les utilités de réservation, ou à une situation où les externalités n'affectent pas les utilités de réservation des agents.

Dans cette thèse, on s'intéresse particulièrement aux cas où le principal a effectivement la possibilité d'offrir un contrat qui induit des paiements différenciés.[3] Concernant la deuxième catégorie, à savoir l'effet des externalités sur les utilités de réservation, cette thèse à pour objectif d'y apporte deux types de contributions.

Dans la littérature, les effets des externalités sur les utilités de réservation des agents conduisent à deux types de résultats qualitatifs. En effet, Segal (1999) montre que le contrat peut conduire à une situation efficace si les externalités n'affectent pas les utilités de réservation des agents. Bloch and Gomes (2006) montrent que lorsque les externalités n'affectent pas les utilités de réservation des agents, un équilibre efficace est toujours possible. Par contre, lorsque les externalités affectent les utilités de réservations, alors les jeux peuvent conduire à des résultats d'équilibre inefficaces. Möller (2007) et Münster and Reisinger (2015) montrent que les contrats simultanés sont efficaces seulement si l'effet des externalités sur les utilités de réservations tend à disparaître avec le nombre de participants. Nos contributions sont en lien avec cette littérature.

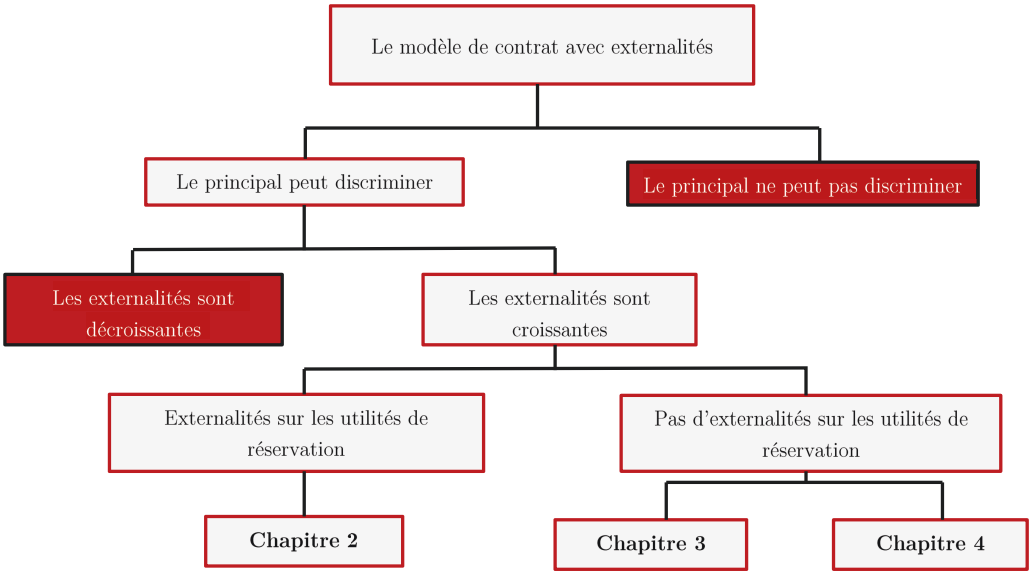
Le schéma suivant présente une vue globale de la manière dont cette thèse s'insère dans la littérature sur les contrats en présence d'externalités entre les agents.

De manière plus spécifique, on se base sur les situations dans lesquelles les externalités affectent les utilités de réservation des agents dans le **chapitre 2**. Ensuite, dans les **chapitres 3** et **4**, on s'intéresse aux situations où les externalités n'influencent pas les utilités de réservation des agents. Plus de détails sont fournis dans le reste de la présentation.

Quand les externalités affectent les utilités de réservation

La capacité d'un contrat à mener vers une situation efficace lorsque les externalités influencent les utilités de réservation des agents est reconnue dans la plupart des études sur les contrats en présence d'externalités (Segal, 1999; Bloch and Gomes, 2006). Il faut toutefois noter que ces dernières ne prennent pas en

[3] Les situations dans lesquelles le principal ne peut pas offrir des contrats induisant des paiements différenciés sont discutées dans Segal (2003).



compte la possibilité que les agents puissent créer des bénéfices privés. En effet, de nombreux cas d'étude montrent que de tels bénéfices peuvent survenir dans un environnement caractérisé par la présence de plusieurs agents. C'est le cas par exemple de producteurs agricoles qui fournissent des efforts destinés à promouvoir une gestion durable de la biodiversité. Ces agriculteurs sont souvent les premiers bénéficiaires de leurs actions (voir Balmford et al. (2002)). De ce fait, il devient nécessaire d'analyser l'impact de tels bénéfices privés dans un modèle de contrat avec plusieurs agents. Dans le **Chapitre 2**, on tente d'apporter un contribution dans ce sens. Ce chapitre a pour objectif d'introduire les bénéfices privés dans un modèle de contrat en présence d'externalités entre les agents.

On s'intéresse plus spécifiquement aux questions suivantes : Quels sont les effets relatifs des bénéfices privés et des externalités sur le design du contrat optimal? Quelles sont les caractéristiques des individus qui reçoivent des contrats conduisant à un résultat efficace ou inefficace? Pour analyser ces questions, on propose un modèle théorique dans lequel un principal offre un contrat à des agents membres d'un groupe. Le contrat stipule que les agents fournissent des efforts de contributions et reçoivent en retour un transfert. Dans ce modèle, la contribution de chaque agent génère des effets spatiaux. Les effets spatiaux sont définis de la manière suivante : on parle *d'effets de rétention* pour faire référence aux bénéfices privés générés par les agents et *d'effets de diffusion* lorsqu'il s'agit des externalités générées par les agents. Ce chapitre met particulièrement l'accent sur la manière

dont le principal aborde la question de l'efficacité du contrat optimal lorsque des effets spatiaux caractérisent le contexte.

Quand les externalités n'affectent pas les utilités de réservation

Segal (1999) et Bloch and Gomes (2006) ont, entre autres, montré que lorsque les externalités n'affectent pas les utilités de réservation des agents, les contrats peuvent être efficaces. Cependant, il faut noter que ce dernier résultat repose sur l'hypothèse selon laquelle il n'y a pas de problème de coordination en cas de multiplicité d'équilibres (les agents vont toujours sélectionner l'équilibre préféré par le principal). En revanche, d'autres études ont montré que le problème de coordination peut surgir lorsque la sélection de l'équilibre souhaité par le principal devient plus problématique (Segal, 2003; Genicot and Ray, 2006; Winter, 2004). De manière plus précise, les recherches conduites dans ce contexte montrent que le contrat optimal permet l'existence d'au moins deux équilibres de Nash dans le jeu. Dès lors, la mise en œuvre d'une approche contractuelle renvoie à une question intéressante, à savoir comment coordonner les agents vers l'équilibre souhaité par le principal.

D'autres résultat d'études suggèrent que le recours à des incitations différenciées est nécessaire pour résoudre le problème de coordination induit par le contrat. Qu'il s'agissent de Bernstein and Winter (2012) dans le contexte d'un jeu de participation volontaire en présence d'externalités hétérogènes ou de Winter (2004) dans un contexte plus général, tous sont d'accord sur le fait que la discrimination est un moyen efficace pour résoudre le problème de coordination. Plus précisément, ces auteurs suggèrent qu'un dispositif de contrat "Divide and Conquer" peut conduire à l'efficacité en permettant la mise en œuvre de la contribution de tous les agents comme un équilibre de Nash strict et unique. Dans la pratique, un contrat "Divide and Conquer" se déroule comme suit : d'abord, le principal procède à un classement des agents en fonction de leurs "identités" dans le groupe.[4] Ensuite, en fonction du classement, le principal propose à chacun des agents une incitation différenciée sachant que l'agent le mieux classé reçoit l'incitation la plus généreuse.

Il faut toutefois noter que Bernstein and Winter (2012) font une hypothèse importante sur le comportement des agents. En effet, ils supposent que les

[4] L'identité d'un agent est caractérisée pas son degré d'influence dans chaque relation bilatérale au sein du groupe (en termes de les externalités générées).

agents choisissent de participer quand ils sont indifférents entre la participation et l'abstention. La question naturelle qui se pose est alors de savoir si les agents se comportent réellement de cette manière ?

Acceptabilité des dispositifs de contrat discriminants

Le rôle de la discrimination est de plus en plus étudié dans la littérature sur les contrats avec externalités.[5] Cependant, il convient de noter que les dispositifs de contrats "Divide and Conquer" conduisent à une distribution inégale des paiements des agents. De plus, comme nous l'avons précédemment indiqué, l'efficacité du dispositif "Divide and Conquer" repose sur l'hypothèse selon laquelle les agents choisissent de participer quand ils sont indifférent entre la participation et l'abstention. En assouplissant cette hypothèse (qui manque de fondements empiriques notamment dans le domaine de l'économie comportementale), le jeu considéré peut comporter plusieurs équilibres de sorte que le plus efficace de ces équilibres conduit à la distribution des paiements la plus inégalitaire. Par conséquent, un potentiel problème d'acceptabilité sociale peut survenir en raison d'un possible compromis entre efficacité et équité. À notre connaissance, peu d'études ont porté sur l'acceptabilité sociale des jeux avec des paiements différenciés[6] et aucune dans le cadre des dispositifs de contrats discriminants. Le **Chapitre 3** analyse l'acceptabilité des contrats discriminants à l'aide d'expériences de laboratoire sur le compromis entre efficacité et équité.

[5] Voir (Caillaud and Jullien, 2003; Che and Spier, 2008; Grossman and Hart, 1988; Innes and Sexton, 1994; Jullien, 2011; Katz and Shapiro, 1986a,b; Segal and Whinston, 2003; Posner et al., 2010) ainsi que Segal (2003) dans une perspective plus générale. Segal (2003); Winter (2004); Segal (2003) et Bernstein and Winter (2012) considèrent des situations dans lesquelles les externalités n'affectent pas les utilités de réservation des agents et soulignent l'importance de la discrimination dans la conception du contrat optimale. Segal and Whinston (2003) analysent un modèle introduit pour la première fois dans Rasmusen et al. (1991) et constatent que la discrimination permet au principal d'internaliser avec succès les externalités existant entre les agents. Sakovics and Steiner (2012) se concentrent sur l'identité des agents qui doivent recevoir les offres du principal dans les situations où les agents sont hétérogènes. Ils soutiennent que les incitations optimales devraient cibler les agents qui produisent plus d'externalités pour leurs voisins, et qui sont relativement insensibles aux variations du niveau global d'externalités.

[6] Devetag and Ortmann (2007) publient une revue de littérature sur les jeux de coordination avec des équilibres classés au sens de Pareto et expliquent la manière dont l'échec de la coordination peut survenir dans la pratique. Landeo and Spier (2009) analysent les contrats d'exclusions et affirment que la discrimination entre les agents peut jouer un rôle important dans l'efficacité. Crawford et al. (2008) étudient le rôle des points focaux (Schelling, 1960) dans les jeux de coordination et montre que les inégalités de paiements peuvent entraîner des problèmes de coordination. López-Hoffman et al. (2010) suivent la même logique que dans Crawford et al. (2008) et suggèrent que l'égalité dans les paiements joue un rôle déterminant dans le succès de la coordination.

Sur l'effet des préférences sociales dans le design du contrat optimal

La théorie des contrats avec des externalités repose principalement sur l'hypothèse que les individus font des choix orientés sur eux mêmes. D'un autre coté, un certain nombre de résultats empiriques suggèrent que les individus démontrent des considérations sociales dans leurs comportements. Parmi celles-ci, l'aversion aux inégalités, la maximisation du bien-être social ou la réciprocité.[7] En particulier, plusieurs études empiriques fournissent des résultats suggérant que l'aversion aux inégalités affecte le résultat d'un contrat (voir Koszegi (2014)). Le **Chapitre 4** est une tentative d'analyse théorique du contrat optimal lorsque les préférences en matière d'aversion aux inégalités sont prises en compte dans le modèle de base de contrat avec externalités. En pratique, on introduit les préoccupations liées à l'aversion aux inégalités (Fehr and Schmidt, 1999) dans le modèle de contrat avec des externalités hétérogènes (Bernstein and Winter, 2012).

Le **Chapitre 4** est motivé par le résultat fondamental de Bernstein and Winter (2012) qui montre qu'un contrat optimal peut induire à des paiements différenciés lorsque les agents font des choix orientés sur eux-mêmes.

Dans ce chapitre, nous abordons la question de la manière suivante : premièrement, on étudie comment les préférences en matière d'aversion aux inégalités influencent le résultat optimal d'un contrat avec plusieurs agents, lorsque les efforts des agents génèrent des externalités (hétérogènes); deuxièmement, on s'intéresse au résultat d'une approche contractuelle lorsque le principal prend en compte à la fois des externalités hétérogènes et les préférences hétérogènes des agents pour des distributions de paiements inégales.

Globalement, cette présente thèse apporte trois contributions qui se situent à l'intersection de la littérature sur les contrats avec externalités et la littérature sur la "théorie du contrat qui prend en compte les comportements des individus". **D'abord**, elle contribue à la littérature sur les contrats avec externalités en analysant comment la présence conjointe d'externalités multilatérales et de bénéfices privés influe sur l'efficacité de la solution optimale du contrat et en caractérisant les agents qui peuvent recevoir le contrat à l'origine de l'inefficacité. **Ensuite**, cette thèse analyse l'acceptabilité des incitations différenciées, qui engendrent potentiellement une tension entre efficacité et équité dans un jeu de coordination. Elle contribue à la littérature qui s'intéresse à la manière dont les

[7] Voir Charness and Rabin (2002); Loewenstein et al. (1989); Fehr and Schmidt (1999); Bolton and Ockenfels (2000); Rabin (1998) et Engelmann and Strobel (2004) pour plus de détails sur les préférences sociales des individus.

sujets se coordonnent vers l'équilibre. À l'aide d'expériences de laboratoires, on montre qu'une inégalité plus grande se traduit par un meilleur succès de la coordination. **Enfin**, cette thèse est liée à la littérature sur la "théorie des contrats prenant en compte les comportements" en analysant le rôle de l'aversion aux inégalités dans une situation où un principal veut implémenter la participation de tous les agents lorsque la participation de chacun génère des externalités pour les autres. Elle vise à comprendre l'impact des préférences en matière d'aversion à l'inégalité des individus sur le design des contrats optimaux.

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Appendix C: Résumé chapitre 2

Ce chapitre est une tentative d'analyse de l'impact des caractéristiques spatiales (effets de rétention ou de diffusion) observées dans la provision de certains biens publics (les biens environnementaux, par exemple) sur l'efficacité du résultat du contrat. Nos résultats révèlent qu'un dispositif de contrat optimal peut conduire à un résultat efficace lorsque les effets de rétention résultant des efforts d'un agent sont suffisamment importants. De plus, on a identifié l'agent qui génère l'inefficacité potentielle d'une approche contractuelle. On montre qu'un agent caractérisé par de faibles effets de rétention et des effets de diffusion modestement élevés peut conduire à l'inefficacité de la solution du contrat. Ce résultat implique que les contrats bilatéraux ne sont pas nécessairement un instrument approprié pour résoudre les problèmes posés par les externalités spatiales.

Mots-clés :
Contrat, Effets spatiaux, Externalités de réseau, Bénéfices privée, Efficacité.

Appendix D: Résumé chapitre 3

Dans ce chapitre, on s'appuie sur une expérience de laboratoire pour analyser la relation entre l'équité et efficacité dans des jeux de coordination avec des équilibres de Pareto. Dans ces jeux, le niveau d'équité diminue en augmentant les paiements à l'équilibre pour certains sujets, tandis que pour les autres, ils restent inchangés. Théoriquement, dans ce contexte, l'aversion à l'inégalité des paiements peut conduire à un effet positif entre l'équité et l'efficacité, tandis que les motivations pour l'accroissement du bien-être social conduisent à une relation négative. On montre que moins d'équité conduit sans ambiguïté à plus de coordination à l'équilibre efficace. De plus, ce résultat est valable même pour *les sujets dont les paiements restent inchangés*. Nos résultats suggèrent que les motivations pour l'accroissement du bien-être social sont à l'origine de la relation négative entre l'équité et coordination dans cette expérience. En outre, nos données montrent que l'ordre de présentation des traitements est important. En effet, les groupes confrontés au fil du temps à une réduction des inégalités atteignent plus souvent le résultat efficace, sur l'ensemble de l'expérience, par rapport aux groupes confrontés à une augmentation des inégalités. Cette étude contribue donc au débat sur le compromis efficacité-équité et fournit des preuves sur l'effet de la variation des inégalités sur l'efficacité des décisions collectives qui en résulte.

Mots-clés :

Jeu de coordination, Equité, Efficacité, Aversion aux inégalités, Bien-être social.

Appendix E: Résumé chapitre 4

On analyse le contrat optimal conçu pour inciter des agents averses aux inégalités à participer à un projet commun. La participation de chaque agent génère des externalités positives pour les autres participants. On montre d'abord que le principal offrant un contrat conçu de manière optimale pour des agents orientés sur eux-mêmes ne susciterait pas la participation d'agents averses aux inégalités. La caractérisation du contrat optimal soulève ensuite des points importants. D'abord, l'aversion aux inégalités avantageuses a un effet de premier ordre. Plus précisément, lorsque les agents ne sont pas averses à une telle inégalité, le contrat optimal est le même que lorsqu'ils ont des préférences standards (centrés sur eux-mêmes). De plus, si les agents ont des préférences homogènes, le contrat optimal avec des externalités symétriques ne dépend pas du paramètre d'aversion aux inégalités désavantageuses. Ensuite, le contrat optimal présente des différences qualitatives notables lorsque les agents sont hétérogènes. En effet, les deux types d'inégalités sont complémentaires : le dispositif optimal ne dépend de l'aversion aux inégalités désavantageuses que si les agents sont averses aux inégalités avantageuses. Enfin, nous caractérisons les conditions dans lesquelles l'agent privilégié (l'agent dont le gain est le plus important dans le contrat optimal) reçoit une récompense supérieure à celle des agents défavorisés, et on discute de la question de savoir si le contrat optimal entraîne plus ou moins d'inégalité (comparativement au cas standard).

Mots-clés :

Théorie des contrats, Externalités, Aversion aux Inégalités, Différentiation.

Appendix F: Conclusion Générale

Jusque-là, la littérature sur les contrats avec externalités a fourni plusieurs résultats concernant le design optimal des contrats. A présent, comprendre comment d'autres caractéristiques de la relation contractuelle entre un principal et plusieurs agents, telles que les effets spatiaux, à savoir les bénéfices privés et les externalités, ou les aspects comportementaux liés aux préférences individuelles, affectent le design et/ou l'acceptabilité du contrat optimal est une étape importante afin d'avancer sur les connaissances dans ce domaine de recherche intéressant. Cette thèse est une tentative d'apporter une telle contribution. Elle analyse l'impact des effets spatiaux (chapitre 2) et des considérations comportementales des agents (chapitre 3 et chapitre 4) sur la conception et l'acceptabilité du contrat optimal.

Dans le Chapitre 2, nous analysons l'impact des effets spatiaux sur la manière dont le principal s'attaque au problème du design des contrats. On montre que le contrat peut induire des résultats efficaces et on caractérise également les agents qui reçoivent les contrats menant à l'inefficacité de la solution optimale. En effet, un contrat avec des agents caractérisés par un niveau élevé de bénéfices privés et un niveau modeste d'externalités rend plus probable l'inefficacité de la solution optimale. Dès lors, l'analyse présentée dans ce chapitre révèle qu'une approche par un contrat bilatéral n'est pas toujours un moyen approprié pour surmonter les problèmes d'inefficacité lorsqu'il s'agit de fournir des biens collectifs impliquant des externalités.

Pour les recherches futures sur ce sujet, certaines extensions doivent être envisagées. Tout d'abord, il peut être intéressant d'étendre le modèle en prenant en compte d'autres formes fonctionnelles pour le paiement des agents. En effet, nous considérons dans le chapitre 2 des fonctions linéaires assez simples, ce qui conduit à des solutions de coin faciles à interpréter. Ensuite, il serait également intéressant d'analyser la performance du contrat optimal en laboratoire. Cela peut révéler des motivations individuelles qui peuvent expliquer davantage l'efficacité ou l'inefficacité de la solution du contrat en plus des effets spatiaux.

Le Chapitre 3 se concentre sur l'acceptabilité sociale des contrats différenciés. En effet, Bernstein and Winter (2012) montrent théoriquement qu'un principal souhaitant mettre en œuvre la participation de tous les agents doit s'appuyer sur un dispositif de contrats Divide and Conquer. Ce dispositif a la propriété d'induire la participation de tous les agents comme un équilibre de Nash strict et unique. Cependant, ce résultat de Bernstein and Winter (2012) repose sur

l'hypothèse que les agents choisissent de participer quand ils sont indifférents entre participer et s'abstenir. Cette hypothèse n'a pas de fondement dans la théorie comportementale, et en son absence, il pourrait y avoir des problèmes de coordination dans le jeu de participation joué par les agents. De plus, il existe un possible compromis entre efficacité et égalité des paiements. En effet, dans ce jeu, l'équilibre le plus efficace étant également le plus inégalitaire (en termes de distribution des paiements) et l'équilibre le moins efficace étant le plus égalitaire. Le chapitre 3 a pour objectif d'examiner la manière dont les agents réagissent face à ce compromis. Pour ce faire, nous nous appuyons sur des expériences de laboratoire. À l'aide de deux traitements qui diffèrent sur les niveaux d'inégalité à l'équilibre le plus efficace, on constate que les sujets se coordonnent plus souvent sur l'équilibre le plus inégalitaire (et le plus efficace), même si uniquement certains d'entre eux bénéficient d'un gain supplémentaire. Notre étude fournit également des résultats suggérant que les sujets peuvent être motivés par la maximisation du bien-être social.

Plus de travail est nécessaire sur ce sujet. Il serait intéressant d'obtenir des informations supplémentaires pour mieux comprendre comment les sujets jouent à un jeu aussi complexe. De plus, étudier les effets du nombre de sujets dans le groupe peut améliorer les connaissances acquises dans ce domaine.

Puisque les résultats dans le chapitre 3 suggèrent que les préférences sociales peuvent affecter la solution du contrat, nous choisissons d'introduire des préférences d'aversion à l'inégalité dans le modèle de contrat avec des externalités hétérogènes. Le Chapitre 4 s'intéresse à l'impact des préférences des agents en matière d'aversion aux inégalités sur le design du contrat optimal en présence d'externalités. Le choix de l'aversion à l'inégalité en tant que préférence sociale des agents est simplement motivé par la solution du dispositif de contrat Divide and Conquer, qui implique des paiements différenciés pour les agents. Ainsi, nous considérons les agents averses aux inégalités qui reçoivent des contrats dans un contexte où l'action de chaque agent génère des externalités sur les autres. On montre que l'inégalité avantageuse a un effet de premier ordre. En effet, lorsque les agents ne sont pas averse à de telles inégalités, le contrat optimal est similaire à celui qui existe lorsque les agents ont des préférences standards. On montre également que le contrat optimal ne dépend de l'aversion pour les inégalités désavantageuses que si les agents sont averse aux inégalités avantageuses.

Il existe des pistes naturelles pour des recherches futures. En particulier, bien que notre étude repose sur l'hypothèse que la coordination ne pose pas problème s'il y a multiplicité d'équilibre, il serait intéressant de caractériser le contrat le

moins coûteux induisant la participation de tous les agents en tant qu'équilibre de Nash unique du jeu. Un autre objectif serait d'étendre le modèle à plusieurs agents. Enfin, il serait également intéressant de mener des expériences de laboratoire afin d'identifier d'autres considérations comportementales qui jouent un rôle dans la performance des dispositifs envisagés.

Appendix G: Appendices of Chapter 2

G.1 Proof of Proposition 1

The maximization program of agent i is given by

$$\max_{x_i} \quad e_{ii}\, x_i + \sum_{j \neq i} e_{ij}\, x_j - x_i$$

subject to

$$x_i \geq 0$$
$$\bar{x} - x_i \geq 0$$

The Lagrangian corresponding to the program is as follows

$$L(x_i, \gamma_i, \rho_i) = e_{ii}\, x_i + \sum_{j \neq i} e_{ij}\, x_j - x_i + \sum_i \gamma_i x_i + \sum_i \rho_i(\bar{x} - x_i) \tag{G.1}$$

The optimality condition is then

$$\frac{\partial L}{\partial_{x_i}}(x^{NE}) = (e_{ii} - 1) + \gamma_i - \rho_i = 0 \tag{G.2}$$

at the optimum, $x^{NE} = (x_1^{NE}, x_2^{NE}, \ldots, x_n^{NE})$, we obtain

$$\gamma_i x_i^{NE} = 0 \tag{G.3}$$

$$\rho_i(\bar{x} - x_i^{NE}) = 0 \tag{G.4}$$

In order to characterize the optimal outcomes, we analyze 3 cases:

Case 1: $e_{ii} - 1$

If $e_{ii} - 1 = 0$, then it consists of an optimization of a constant value. Hence, the case where $e_{ii} - 1 = 0$ is a degenerate case.

Case 2: $e_{ii} - 1 > 0$

In this case, we explore three conditions in order to figure out the consistent outcome.

1. if $x_i^{NE} \in]0, \bar{x}[$, then, according to (G.4), necessarily $\rho_i(\bar{x} - x_i^{NE}) = 0$. Yet, $\bar{x} - x_i^{NE} > 0$. This means that $\rho_i = 0$. Besides, according to (G.3), we also get $\gamma_i = 0$. Consequently, condition (G.2) gives $e_{ii} - 1 = 0$ which is contradictory with this case.

2. Now, assume that $\gamma_i > 0$. Thus, according to (G.3), we have $x_i^{NE} = 0$. With respect to (G.4), this implies that $\rho_i\, \bar{x} = 0$. Hence, $\rho_i = 0$ since

$\bar{x} > 0$. According to the condition (G.2), we have $a\ e + n\ e - 1 + \gamma_i = 0$ et $\gamma_i = -[e_{ii} - 1]$. however, we already assume that $e_{ii} - 1 > 0$. Therefore, $\gamma_i < 0$, which contradicts our beginning assumption, that is $\gamma_i > 0$.

3. Finally, assume that $\rho_i > 0$. therefore, according to (G.4), we obtain $x_i^{NE} = \bar{x}$. According to (G.3), we also get $\gamma_i = 0$. The condition (G.2) becomes $e_{ii} - 1 - \rho_i = 0$. Hence, $\rho_i = e_{ii} - 1$ which satisfy our assumptions.

In the case where $e_{ii} - 1 > 0$, the outcome is given by $\{x_i^{NE} = \bar{x},\ \gamma_i = 0,\ \rho_i = e_{ii} - 1\}$. This means that the non cooperative Nash equilibrium corresponds to a contribution $x_i^{NE} = \bar{x}$ when $e_{ii} - 1 > 0$.

Case 3: $e_{ii} - 1 < 0$

In this case we obtain the following results.

1. If $x_i^{NE} \in]0, \bar{x}[$, then, according to (G.4) since $\bar{x} - x_i^{NE} > 0$, $\rho_i = 0$. Besides, according to (G.3), $\gamma_i = 0$. Therefore, the condition (G.2) gives $e_{ii} - 1 = 0$ which contradicts the following assumption: $e_{ii} - 1 < 0$.

2. Then, assume that $\gamma_i > 0$ which implies $x_i^{NE} = 0$, according to (G.3). Thus, according to (G.4), we get $\rho_i \bar{x} = 0$. Hence, $\rho_i = 0$ because $\bar{x} > 0$. The condition (G.2) gives $e_{ii} - 1 + \gamma_i = 0$ and thereby $\gamma_i = -[e_{ii} - 1]$. Considering that $a\ e + n\ e - 1 < 0$, we can state that the condition (G.2) is true.

3. Finally, assume that $\rho_i > 0$ which gives us (G.4), e.g. $x_i^{NE} = \bar{x}$. In addition, according to (G.3), $\gamma_i = 0$ because $x_i^{NE} > 0$. the condition (G.2) gives $e_{ii} - 1 - \rho_i = 0$. Consequently, $\rho_i = e_{ii} - 1$. Since we hypothesis that $e_{ii} - 1 < 0$, we get $\rho_i < 0$ which contradicts our beginning assumption; that is, $\rho_i > 0$.

In the case where $e_{ii} - 1 < 0$ the outcome is given by $\{x_i^{NE} = 0,\ \gamma_i = -[e_{ii} - 1],\ \rho_i = 0\}$. This means that the non-cooperative game solution corresponds to the contribution $x_i^{NE} = 0$ when $e_{ii} - 1 < 0$.

G.2 Proof of Proposition 2

The proof in this proposition follows the same structure as in the previous proof G.1. Note that the central planer problem is represented by the following program

$$\max_{x^{FB}} \ (\tfrac{a}{n}+1)\sum_i \sum_j e_{ji}x_i - \sum_i x_i$$

subject to

$$x_i \geq 0$$
$$\bar{x} - x_i \geq 0$$

Therefore,

(i) we consider that the case where $(\frac{a}{n}+1)\sum_j e_{ji} = 0$ is a degenerative case.

(ii) In the case where $(\frac{a}{n}+1)\sum_j e_{ji} > 0$, the optimal outcome is such that $\{x_i^{FB} = \bar{x},\ \gamma_i = 0,\ \rho_i = (\frac{a}{n}+1)\sum_j e_{ji}\}$. This means that the social optimum is such that agents contribute $x_i^{FB} = \bar{x}$ when $(\frac{a}{n}+1)\sum_j e_{ji} > 0$.

(iii) In the case where $(\frac{a}{n}+1)\sum_j e_{ji} < 0$, the optimal outcome is given by $\{x_i^{FB} = 0,\ \gamma_i = -[(\frac{a}{n}+1)\sum_j e_{ji}],\ \rho_i = 0\}$. This means that the social optimum is such that $x_i^{FB} = 0$ when $(\frac{a}{n}+1)\sum_j e_{ji} < 0$.

G.3 Proof of Proposition 3

In this proof, the principal program is given by

$$\max_{x^c} \ \tfrac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r)\sum_i x_i$$

subject to

$$x_i \geq 0$$
$$\bar{x} - x_i \geq 0$$

where the agent participation constrain are binding at optimum. Thus, applying the above proof in G.1 to this program, we obtain

(i) a degenerate case if $\frac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r) = 0$

(ii) In the case where $\frac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r) > 0$ the outcome is given by $\{x_i^c = \bar{x},\ \gamma_i = 0,\ \rho_i = \frac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r)\}$. This means that the optimal contracting induces a contribution $x_i^c = \bar{x}$ when $\frac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r) > 0$.

(iii) In the case where $\frac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r) < 0$, instead, the outcome is given by $\{x_i^c = 0,\ \gamma_i = -[\frac{a}{n}(r+(n-1)d)\sum_i x_i - (1-r)],\ \rho_i = 0\}$, meaning that the optimal contracting outcome is $x_i^c = 0$.

G.4 Proof of Proposition 4

We simply solve the following system that leads to an efficient contribution by agents after the intervention of the principal.

$$\begin{cases} \frac{a}{n}(r+(n-1)d)+r>1 \\ (\frac{a}{n}+1)(r+(n-1)d)>1 \\ r<1 \end{cases}$$

However, if $\frac{a}{n}(r+(n-1)d)+r>1$ is true, then $(\frac{a}{n}+1)(r+(n-1)d)>1$ is true too. Therefore, the previous system becomes

$$\begin{cases} \frac{a}{n}(r+(n-1)d)+r>1 \\ r<1 \end{cases}$$

Leading to the following result

$$\frac{n-and+ad}{n+a}<r<1$$

G.5 Proof of Proposition 5

In this proof, the principal program is given by

$$\max_{x_i} \quad \frac{a}{n}\sum_i\sum_j e_{ji}x_j+\sum_i e_{ii}\,x_i-\sum_i x_i$$

Subject to

$$x_i>0$$

$$\bar{x}-x_i>0$$

where the agents' participation constraints are binding at optimum. Thus, applying the above proof in G.1 to this program, we obtain

(i) a degenerate case if $(\frac{a}{n}+1)e_{ii}+\frac{a}{n}\sum_{j\neq i}e_{ji}=0$

(ii) In the case where $(\frac{a}{n}+1)e_{ii}+\frac{a}{n}\sum_{j\neq i}e_{ji}>0$ the outcome is given by $\{x_i^c=\bar{x},\ \gamma_i=0,\ \rho_i=(\frac{a}{n}+1)e_{ii}+\frac{a}{n}\sum_{j\neq i}e_{ji}\}$. This means that the optimal contracting induces a contribution $x_i^c=\bar{x}$ when $(\frac{a}{n}+1)e_{ii}+\frac{a}{n}\sum_{j\neq i}e_{ji}>0$.

(iii) In the case where $(\frac{a}{n}+1)e_{ii}+\frac{a}{n}\sum_{j\neq i}e_{ji}<0$, instead, the outcome is given by $\{x_i^c=0,\ \gamma_i=-[(\frac{a}{n}+1)e_{ii}+\frac{a}{n}\sum_{j\neq i}e_{ji}],\ \rho_i=0\}$, meaning that the optimal contracting outcome is $x_i^c=0$.

G.6 Proof of Proposition 6

Consider the system $\mathcal{J}_2$ that characterizes the agent who drives the inefficiency, namely agent i_2. $\mathcal{J}_2$ is given by

$$\mathcal{J}_2 = \begin{cases} (\frac{a}{3}+1)(e_{i_2 i_2} + e_{i_2}) > 1 \\ e_{i_2 i_2} < 1 \\ \frac{a}{3}(e_{i_2 i_2} + e_{i_2}) + e_{i_2 i_2} < 1 \end{cases}$$

Simplifying $\mathcal{J}_2$, we obtain

$$-\frac{ae_{i_2}+3e_{i_2}-3}{a+3} < e_{i_2 i_2} < -\frac{ae_{i_2}-3}{a+3} \quad \text{G.5}$$

Now, assume that $\underline{r}_{i_2} = -\frac{ae_{i_2}+3e_{i_2}-3}{a+3}$ and $\bar{r}_{i_2} = -\frac{ae_{i_2}-3}{a+3}$. $\underline{r}_{i_2}$ and $\bar{r}_{i_2}$ refer to the minimum and the maximum thresholds of the retention effects characterizing agent i_2, respectively. We also assume that a is an exogenous constant value.

To identify the mechanism, first notice that when the diffusion effects are absent, then $\frac{3}{a+3} < e_{i_2 i_2} < 22\frac{3}{a}$. Hence, in case of inefficiency, the retention effects always belong to an interval of strictly positive values. Second, differentiating $\underline{r}_{i_2}$ and $\bar{r}_{i_2}$ with respect to e_{i_2}, the agent i_2's diffusion effects, yields

$$\frac{\partial \underline{r}_{i_2}}{\partial e_{i_2}} = -1 \quad \text{G.6}$$

$$\frac{\partial \bar{r}_{i_2}}{\partial e_{i_2}} = -\frac{a}{a+3} \quad \text{G.7}$$

Therefore, at the margin, an increase in the diffusion effects induces a decrease of both the maximal and the minimal thresholds but not in the same proportion. Thus, an increase in the diffusion effects have two effects: *(i)* it generates a sift to the lefts of the retention effects' range values; *(ii)* it also enlarges the retention effects range values. This leads us to claim that inefficiency is easier to achieve when retention effects is small and the diffusion effects belong to an interval of intermediate values.

Appendix H: Appendices of Chapter 3

H.1 Proofs of the Propositions

H.1.1 Proof of Proposition 7

In the low inequality treatment we can compute the difference in role-A agent's expected payoffs when choosing 1 and when choosing 0:

$$U_A(1) - U_A(0) = 2p(1-p) + 2(1-p)^2$$

Similarly, in the high inequality treatment, we obtain:

$$U_A(1) - U_A(0) = 51p(1-p) + 51(1-p)^2$$

We thus conclude that this difference is larger when moving from the low to the high inequality treatment. Together with the assumption on the relationship between an agent's probability to choose 1 and the above differences, this concludes the proof for role-A agent.

In the low inequality treatment we then compute the difference in role-B agent's expected payoffs when choosing 1 and when choosing 0:

$$U_B(1) - U_B(0) = 1 - 32p$$

Similarly, in the high inequality treatment, we obtain:

$$U_A(1) - U_A(0) = 27 - 58p$$

We thus conclude (as $0 \leq p \leq 1$) that this difference is larger when moving from the low to the high inequality treatment. Together with the assumption on the relationship between an agent's probability to choose 1 and the above differences, this concludes the proof for role-B agent.

Finally, in the low inequality treatment we compute the difference in role-C agent's expected payoffs when choosing 1 and when choosing 0:

$$U_C(1) - U_C(0) = -\left[50p(1-p) + 50p^2\right]$$

Similarly, in the high inequality treatment, we obtain:

$$U_C(1) - U_C(0) = -\left[50p(1-p) + 50p^2\right]$$

We thus conclude that this difference remains unaffected when moving from the low to the high inequality treatment. Together with the assumption on the relationship between an agent's probability to choose 1 and the above differences, this concludes the proof for role-C agent.

H.1.2 Proof of Proposition 8

In the low inequality treatment, we can compute the following differences:

$$U_A(1,0,0) - U_A(0,0,0) = 0; \;\; U_A(1,1,0) - U_A(0,1,0) = 1 + \frac{29}{2}\beta_A$$

$$U_A(1,0,1) - U_A(0,0,1) = 1 + 10\beta_A; \;\; U_A(1,1,1) - U_A(0,1,1) = 2 + \frac{49}{2}\beta_A$$

Similarly, in the high inequality treatment, we obtain:

$$U_A(1,0,0) - U_A(0,0,0) = 0; \;\; U_A(1,1,0) - U_A(0,1,0) = 30 - \frac{29}{2}\beta_A$$

$$U_A(1,0,1) - U_A(0,0,1) = 21 - 10\beta_A; \;\; U_A(1,1,1) - U_A(0,1,1) = 51 - \frac{49}{2}\beta_A$$

We can finally compare a given difference in either the high inequality or the low inequality treatment. We easily derive that $U_A(1,0,0) - U_A(0,0,0)$ is the same in both treatments, so the difference is non negative. Second, $U_A(1,1,0) - U_A(0,1,0)$ is larger when moving from the low to the high inequality treatment (the difference is equal to $29(1-\beta_A) \geq 0$). Third, $U_A(1,0,1) - U_A(0,0,1)$ is larger when moving from the low to the high inequality treatment (the difference is equal to $20(1-\beta_A) \geq 0$). Finally, $U_A(1,1,1) - U_A(0,1,1)$ is larger when moving from the low to the high inequality treatment (the difference is equal to $49(1-\beta_A) \geq 0$). Together with the assumption on the relationship between an agent's probability to choose 1 and the above differences, this concludes the proof for role-A agent.

Using similar computations in the case of a role-C agent, we derive that $U_C(0,0,1) - U_C(0,0,0)$ is the same in both treatments, so the difference is non negative. Second, $U_C(1,0,1) - U_C(1,0,0)$ is smaller when moving from the low to the high inequality treatment (the difference is equal to $-a_C\frac{19}{2} \leq 0$). Third, $U_C(0,1,1) - U_C(0,1,0)$ is smaller when moving from the low to the high inequality treatment

(the difference is equal to $-9a_C + 4\beta_C \geq 0$). Finally, $U_C(1,1,1) - U_C(1,1,0)$ is smaller when moving from the low to the high inequality treatment (the difference is equal to $-a_C\frac{47}{2} \leq 0$). Together with the assumption on the relationship between an agent's probability to choose 1 and the above differences, this concludes the proof for role-C agent.

Again, using similar computations in the case of a role-B agent, we derive that $U_B(0,1,0) - U_B(0,0,0)$ is larger when moving from the low to the high inequality treatment (the difference is equal to 8). Second, $U_B(1,1,0) - U_B(1,0,0)$ is smaller when moving from the low to the high inequality treatment (the difference is equal to $-a_B\frac{29}{2} \leq 0$). Third, depending on parameter values $U_B(0,1,1) - U_B(0,0,1)$ may be larger or smaller when moving from the low to the high inequality treatment: the difference is equal to $26 - 8a_B + 41\beta_B$ which may be negative if a_B is large enough. Finally, depending on parameter values $U_B(1,1,1) - U_B(1,0,1)$ may be larger or smaller when moving from the low to the high inequality treatment: the difference is equal to $26 - \frac{3}{2}a_B - 13\beta_B$ which may be negative if a_B is large enough. Together with the assumption on the relationship between an agent's probability to choose 1 and the above differences, the overall conclusion is that role-B agent may be more or less likely to participate in the high inequality treatment than in the low inequality treatment.

H.1.3 Proof of Proposition 9

Using similar computations than in the proof of Proposition 2, we conclude easily that each agent's payoff differences are larger when moving from the low to the high inequality treatment. This concludes the proof.

H.2 Additional Figures

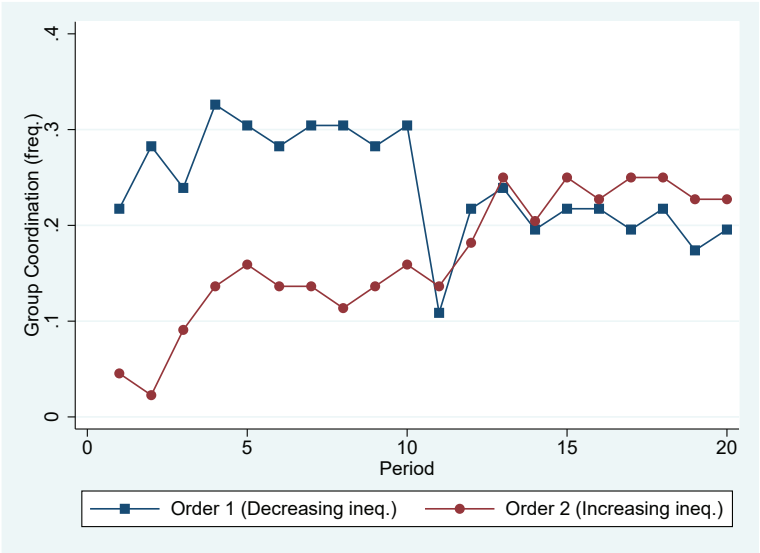

Figure H.1: *Order comparison (between sessions)*

H.3 Direct tests of the effect of individual preferences

In this Appendix, we provide several direct tests of the effect of individual preferences. We first describe the procedure used to estimate the individual preference parameters. We then provide the regression results.

H.3.1 Measures of individual preferences

Risk Aversion

In order to estimate individual risk aversion, we assume a constant relative risk aversion (CRRA) utility function, which enables us to compute the intervals corresponding to each choice proposed in Table H.7. The CRRA utility function has the following form: $U(x) = x^{1-r_i}/(1-r_i)$, where x is the lottery prize and r_i, which denotes the constant relative risk aversion of the individual, is the parameter to be estimated. Expected utility is the probability weighted utility of each outcome in each row. An individual is indifferent between lottery A, with associated probability p of winning a and probability $1-p$ of winning b, and lottery B, with probability p of winning c and probability $1-p$ of winning d, if and only if the two expected utility levels are equal:

$$p.U(a) + (1-p).U(b) = p.U(c) + (1-p).U(d), \tag{H.1}$$

or,

$$p.\frac{a^{1-r_i}}{1-r_i} + (1-p).\frac{b^{1-r_i}}{1-r} = p.\frac{c^{1-r_i}}{1-r_i} + (1-p).\frac{d^{1-r_i}}{1-r_i} \tag{H.2}$$

which can be solved numerically in terms of r_i.

Our measure of individual risk aversion corresponds to the midpoint of the intervals.[1]

Inequality aversion

Since two-player games were used in the dictator and the ultimatum games, we assume Fehr and Schmidt (1999) type of utility functions in order to estimate individuals' inequality aversion parameters. This type of utility functions is defined as:

$$U_i(x_i, x_j) = x_i - a_i\ max\{x_j - x_i; 0\} - \beta_i\ max\{x_i - x_j; 0\}, \tag{H.3}$$

[1] We take the upper bound for the first interval and the lower bound for the last interval.

where x_i and x_j, with $i \neq j$, are the monetary payoffs of i and j, respectively.

We compute a_i, which denotes i's individual parameter of aversion toward disadvantageous inequality, and β_i, which denotes i's individual parameter of aversion toward advantageous inequality aversion, by using respectively an ultimatum game and a modified dictator game. We follow Fehr and Schmidt (1999) and assume that subjects are harmed by increases in advantageous inequality, e.g. $\beta_i \geq 0$; they are also not willing to pay more than one unit for reduction of one unit in advantageous inequality, e.g. $\beta_i < 1$ is satisfied. Finally, we consider that subjects suffer more under disadvantageous inequality than under advantageous inequality, e.g. $\beta_i \leq a_i$ is satisfied.

Advantageous inequality aversion: a_i

Regarding the strategy method we used in our ultimatum game (the game setting is described in Appendix H.4.2), we may identify the minimum acceptable offer for each individual. This offer can allow us to compute an estimation point of a_i. Let us consider that s_i' denotes the minimal offer that individual i is willing to accept. So individual i rejects offer $s_i' - 1$. He/she is then eager to accept a single offer $s_i \in [s_i' - 1, s_i']$. Since individual i is indifferent when offered s_i, he gets a zero payoff when rejecting this offer. Thus, $U_i(s_i, d - s_i) = s_i - a_i(d - s_i - s_i) = 0$, where d denotes the sender's endowment.[2] Therefore, a_i is given by:

$$a_i = \frac{s_i}{2(\frac{d}{2} - s_i)}. \tag{H.4}$$

Our measure of s_i corresponds to a midpoint of the interval $[s_i' - 1, s_i']$. For subjects with $s_i' = 0$, we set $a_i = 0$. Also, for subjects that only accept offer $s_i' \geq \frac{d}{2}$ we follow **?** and set $a_i = 4.5$. a_i thus lies in between 0 and 4.5, as we expect that a greater value of a_i (that is, individual i "hates" disadvantageous inequality) would not be much relevant for the purpose of this study.

Disadvantageous inequality aversion: β_i

Here, we use data from the modified dictator game played in strategy method (see Appendix H.4.1 and Table H.6 in Appendix H.5) to compute the parameter β_i by looking for the distribution (x_i, x_i) which makes the dictator indifferent between keeping the entire endowment d (choose $(d, 0)$) or going for an equal split (x_i, x_i). Suppose that individual i switches toward the equal-share distribution at (x_i', x_i'). Thus, we have $U_i(x_i', x_i') > U_i(d, 0) > U_i(x_i' - 1, x_i' - 1)$. Therefore, individual i is indifferent between $(d, 0)$ and (x_i'', x_i'') where $x_i'' \in [x_i' - 1, x_i']$ and $x_i' \in \{1, ..., d\}$.

[2] d is arbitrarily set equal to 10 in our experiment.

We now get $U_i(d,0) = U_i(x_i'', x_i'')$. This is equivalent to $d - d\beta_i = x_i''$. This equation is solved in β_i such that,

$$\beta_i = 1 - \frac{x_i''}{d}. \tag{H.5}$$

We use the midpoint between $x_i' - 1$ and x_i' as a measure of x'' to compute β_i. For subjects who prefer $(0,0)$ over $(d,0)$, their β_i is greater than 1, and we set $\beta_i = 1$. Also, for those who choose $(d,0)$ over (d,d) we set $\beta_i = 0$.

Altruism

We also define a proxy of altruism by using the modified dictator game. Since the mean spread is kept constant, we use question 6 in Table H.6 to estimate the individuals' degree of altruism. More precisely, using question 6, we compute a dummy equal to 1 (altruist) if individual i selects the distribution $(\frac{d}{2}, \frac{d}{2})$ over $(d,0)$. Otherwise, individual i is considered as non altruistic and we set the dummy equal to 0.

H.3.2 Descriptive statistics

Table H.1 provides descriptive statistics about individual characteristics. Notice that instead of groups, we focus here on the subjects. *Risk aversion* is the individual relative risk aversion parameter computed following the procedure explained in Section H.3.1. *Disadv. ineq. aversion* and *Adv. ineq. aversion* are the inequality aversion parameters (disadvantageous and advantageous, respectively) computed following the procedure explained in Section H.3.1. *Altruist* is a dummy variable which is set to 1 if the individual is altruistic (see Section H.3.1).*Econ* is a dummy which is 1 if the student is majoring in economics or management (and 0 otherwise).

Our sample contains 270 subjects aged around 27, of which 49% of people are men and 51% are women. They are mainly risk-averse $\bar{r} = 0.49$. They also dislike disadvantageous inequality and advantageous inequality with mean coefficients corresponding to, $\bar{a} = 1.65$ and $\bar{\beta} = 0.49$ respectively. Regarding our definition of altruism (see Section H.3.1), we observe that slightly more than a half of the population is altruistic (54%). 35% of the subjects in our sample are students majoring in economics or management.

Table H.1: *Descriptive statistics: individual characteristics*

Variable	Mean	Std. Dev.	Min.	Max	Nb of subjects
Age	26.637	8.776	18	73	270
Gender (male=1)	0.492	0.5	0	1	266
Risk aversion	0.488	0.574	-1.71	1.37	270
Disadv. ineq. aversion	1.647	1.822	0	4.5	270
Adv. ineq. aversion	0.493	0.304	0	1	270
Altruist	0.537	0.499	0	1	270
Econ	0.352	0.478	0	1	267

Notes: The sample consists of 270 subjects, 90 groups playing 2 treatments with 10 repetitions each. *Risk aversion* is the individual relative risk aversion parameter. *Disadv. ineq. aversion* and *Adv. ineq. aversion* are the inequality aversion parameters (disadvantageous and advantageous, respectively). *Altruist* is a dummy variable which is set to 1 if the individual is altruistic.*Econ* is a dummy which is 1 if the student is majoring in economics or management (and 0 otherwise).

H.3.3 Effect of individual preferences

In this section, we provide estimates of heterogeneous treatment effects at the subject level (Table H.2), and correlations between individual characteristics and individual participation decisions (Table H.3). The results are discussed in Section 3.4 in the body of the paper.

Table H.2: *Heterogeneous effect: individual characteristics*

	Dependent variable: Participation decision						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
High ineq.	0.117***	0.162*	0.131*	0.095***	0.080**	0.163**	0.111***
	(0.039)	(0.086)	(0.072)	(0.034)	(0.039)	(0.067)	(0.038)
High ineq.×Risk aversion	-0.030						
	(0.033)						
High ineq.×Disadv. ineq. aversion		-0.072					
		(0.083)					
High ineq.×Adv. ineq. aversion			-0.034				
			(0.074)				
High ineq.×Altruist				0.008			
				(0.043)			
High ineq.×Gender					0.039		
					(0.038)		
High ineq.×Age						-0.002	
						(0.003)	
High ineq.×Econ							-0.024
							(0.040)
Model	LPM	LPM	LPM	LPM	LPM	LPM	LPM
Indiv. FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	5,400	5,400	5,400	5,400	5,320	5,400	5,340
Nb of subjects	270	270	270	270	266	270	267
R^2	0.59	0.59	0.59	0.59	0.59	0.59	0.59

Notes: *** significant at 1% level, ** significant at 5% level, * significant at 10% level. High ineq. is the outcome of the dummy for treatment when it is equal to 1. Participation decision equals 1 when subjects select "participation". × indicates interaction variable. LPM stands for Linear Probability Model. Reported standard errors are clustered at the group level. *Risk aversion* is the individual relative risk aversion parameter. *Disadv. ineq. aversion* and *Adv. ineq. aversion* are the inequality aversion parameters (disadvantageous and advantageous, respectively). *Altruist* is a dummy variable which is set to 1 if the individual is altruistic.*Econ* is a dummy which is 1 if the student is majoring in economics or management (and 0 otherwise).

H.4 Additional experimental modules

In this part, we first present the modified dictator game that is quite specific especially in strategy method (Selten, 1967), which allows to get more information without lowering the size of the sample. Then, we describe the strategy method of the ultimatum game. We conclude by describing the commonly used Holt and Laury (2002) game.

H.4.1 Modified dictator game in strategy method

This modified dictator game is played in two sequences. In each sequence, subjects answer to a set of 11 questions. Each question corresponds to a binary choice between an egalitarian distribution (s, s) and unequal distribution $(10, 0)$, with s an integer lying in $[0, 10]$. During the first sequence, all subjects are

Table H.3: *Individual characteristics instead of indiv. fixed effects*

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
High ineq.	0.099***	0.099***	0.099***	0.099***	0.099***	0.099***	0.102***
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.029)	(0.029)
Risk aversion		-0.092**	-0.092**	-0.092**	-0.092**	-0.102**	-0.101**
		(0.041)	(0.040)	(0.041)	(0.041)	(0.042)	(0.043)
Diadv. ineq. aversion			-0.010	-0.010	-0.010	-0.011	-0.012
			(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Adv. ineq. aversion				0.006	-0.008	-0.038	-0.027
				(0.076)	(0.122)	(0.125)	(0.127)
Altruist					0.011	0.029	0.018
					(0.067)	(0.069)	(0.069)
Age						-0.001	-0.000
						(0.002)	(0.003)
Gender						-0.010	-0.013
						(0.053)	(0.054)
Econ							0.063
							(0.053)
Model	LPM	LPM	LPM	LPM	LPM	LPM	LPM
Indiv. FE	No	No	No	No	No	No	No
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	5,400	5,400	5,400	5,400	5,400	5,320	5,260
Nb of subjects	270	270	270	270	270	266	267
R^2	0.01	0.02	0.02	0.02	0.02	0.02	0.03

Notes: *** significant at 1% level, ** significant at 5% level, * significant at 10% level. High ineq. is the outcome of the dummy for treatment when it is equal to 1. × indicates interaction variable. LPM stands for Linear Probability Model. Reported standard errors are clustered at the group level. *Risk aversion* is the individual relative risk aversion parameter. *Disadv. ineq. aversion* and *Adv. ineq. aversion* are the inequality aversion parameters (disadvantageous and advantageous, respectively). *Altruist* is a dummy variable which is set to 1 if the individual is altruistic.*Econ* is a dummy which is 1 if the student is majoring in economics or management (and 0 otherwise).

assigned the role of dictator and should choose only one distribution for each question. Once the sequence is completed, the second sequence starts. Subjects are randomly matched in groups of two members and receive information about their own role in their group. The subject roles in each group are different. Each subject could be either the dictator or the receiver. The group members payoffs depend on the choice of the dictator. Therefore, each receiver's outcome depends solely on his paired dictator.

H.4.2 Ultimatum game in strategy method

The ultimatum game module is conducted in three sequences. The first sequence relates to the senders' choices. In fact, each subject is first assigned the role of sender and receives a monetary endowment of 10 experimental units (ECUs). Then he/she chooses an amount s he/she wants to offer to his/her partner, thus keeping $10 - s$ units, with s an integer lying in $[0, 10]$. Once the first sequence is completed, subjects move on to the sequence on respondents'

choices. In this sequence, each subject decides which distributions out of the 11 offers they are willing to accept or reject. Finally, the last sequence goes as follows. Subjects are randomly matched into pairs composed by a single proposer and a single respondent. Each proposer offer is matched with his/her paired respondent choice. The payment is then computed as follows: If the proposer offered s units in the first sequence and the respondent chose to accept this offer in the second sequence then, in the last sequence, the proposer receives $(10 - s)$ units and the respondent receives s units. Alternatively, if the respondent chose to reject this offer during the second sequence, they both receive 0 unit.

H.4.3 Multiple price list risk elicitation

In order to elicit individual's risk preferences, we use the well known Holt and Laury (2002) lottery game. In this game, subjects face a list of 10 questions involving paired gambles as presented in Table H.7 in Appendix H.5. For each question, the two gambles are labeled option A and option B. For each question, each subject chooses which gamble he/she prefers to take: either option A or option B. The resulting payoffs in option A and option B are constant, only the probability associated with each payoff varies between questions. A risk-seeking subject would choose option B in the first question. On the other side, if a subject understands the instructions well, he/she should choose option B when dealing with question 10. So, if a subject understands the instructions well and is not a strong risk-seeker, then we expect he/she starts choosing option A then switches and chooses option B at some point. A subject's switching point is used to measure this subject's risk preference.

H.5 Instructions

"As we ran experiments on French population, all instructions provided here are translated from French. "

You are about to participate in a decision-making experiment. We ask you to read the instructions carefully, they will allow you to understand the experiment. When all participants have read these instructions, an experimenter will perform a read-aloud. All your decisions will be handled anonymously. You will only use the computer in front of which you are sitting for entering your decisions.

From now on, we ask you to stop talking. If you have a question, please raise your hand, and an experimenter will come to you to answer it.

This experiment consists in a series of 5 games. You will receive instructions for a game at the end of the previous game. Your payments for each game are either in experimental currency (ECU) or in euros. If the gain is in ECUs the conversion rate will be specified at the end of the instructions of Game 5.

At the end of this experiment one of the first two games and one of the last three games will be drawn randomly, and the sum of your payments for each game that has been drawn will constitute your earning for the experiment. Your earning in euros will be paid in cash at the end of the experiment.

Game 1[3]

At the beginning of the game, the server will randomly create groups of 3 members. You cannot identify other members of your group, and they cannot identify you. In each group there are three roles: player A, player B and player C. Each member of the group will have a randomly assigned role. Groups, as well as roles within each group, will remain unchanged throughout the game. You will be informed about your role at the beginning of the game.

The game has 10 consecutive periods. For each period, there are two stages:

1. Each member of the group chooses between the option "0" and the option "1" .

2. When all participants have made their choice, a screen is displayed. This screen provides you with information on the choices of the other members of your group and on your earning for the period.

The payment of each player depends on his/her role (player A, player B or player C), on his/her choice, and on the choices made by other members of his/her group. Table H.4 provides the payments of each player, according to his/her role and the combination of option 0 or option 1 chosen in the group. since there are three players in the group who each chooses either option 0 or option 1, we obtain a total of 8 possible combinations. Each row in this table corresponds to a given combination, which is provided in the second column. For example, line 4 states that players A and B have chosen option 0, while player C has chosen option 1. For this combination of choices, the gain of players A and B is 60 ECUs each, and the gain of player C is 10 ECUs.

Payment

[3]This game setting corresponds to the high inequality payoff treatment.

Table H.4: *Payoff matrix of game 4*

	Combinations	Payoffs		
	(A, B, C)	*A*	*B*	*C*
1	(0, 0, 0)	60	60	60
2	(1, 0, 0)	60	60	60
3	(0, 1, 0)	60	29	60
4	(0, 0, 1)	60	60	10
5	(1, 1, 0)	90	60	60
6	(1, 0, 1)	81	60	32
7	(0, 1, 1)	60	56	38
8	(1, 1, 1)	111	87	60

The payment for this game is equal to the sum of the payment in the first period and of the payment corresponding to one period that is randomly drawn among the other 9 periods.

Game 2[4]

The groups and the roles remain the same as in Game 1: you still belong to the same group, and hold the same role as in Game 1. As before, this game has 10 consecutive periods, and in each period you must choose between option “0” and option “1". For each period there are two stages:

1. Each member of the group makes a choice between option 0 and option 1.

2. When all participants have made their choice, a screen is displayed. This screen provides you with information on the choices of the other members of your group, and on your earning for the period.

The payment of each player depends on his/her role (player A, player B or player C), on his/her choice, and on the choices made by other members of his/her group. Table H.5 provides the gain of each player, according to his/her role and the combination of option 0 or option 1 chosen in the group. Since there are three players in the group who each chooses either option 0 or option 1, we obtain a total of 8 possible combinations. Each row in the table corresponds to a given combination, which is provided in the second column. For example, line 7 states that players B and C have chosen option 1, while player A has chosen option 0. For this combination of choices, the gain of player A is 60 ECUs, the gain of Player B is 30 ECUs, and the gain of Player C is 38 ECUs.

Payment

[4]This game setting corresponds to the low inequality payoff treatment.

Table H.5: *Payoff matrix of game 5*

	Combinations	Payoffs		
	(A, B, C)	*A*	*B*	*C*
1	(0, 0, 0)	60	60	60
2	(1, 0, 0)	60	60	60
3	(0, 1, 0)	60	29	60
4	(0, 0, 1)	60	60	10
5	(1, 1, 0)	61	60	60
6	(1, 0, 1)	61	60	32
7	(0, 1, 1)	60	30	38
8	(1, 1, 1)	62	61	60

The payment for this game is equal to the sum of the gain in the first period and of the gain corresponding to one period that is randomly drawn among the remaining 9 periods.

Game 3

At the beginning of the game, the server will randomly create pairs (groups of 2 members). You cannot identify the other member of your pair, and he/she cannot identify you. In each pair, one member is assigned the role of player E and the other is assigned the role of player R. You do not know whether you are player E or player R.

There are 11 questions in the game. For each question you must choose between option *X* and option *Y*. Each option corresponds to a payoff split between you and the other member of your pair.

There are two stages in the game:

1. Each member responds individually to each of the 11 questions provided in table H.6 which describes options *X* and *Y* for each question in the game.

2. The server reveals whether you are player E or player R. In each pair, the gain of each player will depend on the choices made by player E only.

Payment

At the end of the game, one question will be randomly drawn among the 11 questions. Your gain for this question will constitute your payment for the game.

Example:

At the end of the game, question 3 is drawn randomly.

If you are player E and you have chosen option *X* for this question, then your gain is 2 ECUs and the gain of the other member of your pair (player R) is 2 ECUs

too. If you have chosen option *Y* your gain is 10 ECUs, and the gain of the other member of your pair is 0 ECU .

If you are player R and the other member of your pair (player E) has chosen *X*, then your gain is 2 ECUs, and if he has chosen *Y* then your gain is 0 ECU.

Table H.6: *Illustration of the modified dictator game*

Questions	Options	Your choice
1	Option *X*: You earn 0 and your paired partner earns 0 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
2	Option *X*: You earn 1 and your paired partner earns 1 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
3	Option *X*: You earn 2 and your paired partner earns 2 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
4	Option *X*: You earn 3 and your paired partner earns 3 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
5	Option *X*: You earn 4 and your paired partner earns 4 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
6	Option *X*: You earn 5 and your paired partner earns 5 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
7	Option *X*: You earn 6 and your paired partner earns 6 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
8	Option *X*: You earn 7 and your paired partner earns 7 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
9	Option *X*: You earn 8 and your paired partner earns 8 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
10	Option *X*: You earn 9 and your paired partner earns 9 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O
11	Option *X*: You earn 10 and your paired partner earns 10 Option *Y*: You earn 10 and your paired partner earns 0	Option *X* O Option *Y* O

Game 4

In this game, there are two roles: player E and player R.

Player E has an endowment of 10 ECUs, which he/she must distribute between himself/herself and player R. Player R must then decide whether he/she accepts or rejects the distribution chosen by player E. If he/she accepts, the distribution is implemented and it determines the earning of each player. If he/she rejects, then each of the two players gains 0 ECU.

The game takes place in 3 stages:

1. Each participant is assigned the role of player E and must choose a distribution of the 10 ECUs.

2. Each participant is assigned the role of player R and must decide, for each of the 11 possible distributions ([10, 0], [9, 1], [8, 2] . . . [1, 9], [0, 10]), whether he/she accepts or rejects the distribution.

3. The server randomly forms pairs of participants, and for each pair the server

randomly assigns the roles of player E and of player R. A screen will provide information on your role.

Payment

Your payment will depend on your decisions and on the decisions made by the other member of your pair.

If you are assigned the role of player E, your payment depends on whether player R accepts or rejects your distribution choice. If player R has accepted the distribution you have chosen, then this distribution is implemented. If player R has rejected it, each member in the pair earns 0 ECU.

If you are assigned the role of player R, your payment depends on your decision to accept or reject the distribution chosen by player E. If you have accepted the distribution chosen by player E, then this distribution is implemented. If you have rejected this distribution, each member in the pair earns 0 ECU.

Example 1

You are player E. In stage 1 you chose to keep 7 ECUs and to offer 3 ECUs to player R.

If player R has decided to accept this distribution, then this distribution is implemented, you earn 7 ECUs and player R earns 3 ECUs.

If player R has rejected this distribution, then each member in the pair earns 0 ECU.

Example 2

You are player R. In stage 1 player E in your pair has chosen to keep 7 ECUs and to offer 3 ECUs.

If at stage 2 you decided to accept this distribution, then this distribution is implemented, you earn 3 ECUs and player E earns 7 ECUs.

If you rejected it, then each member in the pair earns 0 ECU.

Game 5

In this game, your payments depend solely on your individual choices.

There are 10 questions in the game. For each question you must choose one of the two options: option *A* or option *B*. Options are shown in Table H.7 below. Payments are in euros.

Payment

One of the 10 questions will be randomly drawn. A second draw will determine your payment based on the option (A or B) that you have chosen for the question

Table H.7: *Holt & Laury game table*

Questions	Options	Your choices
1	Option A: 1 chance out of 10 to earn 2,00€ and 9 chance out of 10 to earn 1,60€ Option B: 1 chance out of 10 to earn 3,85€ and 9 chance out of 10 to earn 0,10€	Option A O Option B O
2	Option A: 2 chance out of 10 to earn 2,00€ and 8 chance out of 10 to earn 1,60€ Option B: 2 chance out of 10 to earn 3,85€ and 8 chance out of 10 to earn 0,10€	Option A O Option B O
3	Option A: 3 chance out of 10 to earn 2,00€ and 7 chance out of 10 to earn 1,60€ Option B: 3 chance out of 10 to earn 3,85€ and 7 chance out of 10 to earn 0,10€	Option A O Option B O
4	Option A: 4 chance out of 10 to earn 2,00€ and 6 chance out of 10 to earn 1,60€ Option B: 4 chance out of 10 to earn 3,85€ and 6 chance out of 10 to earn 0,10€	Option A O Option B O
5	Option A: 5 chance out of 10 to earn 2,00€ and 5 chance out of 10 to earn 1,60€ Option B: 5 chance out of 10 to earn 3,85€ and 5 chance out of 10 to earn 0,10€	Option A O Option B O
6	Option A: 6 chance out of 10 to earn 2,00€ and 4 chance out of 10 to earn 1,60€ Option B: 6 chance out of 10 to earn 3,85€ and 4 chance out of 10 to earn 0,10€	Option A O Option B O
7	Option A: 7 chance out of 10 to earn 2,00€ and 7 chance out of 10 to earn 1,60€ Option B: 7 chance out of 10 to earn 3,85€ and 3 chance out of 10 to earn 0,10€	Option A O Option B O
8	Option A: 8 chance out of 10 to earn 2,00€ and 2 chance out of 10 to earn 1,60€ Option B: 8 chance out of 10 to earn 3,85€ and 2 chance out of 10 to earn 0,10€	Option A O Option B O
9	Option A: 9 chance out of 10 to earn 2,00€ and 1 chance out of 10 to earn 1,60€ Option B: 9 chance out of 10 to earn 3,85€ and 1 chance out of 10 to earn 0,10€	Option A O Option B O
10	Option A: 10 chance out of 10 to earn 2,00€ and 0 chance out of 10 to earn 1,60€ Option B: 10 chance out of 10 to earn 3,85€ and 0 chance out of 10 to earn 0,10€	Option A O Option B O

that has been randomly drawn.

Example

Question 3 is randomly drawn.

If you have chosen option A in question 3 then a second draw determines if you earn 2.00 € or 1.60 €. Specifically, the server randomly draws a number between 1 and 10. If this number is 1, 2 or 3 then you earn 2.00 € and if this number is 4, 5, 6, 7, 8, 9 or 10 then you earn 1.60 €.

If you have chosen option B in question 3 then a second draw determines if you earn 3.85 € or 0.10 €. Specifically, the server randomly draws a number between 1 and 10. If this number is 1, 2 or 3 then you earn 3.85 € and if this number is 4, 5, 6, 7, 8, 9 or 10 then you earn 0,10 €.

Conversion rate: 1 ECU = 0.09 €/ 1 €= 11.11 ECUs

Appendix I: Appendices of Chapter 4

I.1 Proof of Proposition 10

If the agents' full participation is a Nash equilibrium, then a deviation is not profitable for no one of them. Suppose that agent n, the agent ranked in the last position because, according to the standard theory Bernstein and Winter (2012), chooses to deviate from the full participation strategy profile $(p, p, ..., p)$. Recall that his outcome when he participates is at most equal to his outside option. This agent gets his reservation utility, that is

$$R_n(p, p, ..., np) = c - \frac{1}{n-1} a_n \sum_{i=1}^{n-1} \sum_{j=i}^{n-1} e_i(j); \tag{I.1}$$

$$\text{with} \quad s_1 = s_2 = .. = s_{n-1} = p, \ s_n = np \text{ and } n \geq 2$$

instead of his utility $U_n^{p,\ p,\ ....,\ p}$ when he participates with others, that is

$$U_n(p,\ p,\ ...,\ p) = c - \frac{1}{n-1} a_n \sum_{i=1}^{n} \sum_{j=i}^{n} e_i(j) \ \text{ with } \ n \geq 2 \tag{I.2}$$

This is equivalent to

$$U_n(p,\ p,\ ...,\ p) = c - \frac{1}{n-1} a_n \sum_{i=1}^{n-1} \sum_{j=i}^{n-1} e_i(j) - \frac{1}{n-1} a_n \sum_{i=1}^{n-1} e_i(n) \tag{I.3}$$

Therefore, the participation constraint $U_n(p,\ p,\ ...,\ p) \geq R_n(p, p, ..., np)$ of agent n is equivalent to

$$R_n(p, p, ..., np) - U_n(p,\ p,\ ...,\ p) = \frac{1}{n-1} a_n \sum_{i=1}^{n-1} e_i(n) \tag{I.4}$$

which is strictly positive since a_n and the heterogeneous externalities are positive. The reservation utility of agent n is greater than his utility when he participates with other agents. The deviation is therefore always profitable for this agent. Hence, the full participation strategy profile is not a Nash equilibrium.

I.2 Proof of Propositions 11-13

We first prove the following Lemma:

Lemma 9.1. *Assume that at the optimal contract is such that $\pi_i \geq \pi_j$. The contract that induces the participation of together agent i and agent j is a Nash equilibrium of the participation game if it is given by the vector $v = (v_i, v_j)$ such that v satisfies one of the following conditions:*

$$(a) \begin{cases} v_i \geq \max\{\frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i);\ c\} \\ v_j \geq \max\{c - e_j(i) + \frac{a_j}{1+a_j}e_i(j);\ c\} \end{cases} \text{, or}$$

$$(b) \begin{cases} c - e_i(j) - \frac{\beta_i}{(1-\beta_i)}e_j(i) \leq v_i \leq c \\ v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \\ v_j \leq c \end{cases} \text{, or}$$

$$(c) \begin{cases} v_i \geq c \\ v_j \geq c - e_j(i) + \frac{a_j}{1+a_j}e_i(j) \\ v_j \leq c \end{cases} \text{, or}$$

$$(d) \begin{cases} v_i \geq \frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i) \\ v_i \leq c \\ v_j \geq \max\{\frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j-\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j);\ c\} \end{cases}$$

Proof of Lemma 9.1:

We have $\pi_i \geq \pi_j$ which is exactly materialized by $v_i + e_i(j) \geq v_j + e_j(i)$.

If the full participation strategy profile, denoted by (p, p), is a Nash equilibrium of the game, then agents i as well as agent j do not have incentives to deviate from this strategy profile. In case of full participation, agent i obtains

$$U_i(p,\ p) = v_i + e_i(j) - \beta_i(v_i + e_i(j) - v_j - e_j(i)) \tag{I.5}$$

Agent j obtains

$$U_j(p,\ p) = v_j + e_j(i) - a_j(v_i + e_i(j) - v_j - e_j(i)) \tag{I.6}$$

However, in case of unilateral deviation, agent i and j get their reservation utilities captured by $R_i(np,\ p)$ and $R_j(p,\ np)$, respectively. Formally, we have

$$R_i(np,\ p) = c - a_i \max\{v_j - c; 0\} - \beta_i \max\{c - v_j; 0\} \tag{I.7}$$

$$R_j(p,\ np) = c - a_j \max\{v_i - c; 0\} - \beta_j \max\{c - v_i; 0\} \tag{I.8}$$

We can now analyze the conditions under which the full participation is a Nash equilibrium knowing that an agent chooses to participate if his utility of joining the project with the other agent is greater than his reservation utility when the other agent joins the project. We explore different cases.

Case 1: if $v_i \geq c$ and $v_j \geq c$

In this case, agent i's reservation utility is

$$R_i(np,\ p) = c - a_i(v_j - c)$$

Agent i then participates if his reservation utility $U_i(p,\ p) \geq R_i(np,\ p)$. This is equivalent to

$$(1 - \beta_i)v_i + (1 - \beta_i)e_i(j) + \beta_i v_j + \beta_i e_j(i) \geq (1 + a_i)c - a_i v_j$$

which is

$$v_i \geq \frac{1 + a_i}{1 - \beta_i}c - e_i(j) - \frac{\beta_i + a_i}{1 - \beta_i}v_j - \frac{\beta_i}{1 - \beta_i}e_j(i) \tag{I.9}$$

Agent j's reservation utility is given by

$$R_j(p,\ np) = c - a_j(v_i - c)$$

Thus, $U_j(p,\ p) \geq R_j(p,\ np)$ is equivalent to

$$(1 + a_j)v_j + (1 + a_j)e_j(i) - a_j v_j - a_j e_i(j) \geq (1 + a_j)c - a_j v_j$$

Which is equivalent to

$$v_j \geq c - e_j(i) + \frac{a_j}{1 + a_j}e_i(j) \tag{I.10}$$

The conditions for the full participation to be a Nash equilibrium is then given by

$$\begin{cases} v_i \geq c \\ v_j \geq c \\ v_i \geq \frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i) \\ v_j \geq c - e_j(i) + \frac{a_j}{1+a_j}e_i(j) \end{cases}$$

This is equivalent to

$$\begin{cases} v_i \geq \max\{\frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i);\ c\} \\ v_j \geq \max\{c - e_j(i) + \frac{a_j}{1+a_j}e_i(j);\ c\} \end{cases}$$

Case 2: if $c \geq v_i$ and $c \geq v_j$

In this case, agent i's reservation utility is given by

$$R_i(np,\ p) = c - \beta_i(c - v_j)$$

Thus, $U_i(p,\ p) \geq R_i(np,\ p)$ is equivalent to

$$(1-\beta_i)v_i + (1-\beta_i)e_i(j) + \beta_i v_j + \beta_i e_j(i) \geq (1-\beta_i)c + \beta_i v_j$$

<=>

$$v_i \geq c - e_i(j) - \frac{\beta_i}{1-\beta_i}e_j(i) \tag{I.11}$$

Agent j's reservation utility is instead given by

$$R_j(p,\ np) = c - \beta_j(c - v_i)$$

Thus, $U_j(p,\ p) \geq R_j(p,\ np)$ is equivalent to

$$v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \tag{I.12}$$

The conditions for the full participation to be a Nash equilibrium is then given by

$$\begin{cases} c \geq v_i \\ c \geq v_j \\ v_i \geq c - e_i(j) - \frac{\beta_i}{(1-\beta_i)}e_j(i) \\ v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \end{cases}$$

<=>

$$\begin{cases} c - e_i(j) - \frac{\beta_i}{(1-\beta_i)}e_j(i) \leq v_i \leq c \\ v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \\ v_j \leq c \end{cases}$$

Case 3: if $v_i \geq c$ and $v_j \leq c$

In this case, agent i's reservation utility is given by

$$R_i(np,\ p) = c - \beta_i(c - v_j)$$

The participation condition $U_i(p,\ p) \geq R_j(np,\ p)$ is then equivalent to

$$v_i \geq c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i) \tag{I.13}$$

Agent j's reservation utility is given by

$$R_j(p,\ np) = c - a_j(v_i - c)$$

The participation condition $U_j(p,\ p) \geq R_j(p,\ np)$ is equivalent to

$$v_j \geq c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) \tag{I.14}$$

The conditions for the full participation to be a Nash equilibrium is then

$$\begin{cases} v_i \geq c \\ c \geq v_j \\ v_i \geq c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i) \\ v_j \geq c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) \end{cases}$$

Since $c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i) < c$, this is equivalent to

$$\begin{cases} v_i \geq c \\ v_j \geq c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) \\ v_j \leq c \end{cases}$$

Case 4: if $v_j \geq c$ and $v_i \leq c$

In this case, the reservation utility of agent i is given by

$$R_i(np,\ p) = c - a_i(v_j - c)$$

Thus, the participation condition $U_i(p,\ p) \geq R_i(np,\ p)$ is equivalent to

$$v_i \geq \frac{1+a_i}{1-\beta_i} c - e_i(j) - \frac{\beta_i + a_i}{1-\beta_i} v_j - \frac{\beta_i}{1-\beta_i} e_j(i) \tag{I.15}$$

On the other hand, the reservation utility of agent j is given by

$$R_j(p,\ np) = c - \beta_j(c - v_j)$$

The participation condition for this agent is then equivalent to

$$v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \qquad \text{I.16}$$

Therefore, the conditions for the full participation is

$$\begin{cases} v_j \geq c \\ c \geq v_i \\ v_i \geq \frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i) \\ v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \end{cases}$$

Which gives

$$\begin{cases} v_i \geq \frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i) \\ v_i \leq c \\ v_j \geq \max\{\frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j);\ c\} \end{cases}$$

This concludes the proof of the Lemma.

Assume that $\pi_i \geq \pi_j$. The set of contracting schemes that satisfy the participation of all agents as a Nash equilibrium is given by

(a) $\begin{cases} v_i \geq \max\{\frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i);\ c\} \\ v_j \geq \max\{c - e_j(i) + \frac{a_j}{1+a_j}e_i(j);\ c\} \end{cases}$, or

(b) $\begin{cases} c - e_i(j) - \frac{\beta_i}{(1-\beta_i)}e_j(i) \leq v_i \leq c \\ v_j \geq \frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j) \\ v_j \leq c \end{cases}$, or

(c) $\begin{cases} v_i \geq c \\ v_j \geq c - e_j(i) + \frac{a_j}{1+a_j}e_i(j) \\ v_j \leq c \end{cases}$, or

(d) $\begin{cases} v_i \geq \frac{1+a_i}{1-\beta_i}c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i}v_j - \frac{\beta_i}{1-\beta_i}e_j(i) \\ v_i \leq c \\ v_j \geq \max\{\frac{1-\beta_j}{1+a_j}c - e_j(i) + \frac{a_j+\beta_j}{1+a_j}v_i + \frac{a_j}{1+a_j}e_i(j);\ c\} \end{cases}$

Now, we seek the least costly vector of reward that belongs to these sets.

Doing so, let us first examine the condition (a). Since the maximum reward is at least equal to c, we can simply infer that the offer that minimize the principal's

cost according to the conditions in (a) is such that

$$\begin{cases} \upsilon_i = c \\ \upsilon_j = c \end{cases}$$

The total cost for this offer is then equal to $2c$.

Now, consider the condition (b). For this condition, we can simply observe that the minimum υ_i is such that

$$\upsilon_i = c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i)$$

Thus, plugging the minimum of υ_i into the expression of υ_j, we obtain the minimum υ_j since at the minimum, υ_j increases with υ_i. We then have

$$\upsilon_j = c - (1 + \frac{(a_j + \beta_j)\beta_i}{(1+a_j)(1-\beta_i)}) e_j(i) - \frac{\beta_j}{1+a_j} e_i(j)$$

Therefore, the offer that minimizes the principals cost in (b) is such that

$$\begin{cases} \upsilon_i = c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i) \\ \upsilon_j = c - (1 + \frac{(a_j+\beta_j)\beta_i}{(1+a_j)(1-\beta_i)}) e_j(i) - \frac{\beta_j}{1+a_j} e_i(j) \end{cases}$$

The total cost of this offer is strictly lower than $2c$.

Exploring now the condition (c), we simply deduce that $\upsilon_i = c$ is the minimum offer for the principal while the minimum υ_j can be either equal to c or $c - e_j(i) + \frac{a_j}{1+a_j} e_i(j)$. This leads us to consider 2 cases.

Case 1: $c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) < c$

In the case, the optimal offer is such that

$$\begin{cases} \upsilon_i = c \\ \upsilon_j = c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) \end{cases}$$

and the total cost is equal to $2c - e_j(i) + \frac{a_j}{1+a_j} e_i(j)$. Note that the total cost is lower than $2c$ in this case.

Case 2: $c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) \geq c$

In this case, the optimal rewards is such that

$$\begin{cases} \upsilon_i = c \\ \upsilon_j = c \end{cases}$$

The total cost of this offer is equal to $2c$.

Finally, consider the condition (d). We analyze two cases to derive all the

possible minimal offers for the principal.

Case 1: $\upsilon_i = c$

In this case, the minimum rewards are such that

$$(\gamma_1^*)\begin{cases} \upsilon_i = c \\ \upsilon_j = c \end{cases}$$

And the total cost of this offer is equal to $2c$. In this case, the minimum offer that be also given by

$$(\gamma_2^*)\begin{cases} \upsilon_i = c \\ \upsilon_j = c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) \end{cases}$$

The total cost of this offer is equal to $2c - e_j(i) + \frac{a_j}{1+a_j} e_i(j)$. This implies that the offers in γ_2 is better off if and only if $c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) < c$.

Case 2: $\upsilon_i = \frac{1+a_i}{1-\beta_i} c - e_i(j) - \frac{\beta_i+a_i}{1-\beta_i} \upsilon_j - \frac{\beta_i}{1-\beta_i} e_j(i)$

Two results corresponding to the minimum offer for the principal can hold.

$$(\gamma_3^*)\begin{cases} \upsilon_i = c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i) \\ \upsilon_j = c \end{cases}$$

Yet, this condition can not satisfy the assumption $\pi_i \geq \pi_j$. Therefore, the remaining offer is such that

$$(\gamma_4^*)\begin{cases} \upsilon_i = c + \frac{a_i a_j (e_j(i) - e_i(j)) + (\beta_i - a_j - 1) e_i(j) + a_i e_j(i)}{a_i a_j + a_i \beta_j + \beta_i \beta_j + a_j - \beta_i + 1} \\ \upsilon_j = c + \frac{\beta_i \beta_j (e_i(j) - e_j(i)) + (\beta_i - a_j - 1) e_j(i) - \beta_j e_i(j)}{a_i a_j + a_i \beta_j + \beta_i \beta_j + a_j - \beta_i + 1} \end{cases}$$

Notice that υ_j should be at least as greater than c.

Knowing the minimum offer for each case, we can now figure out the optimal partial implementation for the principal. First, remark all offers that cost $2c$ in total for the principal are dominated by the offer corresponding to condition (b). This is the case for condition (a), for condition (c) case 2 and for condition (d), case 1, γ_1^*. we can rule out these offer and it remains the condition (c) case 1, the condition (d) case 1, γ_2^*, which has the same total cost than condition (c) case 1, and finally the condition (d) case 2, γ_4^*.

Exploring the condition (c) case 1, we can observe that $c > c - e_i(j) - \frac{\beta_i}{1-\beta_i} e_j(i)$ and $c - e_j(i) + \frac{a_j}{1+a_j} e_i(j) > c - (1 + \frac{(a_j+\beta_j)\beta_i}{(1+a_j)(1-\beta_i)}) e_j(i) - \frac{\beta_j}{1+a_j} e_i(j)$ since the difference is equivalent to $\frac{a_j+\beta_j}{1+a_j} e_i(j) + \frac{a_j+\beta_j}{1+a_j} \frac{\beta_i}{1-\beta_i} e_j(i)$ which is strictly positive. Therefore, we can argue that the minimum offer in condition (b) dominates the ones in condition (c) case 1 and condition (d) case 1, γ_2^*. We also eliminate these conditions. The remaining condition is the condition (d) case 2, γ_4^*.

For this condition, we know that $v_j \geq c$. Therefore, $c+\frac{\beta_i\beta_j(e_i(j)-e_j(i))+(\beta_i-a_j-1)e_j(i)-\beta_j e_i(j)}{a_ia_j+a_i\beta_j+\beta_i\beta_j+a_j-\beta_i+1} > c-(1+\frac{(a_j+\beta_j)\beta_i}{(1+a_j)(1-\beta_i)})e_j(i)-\frac{\beta_j}{1+a_j}e_i(j)$. Now, let us compare $c+\frac{a_ia_j(e_j(i)-e_i(j))+(\beta_i-a_j-1)e_i(j)+a_ie_j(i)}{a_ia_j+a_i\beta_j+\beta_i\beta_j+a_j-\beta_i+1}$ and $c-e_i(j)-\frac{\beta_i}{1-\beta_i}e_j(i)$. The difference is equivalent to $\frac{(a_ia_j+a_i)e_j(i)+(a_i\beta_j+\beta_i\beta_j)e_i(j)}{a_ia_j+a_i\beta_j+\beta_i\beta_j+a_j-\beta_i+1}+\frac{\beta_i}{1-\beta_i}e_j(i)$ which is strictly positive. Hence, the offer in condition (b) dominates all the other offers.

Therefore, the least expensive offer (partial implementation) is such that

$$\begin{cases} v_i = c - e_i(j) - \frac{\beta_i}{1-\beta_i}e_j(i) \\ v_j = c - (1+\frac{(a_j+\beta_j)\beta_i}{(1+a_j)(1-\beta_i)})e_j(i) - \frac{\beta_j}{1+a_j}e_i(j) \end{cases}$$

This result applies if and only if $\pi_i \geq \pi_j$, meaning that

$$c - e_i(j) - \frac{\beta_i}{1-\beta_i}e_j(i) + e_i(j) \geq c - \frac{(1+a_j)(1-\beta_i)+(a_j+\beta_j)\beta_i}{(1+a_j)(1-\beta_i)}e_j(i) - \frac{\beta_j}{1+a_j}e_i(j) + e_j(i)$$

After simplification, we obtain the following condition

$$e_j(i) \leq \frac{\beta_j(1-\beta_i)}{\beta_i(1-\beta_j)}e_i(j)$$

Notice that in the case where $\pi_j \leq \pi_i$, the proof is the same up to a permutation of i and j;

I.3 Proof of Corollary 1

The reward paid to agent 1 is larger than the reward paid to agent 2 if and only if:

$$c - e_1(2) - \frac{\beta_1}{1-\beta_1}e_2(1) \geq c - e_2(1) - \frac{(a_2+\beta_2)\beta_1}{(1+a_2)(1-\beta_1)}e_2(1) - \frac{\beta_2}{1+a_2}e_1(2), \quad \text{I.17}$$

or,

$$\frac{\beta_2}{1-\beta_2}e_1(2)\left[1-\frac{\beta_2+a_2}{1+a_2}\right] - \frac{\beta_1}{1-\beta_1}e_2(1)\left[1-\frac{\beta_2+a_2}{1+a_2}\right] \geq e_1(2) - e_2(1), \quad \text{I.18}$$

which is equivalent to:

$$\frac{1+a_2}{1-\beta_2}\left[e_1(2)-e_2(1)\right] \leq \frac{\beta_2}{1-\beta_2}e_1(2) - \frac{\beta_1}{1-\beta_1}e_2(1). \quad \text{I.19}$$