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MODELS OF INDIVIDUAL AND STRATEGIC BEHAVIOUR: THEORY AND EXPERIMENTS

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Contents

Preface

I thank my parents, Fedele and Rina, for the unconditional trust and the everlasting support they always gave me.

I do not know the best way to say "thank you" to Professor Aldo Montesano and Professor Pierpaolo Battigalli for what they have done for me during the last five years at Bocconi. I could start by saying that, without the help and the advice of the former, I would have never started my PhD, without the advice and the help of the latter, I would have never completed it.

Professor Aldo Montesano is one of the few "gentlemen" left in this world. He is always modest, helpful and kind; in all our academic discussions, he never boasted his deep cultural background and the huge flow of economic knowledge he was transferring on to me.

For what concerns prof. Pierpaolo Battigalli, despite our Catullian "*odi et amo*" professional relationship, I can confirm *in toto* what everyone told me about him before our first meeting: "He is one of the best game theorists one could find in the worldwide academia". Working under his supervision is one of the few possibilities a graduate student - doing his PhD in Italy - has in order to get to the frontier of economic research.

I also thank Professor Andreu Mas-Colell and Professor Rosemarie Nagel for the precious advice and the enthusiasm they have offered to me while visiting Universitat Pompeu Fabra.

I will never forget the first time I met Professor Mas-Colell, when he said: "Come on, Attanasi, explain to me what these psychological games are. I am completely ignorant on that matter". His direct and unsophisticated way of being surprised me: I already knew he was a very famous economist. From that moment onward, I have discovered he is also a great man.

Finally, I have to thank Rosemarie Nagel for the professional help and the deep personal advice she gave me in one of the worst moments of my research activity. She helped me to resume work at a time when I believed I was no longer able to continue.

This work is dedicated to Francesco, who disappeared from my sight and from this world a cold night of the last February. He was not only my brother, but also the best man I had known from the day I was born. He will never disappear from my life, he will never leave my heart: a part of me has died with him, a part of him survives with me. To whom, to his ideas, to his dreams I will try to dedicate my life itself.

Introduction

Our thesis can be logically divided into two main subsections: the first one is mainly focused on economic agents' individual behaviour, when not interacting with other agents; the second analyzes agents' strategic behaviour, both from a theoretical and from an experimental point of view. *Chapter 1* belongs to the first subsection. *Chapters 2* and *3* form the second one.

The aim of *Chapter 1* is to analyze environmental decisions under uncertainty and irreversibility, by introducing a value - the *Testing Value*. This value emerges in all those situations in which the level of information concerning future economic benefits of development (and its future environmental costs) depends on the level of development carried out. We show that including the Testing Value into the analysis could push the decision maker towards a higher level of preservation of the environmental resource.

The reason is that the Testing Value leads the decision maker to develop only a certain amount of the environmental asset (*internal solutions*); on the contrary, the Waiting or Quasi-Option Value (widely used in the environmental literature) would lead more frequently to *corner solutions*. In other words, we prove that when the decision maker is faced with an intertemporal environmental choice problem where information is endogenous, destroying now a small part of an environmental resource induces her to destroy less in the future.

The main goal of *Chapter 2* is to study in an experimental setting the relations between actions and beliefs and those between actions and feelings (expressed in terms of belief-dependent motivations), through the application of psychological game theory.

Even though one traditional assumption in neoclassical economics has been material self-interest, in the last few decades economists have studied the role played by *emotions* in generating human behavior (i.e. actions), hence suggesting general ways of incorporating emotions and feelings into the economic models. In particular, it has been widely accepted in the economic theory that *feelings* can be expressed in terms of *belief-dependent motivations*, for example in terms of one's expectations about other agents' actions (first-order beliefs) and in terms of one's guess about other agents' expectations about her own action (second-order beliefs) and so on. Many experimental economists have studied these relations within *one-shot* interactions, allowing for *ex-post explanations* claiming for belief-dependent motivations as source of the "irregularities" in the experimental results.

Our experimental study goes three steps beyond the existing experimental literature: (*a*) we test players' behavior in a *finitely repeated game*, in which we elicit beliefs at the beginning of each period; (*b*) we elicit players' *sensitivity to feelings* (as guilt aversion or reciprocity), in order to analyze the relationships between actions, beliefs and feelings in a *dynamic* setting: the evolution of beliefs, their correlation with the played action profile and the way through which they incorporate players' feelings; (*c*) we test *directly* games with beliefs-dependent payoffs, i.e. *psychological games*: we study whether psychological payoffs depend (only) on the beliefs of others, as Battigalli and Dufwenberg (2005) suggest.

Hence, we propose experimentally a repeated game of trust in which the psychological payoffs of one of the two players (the trustee) are gleaned by means of a questionnaire and transmitted to the other player (the truster) before the game is played. We call this experimental procedure "*questionnaire-transmission treatment*", as opposed to the "*standard treatment*", in which psychological payoffs are not measured and transmitted before the game is played. In this second case, the impact of 'belief-dependent' motivations can be inferred only ex-post as one of the possible explanations for the deviations of the experimental results from those predicted by *traditional* game theory. This aspect is in line with what Charness and Dufwenberg (2004) do.

Our experimental results show that eliciting and transmitting the psychological payoffs and letting the two players play the *complete information* (repeated) game of trust leads them to behave in a visibly different manner (with respect to their behavior in the corresponding *incomplete information* game setting). More precisely, the *public information* of the psychological payoffs in the (repeated) game of trust results in players' perception of feelings like guilt aversion and/or reciprocity which otherwise would be underestimated. That in turn ends in a more cooperative behavior for both players. Moreover, our experimental results on the repeated psychological game demonstrate how feelings' sensitivity elicitation and transmission (needed to measure and communicate experimentally the psychological payoffs) enhance cooperation more than the traditional repeated-game reputation building explanation would suggest: reputation building arguments would ensure cooperation until a couple of periods from the end of the repeated game. Specific belief-dependent motivations incorporated in the psychological payoffs (e.g. guilt aversion) frequently lead to trust and cooperation until the *last* stage of the repeated game.

Chapter 3 focuses on private or interdependent valuations and independent or correlated signals. Our goal is design experiments to test the assumption that bidders' conjectures are *strategically sophisticated* (hence consistent with a careful introspective analysis of the game), but not necessarily *correct.*

The analysis of simultaneous bidding games generally builds upon the notion of (Bayesian) Nash equilibrium, in which are implicit the assumptions that players are rational and hold *correct* conjectures about the bidding behavior of their opponents. Battigalli and Siniscalchi (2003) make a first step forward in the analysis of simultaneous bidding games: they do not assume equilibrium behavior in first-price sealed-bid auctions and show theoretically that although strategic sophistication of bidders' conjectures has nontrivial implications for bidding behavior, it is consistent with a wide range of *non-equilibrium beliefs.* Hence, introspection alone does not provide a justification for equilibrium analysis.

Their theoretical findings suggest that it may be interesting to test experimentally the extent to which the predictions of standard auction theory are dependent on the assumption that bidders' conjectures are correct.

What we think it can be shown through experiments, is that even if bidders are strategically sophisticated there are no compelling reasons to assume approximate equilibrium behavior in the short run. For example, one may think at the fact that, in recent years, many novel auction designs have been implemented in practice: when faced with such "novelties", bidders cannot be expected to have learned the shape of each other's valuation functions, each other's signal distribution, and so on. In such situations, we find the case for an analysis based on strategic sophistication alone, particularly compelling.

Part I

Models of Individual Behaviour

Chapter 1

Testing value *vs* Waiting value: a more general approach to Environmental Decisions under Uncertainty and Irreversibility

1.1 Introduction

1.1.1 The "history" of the Waiting Value

The issue of irreversibility and uncertainty in environmental decisions has been largely analyzed in the last three decades. From the first definition of the *Quasi-Option Value* (*QOV*), given by Arrow and Fisher (1974), the key concept has been developed in several articles, among others, by Henry (1974), Dasgupta and Heal (1979), Hanemann (1982, 1989), Fisher and Krutilla (1985), Beltratti, Chichilnisky and Heal (1996), Fisher (2000), Pindyck (2000).

Arrow and Fisher (1974), while examining the optimal level of development of a natural resource, identified a concept that they termed "quasi-option" value. The concept emerged from a two-period model of choice (develop or preserve), where development is irreversible [1] and the expected net benefits of preservation in future periods are conditional upon the choice in the present period.

Fisher and Hanemann (1987) [2] started their analysis using the same context of Arrow and Fisher's model, characterized by *risk neutrality* of the *D*ecision *M*aker (*DM* henceforth), *irreversibility* of the action "development", *uncertainty* about the future benefits (of development and preservation) and by independent learning (*exogenous information*): the *DM* can receive *new* information about the environmental asset (about the future benefits of his action) only by letting time pass; the acquisition of information is independent from the choice made in the first period.[3] More specifically, in Fisher and Hanemann's model, there are two alternative scenarios for the acquisition of information about the future consequences of development. In the first scenario, *exogenous* information is *available* (and it is known it will be available) *with certainty* at the end of the first period, in sufficient time to be incorporated into the decision to be taken in the second (and last) period; in this scenario, the prospect of future information is fully recognized and incorporated explicitly in the current decision. In the second information scenario, either information is *not available* (and it is known that it will be not available) in sufficient time to be incorporated into the choice in the future period or it is *disregarded* by the *DM* when he sets the current level of development.

[1] In the sense that development of the environmental resource can take place either "now" or "in the future" but, once undertaken, it is irreversible.

[2] See also Hanemann (1989), Fisher (2000).

[3] In particular, information can emerge by only "waiting" (as the second period approaches, one is able to make a more accurate assessment of the social value of wilderness preservation in that period) or as the result of a separate research program.

Let us identify with c_t the amount of environmental resource preserved in period $t = 1, 2$, with $q \in [0, 1]$ the probability of acquiring new information exogenously at the end of period 1 and assume that the level of the environmental resource is normalized to 1. If we define with $EV_{exo|q=1}(c_1)$ the expected net benefits over both periods (of preserving c_1 in the first period) under the first information scenario [4] and with $EV_0(c_1)$ the same expected net benefits under the second information scenario, requiring the investment decision to be confined to a binary choice between full development ($c_1 = 0$) and no development at all ($c_1 = 1$), Fisher and Hanemann define as option value *à la* Arrow-Fisher (*Quasi-Option Value*)

$$QOV = \left[EV_{exo|q=1}(1) - EV_{exo|q=1}(0)\right] - \left[EV_0(1) - EV_0(0)\right]$$

This is a correction factor, that can be interpreted in the following way: let us rewrite the QOV as

$$QOV = \left[EV_{exo|q=1}(1) - EV_0(1)\right] - \left[EV_{exo|q=1}(0) - EV_0(0)\right]$$

In the terminology of decision theory, $\left[EV_{exo|q=1}(1) - EV_0(1)\right]$ is the value of perfect information conditional on having preserved the whole environmental area in $t = 1$ (it is the gain deriving from exogenous information when choosing c_2 conditional on having set $c_1 = 1$). Similarly, $\left[EV_{exo|q=1}(0) - EV_0(0)\right]$ is the value of perfect information conditional on having destroyed the whole environmental area in $t = 1$. The QOV is the difference between these two values. But irreversibility creates asymmetry: if one decides to preserve initially, he can always reverse that decision later when he obtains more accurate information about the consequences of development; on the contrary, if he decides to develop (everything) now ($c_1 = 0$), the decision cannot be reversed and any subsequent information he may receive has no economic value. Hence, $EV_{exo|q=1}(0) = EV_0(0)$ and the expression of the option value *à la* Arrow-Fisher becomes

$$QOV = EV_{exo|q=1}(1) - EV_0(1)$$

Consequently, the QOV is always non-negative,[5] since (exogenous) information is not

[4] Remember that in the first information scenario new information comes about *exo*genously with certainty, hence $q = 1$.

[5] However, when there is a continuum of preservation (development) levels, rather than a binary choice between full development and full conservation, this conclusion needs to be modified. Let $c_1 \in [0, 1]$ and $c_2 \in [0, c_1]$, because of irreversibility. Analyzing this case, Epstein (1980) established that it is not necessarily true that $(c_1^*)_{exo|q=1} \geq (c_1^*)_0$. He developed also a set of sufficients conditions for Arrow

dangerous, so that $EV_{exo|q=1}(1) - EV_0(1) > 0$. A decision to set $c_1 = 1$ preserves flexibility, and the QOV is the value of such flexibility. In particular, it is the gain the DM obtains when he can receive (exogenous) information regarding future benefits, *if* he decides not to develop in the current period (with respect to the case in which he ignores the possibility of receiving this kind of information).[6]

This does not mean that developing in the first period should never be optimal, hence $(\hat{c}_1)_{exo|q=1}$ could be different from 1; after all, it may happen that $EV_{exo|q=1}(1) < EV_{exo}(0)$.

Rather, it means that the case for preservation is strenghtened when one recognizes the prospect of further information about the future consequences of development: in general, the amount of environmental resource preserved under the first information scenario is higher, i.e. $(\hat{c}_1)_{exo|q=1} \geq (\hat{c}_1)_0$.

According to the definition of Arrow and Fisher (1974), the QOV is a particular "Waiting Value", i.e. a value emerging when the DM "stands by" in the current periods, moving his decision to the future when new (exogenous) information may be available. Differently from the definition above, the interpretation we give of the waiting value (intended as the money the DM is willing to pay in order to shift the decision from now to the future) is closer to the formulation of Conrad (1980) and Miller and Lad (1984): Conrad (1980) states that the QOV - so defined - is identical to the expected net value at time $t = 1$ of information in c_1; Miller and Lad (1984) state that "the existence of a QOV, as defined generally, depends only the name on the irreversible character of development. Under conditions of irreversibility, an option value is called a QOV. But any option value, quasi or otherwise, stems from the relative values of flexible and inflexible decisions, not from the existence of irreversibility per se".

In line with Conrad's and Miller's and Lad's intuitions, we agree that, in general, a waiting value (whose family the QOV belongs) has to be interpreted as the difference between the expected value of the *optimal flexible decision* and that of the *optimal fixed decision*: this difference is greater than zero. Hence, we define in general the *Waiting Value* (WV henceforth) as

$$WV = EV_{exo}((\hat{c}_1)_{exo}) - EV_0((\hat{c}_1)_0)$$

and Fisher's result to carry over when there is a continuum of preservation (development) levels.

[6] Another interpretation: if the DM ignored the possibility of exogenously acquiring information about the future benefits of development/preservation and myopically based his decision on the maximization of $EV_0(c_1)$, QOV is the shadow tax that would have to be imposed on development in order to steer him the correct choice on whether or not to develop at all.

In the first information scenario, the DM can choose c_2 after having received (with a given probability $q \in (0,1]$) information about the relative benefits of the second period (what Miller and Lad called *flexible decision*); hence, we indicate with $EV_{exo}(c_1)$ the expected value of net benefits over both periods (of preserving c_1 in the first period) when (only) exogenous information arrives with probability $q \in (0,1]$ at the end of period 1.

In the second information scenario, where the myopia of the DM prevents him from recognizing the possibility of acquiring new information exogenously, the optimal choices of c_1 and c_2 are made simultaneously in the first period (what Miller and Lad called *inflexible decision*). [7]

According to our formulation of the problem, the QOV *à la* Arrow-Fisher becomes a particular case of WV that comes around when the DM chooses to preserve the entire environmental resource in the first period: it is the expected value of information conditional on having set $\hat{c}_1 = 1$. Also, it has to be intended as the upper bound of the WV, since, by preserving everything in the first period, the DM, in the second period, can choose an action in the same set of possible actions available in the first period. Hence, $QOV \geq WV$ [8].

1.1.2 The need for a Testing Value

The conclusions drawn by Arrow and Fisher (1974) and Fisher and Hanemann (1987) on the QOV still hold, even if the cost of information is included in the model.[9]

On the other hand, independently from the fact that information arrives at a cost or not, Arrow and Fisher's results on the optimality of a complete preservation of environmental resources when their destruction is irreversible are derived in the framework of *independent learning*, i.e. with exogenous information.

It is commonly accepted in the literature on environmental option values that this

[7] Hence the DM chooses the amount of c_2 without knowing the realizations of the second period benefits.

[8] Fisher and Hanemann (1987) suppose that, in what we called the "exogenous information scenario", information arrives with probability $q = 1$. We instead generalise such framework by allowing information to come out not with certainty, but according to a given probability $q \in (0,1]$. See Section 1.3.2 for a complete analysis of this more general case.

[9] They recognize the fact that information about the consequences of development arriving automatically, by simply letting time get by, is unrealistic (or, at least, rare): the acquisition of information usually requires the expenditure of resources and occurs only if some (other) agents take appropriate actions. Indeed, if the cost of information exceeded the expected value of information given $c_1 = 1$, the difference $EV_{exo|q=1}(1) - EV_0(1)$ would be negative, hence it would not be optimal for the DM to acquire it.

result does not hold if *information* is *endogenous* (i.e., *dependent learning*). Miller and Lad (1984) and Freeman (1984) stated that *"if information concerning future effects of the irreversible depletion of an environmental resource can be obtained only carrying out depletion itself in $t = 1$, than it is optimal to develop (only) one portion of the environmental asset in the current period"*. In other words, the policy of postponing the choice in order to enable the DM to profit from the coming information is sub-optimal when this is endogenous: if the uncertainty is primarily about the benefits of preservation/development, this strengthens the case for some development. On the other hand, even when more information is provided solely by development, *substantial* development [10] may not be in order.

Freeman (1984) and Fisher and Hanemann (1987) assume that *full* information is provided by *any* amount of development; moreover, no exogenous information arrives. Let us identify with $\lambda \in [0,1]$ the probability of acquiring new information endogenously; the resulting expected value function under this scenario, denoted as $EV_{endo|\lambda=1}(c_1)$, is equivalent to that in the "no-information" scenario, EV_0, in the event no development is undertaken, and to that in the "new exogenous information" (with certainty) scenario, $EV_{exo|q=1}$, in the event *any* development is undertaken [11]. In symbols, [12]

$$EV_{endo|\lambda=1}(c_1) = \begin{cases} EV_0(1) & \text{if} \quad c_1 = 1 \\ EV_{exo|q=1}(c_1) & \text{if} \quad c_1 \in [0,1) \end{cases}$$

Several results follow form this (particular) formulation of the problem:
1) It can never be optimal to preserve the whole amount of the environmental resource, i.e. $(\hat{c}_1)_{endo} \neq 1$.
2) There is still a corner solution for c_1, in the sense that one either develops fully now, i.e. $(\hat{c}_1)_{endo} = 0$, or engages in an infinitesimal amount $\varepsilon > 0$ of development, i.e. $(\hat{c}_1)_{endo} = \varepsilon$.
3) The QOV *of the minimum feasible development* (ε *− development*), defined as

[10] To be intended as the destruction of a high proportion of the environmental area.

[11] As one can notice, this is a very particular information structure, where only a very particular "kind" of endogenous information is allowed: the new information coming around when any level of development is undertaken is of the same "kind" we discover under the exogenous information context. We maintain this assumption in our model. As in the exogenous information case, we instead do not maintain the assumption that information arrives endogenously with certainty (i.e., $\lambda = 1$) and that the level of the information received is independent from c_1. See Section 1.3.3 for that.

[12] Notice that we indicate with $EV_{endo|\lambda=1}$ the expected value of endogenous information given that it will come with probability $\lambda = 1$ in case of (some) development of the environmental resource.

$$QOV_\varepsilon = EV_{endo|\lambda=1}(\varepsilon) - EV_0(\varepsilon)$$

is always positive.
4) $(\hat{c}_1)_{endo} \geq (\hat{c}_1)_0$, i.e. if the decision is to develop when one disregards the possibility of dependent learning, the correct decision when recognizing this possibility cannot be more development and may be less.

The specificity of Freeman's (1984) and Fisher and Hanemann's (1987) results on the QOV_ε raises doubts as to whether the policy implications of the described environmental decision problem could depend on the precise manner in which development generates information (i.e., on the form of the "information production function"). Hence, in our framework (Section 2.1 and 2.2) we try to model endogenous uncertainty in order to be as much "general" and "near to reality" as possible.

First of all, contrarily to what is assumed in the environmental option values literature, we think there are a large number of environmental problems in which the possibility of acquiring new information endogenously depends on the "size" of the development the DM chooses to perform. In the case of oil extraction in one country, for example, there may be uncertainty as to whether and where the land contains oil in commercial quantities. If this is the case, it is likely that the uncertainty can be solved by undertaking some development. But it is doubtless that if you drill the land (by destroying a part of the natural resource) the deeper you drill the higher the probability of discovering an oil well. Another example: if you destroy only one or two trees of the Amazon forest, you obtain very little information about the possible extinction of a certain species. If instead you keep on destroying a larger portion of the forest, you can obtain higher information about the pervasive effects of the development activity. Thus, it seems plausible that, in case information comes out through development of the natural resource, *the level of information coming out must depend on the level of development carried out.* In other words, it must be inversely related to c_1. This is an assumption we introduce in our model, when we characterize the endogenous information framework.

Moreover, differently from Fisher and Hanemann's QOV_ε, we define the *Testing Value* (TV, henceforth) not as the difference between $EV_{endo|\lambda=1}(\varepsilon)$ and $EV_0(\varepsilon)$ but rather as

$$TV = EV(c_1^*) - EV_{exo}((\hat{c}_1)_{exo})$$

where $EV(c_1)$ is the expected value of net benefits when there is *both exogenous* (arriving with probability $q \in (0,1])$ *and endogenous* (arriving with probability $\lambda \in (0,1]$, whose level is decreasing in c_1) information[13]; c_1^* is the optimal preservation level in the current period, under this information structure.

According to our definition, the TV has to be interpreted as the *additional value attached to endogenous information,* additional with respect to information exogenously arriving. In other words, it is the gain the DM obtains when he can receive information regarding future benefits, by developing in the current period (with respect to the case in which he ignores the possibility of receiving information in this way). Obviously, if $c_1^* = 1$, there is only exogenous information, then $EV \equiv EV_{exo}$ and also $(\hat{c}_1)_{exo} = 1$; hence, in this case, $TV = 0$ [14].

The QOV *of the minimum feasible development* defined by Freeman (1984) and Hanemann and Fisher (1987) becomes a particular TV that emerges when the following two conditions are contemporaneously satisfied:

- only endogenous information is available (exogenous information is completely absent);

- information coming out is the same for every $c_1 \in [0,1)$.

1.2 The Model

1.2.1 Assumptions and notation

Let us consider a two-period model of choice ($t = 1,2$), where in $t = 1$ the DM has to choose the amount of environmental resource he wants to preserve (not develop) until t =2. Assuming the level of the environmental resource is normalized to 1, let us indicate with $c_1 \in [0,1]$ the amount preserved in period 1. We indicate with b_1 the marginal net benefit deriving from the decision of preserving at time $t = 1$ [15]. We assume current net benefits from preservation are known with certainty by the DM and are negative, i.e.

[13] In what follows, we also define $EV_{|q+\lambda=1}(c_1)$ as the expected value of net benefits when both exogenous and endogenous information is available, given that the sum of the probability that it comes out is equal to 1 ($q + \lambda = 1$).

[14] For the properties of the Testing Value, see Section 1.4.3.

[15] Marginal net benefits in period t, b_t, could be interpreted as

$$b_t = (pb_t - pc_t) - (db_t - dc_t)$$

where pb_t, pc_t, db_t, dc_t represent, respectively, marginal preservation benefits, marginal preservation costs, marginal development benefits and marginal development costs in t.

$b_1 < 0$ [16]; thus, the unique incentive to preserve in $t = 1$ is given by the possibility to obtain a positive future benefit in $t = 2$ [17].

In the second period, the DM chooses again the amount of resource to be preserved. Since we assume development is irreversible, it is straightforward that in t =2 it is not possible to preserve more than one has done in t =1: the DM's options in 2 are constrained by the decision made in 1. Thus, if we indicate with c_2 the amount preserved in period 2, by irreversibility it is $c_2 \in [0, c_1]$: the amount chosen in $t = 2$ cannot be higher than the one chosen in $t = 1$.

In the second period, there are two possible states of the world. With probability π, the true state is revealed before the decision in $t = 2$ is taken by the DM. With probability $1 - \pi$, the DM does not know the true state of the world when he chooses the optimal level of c_2 in $t = 2$: this state will be revealed after this decision has been made. We indicate with b_2^j the marginal benefit deriving from preservation in period 2, when the revealed state of the world is s^j, $j = u, f$. The probability distribution over the states of the world is $(s^u, p; s^f, 1 - p)$ [18]. We also assume the benefit from preservation is negative if the state of the world is s^u (*u*nfavorable state), and positive if the state of the world is s^f (*f*avorable state), i.e. $b_2^u < 0, b_2^f > 0$ [19].

According to our assumptions, we indicate with:

c_2: amount of environmental resource preserved in $t = 2$, when the true state of the world has not been revealed before;

c_2^u: amount of environmental resource preserved in $t = 2$, when the DM knows the true state of the world is $s^j, j = u, f$.

A more intuitive way to identify the decision problem described above is to sum up

[16] The framework could be further generalized by considering a larger state of nature space, namely

$$\Theta = [b_1(c_1), b_2(c_1, c_2)|(c_1, c_2) \in D]$$

where D is the decision space.

The members of Θ are the various pairs of benefits and costs which could possibly accrue during the first period and second period for each possible decision which could be made. In that case, also benefits in period $t = 1$ are not known when choosing the level of preservation c_1.

The components of the pairs in Θ, b_t, can be thought of as four dimensional vectors (pc_t, pb_t, dc_t, db_t) representing preservation costs, preservation benefits, development costs and development benefits associated with the action taken in period t.

[17] We chose not to contemplate into the analysis the case $b_1 = 0$, since it makes the choice of c_1 irrelevant for what concerns benefits received in the first period. The same reasoning holds for b_2 (with respect to c_2).

[18] p is the probability of the state s^u before this state is revealed.

[19] Differently form Beltratti, Chichilnisky and Heal (1996), we do not assume that the expected benefit of preservation in the second period is positive, i.e. $pb_2^u + (1 - p)b_2^s > 0$. We allow this quantity to be greater, equal or less than zero.

the sequence of events through four main steps:

- Step (*a*). The *DM* chooses the amount of the environmental resource he wants to preserve in $t = 1$ (until $t = 2$).

- Step (*b*). Either the true state of the world is revealed or it is not.

- Step (*c*). The *DM* chooses the amount of the environmental resource he wants to preserve in $t = 2$.

- Step (*d*). If in Step (*b*) no information has come out, now the true state of the world is revealed.

The structure of the decision problem is summarized in *Figure* 1.

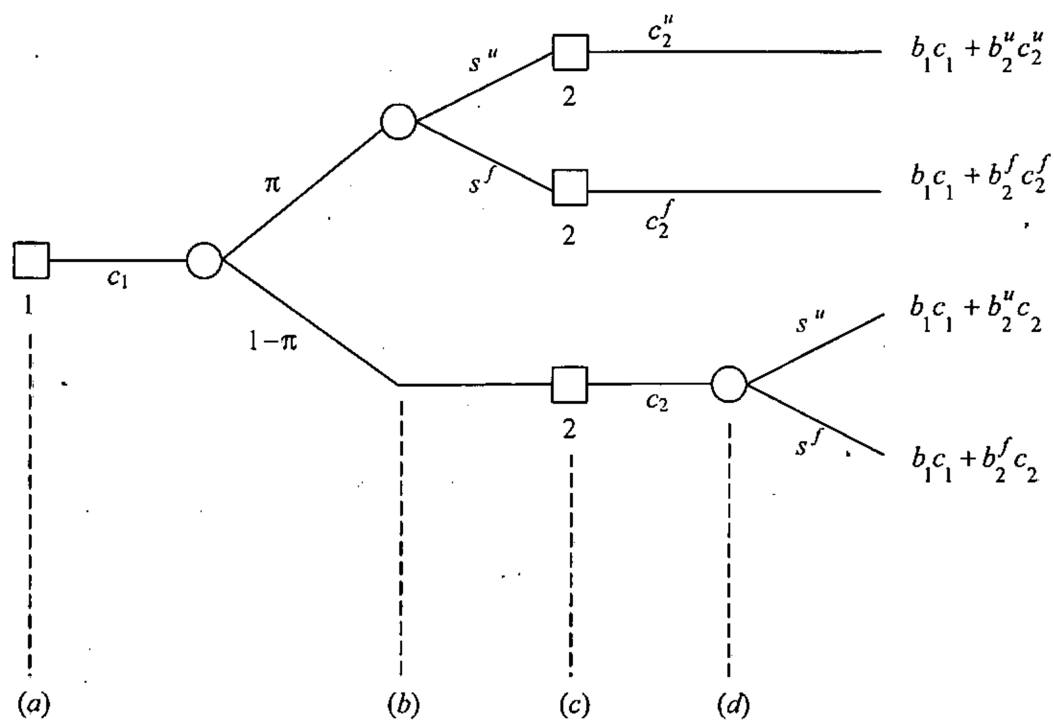

Figure 1

Before starting the analysis of the optimal preservation choice under the different information scenarios, it is useful to state a pair of results which holds independently from the kind of information structure we deal with (i.e., independently from the way in which π is defined):

Result 1

If in Step (b) the true state of the world is revealed, then $(c_2^u)^* = 0, (c_2^f)^* = c_1$.

Result 2

If in Step (b) the true state of the world is not revealed, then

$$c_2{}^* = \begin{cases} 0 & \text{if} \quad pb_2^u + (1-p)b_2^s < 0 \\ c_1 & \text{if} \quad pb_2^u + (1-p)b_2^s > 0 \end{cases}$$

1.2.2 Modelling uncertainty

In our framework, uncertainty characterizes Step (b): the DM does not know if the true state of the world will be known or not when he takes his choice c_2 in Step (c). The key parameter is $\pi \in [0,1]$, the probability that the true state is revealed before choosing c_2, i.e. the probability new (complete) information arrives before Step (c).

According to the way in which we define the form and the properties of π, we are able to:

- allow for different "degrees of certainty" of the coming of new information. Information can arrive with certainty ($\pi = 1$), with a certain probability ($\pi \in (0,1]$) or may not come out with certainty ($\pi = 0$);

- identify different kinds of new "information", according to its nature (looking at the components inside π). Information can be (only) exogenous, (only) endogenous, or both:

• in the first case, π does not depend on $(1-c_1)$, the amount of environmental resource developed in (and, obviously, on c_1, the amount of environmental resource preserved in) Step (a);

• in the second case, π does depend on c_1, or, rather, on $(1-c_1)$, the level of development. In particular, we assume that (as stated in Section 1.1.2), *in case of dependent learning, the level of information coming out is directly proportional to the level of development carried out*;

• in the third case, one part of information arrives exogenously and the rest comes out according to $(1-c_1)$; hence, $\pi = q + \lambda f(1-c_1)$, with $f'(\cdot) > 0$, $\lambda \in [0,1]$ being the probability of acquiring endogenous information (of the specified form) and $q \in [0,1]$ being the probability of acquiring exogenous information. In particular, we analyze the case where $f(1-c_1) = 1-c_1$, i.e. it is a linear (decreasing) function of c_1.

We summarize all information categories described above in a general case (and we call it *Case A*), then derive all the other subcases by imposing certain restrictions on the key parameters:

CASE A: Complete (i.e. Exogenous and Endogenous) information

$$\pi = q + \lambda(1 - c_1) \quad \text{for} \quad c_1 \in [0,1]$$
$$\text{with} \quad q \in [0,1], \quad \lambda \in [0, 1-q].$$

CASE B: (Only) Exogenous information

$$\textit{CASE A} \text{ with } \lambda = 0 \quad \text{for} \quad c_1 \in [0,1]$$

CASE C: (Only) Endogenous information

$$\textit{CASE A} \text{ with } q = 0 \quad \text{for} \quad c_1 \in [0,1]$$

CASE D: No information

$$\lambda = q = 0 \quad \text{for} \quad c_1 \in [0,1]$$

The subcases *"information arriving with certainty"* [20] can be derived in the following ways:

- *Case A* with $\lambda = 1 - q$ (Complete information arriving with certainty, if $c_1 = 0$);
- *Case B* with $q = 1$ (Exogenous information arriving with certainty);
- *Case C* with $\lambda = 1$ (Endogenous information arriving with certainty, if $c_1 = 0$).

1.3 Maximization Problem and Optimal Choices

In this section, we write down the *DM*'s maximization problem and find the optimal choices c_1^*, c_2^* in each of the four information structures described in Section 2.2.

[20] We analyze this case separately only because it is the most frequently analyzed in environmental option value literature: thus, it allows us to make comparisons and to show that our results hold even under the restriction of information arriving with certainty.

1.3.1 *Case A*: Complete (i.e. Endogenous and Exogenous) Information

Let us write and solve the *DM*'s utility maximization problem in the most general case, in which both exogenous and endogenous information are available with a certain probability (respectively, $q \in [0,1]$ and $\lambda \in [0,1]$) after the decision made in $t = 1$, i.e. at Step (b).

Given *Result* 1 and *Result* 2, the realized payoffs are those indicated in *Figure* 2 below.

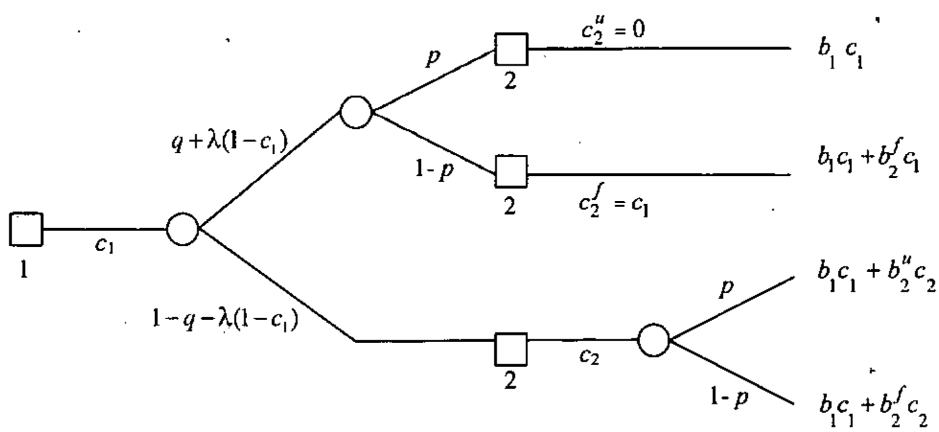

Figure 2

The *DM*'s expected value of net benefits of preservation in both periods (given *Result* 1 and *Result* 2) is

$$\begin{aligned} EV(c_1, (c_2^u)^*, (c_2^f)^*, c_2) &= [q + \lambda(1 - c_1)] \left[(pb_1 + (1-p)(b_1 + b_2^f)\right] c_1 + \\ &\quad \{1 - [q + \lambda(1 - c_1)]\} \left[p(b_1 c_1 + b_2^u c_2) + (1-p)(b_1 c_1 + b_2^f c_2)\right] \end{aligned}$$

Let us now analyze the "low part" of the compound lottery represented in *Figure* 2. We can distinguish among two cases, according to the expected value of the second-period net benefits when the *DM* does not receive new information at Step (b):

(i) $\quad pb_2^u + (1-p)b_2^f < 0 \quad \Longrightarrow \quad c_2{}^* = 0$

The compound lottery in *Figure* 2 can be reduced into the one-stage lottery in *Figure* 3 below.

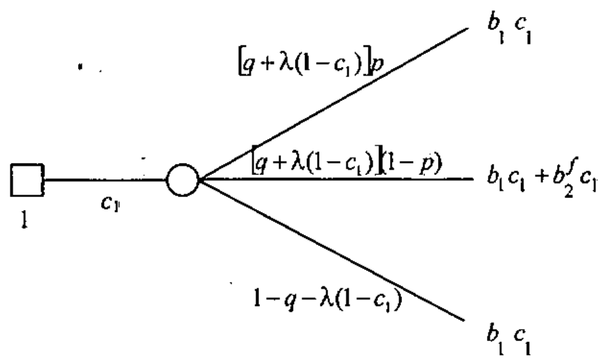

Figure 3

The expected value of the lottery (given that at *Step* (*c*) the *DM* follows an optimal choice strategy independently from information he has received at Step (*b*)) is

$$\begin{aligned} EV\left(c_1, (c_2^u)^*, (c_2^f)^*, c_2{}^* = 0\right) &= \{1-(1-p)\left[q+\lambda(1-c_1)\right]\} b_1 c_1 + \\ &\quad +(1-p)\left[q+\lambda(1-c_1)\right](b_1+b_2^f)c_1 \\ &= b_1c_1 + (1-p)\left[q+\lambda(1-c_1)\right] b_2^f c_1 \end{aligned}$$

By the First Order Condition, we obtain

$$\left.\frac{dEV(c_1)}{dc_1}\right|_{c_2{}^*=0} = b_1+(1-p)(q+\lambda)b_2^f - 2(1-p)\lambda b_2^f c_1 = 0 \quad \Longrightarrow \quad c_1{}^* = \frac{b_1+(1-p)(q+\lambda)b_2^f}{2(1-p)\lambda b_2^f}$$

Considering that the quantity $\frac{b_1+(1-p)(q+\lambda)b_2^f}{2(1-p)\lambda b_2^f}$ could be lower than 0 or greater than 1, the optimal level of preservation in $t=1$ is

$$c_1{}^* = \begin{cases} 0 & \text{if} \quad b_1 < -(1-p)(q+\lambda)b_2^f & (i)' \\ \frac{b_1+(1-p)(q+\lambda)b_2^f}{2(1-p)\lambda b_2^f} & \text{if} \quad -(1-p)(q+\lambda)b_2^f < b_1 < (1-p)(\lambda-q)b_2^f & (i)'' \\ 1 & \text{if} \quad b_1 > (1-p)(\lambda-q)b_2^f & (i)''' \end{cases}$$

Remembering that $c_2{}^* = 0$, the optimal expected value function $EV^*(\cdot)$ is

$$EV^*(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if} \quad b_1 < -(1-p)(q+\lambda)b_2^f & (i)' \\ \frac{\left[b_1+(1-p)(q+\lambda)b_2^f\right]^2}{4(1-p)\lambda b_2^f} & \text{if} \quad -(1-p)(q+\lambda)b_2^f < b_1 < (1-p)(\lambda-q)b_2^f & (i)'' \\ b_1+(1-p)(q+\lambda)b_2^f & \text{if} \quad b_1 > (1-p)(\lambda-q)b_2^f & (i)''' \end{cases}$$

$$(ii) \qquad pb_2^u + (1-p)b_2^f > 0 \qquad \Longrightarrow \qquad c_2{}^* = c_1$$

The compound lottery in *Figure* 2 can be reduced to the one-stage lottery in *Figure* 4 below.

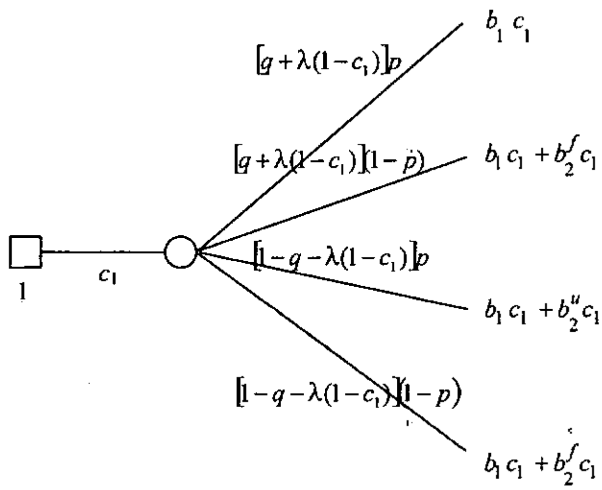

Figure 4

that can be still reduced to the lottery

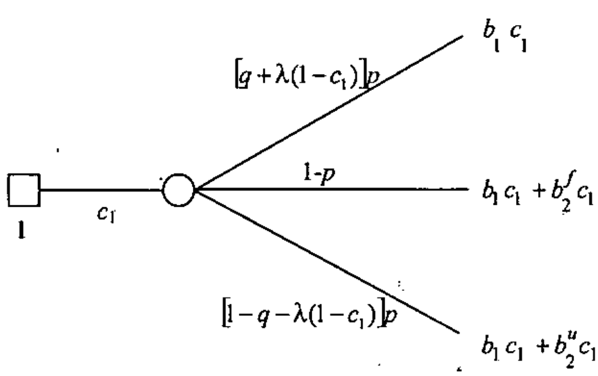

Figure 5

The expected value of the lottery (given that in *Step* (*c*) the *DM* follows an optimal choice strategy independently from information he has received in Step (*b*)) is

$$\begin{aligned} EV\left(c_1, (c_2^u)^*, (c_2^f)^*, c_2{}^* = c_1\right) &= b_1c_1 + (1-p)b_2^f c_1 + \{1 - [q + \lambda(1-c_1)]\}\, pb_2^u c_1 \\ &= b_1c_1 + (1-p)b_2^f c_1 + p(1-q-\lambda+\lambda c_1)b_2^u c_1 \end{aligned}$$

By the First Order Condition, we obtain

$$\left.\frac{dEV(c_1)}{dc_1}\right|_{c_2{}^*=c_1} = b_1 + (1-p)b_2^f + p(1-q-\lambda)b_2^u + 2\lambda p b_2^u c_1 = 0$$

$$\Longrightarrow \quad c_2{}^* = -\frac{b_1 + (1-p)b_2^f + p(1-q-\lambda)b_2^u}{2p\lambda b_2^u}$$

Considering that the quantity $-\frac{b_1+(1-p)b_2^f+p(1-q-\lambda)b_2^u}{2p\lambda b_2^u}$ could be lower than 0 or greater than 1, the optimal level of preservation in $t = 1$ is

$$c_1{}^* = \begin{cases} 0 & \text{if} \quad b_1 + (1-p)b_2^f + (1-q)b_2^u < \lambda b_2^u & (ii)' \\ -\frac{b_1+(1-p)b_2^f+p(1-q-\lambda)b_2^u}{2p\lambda b_2^u} & \text{if} \quad \lambda b_2^u < b_1 + (1-p)b_2^f + (1-q)b_2^u < -\lambda b_2^u & (ii)'' \\ 1 & \text{if} \quad b_1 + (1-p)b_2^f + (1-q)b_2^u > -\lambda b_2^u & (ii)''' \end{cases}$$

Since $c_2{}^* = c_1{}^*$, the optimal expected value function $EV^*(\cdot)$ is [21]

$$EV^*(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if} \quad b_1 + (1-p)b_2^f + (1-q)b_2^u < \lambda b_2^u & (ii)' \\ -\frac{\left[b_1+(1-p)b_2^f+p(1-q-\lambda)b_2^u\right]^2}{4p\lambda b_2^u} & \text{if} \quad \lambda b_2^u < b_1 + (1-p)b_2^f + (1-q)b_2^u < -\lambda b_2^u & (ii)'' \\ b_1 + (1-p)b_2^f + p(1-q)b_2^u & \text{if} \quad b_1 + (1-p)b_2^f + (1-q)b_2^u > -\lambda b_2^u & (ii)''' \end{cases}$$

1.3.2 *CASE B*: (Only) Exogenous Information

When $\lambda = 0$ (no endogenous information) the *DM* in *Step* (a) knows that at *Step* (b) with probability $q \in [0,1]$ he will know the realized value of the net benefit b_2^j. Hence, he knows that information coming is independent from the preservation level chosen in *Step* (a), although in the same step he is not sure that he will know the true state of the world when he will choose at *Step* (c).

We solve the *DM*'s utility maximization problem by applying the same principle of reduction of the compound lotteries and the same procedure of maximization we use in *Case A*.

Given *Result* 1 and *Result* 2, the realized payoffs are those indicated in *Figure* 2,

[21]When $q + \lambda \in [0, 1)$, the *DM* at *Step* (a) knows that, even if he decides to destroy the entire environmental resource ($c_1 = 0$), he is not certain that at *Step* (b) the true state of the world will come out. Hence, even if he destroys everything in $t = 1$, he is not sure that he will know the realized value of the net benefit b_2^i when choosing c_2 at *Step* (c). On the contrary, when $q + \lambda = 1$, the *DM* is sure that, in case he destroys everything ($c_1 = 0$) he will receive with certainty some information at *Step* (b). We call this subcase "Complete information arriving with certainty, if $c_1 = 0$". The optimal values for c_1 and c_2 and the optimal expected value of net benefits over both periods can be easily found by substituting $q + \lambda = 1$ into the results obtained for the general case.

even if one has to change the probability assigned to the branches of the trees (with q in place of $q + \lambda(1 - c_1)$).

Taking into account *Result* 1 and *Result* 2, the DM's expected payoff is

$$\begin{aligned} EV_{exo}(c_1, (c_2^u)^*, (c_2^f)^*, c_2) &= q\left[(pb_1 + (1-p)(b_1 + b_2^f)\right] c_1 + \\ &+(1-q)\left[p(b_1c_1 + b_2^u c_2) + (1-p)(b_1 c_1 + b_2^f c_2)\right] \\ &= q\left[b_1 + (1-p)b_2^f\right] c_1 + (1-q)\left[b_1 c_1 + (pb_2^u + (1-p)b_2^f)c_2\right] \end{aligned}$$

(*i*) If $pb_2^u + (1-p)b_2^f < 0$, the optimal levels of preservation in the two periods are

$$\begin{aligned} {c_1}^* &= \begin{cases} 0 & \text{if} \quad b_1 + q(1-p)b_2^f < 0 \quad (i)' \\ 1 & \text{if} \quad b_1 + q(1-p)b_2^f > 0 \quad (i)'' \end{cases} \\ {c_2}^* &= 0 \end{aligned}$$

consequently the optimal expected value function is

$$EV_{exo}^*(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if} \quad b_1 + q(1-p)b_2^f < 0 \quad (i)' \\ b_1 + q(1-p)b_2^f & \text{if} \quad b_1 + q(1-p)b_2^f < 0 \quad (i)'' \end{cases}$$

(*ii*) If $pb_2^u + (1-p)b_2^f > 0$, the optimal level of preservation in the two periods are

$$\begin{aligned} c_1^* &= \begin{cases} 0 & \text{if} \quad b_1 + (1-q)pb_2^u + (1-p)b_2^f < 0 \quad (ii)' \\ 1 & \text{if} \quad b_1 + (1-q)pb_2^u + (1-p)b_2^f > 0 \quad (ii)'' \end{cases} \\ {c_2}^* &= {c_1}^* \end{aligned}$$

and the optimal expected value function is

$$EV_{exo}^*(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if} \quad b_1 + (1-q)pb_2^u + (1-p)b_2^f < 0 \quad (ii)' \\ b_1 + (1-q)pb_2^u + (1-p)b_2^f & \text{if} \quad b_1 + (1-q)pb_2^u + (1-p)b_2^f > 0 \quad (ii)'' \end{cases}$$

A particular subcase: Exogenous Information arriving with certainty

This is the case in which the "standard" QOV *à la* Arrow-Fisher (as analyzed in Section 1.1) emerges: if new exogenous information arrives with certainty ($q = 1$) in *Step* (*b*), the DM at *Step* (*a*) knows that when deciding at *Step* (*c*) he will know if the net benefit is b_2^u or b_2^f.

Hence, the decision problem in *Figure* 1 can be reduced to the one in *Figure* 6 below.

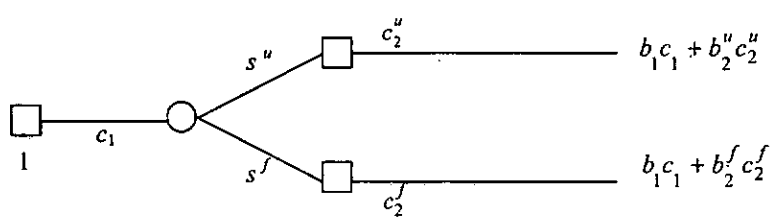

Figure 6

The expected value of the lottery is

$$EV_{exo|q=1}(c_1, c_2^u, c_2^f) = b_1c_1 + pb_2^uc_2^u + (1-p)b_2^fc_2^f$$

Given *Result* 1,

$$EV_{exo|q=1}(c_1, (c_2^u)^*, (c_2^f)^*) = b_1c_1 + (1-p)b_2^fc_1$$

Since the expected value function is linear in c_1, the optimal level of preservation in $t=1$ is

$$\begin{array}{lll} {c_1}^* = 0 & \text{if} \;\; b_1 + (1-p)b_2^f < 0 & (i) \\ {c_1}^* = 1 & \text{if} \;\; b_1 + (1-p)b_2^f > 0 & (ii) \end{array}$$

and the optimal expected value function is

$$\begin{array}{rll} EV_{exo|q=1}(0) = 0 & \text{if} \;\; b_1 + (1-p)b_2^f < 0 & (i) \\ EV_{exo|q=1}(1) = b_1 + (1-p)b_2^f & \text{if} \;\; b_1 + (1-p)b_2^f > 0 & (ii) \end{array}$$

1.3.3 *Case C*: (Only) Endogenous Information

The optimal values of c_1, c_2 and of the expected benefits in case only endogenous information is possible can be easily derived by writing down results found in *Case A* and imposing $q=0$ (no exogenous information).

(i) If $pb_2^u + (1-p)b_2^f < 0$, it can never be $b_1 > (1-p)\lambda b_2^f$, thus the region $(i)'''$ in which ${c_1}^* = 1$ disappears (i.e. it will never be ${c_1}^* = 1$ in the subcase (i)) and the optimal levels of preservation in the two periods are

$$\begin{array}{rcl} {c_1}^* & = & \begin{cases} 0 & \text{if} \quad b_1 < -(1-p)\lambda b_2^f \quad (i)' \\ \frac{b_1 + (1-p)\lambda b_2^f}{2(1-p)\lambda b_2^f} & \text{if} \quad -(1-p)\lambda b_2^f < b_1 < (1-p)\lambda b_2^f \quad (i)'' \end{cases} \\ {c_2}^* & = & 0 \end{array}$$

and thus the optimal expected value function is

$$EV^*_{endo}(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if} \quad b_1 < -(1-p)\lambda b_2^f & (i)' \\ \frac{\left[b_1+(1-p)\lambda b_2^f\right]^2}{4(1-p)\lambda b_2^f} & \text{if} \quad -(1-p)\lambda b_2^f < b_1 < (1-p)\lambda b_2^f & (i)'' \\ b_1+(1-p)\lambda b_2^f & \text{if} \quad b_1 > (1-p)\lambda b_2^f & (i)''' \end{cases}$$

(ii) If $pb_2^u + (1-p)b_2^f > 0$, the optimal levels of preservation in the two periods are

$$c_1{}^* = \begin{cases} 0 & \text{if} \quad b_1+(1-p)b_2^f+b_2^u < \lambda b_2^u & (ii)' \\ -\frac{b_1+(1-p)b_2^f+p(1-\lambda)b_2^u}{2p\lambda b_2^u} & \text{if} \quad \lambda b_2^u < b_1+(1-p)b_2^f+b_2^u < -\lambda b_2^u & (ii)'' \\ 1 & \text{if} \quad b_1+(1-p)b_2^f+b_2^u > -\lambda b_2^u & (ii)''' \end{cases}$$

$$c_2{}^* = c_1{}^*$$

and thus the optimal expected value function is

$$EV^*_{endo}(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if} \quad b_1+(1-p)b_2^f+b_2^u < \lambda b_2^u & (ii)' \\ -\frac{\left[b_1+(1-p)b_2^f+p(1-q-\lambda)b_2^u\right]^2}{4p\lambda b_2^u} & \text{if} \quad \lambda b_2^u < b_1+(1-p)b_2^f+b_2^u < -\lambda b_2^u & (ii)'' \\ b_1+(1-p)b_2^f+pb_2^u & \text{if} \quad b_1+(1-p)b_2^f+b_2^u > -\lambda b_2^u & (ii)''' \end{cases}$$

A particular subcase: Endogenous Information arriving with certainty, if $c_1 = 0$

The case $\lambda = 1$ serves the aim of comparing our results with those common in environmental option values literature, in which the most representative framework of environmental decisions under uncertainty and irreversibility is that of Freeman (1984) and Fisher and Hanemann (1987): within this model, in the information scenario where information is completely endogenous ($q = 0$), it arrives with certainty ($\lambda = 1$). Under these two restrictions, we could compare our TV to the "standard" QOV_ε *à la* Arrow-Fisher (as analyzed in Section 1.2).
The optimal values for c_1 and c_2 and the optimal expected value of net benefits over both periods can be easily found by substituting $\lambda = 1$ in the results obtained for the general case (*Case A*).

1.3.4 *Case D*: No information

The decision problem represented in *Figure* 1 is reduced to that in *Figure* 6 below.

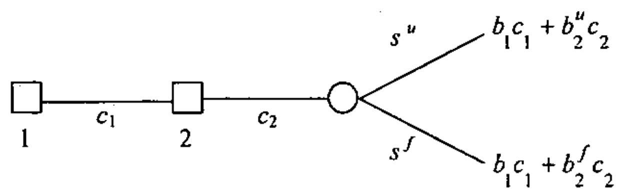

Figure 6

The expected value of the lottery is

$$EV(c_1, c_2) = b_1c_1 + \left[pb_2^u + (1-p)b_2^f\right] c_2$$

Let us write the expected value of net benefits of preservation as a function of c_1 only, by choosing c_2 optimally in the second period: by this way, we obtain the expected value of preserving in *Step* (a), given that the DM's choice in *Step* (c) is optimal.

By looking at *Result* 2,

(i) $pb_2^u + (1-p)b_2^f < 0 \implies c_2{}^* = 0 \implies EV_0(c_1, c_2{}^* = 0) = b_1c_1$

By maximizing with respect to c_1,

$$c_1{}^* = c_2{}^* = 0$$

thus the optimal expected value function is

$$EV_0{}^*(b_1, b_2^u, b_2^f) = 0$$

(ii) $pb_2^u+(1-p)b_2^f > 0 \implies c_2{}^* = c_1 \implies EV_0(c_1, c_2{}^* = c_1) = \left[b_1 + pb_2^u + (1-p)b_2^f\right] c_1.$

By maximizing,

$$c_1{}^* = \begin{cases} 0 & \text{if} \quad b_1 + pb_2^u + (1-p)b_2^f < 0 \quad (ii)' \\ 1 & \text{if} \quad b_1 + pb_2^u + (1-p)b_2^f > 0 \quad (ii)'' \end{cases}$$

$$c_2{}^* = c_1{}^*$$

thus the optimal expected value function is

$$EV_0{}^*(b_1, b_2^u, b_2^f) = \begin{cases} 0 & \text{if } \; b_1 + pb_2^u + (1-p)b_2^f < 0 \quad (ii)' \\ b_1 + pb_2^u + (1-p)b_2^f & \text{if } \; b_1 + pb_2^u + (1-p)b_2^f > 0 \quad (ii)'' \end{cases}$$

Noting that condition $(ii)''$ implies (ii) and that condition (i) and (ii) are complementary, we can sum up the optimal choices in the two subcases:

$$\begin{array}{ll} c_1{}^* = c_2{}^* = 0 & \text{if } \; pb_2^u + (1-p)b_2^f < -b_1 \\ c_1{}^* = c_2{}^* = 1 & \text{if } \; pb_2^u + (1-p)b_2^f > -b_1 \end{array}$$

and the relative optimal expected value function

$$\begin{array}{ll} EV_0{}^* = 0 & \text{if } \; pb_2^u + (1-p)b_2^f < -b_1 \\ EV_0{}^* = b_1 + pb_2^u + (1-p) & \text{if } \; pb_2^u + (1-p)b_2^f > -b_1 \end{array}$$

1.4 Calculus of the WV and of the TV

In this section, we use the results of the DM's maximization problem (the optimal level of c_1 and c_2 and the optimal expected value functions in each of the four information structures) in order to express the WV and the TV as functions of the parameters of the decision problem and describe their properties and their effects on DM's optimal behaviour.

1.4.1 Graphical representation of the optimal preservation choices

First of all, let us represent graphically the results we have obtained on the optimal level of c_1 and c_2 and on the expected value functions $EV(\cdot)$. We introduce a Cartesian plane with the relative benefits $-\frac{b_1}{b_2^f}$ on the x-axis and the relative benefits $-\frac{b_2^u}{b_2^f}$ on the y-axis. [22] Obviously, when these two ratios vary (when the values of the net benefits of preservation in $t = 1$ and $t = 2$ vary), the optimal preservation choices for the first and for the second period change too. In *Table* 1, we indicate for each figure the information scenario represented inside and the specific values of the three parameters p, q and λ.

[22] Our choice of these two ratios as variables for the Cartesian axes can be explained, among others, by the need of working with positive quantities (since $b_1, b_2^u < 0, b_2^f > 0$), in order to concentrate in quadrant I of the Cartesian plane the analysis of the conditions (inequalities) we have found by solving the maximization problem.

Figure A.1	*Case A* with $p = \frac{1}{2}, q = \frac{1}{3}, \lambda = \frac{1}{3}$
Figure A.2	*Case A* with $p = \frac{1}{2}, q = \frac{1}{3}, \lambda = \frac{1}{4}$
Figure A.3	*Case A* with $p = \frac{1}{2}, q = \frac{1}{3}, \lambda = \frac{2}{3}$
Figure A.4	*Case A* with $p = \frac{1}{2}, q = \frac{2}{3}, \lambda = \frac{1}{3}$
Figure B.1	*Case B* with $p = \frac{1}{2}, q = \frac{1}{3}$
Figure B.2	*Case B* with $p = \frac{1}{2}, q = 1$
Figure C	*Case C* with $p = \frac{1}{2}, \lambda = 1$
Figure D	*Case D* with $p = \frac{1}{2}$

(*Table* 1. Cases and parameters relative to each *Figure.*)

A brief description of the preservation choice path in each of the different colorful regions of the quadrant I of the Cartesian plane:

- "*White*" region: the *DM* does not preserve anything in $t = 1$ and so also in $t = 2$;

- "*Green*" region: the *DM* preserves everything both in $t = 1$ and also in $t = 2$;

- "*Yellow*" region: the *DM* preserves only a part of the resource in $t = 1$ and the same amount in $t = 2$;

- "*Blue*" region: the *DM* preserves everything in $t = 1$ and nothing in $t = 2$;

- "*Orange*" region: the *DM* preserves only a part of the resource in $t = 1$ and nothing in $t = 2$;

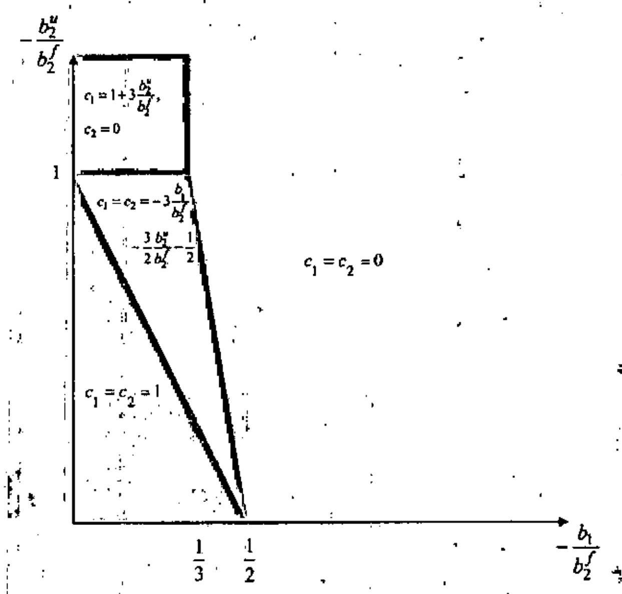

Figure A.1

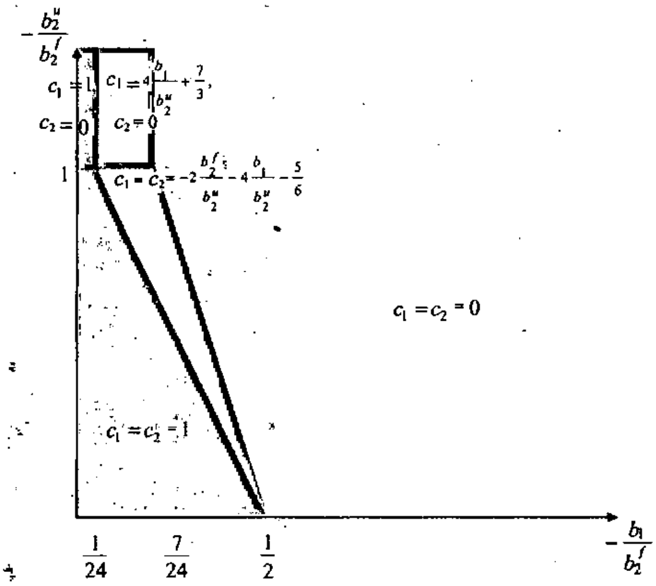

Figure A.2

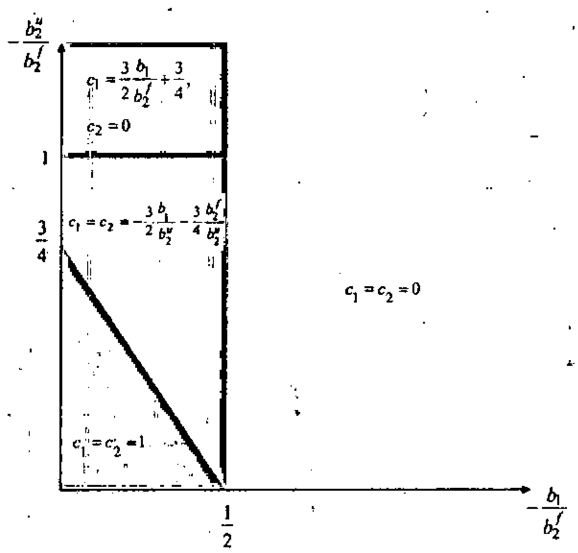

Figure A.3

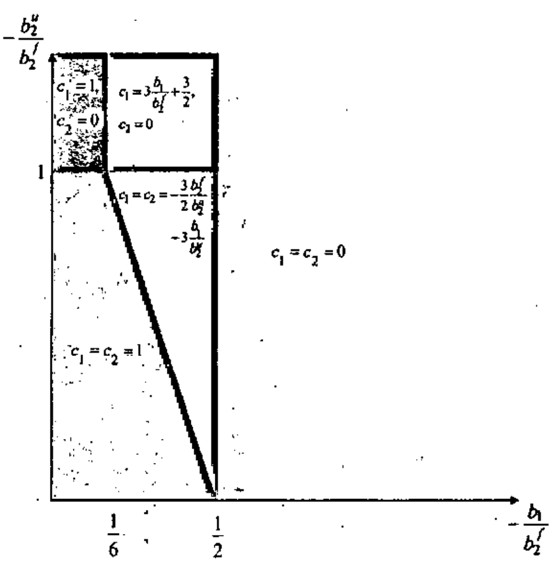

Figure A.4

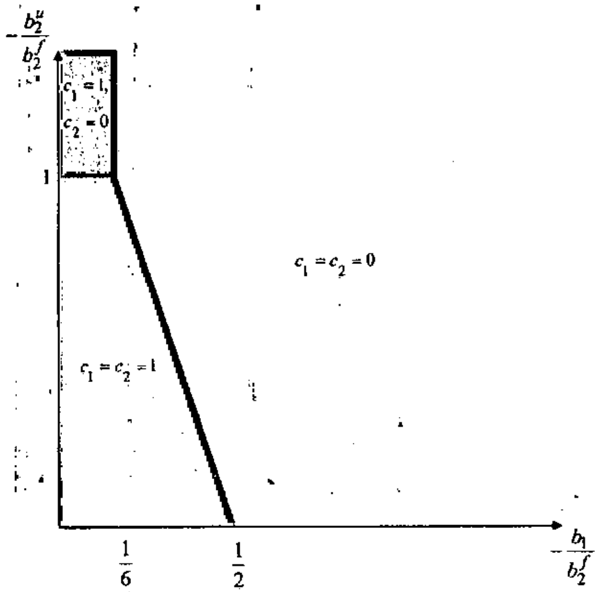

Figure B.1

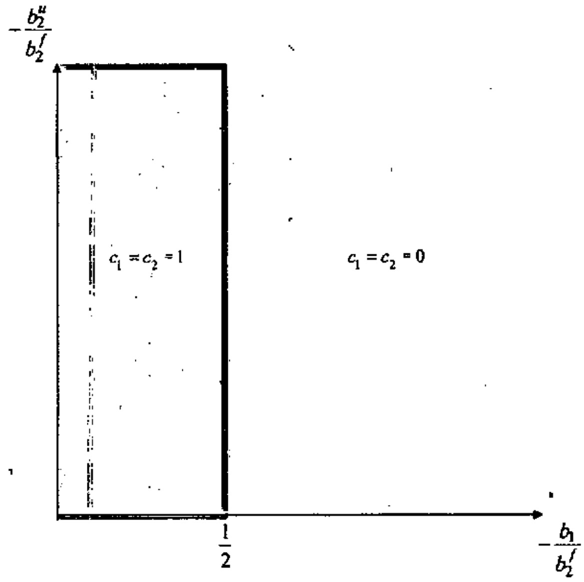

Figure B.2

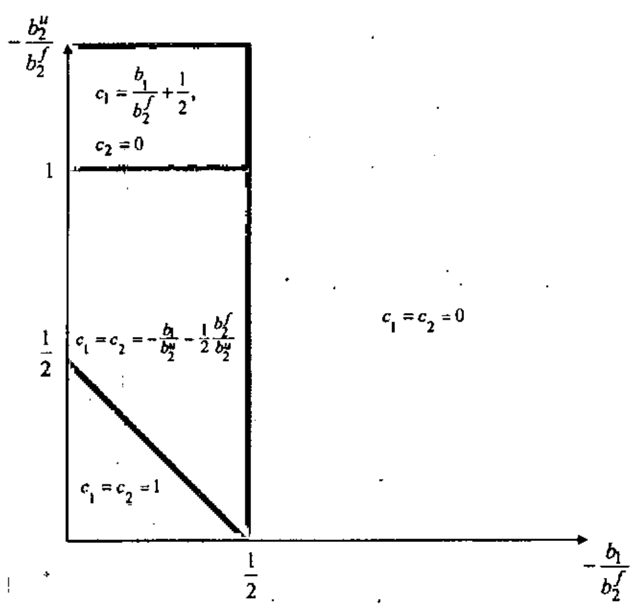

Figure C

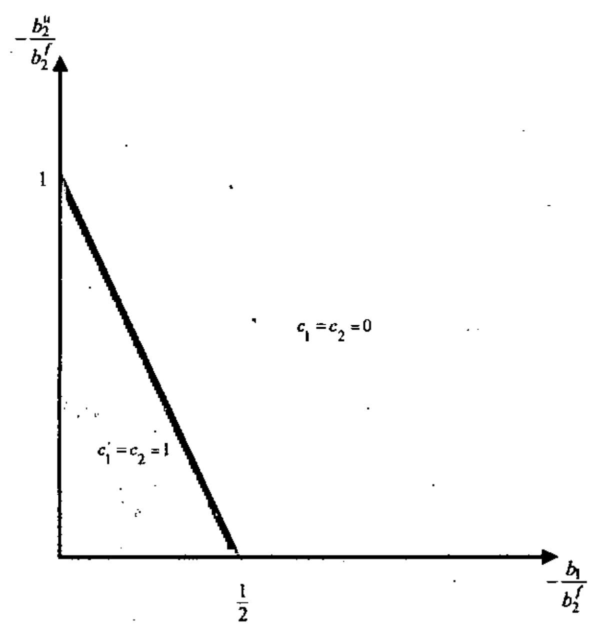

Figure D

1.4.2 Properties of the Waiting Value

Let us calculate the Waiting Value using the expression we have introduced in Section 1.1, i.e.

$$WV = EV_{exo}{}^* - EV_0{}^*$$

Since $EV_{exo}{}^*$ and $EV_0{}^*$ vary according to the values of b_1, b_2^u and b_2^f, we have to calculate the difference between the two optimal expected values by looking at the different regions we identify in the Cartesian plane $\left(-\frac{b_1}{b_2^f}, -\frac{b_2^u}{b_2^f}\right)$: we do it by comparing the optimal expected values in *Figure B*.1 to those in *Figure D*.

· For $-\frac{b_2^u}{b_2^f} > 1$ and $-\frac{b_1}{b_2^f} > 1$, $\quad WV = 0$.

· For $-\frac{b_2^u}{b_2^f} < 1$ and $-\frac{b_2^u}{b_2^f} > \frac{1-p}{(1-q)p} - \frac{1}{(1-q)p}\left(-\frac{b_1}{b_2^f}\right)$, $\quad WV = 0$.

· For $-\frac{b_2^u}{b_2^f} > 1$ and $-\frac{b_1}{b_2^f} > q(1-p)$, $\quad WV = b_1 + q(1-p)b_2^f > 0$.

· For $\frac{p}{1-p} - \frac{1}{1-p}\left(-\frac{b_1}{b_2^f}\right) < -\frac{b_2^u}{b_2^f} < 1$ and $-\frac{b_2^u}{b_2^f} < \frac{1-p}{(1-q)p} - \frac{1}{(1-q)p}\left(-\frac{b_1}{b_2^f}\right)$,
$WV = b_1 + (1-q)pb_2^u + (1-p)b_2^f > 0$.

· For $-\frac{b_2^u}{b_2^f} < \frac{p}{1-p} - \frac{1}{1-p}\left(-\frac{b_1}{b_2^f}\right)$, $\quad WV = -qpb_2^u > 0$.

Thus, the WV is increasing in the probability of receiving new information (exogenously) and in the level of the net benefits in the favorable state; it is decreasing both in the level of the net benefits in the current period (considered in absolute value, given that they are negative by assumption) and in the level of the net benefits in the unfavorable state (taken in absolute value and given that they are negative by assumption). For what concerns the *a priori* probability of the state s^u (unfavorable state) before this state is revealed, the WV is decreasing in p in "unfavorable" regions (i.e. regions where $|b_1|$ and/or $|b_2^u|$ are very high and/or b_2^f is very low) and increasing in p in "favorable" regions (defined in the opposite way). Briefly,

$$WV = WV(\underset{+,-}{p}, \underset{+}{q}, \underset{-}{|b_1|}, \underset{-}{|b_2^u|}, \underset{+}{b_2^f})$$

If following the literature on quasi-option values we would calculate the WV as the difference between the optimal expected value in case of *certain* exogenous information and the optimal expected value in the no information case, i.e.

$$WV_{|q=1} = EV_{exo|q=1}{}^* - EV_0{}^* \geq 0$$

we would find an upper bound for the WV we have calculated above, i.e. $WV_{|q=1} \geq WV$, since WV is increasing in q.

Our conclusions on the properties of the WV are more general and "robust" than those of the standard literature on quasi-option values: we find that *in absence of endogenous information, even though exogenous information does not arrive with certainty (but with a given probability $q \in (0,1)$), the WV is always non-negative, thus forcing the DM towards a higher level of preservation of the environmental area during the first and the second period of choice.*

In fact, looking at the results shown in *Figure* $B.1$ and D, it is not difficult to notice that in all regions of the quadrant I of the Cartesian plane it is always

$$\begin{aligned} ({c_1}^*)_{exo} &\geq ({c_1}^*)_0 \qquad (a) \\ ({c_2}^*)_{exo} &\geq ({c_2}^*)_0 \qquad (b) \end{aligned}$$

Result (a) is obvious.

Result (b) can be proved by applying this reasoning: because of irreversibility, $({c_2}^*)_{exo} \leq ({c_1}^*)_{exo}, ({c_2}^*)_0 \leq ({c_1}^*)_0$, but since $({c_1}^*)_{exo} \geq ({c_1}^*)_0$ in Step (c) the DM has a larger choice set from which choosing $({c_2}^*)_{exo}$; since the choice $({c_2}^*)_0$ is possible also in case of exogenous information (because it is surely $({c_1}^*)_{exo} \geq ({c_1}^*)_0$), being objective function the same under each information structure, $({c_2}^*)_{exo}$ cannot be lower than $({c_2}^*)_0$.

1.4.3 Properties the Testing Value

According to the definition we have introduced in Section 1.2, we define the Testing value as

$$TV = EV^* - EV^*_{exo}$$

Hence,

$$EV^* - EV^*_0 = WV + TV$$

We could calculate the TV not (only) as an *additional* value of endogenous to exogenous information (as we did above), rather as a value emerging in the particular information context in which *only* endogenous information is available, i.e.

$$TV' = EV^*_{endo} - EV^*_0$$

In case the utility function would be linear (and in our case it is), one could easily verify that $TV = TV'$.

By applying the latter method, one could get an environmental value (linked to endogenous information) closer to the QOV_ε, as defined by Freeman (1984) and Fisher and Hanemann (1987), i.e. the difference between the expected benefits in case of *certain* endogenous information and the expected benefits in the no information case:

$$TV'_{|\lambda=1} = EV^*_{endo|\lambda=1} - EV^*_0$$

The $TV'_{|\lambda=1}$ represents a base of comparison between our results and those coming from the standard literature, that we have exhibited in Section 1.2. Nonetheless, assuming again that the DM's utility function is linear, through the $TV'_{|\lambda=1}$ we could easily derive the upper bound for the TV, i.e. $TV'_{|\lambda=1} \geq TV' = TV$, since the TV is increasing in λ.

Now, let's turn to the first definition of TV, the one we have introduced *ex novo* in this thesis chapter. Since EV^* and $EV_{exo}{}^*$ vary according to the values of b_1, b_2^u and b_2^f, we have to calculate the difference between the two optimal expected values in the different regions of the Cartesian plane $\left(-\frac{b_1}{b_2^f}, -\frac{b_2^u}{b_2^f}\right)$ under the "both exogenous and endogenous" information scenario and under the "only exogenous" information scenario, respectively.

We calculate the TV for different values of λ and q , for two reasons:

- to show that our results hold independently from the values one can assign to λ and q; [23]

- to analyze the behavior of the TV as a function of λ and q.

Let us first compare *Figure A*.3 to *Figure B*.1 and calculate the $TV(b_1, b_2^u, b_2^f)$ in case $p = \frac{1}{2}, q = \frac{1}{3}$ and $\lambda = \frac{1}{3}$.

For $-\frac{b_2^u}{b_2^f} > 1$ and $-\frac{b_1}{b_2^f} > \frac{1}{3}$, $\quad TV = 0$.

For $-\frac{b_2^u}{b_2^f} > 1$ and $\frac{1}{6} < -\frac{b_1}{b_2^f} < \frac{1}{3}$, $\quad TV = \frac{3}{2}\frac{\left(b_1 + \frac{1}{3}b_2^f\right)^2}{b_2^f} > 0$.

For $-\frac{b_2^u}{b_2^f} > 1$ and $0 < -\frac{b_1}{b_2^f} < \frac{1}{6}$, $\quad TV = \frac{3}{2}\frac{(b_1)^2}{b_2^f} > 0$.

For $-\frac{b_2^u}{b_2^f} < 1$ and $-\frac{b_2^u}{b_2^f} > 3 - 6\left(-\frac{b_1}{b_2^f}\right)$, $\quad TV = 0$.

For $-\frac{b_2^u}{b_2^f} < 1, -\frac{b_2^u}{b_2^f} < 3-6\left(-\frac{b_1}{b_2^f}\right)$ and $-\frac{b_2^u}{b_2^f} > \frac{3}{2}-3\left(-\frac{b_1}{b_2^f}\right)$, $TV = -\frac{3\left(b_1 + \frac{1}{2}b_2^f + \frac{1}{6}b_2^u\right)^2}{2b_2^u} > 0$.

For $-\frac{b_2^u}{b_2^f} < 1, -\frac{b_2^u}{b_2^f} < \frac{3}{2}-3\left(-\frac{b_1}{b_2^f}\right)$ and $-\frac{b_2^u}{b_2^f} > 1-2\left(-\frac{b_1}{b_2^f}\right)$, $TV = -\frac{3}{2}\frac{\left(b_1 + \frac{1}{2}b_2^f - \frac{1}{2}b_2^u\right)^2}{b_2^u} > 0$.

[23] We will show also that our results hold for every $p \in [0, 1]$; but, since this is immediate (just look at the formulas we write down), we don't need to do any comparative statics analysis based on p.

For $-\frac{b_2^u}{b_2^f} < 1 - 2\left(-\frac{b_1}{b_2^f}\right)$, $\qquad TV = 0$.

Let us now compare *Figure A*.4 to *Figure B*.1 and calculate the $TV(b_1, b_2^u, b_2^f)$ in case $p = \frac{1}{2}$ and $\lambda = \frac{1}{4} < q = \frac{1}{3}$.

The only "relevant" difference with the case in which $\lambda \geq q$ is in the north-west of quadrant I of the Cartesian plane, where we can find a region s.t. even with endogenous information (additional to the exogenous one) the DM preserves everything in the first period ($c_1^* = 1$) and nothing in the second ($c_2^* = 0$). This region comes out only when $\lambda < q$; in other words, when it is more likely that new information at *Step* (*c*) arrives exogenously than endogenously, . This happens only for $|b_1|$ very low and $|b_2^u|$ much higher than b_2^f.

For the values of the net benefits (b_1, b_2^u, b_2^f) belonging to this region, defined by the inequalities

$$\begin{cases} -\frac{b_2^u}{b_2^f} > 1 \\ -\frac{b_1}{b_2^f} < \frac{1}{24} \end{cases}$$

the Testing Value is again positive,

$$TV = (1-p)\lambda b_2^f = \frac{1}{8} b_2^f > 0.$$

From the discussion above and from a careful analysis of *Figures A*.1 - *D*, the main features of the Testing value turn out to be:

(1) $TV \geq 0$

(2) $TV = TV(\underset{+,-}{p}, \underset{-}{q}, \underset{+}{\lambda}, \underset{+,-}{|b_1|}, \underset{+,-}{|b_2^u|}, \underset{+}{b_2^f})$

(3.a). Given b_2^f and $|b_2^u|$, for high values of $|b_1|$ (but not so high), it happens that $c_1^* > (\hat{c}_1)_{exo}$.

(3.b) Given b_2^f, for high values of $|b_1|$ (but not so high) and low values of $|b_2^u|$ (but not so low), it happens that $c_1^* > (\hat{c}_1)_{exo}$ and $c_2^* = (\hat{c}_2)_{exo}$.

(4) The higher (lower) the value of λ (q), the larger the region in which $c_1^* > (\hat{c}_1)_{exo}$ and the region in which $c_t^* > (\hat{c}_t)_{exo}$ $\forall t = 1, 2$. [24]

[24] As a final remark, we want to underline that we have verified that all the results about the optimal preservation levels, the WV and the TV we have presented in this paper hold also in case the DM is risk-adverse, i.e. if his utility function is concave; they hold independently from its concavity, i.e. independently from the DM's degree of risk aversion. Nonetheless, the results on the TV hold all the more so when the DM is risk-averse. Details on calculations are available upon request.

1.5 Conclusions

Our theoretical work presented in this first chapter of this thesis goes several steps beyond the existing literature on environmental option values.

First of all, we generalize the features and extend the application of the existing environmental choice framework.

More specifically, starting with the traditional two-period model of choice (develop or preserve), we allow for a continuous choice set and analyze the information side in the most complete possible way; in our model, we are able to identify:

- if information comes out with certainty, with a certain probability or if it does not;

- if information is (only) exogenous, (only) endogenous, or both.

In this more general framework, moving from the analysis of the meaning of the QOV, we have defined a more general *Waiting Value* (WV) as the value attached to the increase in expected utility (of preservation and development net benefits) due to the possibility of acquiring new *information exogenously*. We have shown the WV (as the QOV) is always positive, thus forcing the DM towards a higher level of preservation of the environmental area during the first and the second period of choice.

In the environmental option values literature little attention has been devoted to the "*endogenous information*" (dependent learning) case. Our "general" framework allows for it.

There are several environmental choice problems needing to be modelled by accounting for the fact that by developing (destroying) even a little portion of an environmental resource, you are able to obtain (more) information on future net benefits of preservation; nonetheless, the level and the quantity of information coming out endogenously depends on the amount of the resource developed (destroyed).

Miller and Lad (1984), Freeman (1984), Hanemann and Fisher (1987) and again Fisher (2000) have shown that if information about the consequences of an irreversible development action can be obtained only by undertaking development, this strengthens the case for some development. In other words, allowing for the possibility of new information acquired by developing (destroying) at least a portion of the environmental resource would surely lead to a lower amount of preservation in both periods with respect to the case in which information comes out only exogenously. Their conclusion is really intuitive: the fact that "the more you destroy, the higher the possibility of obtaining new information" would increase dramatically the amount of resource developed in the first period.

In the second part of this chapter, we prove the *counterintuitive result* that (for a large set of values of net benefits of preservation) the possibility of endogenous information pushes the DM towards a higher level of preservation with respect to the case where information arrives only exogenously.

By generalizing Hanemann and Fisher's (1987) analyses, throughout this chapter of our thesis we have introduced a *Testing Value* (TV), defined as the additional value attached to endogenous information (additional with respect to information exogenously arriving); in other words, it is the gain the DM obtains when he can receive information regarding future benefits, by developing in the current period (with respect to the case in which he ignores the possibility of receiving information in this manner). The need for a TV arises in all those situations in which development of an environmental area itself generates information about the future economic benefits of development (and its future environmental costs).

We have shown the TV too is always positive and that it always pushes the DM in the same direction of the WV (i.e. towards a higher level of preservation of environmental resources).

Moreover, in many cases the TV pushes the DM towards preservation of environmental resources more than waiting value (alone) does.

With regard to the level of preservation in the "exogenous and endogenous" information scenario, we find that, with respect to the case in which only exogenous information is available, in many cases (depending on the values of b_1, b_2^u and b_2^f), c_1^* and c_2^* are higher (see *Figure* $B.3$ and $B.4$ as compared to *Figure* $C.1$). This means that in all these cases, accounting for the TV pushes the DM towards a higher level of preservation of the environmental resource.

The reason is that the TV can lead the DM to develop only a certain amount of the environmental asset (*internal solutions*); on the contrary, the WV leads more frequently to *corner solutions*.

Some crucial *Environmental Policy Issues* can be deeply investigated through our "more general" framework. According to the results presented in this chapter, when both exogenous and endogenous information are available,

- it is not obvious that preserving the whole amount of an environmental resource is the optimal choice;

- it is not obvious that the possibility of acquiring new information endogenously leads to develop (destroy) a larger amount of the environmental resource;

- for a large set of values of the benefits of development/preservation, the possibility of endogenous information being acquired and the consequent emergence of the TV leads the DM to destroy less of an environmental resource, with respect to the case in which he takes into account only the WV (allowing only for the possibility of acquiring new information exogenously); hence, for this set of values, "testing" the environmental resource (by destroying a small part of it in $t = 1$) is not only the choice maximizing the DM's intertemporal expected utility, but also the one minimizing the amount of environmental resource destroyed in the current and in the future periods.

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Part II

Models of Strategic Behaviour

Chapter 2

Actions, Beliefs and Feelings: an experimental study on Dynamic Psychological Games

2.1 Introduction

Causal relations among *beliefs* and *actions* have been widely studied in economics and psychology. One regularity emerging from both disciplines involves a positive relationship between individuals' actions and their (first-order) beliefs of others' actions in strategic decision environments [1]. Moreover, even though one traditional assumption in neoclassical economics has been material self-interest, in the last few decades economists have studied the role played by *emotions* in generating human behavior (i.e. actions), hence suggesting general ways of incorporating emotions and feelings into the economic models; in particular, it has been widely accepted in the economic theory that *feelings* can be expressed in terms of *belief-dependent motivations*, for example in terms of one's expectations about other agents' actions (first-order beliefs) and in terms of one's guess about other agents' expectations about his own action (second-order beliefs) and so on. The main goal of this chapter of our thesis is to study in an experimental setting the relations between actions and beliefs, those between beliefs and feelings and those between actions and feelings, through the application of psychological game theory. Many experimental economists have studied these relations within *one-shot* interactions, allowing for *ex-post explanations* claiming for belief-dependent motivations as source of the "irregularities" in the experimental results [2]. We depart from the experimental paper by Charness and Dufwenberg (2004) on a one-shot trust game with first-order and second-order beliefs elicitation and from the theoretical paper by Battigalli and Dufwenberg (2005) on dynamic psychological game theory.

Our experimental study goes three steps beyond the existing experimental literature:

a. we test players' behavior in a *finitely repeated game*, in which we elicit beliefs at the beginning of each period;

b. we elicit players' *sensitivity to feelings* (as guilt aversion or reciprocity), in order to analyze the relationships between actions, beliefs and feelings in a *dynamic* setting: the evolution of beliefs, their correlation with the played action profile and the way through which they incorporate players' feelings.

c. we test *directly* games with beliefs-dependent payoffs, i.e. *psychological games.* We study whether psychological payoffs depend (only) on the beliefs of others,

[1] See Section 2.1.

[2] See Section 2.2.

as Battigalli and Dufwenberg (2005) [3] suggest. Their approach, crucial for our experimental setting, clearly separates two channels through which beliefs and information affect behavior: the direct (psychological) impact of beliefs on preferences over terminal histories, and the (traditional) impact of updated beliefs about the opponents on the preferences over own strategies.

In other words, our experimental setting could be seen as a direct test of the casual relations and the potential correlation between actions, beliefs and feelings in a repeated *psychological* game, i.e. a game in which players have 'belief-dependent' motivations, giving rise to psychological payoffs. This could be also seen as an indirect test on the usefulness of psychological games setting while interpreting real life decisions in strategic environments. Charness and Dufwenberg (2004) provide evidence supporting a theory according to which people strive to live up to others' beliefs in order to avoid guilt. This allows them to provide a general theory of guilt aversion, by means of an application of Geanakoplos, Pearce and Stacchetti (1989; henceforth GPS) psychological games tools. However, in their experimental setting, they let participants play a one-shot trust game and, once they check that (traditional) game theoretical predictions are not matched by their experimental results, they show how this allows for incorporating a guilt-aversion argument into players' payoffs, theoretically constructing a specific psychological game of trust. Nevertheless, we think that their experiment represents only an indirect proof of the relevance of psychological games in explaining belief-dependent motivations. In order to stress this relevance, we chose to test directly the impact of accounting for the presence of psychological payoffs already in the experimental setting. Moreover, differently from Charness and Dufwenberg (2004), we test the impact of psychological payoffs in a repeated game (they do it in a one-shot game). Hence, we propose experimentally a repeated game of trust in which the psychological payoffs of one of the two players (the trustee) are gleaned by means of a questionnaire and transmitted to the other player (the truster) before the game is played. We call this experimental procedure "*questionnaire-transmission treatment*", as opposed to the "*standard treatment*", in which psychological payoffs are not measured and transmitted before the game is played; in this second case, the impact of 'belief-dependent' motivations can be inferred only ex-post as one of the possible explanations for the deviations of the experimental results from those predicted by *traditional* game theory. This aspect is in line with what Charness and Dufwenberg (2004) do.

[3] Battigalli and Dufwenberg's work can be interpreted as a generalization and extension of Geanakoplos, J., D. Pearce and E. Stacchetti (1989), the first paper on Psychological Game Theory.

Our experimental results show that eliciting and transmitting the psychological payoffs and letting the two players play the *complete information* (repeated) game of trust leads them to behave in a visibly different manner (with respect to their behavior in the corresponding *incomplete information* game setting). More precisely, the *public information* of the psychological payoffs in the (repeated) game of trust results in players' perception of feelings like guilt aversion and/or reciprocity which otherwise would be underestimated. That in turn ends in a more cooperative behavior for both players. Moreover, our experimental results on the repeated psychological game demonstrate how feelings' sensitivity elicitation and transmission (needed to measure and communicate experimentally the psychological payoffs) enhance cooperation more than the traditional repeated-game reputation building explanation [4] would suggest: reputation building arguments would ensure cooperation until a couple of periods from the end of the repeated game. Specific belief-dependent motivations incorporated in the psychological payoffs (e.g. guilt aversion) frequently lead to trust and cooperation until the *last* stage of the repeated game.

In the next section, we provide related literature of the main experimental works from which our work draws inspiration. In Section 3, we describe and motivate our experimental design. In Section 4, we briefly expose our null hypothesis and experimental results. In Section 5, we suggest a theoretical interpretation to our experimental results.

2.2 Previous Research and Background

In this section, we mention and interpret previous experiments and papers studying and demonstrating relations between beliefs and actions (Section 2.1) and between emotions and actions (Section 2.2) in strategic settings in which players' private interest conflicts with the "public" interest.

2.2.1 Relationship between Actions and Beliefs

Strategic settings in which players' private interest conflicts with the "public" interest (like prisoners' dilemma, partnership games, public goods provision, common-pool

[4] In multistage games, trust can usually be supported by repeated-game reputation building, so multistage games are not evidence of blind trust (Camerer, 2004). In centipede games, the typical finding (McKelvey and Palfrey, 1992) is that players pass until a couple of steps from the end. Play in repeated prisoners' dilemmas is similar.

resource game, etc.) have been studied both by several experimental economists and psychologists. One regularity among all these studies involves the relationship between individual's beliefs and actions: in particular, expectations of others' cooperation and one's actual cooperation are robustly and positively correlated. However, two competing class of (casual) theories have been proposed to explain this relationship.

The first class of theories, coming from economics, suggests that beliefs cause actions. For example, in the prisoner dilemma one player will cooperate if he/she expects the other to do so. These theories are defined by Croson and Miller (2004) *reaction theories*, since individuals choose actions to *react* to beliefs.

The second class of theories, which, on the other hand, belongs to psychology, suggests that actions cause beliefs. There is a number of different specific theories in this class: Croson and Miller (2004) provides a critical analysis of many of them. They conclude that, whichever of these theories one believes, they all have the similar property that expectations are projected from own (anticipated) behavior. They refer to these theories as *projection theories.*

Belonging to the former or to the latter class, almost all the experimental works on the relation between actions and beliefs in social dilemmas have assumed one theory or another in experimental design (for example, psychologists tend to elicit beliefs *after* individuals make decisions in strategic settings, economists *before*). Some studies show that manipulated expectations can affect choices (e.g. Messick et al., 1983, Schroeder et al., 1983, Weimann 1994). Other studies argue that choices are justified ex-post by adjusting expectations (e.g. Yamagishi and Sato, 1986) or that differences between the variance of the player estimates of others' actions and the observer estimates of others' actions demonstrates "false" consensus (e.g. Dawes et al., 1977). However, none of these previous experiments were designed to explicitly distinguish between these competing classes of theories, even though, as anticipated above, both classes of theories are consistent with the existing evidence of a positive relationship between beliefs and actions in social dilemmas.

Croson and Miller (2004) attempts a clean separation of these two classes of explanation. They design an experiment using an off-diagonal battle-of-the-sexes game with successfully exit to distinguish these theories: their results are consistent with the reaction hypothesis as opposed to the projection hypothesis. This is not to conclude that people don't project in dilemma settings, but that in settings where reaction and projection predict different outcomes, reaction proves the stronger effect.

That would lead us to conclude that, while introducing belief elicitation in an experimental setting, the influence of belief elicitation on subsequent chosen actions should be greater in size with respect to the one that actions could have on subsequent beliefs.

Experimental literature summed up in the next subsection, among other things, show that in trust games (particular case of social dilemma games) the influence of belief elicitation (and transmission) on subsequent chosen actions is quite null: different kinds of "belief manipulation" do not affect players' behavior.

2.2.2 Relationship between Actions and beliefs-dependent motivations

In this subsection, we analyze the main features of the most important experiments concerning *trust games* in the last few years. In order to ensure uniformity while summarizing the different papers listed below, in each trust game we describe, we call *truster* the player who has to choose to place trust (or not) and *trustee* the player who has to choose to fulfill trust (or not). In the review below, we concentrate on the analysis of the techniques of belief elicitation and transmission used in the previous experimental settings to investigate players' sensitivity to some feelings. Notice that in these experimental settings all games participants play are one-shot, repeated one-shot with random matching or with no information between periods.

In Dufwenberg and Gneezy (2000), each pair in the experimental setting plays the following game: the truster may take $x \in [0, 20]$ Dutch guilders, or leave it and let the trustee 2 split 20 guilders between them. During the the game, there is beliefs elicitation both from trusters (first-order beliefs) and from trustees (second-order beliefs), but there is not belief transmission. They analyze the relevance of trust responsiveness in this kind of trust games. *Trust responsiveness* is "a tendency to fulfil trust because you believe that it has been placed on you" (see also Bacharach, Guerra and Zizzo (2001)). They conclude that trust responsiveness [5] should hold even if belief transmission did not take place.

The problem with this kind of procedure is that beliefs' elicitation may influence players' behavior: for example, Croson (2000) discusses how belief elicitation distorts behavior in the context of social public goods and prisoner dilemma experiments.

Bacharach, Guerra and Zizzo (2001) test trust responsiveness in basic 2X2 trust games with different payoff structures. In their experimental setting, beliefs are elicited

[5] *Trust responsiveness* predicts that trustees who have higher guesses will be more likely to fulfil trust.

in an incentive-compatible way on the part both of trusters and of trustees, using the same technique of Dufwenberg and Gneezy (2000), but (a descriptive statistics on) trusters' first-order beliefs are transmitted to each trustee, before eliciting her second-order beliefs. More specifically,

a) *before playing*, each truster is asked to state as a probability his confidence that the trustee would fulfill his trust (first-order beliefs);

b) *before playing*, each trustee is told the *average value* of the probability assessments of the trusters *other than her opponent's one*;

c) *before playing (but after b))*, each trustee is asked to state as a probability the (opponent) truster's confidence about her trust fulfilment (second-order beliefs);

d) the procedure at points a) and b) is common knowledge.

We find in Bacharach, Guerra and Zizzo's (2001) analysis two main problems:

1) by having (belief elicitation and) transmission of beliefs from trusters to trustees, results may have not been very general. Belief transmission was motivated in the paper by the desire to enable trustees to form definite enough beliefs about the trusters' confidence on them. While this is reasonable, this may have biased trust responsiveness upwards for at least two reasons: a) it may draw the attention of subjects to the truster's confidence in them, possibly making any psychological factor leading to trust responsiveness more salient than otherwise; b) it is not obvious that in real world people typically receive this kind of information.

2) same problem of Dufwenberg and Gneezy (2000) for what concerns beliefs' elicitation.

Guerra and Zizzo (2004) use two simple trust games to measure directly or indirectly the robustness of trust responsiveness in three experimental treatments: beliefs are not elicited (*Condition 1*); beliefs are *elicited* but not transmitted (*Condition 2*); beliefs are *elicited* and *transmitted* from trusters to trustees [6] (*Condition 3*) [7]. Their two null hypothesis are: lack of belief elicitation implies a different value of trust responsiveness (H.1); belief transmission in experiments can bias trust responsiveness upwards (H.2).

They provide an indirect (partial) test of H.1 (robustness of trust responsiveness when beliefs are not elicited): they check that *observable measures* of trusting and fulfilling rates do not change in comparable conditions with and without belief elicitation (respectively, under Condition 2 and under Condition 1). They provide also a direct test

[6] To be precise, each trustee received a report of the mean value of first-order beliefs of her non-coplayers.

[7] From Bacharach, Guerra and Zizzo (2001).

of H.2 (robustness of trust responsiveness when beliefs are transmitted): moving from a situation in which beliefs are (elicited and) transmitted (Condition 3) to a situation in which beliefs are (only) elicited (Condition 2), trust responsiveness remains altered or disappears. [8] The data they find allow to reject both the null hypothesis: they find that trust responsiveness is robust with respect to any kind of "belief manipulation", hence strengthening the case for the real-world significance of trust responsiveness.

Charness and Dufwenberg (2004) [9] choose to run one-shot interactions between participants in their experiment to test for *guilt aversion*, defined [10] as the psychological aversion to the suffering experienced by letting others down. Charness and Dufwenberg (2004) states they are not interested in reputation or repeat-game effects; moreover, they reveal their experimental setting is structured in such a way to eliminate these effects (p. 10). Notice that also Dufwenberg and Gneezy (2000), Bacharach et al. (2001) and Guerra and Zizzo (2002, 2004) are not interested in analyzing repeated games: they provide more than one interaction of the trust game, but without telling the participants the result of every interaction. Nonetheless, they do again random matching before each new interaction.

Charness and Dufwenberg (2004) experimental design is the starting point of our experimental setting. We allow for reputation or repeat-game effects and we try to test directly the psychological game the truster and the trustee actually play (see Section 3).

Finally, Masclet et al. (2003) experiment provides an example of how cooperation can be enhanced purely by *informal sanctions.* They give to all agents the opportunity to express disapproval on others' contribution decision thus showing how this nonmonetary system is able (as much as monetary sanctions) to increase contribution levels (and hence average payoffs) in a Voluntary Contribution Mechanism game. However, they stress the fact that punishment may be a particular form of communication and, in repeated game, it serves as a form of pre-play communication for future periods.

We are interested in the "psychological pressure" created by Masclet et al. (2003) nonmonetary punishment scheme: using their intuition, we build a simple mechanism to elicit and transmit agents' sensitivity to some particular feelings in our psychological game of trust. Our experimental setting is designed to mainly investigate two kinds of

[8] They compare only Condition 3 to Condition 2 and Condition 2 to Condition 1, they do not compare directly Condition 3 to Condition 1.

[9] We do not summarize here all the features of Charness & Dufwenberg's experimental setting: in particular, over the five treatments they run, we report only the main features of Treatment 3 and Treatment 5, in which messages are not sent from player A to player B. This is because we are not interested in the impact of communication on trust and cooperation, as they instead are.

[10] See, among others, Dufwenberg and Gneezy (2000).

feelings characterizing players' psychology in trust games: *guilt aversion* and (positive) *reciprocity.*

Guilt aversion can be defined in the following way: people suffer from guilt if they inflict harm on others; although guilt could have a variety of sources, one preeminent way to inflict harm is to let others down (see Tangney, 1995). Comparing Guerra and Zizzo (2004) with Dufwenberg and Gneezy (2000) and Charness and Dufwenberg (2004), one can conclude that *trust responsiveness* and guilt aversion are two sides of the same coin: they describe the same feeling, the former from a positive point of view and the latter from the negative one. If not, they are anyhow similar when considering the consequences in terms of players' economic behavior. In fact, they both predict the same behavior for the trustee: positive correlation between her second-order beliefs (as statement of trusters' confidence that she would fulfill trust) and trust fulfilment. In other words, in the experimental settings described above, they both lead to higher expected mean guess of the trustees who fulfils trust than the mean guess of the trustees who withdraw it.

Reciprocity has two sides: *positive* reciprocity, where a player is kind in return to another's kind choice, and *negative* reciprocity, where a player is unkind in return to another's unkind choice. Rabin's (1993) theory of reciprocity, in which players reciprocate belief dependent (un)kindness with (un)kindness, is probably the most well-known application of GPS' psychological game theory. Rabin works with the normal form version of GPS' theory. His goal is to highlight certain key qualitative features of reciprocity, and he does not address issues of dynamic decision making, although he points out that this is important for applied work (p. 1296). Dufwenberg & Kirchsteiger (2004) pick up from there, and develop a theory of reciprocity for extensive games. In motivating their exercise, they argue that it is necessary to deviate from GPS' extensive form framework: GPS only allow initial beliefs to enter the domain of a player's utility, while the modeling of reciprocal response at various ventures of a game tree requires that kindness be re-evaluated using updated belief. Battigalli and Dufwenberg (2005), building on recent works on dynamic interactive epistemology, propose a more general framework for dynamic psychological games where updated higher-order beliefs, beliefs of others, and plans of action may influence motivation. They capture dynamic psychological effects (such as *sequential reciprocity*) that were previously ruled out.

In Section 3 and 4 it is explained how a simple *belief-dependent nonmonetary reimbursement scheme* is able to both infer and disclose trustees' sensitivity to *guilt aversion* and to (*sequential*) *reciprocity* in a *repeated psychological game of trust.*

2.3 Experimental Setting

2.3.1 The stage game

From an economical point of view, the stage game represents the following situation [11]. Players A (the truster) and B (the trustee) are partners on a project that has thus far yielded total profits of 2€. Player A can now withdraw from the project. If player A dissolves the partnership, the contract dictates that the players split the profit fifty-fifty. But total profits would be higher (4€) if player A leaves his resources in the project . To do so, however, he must forgo his contractual rights and trust player B to share the profits after the project is completed. So, player A must decide whether to *Dissolve* or to *Continue* the partnership; when he chooses to *Continue*, player B can either *Take* or *Share* the higher profits. We let players play the simultaneous game: player B must choose between *Take* and *Share* without knowing if A has trusted her.
The simultaneous stage game is summarized in the following table:

	A receives	**B** receives
A chooses *Dissolve*	€1	€1
A chooses *Continue*, **B** chooses *Share*	€2	€2
A chooses *Continue*, **B** chooses *Take*	€0	€4

Table 1. Payoff matrix for the constituent game

2.3.2 The experimental design

Participants were recruited at Bocconi University (Milan) by sending out an E-mail message to students coming from several universities in Milan (not only Bocconi) and by affixing posters in the Bocconi campus. Sessions were conducted in a computerized classroom that was divided into two sides by a center aisle, and people were seated at spaced intervals. The number of participants in a session was 20, for a total of 200 people; each person could only participate in one of these sessions. Average earnings were €17, including a €5 show-up fee; average duration of a session was one hour and a quarter.

At the beginning of each session, each participant is randomly chosen to be role A or role B. She maintains the same role until the end of the experiment.
Each session is composed by one of three possible treatments.

[11] This game is borrowed from Rabin (1993).

We define the three treatments as *S*tandard *T*reatment (*ST*), *Q*uestionnaire *T*ransmission *T*reatment (*QTT*) and *Q*uestionnaire *N*o-transmission *T*reatment (*QNT*), respectively. So far we run four sessions with *ST* (40 pairs), four with *QTT* (40 pairs) and two with *QNT* (20 pairs).
ST consists of three stages, while *QTT* and *QNT* consist each one of four stages. The first, the second and the forth stage of *ST* are similar to the first, the third and the fourth stage of *QTT* and *QNT*, respectively.
We sum up the different stages for each treatment in Figure 1.

	One-shot game	*Questionnaire Stage*	4-period repeated game	*Final Questionnaire*
Tr. 1	**Decision Stage 1** with beliefs elicitation but no results told		**Decision Stage 2** with beliefs elicitation and choices told	Feelings Elicitation *without* Transmission
Tr. 2	**Decision Stage 1** with beliefs elicitation but no results told	Feelings Elicitation *and* Transmission	**Decision Stage 2** with beliefs elicitation and choices told	Feelings Elicitation *without* Transmission
Tr. 3	**Decision Stage 1** with beliefs elicitation but no results told	Feelings Elicitation *without* Transmission	**Decision Stage 2** with beliefs elicitation and choices told	Feelings Elicitation *without* Transmission

Figure 1. Experimental Treatments

Before each stage, instructions of the next stage are read aloud by the experimenter. Subjects know the number of stages from the beginning but not the content of later stages. *Decision Stage* 1 contains the one-shot game (see Table 1) and a belief elicitation described in detail below. *Decision Stage* 2 (second stage in *ST*, third stage in *QTT* and *QNT*) consists of 4 rounds of the same game described in Table 1 and the same belief elicitation as in Decision Stage 1. The second stage in *QTT* and in *QNT* consists of the *Questionnaire Stage* explained below. The forth and last stage consists of a *Final Questionnaire*, same for all treatments, similar to the one introduced in the questionnaire stage (of *QTT* and *QNT*). We now describe the details of each stage:

• Before Decision Stage 1, each player *A* is matched with a player *B* and viceversa, randomly creating 10 pairs.

• *Decision Stage* 1 (same for all treatments)
- *Beliefs elicitation*: *before* the one-stage interaction described in Table 1, we ask each player *A* to *guess the percentage* of *B* players who will choose *Share* (*A*'s first-order beliefs);[12] we ask each player *B* to *state the guess* of her co-paired *A* about the percentage

[12] We do not ask *A*s to guess the likelihood that the paired *B* would choose *Share*, as we don't observe

of B players who will choose *Share* (B's second-order beliefs) [13] and also to *guess the choice* her co-paired A will make. [14]
- As said above, player A and player B simultaneously state their action for the one-shot game, after the belief elicitation. [15]

• *Information after Decision Stage* 1: we don't give any information about other players' action or beliefs after this stage. Players are informed that the resulting payoffs of the interaction and the gains for the correctness of the guesses will be both paid to them at the end of the experiment.

Remark. The reason for this initial one-shot interaction is twofold: first, we want to know how players form their beliefs without introducing any reputation or repeat-game effect; second, we introduced the first stage to let them understand the game and the beliefs elicitation very well before they answer the questionnaire stage (QTT and QNT) and interact later in the repeated game with always the same opponent (all treatments). We don't give them any information about the opponent's behavior in Decision Stage 1, since we want them to answer the questionnaire without any knowledge of an opponent's behavior. For ST, we mainly introduced Decision Stage 1 to maintain the same structure as in QTT and QNT and to make behavior in the two treatments more comparable.

• After Decision Stage 1, players know that they are randomly rematched for the next stage(s).

• *Decision Stage* 2 of ST

Participants elicit their beliefs as mentioned above and play the same simultaneous game (they played in Decision Stage 1) *four* times within the *same* pair. After each period,

this likelihood: the observed binary choice would make this simply a *Yes* or *No* guess. We instead ask As to indicate a percentage $x\%$, with $x = 10n$ and $n \in \{0, 1, 2, ..., 10\}$, since it is common knowledge there are 10 Bs in each session.

[13] We ask also Bs to indicate a percentage $x\%$, with $x = 10n$ and $n \in \{0, 1, 2, ..., 10\}$ (see previous footnote).

[14] Charness and Dufwenberg (2004) elicit B players' second-order beliefs by asking them to state the average of A players' (choosing *Continue*) guesses about the percentage of B players choosing *Share*. We think their second-order beliefs elicitation procedure is too complex to let B players understand what they are guessing about.

[15] Among other reasons, we have chosen to let each pair play a static (constituent) game, in order to avoid the anticipated loss of public anonymity for B's choosing *Take*: if the constituent game would be dynamic (with A playing first), when A chooses *Dissolve*, B's choice would be payoff immaterial, hence unobservable to A; that could increase B's incentive for choosing *Take*. Player A could anticipate this fact, thus leading to a higher frequency of (*Dissolve,Take*) play not justified by reputation-building or fairness considerations. Nonetheless, in Decision Stage 2, where the consituent game is repeated four times, other kind of "distortions" could emerge: each period in which A would choose *Dissolve*, he could not know what B has chosen. Hence (expecially in the first of the four periods), A could be pushed to choose *Continue* only because he would like to know the action chosen in that period by B, in order to play the next round of the game having more information on his opponent's past behavior.

we communicate to each player his/her opponent's choice and the resulting payoffs. Note that, since the game is simultaneous, after each period player A knows player B's choice even if the latter has chosen *Take*. Neither of each player's beliefs (guesses) are transmitted to either his/her paired person or to other participants in any round. Each player knows the gains for the correctness of his/her guesses only at the end of the session.

- *Questionnaire Stage* of QTT and QNT

In both QTT and QNT, we *elicit* each B's *feeling sensitivity* through a non-monetary Hypothetical Pay back Scheme (HPS) and, only in QTT, we *transmit* it to her new co-paired A; in QNT there is elicitation without transmission.

The elicitation procedure is the following: we ask each B to suppose that we do new pairings, that the new A paired with her chooses *Continue* and that she chooses *Take*, hence earning €4 and leaving the new co-paired A with €0. We also ask B to suppose that, once she gets the €4, she has the possibility to give back some euros to A according to A's guess she might have chosen *Share*. Hence, we show to each B all possible new co-paired A's guesses about the probability she would have chosen *Share*; remembering that A (supposedly) has chosen to *Continue* and that she (supposedly) has chosen to *Take*, we ask her how much of her €4 she would be willing to give back to A according to each A's possible assessments of the probability of B's choosing *Share*. Hence, each player B puts a value (between 0.00 and 4.00) in each of the eleven rows of the following table, according to each different A's guess:

A's possible assessments of *Share*	Your reimbursement
0%	between 0.00 and 4.00
10%	between 0.00 and 4.00
20%	between 0.00 and 4.00
30%	between 0.00 and 4.00
40%	between 0.00 and 4.00
50%	between 0.00 and 4.00
60%	between 0.00 and 4.00
70%	between 0.00 and 4.00
80%	between 0.00 and 4.00
90%	between 0.00 and 4.00
100%	between 0.00 and 4.00

(Table 2. *Hypothetical Pay back Scheme* (*HPS*))

Notice that:

- in *QTT*:

(a) each B knows that she will not receive any payment for the answers given in *HPS*;
(b) each B knows the values she inserts in *HPS* will not lead to any direct monetary transfer to any player A;
(c_2*)* each B knows we will transmit her *HPS* to a randomly chosen person A;
(d) each A looks at all the instructions of this stage (but without filling *HPS*) and thus knows *(a)*, *(b)* and *(*c_2*)*.

- in *QNT*:

(a) each B knows that she will not receive any payment for the answers given in *HPS*;
(b) each B knows the values she inserts in *HPS* will not lead to any direct monetary transfer to any player A;
(c_3*)* each B knows we will not transmit her *HPS* to anyone;
(d) each A looks at all the instructions of this stage (but without filling *HPS*) and thus knows *(a)*, *(b)* and *(*c_3*)*.

- *Decision Stage* 2 of *QTT*

Once all B players have filled their *HPS*, we randomly pair again and transmit each B's filled *HPS* to her new co-player. Hereafter, each A can look at *HPS* filled by his new co-player any time he needs to do it. All this is common knowledge to all players. Then, they play according to the same instructions as stated in Decision Stage 2 of *ST*, i.e. they play the same simultaneous game (played in Decision Stage 1) *four* times within the *same* pair and everyone knows his/her co-paired player is not the same he/she has played with in Decision Stage 1.

- *Decision Stage* 2 of *QNT*

Same as *Decision Stage* 2 of *ST*.

- *Final Questionnaire*

- At the end of Decision Stage 2 of *ST*, we ask B players to fill *HPS*, knowing that it will not be transmitted to anyone.
- At the end of Decision Stage 2 of *QTT*, we ask B players to fill again *HPS*, this time knowing that it will not be transmitted to anyone.
- At the end of Decision Stage 2 of *QNT*, we ask B players to fill again *HPS*, again knowing that it will not be transmitted to anyone.

⋆ Payments for:

Choices. In the simultaneous game of Decision Stage 1 and in each of the four rounds interactions of Decision Stage 2, participants are paid according to their role and to the resulting payoffs.

Guesses. Player A : every time his guess is correct, €5 are added to the total payoff (at the end of the experiment); every time his guess is not correct, he obtains nothing for that guess. Player B: every time both her guesses are correct, €5 are added to the total payoff (at the end of the experiment); every time at least one of her two guesses is not correct, she obtains nothing for those guesses.

2.4 Experimental hypothesis and results

As anticipated in Section 1, our goal is twofold: we want to state the accuracy of psychological game theory in explaining agents' behavior as motivated by feelings and emotions (i.e., not only by self-interest) and to analyze the path of beliefs through time in situations of finitely repeated interactions.

2.4.1 Relevance of Psychological Payoffs

Traditional game theory admitting monetary preferences with self-interest players suggests the unique subgame perfect equilibrium of the repeated game of trust (see previous section) is given by the repetition of the action profile $(Dissolve, Take)$ in each of the four periods of playing [16].

Psychological game theory (see Battigalli and Dufwenberg, 2005) allows instead for several subgame perfect (psychological) equilibria for the similar repeated game (see Section 5).

From an experimental point of view, in multistage games trust can usually be supported by repeated-game reputation building, so multistage games are not evidence of blind trust (Camerer, 2004). [17] Thus, given the richness of experimental data on social preferences, we presume that behavior will differ from the selfish paradigm both in all treatments. However, it is an open question whether the *questionnaire stage* (in QTT and QNT) will affect players' behavior in the subsequent repeated trust game,

[16] In the simultaneous constituent game, action *Take* is weakly dominant for player B and so A, in order to best reply to *Take*, has to choose *Dissolve*. Hence, the constituent game has the unique Nash equilibrium (*Dissolve, Take*). By the Folk theorem, the correspondent finitely repeated game has a unique subgame perfect equilibrium, given by the repetition of (*Dissolve, Take*) independently from the previous history.

[17] As an example, in centipede games, the typical finding (McKelvey and Palfrey, 1992) is that players pass until a couple of steps from the end. Play in repeated prisoners' dilemmas is similar.

and if it does so, whether this relationship is consistent with psychological game theory previsions. In a *psychological game* utility functions depend on (actions and) *beliefs*, including beliefs about the beliefs of others. In other words, belief-dependent motivations enter the (psychological part of the) utility function through players' first- and/or second-order beliefs and one or more parameters embedding sensitivities to particular feelings. Obviously, beliefs (about opponent's actions or opponent's beliefs) cannot be "known" by the opponent, that is by construction of the psychological payoffs. In general, also players' feelings sensitivities are not known to their opponents: ample evidence in psychology suggests emotional sensitivities differ among people [18]. Hence, if player's particular feeling sensitivity is *not elicited* before the game is played, we can easily state we are dealing with a *psychological game with incomplete information.* The same applies when the (same) player's particular feeling sensitivity is *elicited but not transmitted.* Only in case all players' particular feeling sensitivities are *elicited and transmitted* to all their co-players we can say we are in front of a *psychological game with complete information* [19]. This happens in QTT, where we elicit (all) player B's feeling sensitivities and transmit them to her co-player A [20].

Given the previous arguments, the interpretation of ST and QNT as (the same) *incomplete information treatment* is straightforward: in those two treatments, players are playing the same psychological game they would play in QTT; the only difference is that B's feelings sensitivity (and so her psychological payoff) is not known to her co-player A. It is crucial to understand that in ST and in QNT players are not playing a "standard" game with (only) material payoffs: the fact that feeling sensitivities are not elicited and transmitted before the game is played does not allow to conclude that players' payoff functions are only "material", i.e. do not contain a psychological part. Rather, players play a game in which the psychological payoffs are part of their payoff function, but are not common knowledge among them.

Nonetheless, one could reasonably object that because of the different framing of ST and of QNT, experimental results differ. In that case, one could also doubt about the existence of psychological payoffs even when they are not elicited. This would mean that they have been "induced" by our own elicitation procedure.

Than, our first null hypothesis is that the questionnaire stage in QNT (i.e. psychological payoffs elicitation *without* transmission) influences players' behavior and guesses:

[18] See Krohne (2003) for a general discussion, and Tangney (1995) on guilt specifically.

[19] Obviously, also in a *psychological game with complete information* players' first- and second-order beliefs are unknown to his opponent.

[20] We suppose that player A's payoff function is "only" material.

H1 *(framing effect).*

Feeling elicitation (without transmission) increases both the proportion of As who choose Continue and the proportion of Bs who choose Share in each period of the repeated game. The same happens both to A's guess about the percentage of Bs who choose Share and to B's statement on the guess of her co-paired A about the percentage of Bs who choose Share.

By looking at the experimental results represented in Table 3.a and Table 3.b, one can notice that H1 is strongly rejected: players' and pairs' behaviour [21] and guesses are quite the same in ST (no elicitation) and in QNT (elicitation without transmission).

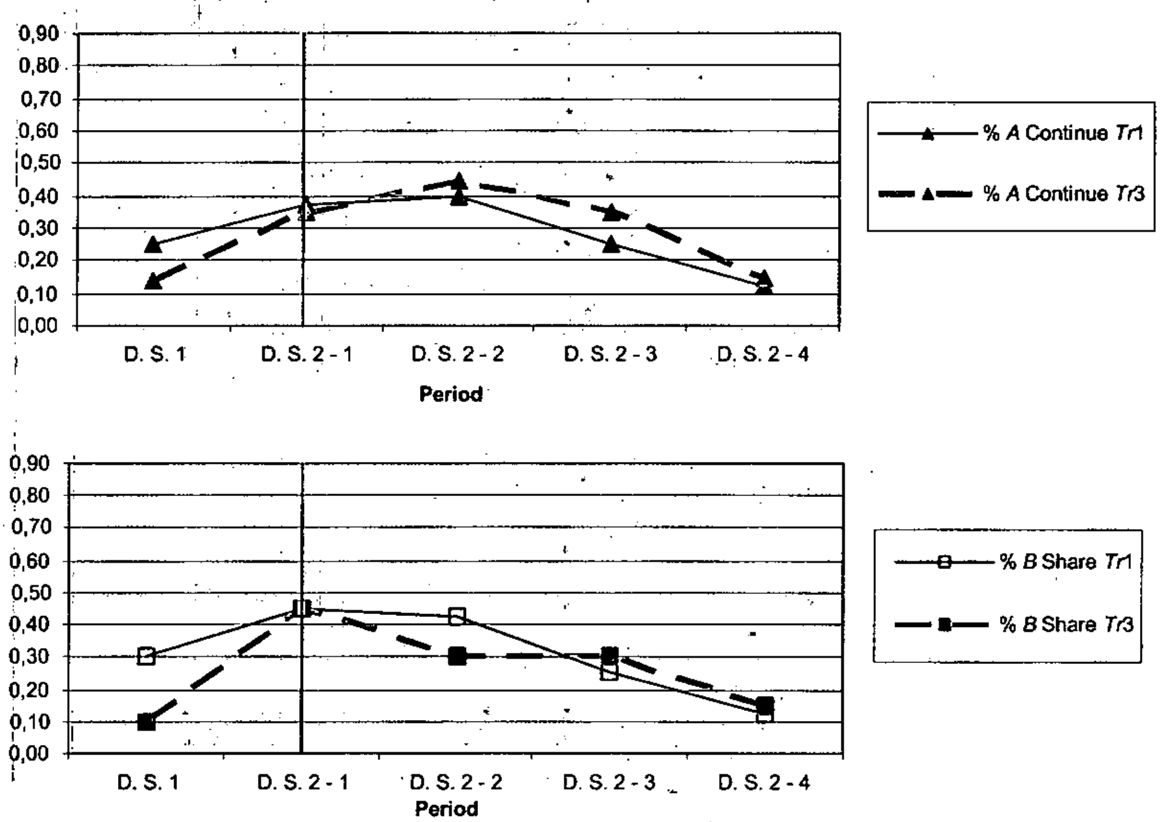

Table 3.a. Choices in ST ($Tr1$) and in QNT ($Tr3$)

[21] For what concerns pairs' behaviour, see Table 5.

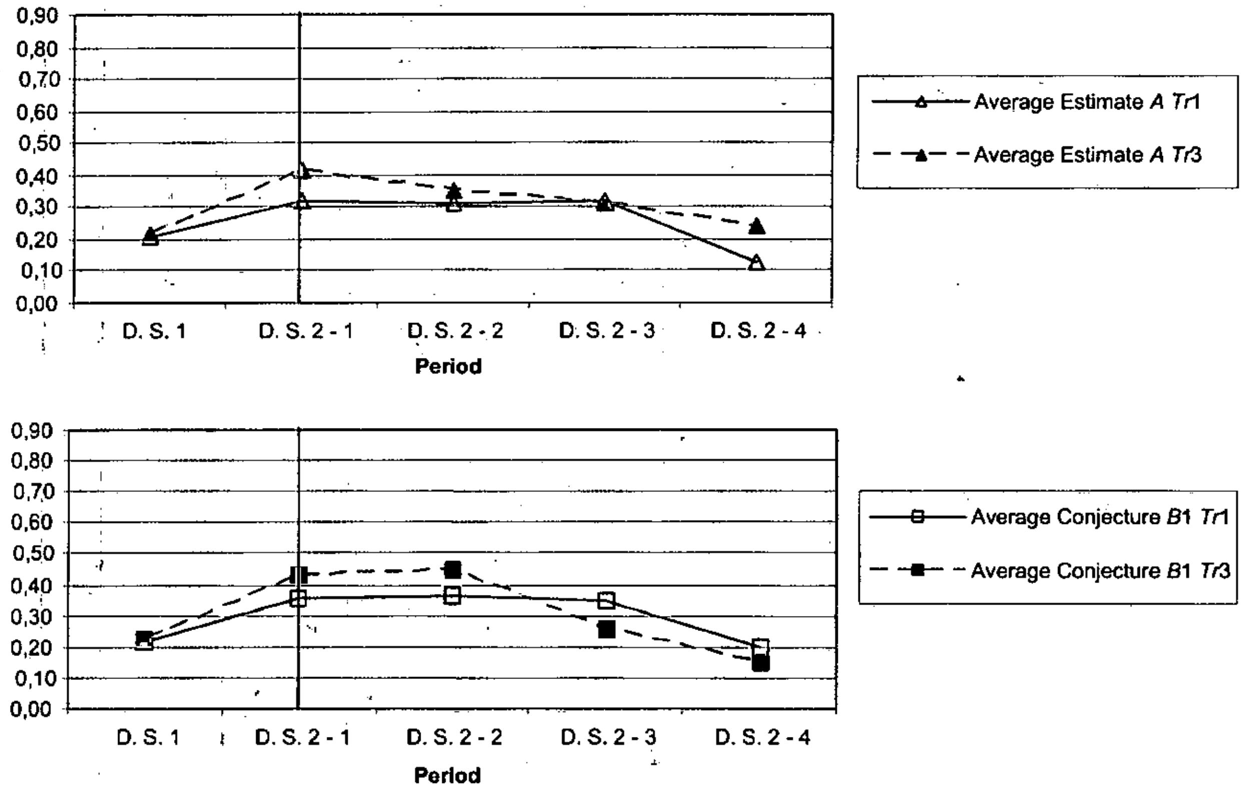

Table 3.b. Average first- and second-order beliefs of Share in ST ($Tr1$) and in QNT ($Tr3$)

Hence, from now onward, when we compare the results of ST to those in QTT (leaving out QNT), it's straightforward we are comparing also results of QNT to those of QTT.

Let us now come to examine the output of QTT. Given the similarities between experimental results in ST and in QNT, one could now object that also the transmission of the elicited feeling sensitivities in QTT does not influence players' behavior and guesses, with respect to ST.

Our second null hypothesis is that the questionnaire stage in QTT (i.e. psychological payoffs elicitation *with* transmission) is irrelevant on players' behavior:

H2 *(public information of psychological payoffs has no effect on behaviour).*

The questionnaire stage in QTT will increase neither the proportion of As who choose Continue nor the proportion of Bs who choose Share in period 1 of the repeated game. Moreover, (Continue, Share) outcomes in each stage of the repeated game are not more *common when feelings' sensitivity elicitation and transmission is introduced in the experimental setting.*

By looking at the experimental results represented in Table 4 and in Table 5, one can notice that H2 is strongly rejected: feelings' sensitivity elicitation and transmission from B to A is very useful in enhancing successful partnership formation and length. This is true for every experimental sessions we run. More specifically,

- *Partnership Formation.* In Decision Stage 1, both the proportion of As choosing *Continue* (25% in ST, 28% in QTT) and the proportion of Bs choosing *Share* (30% in ST, 20% in QTT) are not significantly different between the two treatments. In Period 1 of Decision Stage 2 of ST (QTT), the proportion of As choosing *Continue* is 38% (78%) and the proportion of Bs choosing *Share* is 45% (75%). Hence, the increase in both proportions from period 0 to period 1 is significantly higher in QTT (+50% of As continuing, +55% of Bs sharing) than in ST.(+13% of As continuing, +15% of Bs sharing).

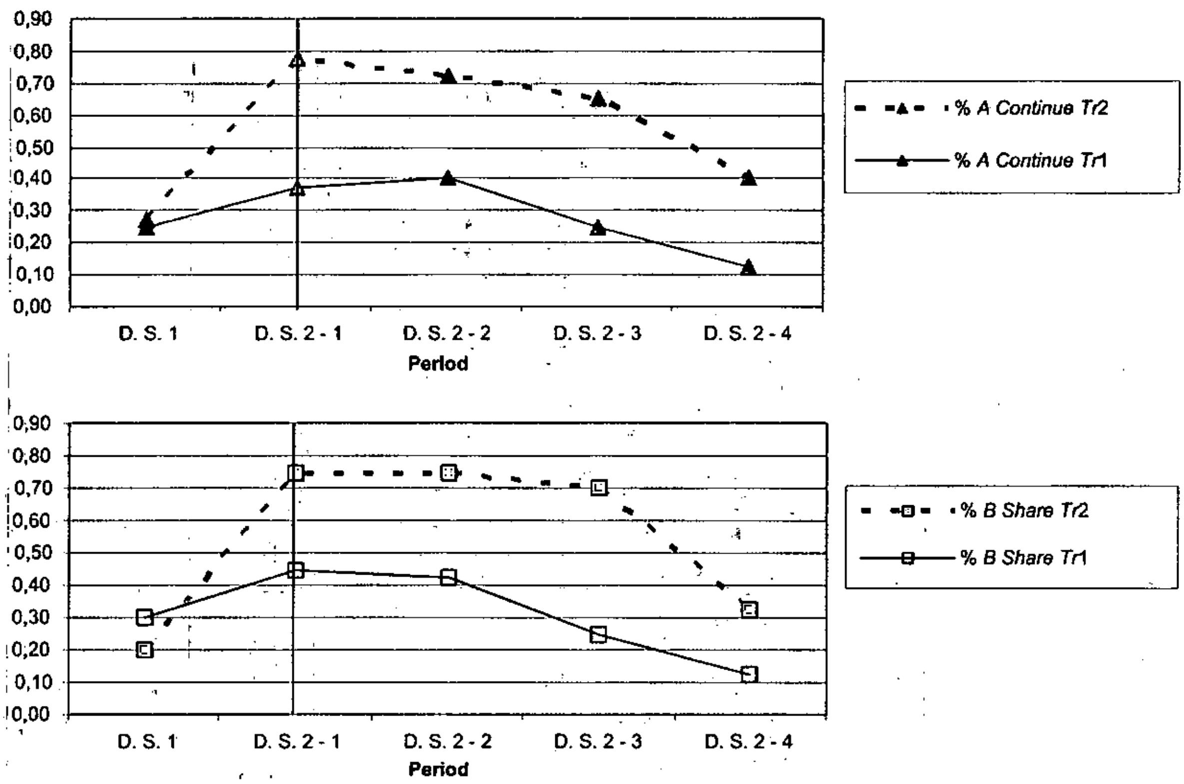

Table 4. Choices in ST ($Tr1$) and in QTT ($Tr2$)

• *Partnership Length.* Let us have a look at Table 5. In Decision Stage 1 ($t = 0$), the number of pairs cooperating is quite the same among different treatments (4/40 in ST, 2/40 in QTT, 0/20 in QNT). In period 1 of Decision Stage 2, there is a sharp increase of the number of pairs cooperating only in QTT (23/40). In ST and in QNT, there is not a sensible increase; moreover, in both treatments there are only 2/40 pairs cooperating in the third period of the repeated game and no pair cooperating in the last one. On the contrary, in QTT there are 20% of pairs (8/40) still cooperating in the last period; moreover, the only pairs cooperating in period $t = 4$ are those cooperating from $t = 0$ to $t = 4$. Hence, in QTT cooperation in the last period of the repeated game seems to be a result of successful partnership formation in $t = 1$ and of continuing trust within those pairs.

	Decision Stage 1	Decision Stage 2			
	% pairs cooperating in $t = 0$	% pairs cooperating in $t = 1$	% pairs cooperating also in $t = 2$	% pairs cooperating also in $t = 3$	% pairs cooperating also in $t = 4$
Tr 1	10%	18%	15%	5%	0%
Tr 2	5%	58%	50%	33%	20%
Tr 3	0%	15%	5%	5%	0%

Table 5. % of pairs choosing $(Continue, Share)$ in ST ($Tr1$), in QTT ($Tr2$) and in QNT ($Tr3$).

The sharp increase in the percentage of pairs cooperating in Decision Stage 2 of QTT has been given by the public information of Bs' feelings sensitivity. Let us investigate the size of this effect, that cannot be explained through traditional game theory. Is this effect greater or smaller in size with respect to the standard "reputation effect" typical of repeated games?

Our third null hypothesis is that the standard reputation effect characterizing repeated games leads to cooperative behaviour more than the public information of the opponent's psychological payoffs does:

H3 *(reputation vs public information of psychological payoffs).*

In the 4-period repeated game of trust, feelings' sensitivity elicitation and transmission pushes players towards cooperation in the first period more than strategic reputation building does.

Let us put ourselves in the worst possible situation with the presumed relevance of the psychological game theory explanation: suppose that in ST all the increase in the proportions of As choosing *Continue* and of Bs choosing *Share* in the first period of Decision Stage 2 derives from non-psychological concerns, among which the strongest is strategic reputation building. Comparing these results with those in *QTT*, we discover that the part of the increase in period 1 of the repeated game given to non-psychological concerns (+13% of As continuing, +15% of Bs sharing, in *ST*) is lower than the one given to the public information of B's feelings sensitivity: [22] with respect to *ST*, passing from Decision Stage 1 to Decision Stage 2 in *QTT* there are a 37% more (50%-13%) of As continuing and a 40% more (55%-15%) of Bs sharing. Hence, we could conclude that in our 4-period repeated game of trust the public information of B's psychological payoffs pushes both players towards cooperation in the first period more than strategic reputation building does: the first effect is more than two times the second one in size (Look at Table 6, where Treatment 1 stands for *ST* and Treatment 2 stands for *QTT*). Thus, we can conclude that H3 is strongly rejected.

Treatment 1	Decision Stage 1	Period 1 of Decision Stage 2	Δ_1 = reputation
% *A's Continue*	25%	38%	13%
% *B's Share*	30%	45%	15%

Treatment 2	Decision Stage 1	Period 1 of Decision Stage 2	Δ_2 = reputation + public information of *B*'s feelings sensitivity
% *A's Continue*	28%	78%	50%
% *B's Share*	20%	75%	55%

	$\Delta_2 - \Delta_1$ = public information of *B*'s feelings sensitivity	
Increase in % *A's Continue*	37%	> 13%
Increase in % *B's Share*	40%	> 15%

Table 6. Measure of the effect of public information of Bs' feelings sensitivities on cooperation

[22] The only difference between $Tr1$ and $Tr2$ is the (elicitation and) transmission of B's feelings sensitivity to her co-paired A. Therefore, we assume that the difference between the increase (in the percentages of As continuing and Bs sharing) in $Tr2$ and the increase (in the same variables, respectively) in $Tr1$ is entirely due to the public information of B's psychological payoffs.

Moreover, the fact that, independently from the treatment, in Decision Stage 1 there are a certain percentage of players (between 20% and 30%) choosing the "cooperating" action (*Continue* for *A*s, *Share* for *B*s) it's a direct proof of the fact that players' payoff functions are not only "material", rather containing a psychological part. Otherwise it would be impossible to explain through traditional game theory why in a simultaneous game (where, by construction, strategic reputation building is absent) players choose actions that do not correspond to the Nash equilibrium; nonetheless, for player *B* the action *Share* is weakly dominated by *Take*.

Let us now conclude this subsection by having a look on the path of *A*s first-order beliefs and *B*s second-order beliefs on *Share* in *ST* and in *QTT*.

Our fourth null hypothesis is that the questionnaire stage in *QTT* (i.e. psychological payoffs elicitation *with* transmission) is irrelevant on players' initial (first and second-order) beliefs and on their path through time:

H4 *(public information of psychological payoffs has no effect on behaviour).*

Feelings elicitation with transmission in QTT will increase in period 1 of the repeated game neither A's guess about the percentage of Bs who choose Share nor B's statement on the guess of her co-paired A about the percentage of Bs who choose Share. Moreover, in the last period of the repeated game, both guesses converge to the same values we find in ST.

By looking at the experimental results summarized in Table 7, one can notice that also H4 is strongly rejected: this means that public information of *B*'s feelings' sensitivity (to belief-dependent motivations) increases both *A*'s trust on *B* and *B*'s perception of *A*'s trust on her. This is true for every experimental sessions we run.

More specifically, [23]

- In Decision Stage 1, the average guess of *A*s on the proportion of *B*s choosing *Share* is 21% in *ST* and 28% in *QTT*, hence it does not differ significantly (on 5% level) between the two treatments. In Period 1 of Decision Stage 2 of *ST* (*QTT*), the average guess of *A*s on the proportion of *B*s choosing *Share* is 32% (63%), hence significantly higher in *QTT* (on 0,1% level).

- In Decision Stage 1, the average statement of *B*s on their own co-player guess about the proportion of *B*s choosing *Share* is 22% in *ST* and 28% in *QTT*, hence it does not differ significantly (on 5% level) between the two treatments. In Period

[23] In this part, we compare individual guesses between the two treatments, using Mann-Whitney U-Test (one sided).

1 of Decision Stage 2 of ST (QTT), the same Bs' average statement is 36% (50%), hence significantly higher in QTT (on 5% level).

- In the last period of the repeated game, As' average first-order beliefs and Bs' average second-order beliefs are both higher in QTT (35% and 41%, respectively) than in ST (13% and 20%, respectively), on 1% level. This is a direct proof of the fact that the increase in A's trust and in B's perception of that, caused in period 1 by common knowledge of B's feelings' sensitivity, is not fictitious: it lasts until the end of the repeated game.

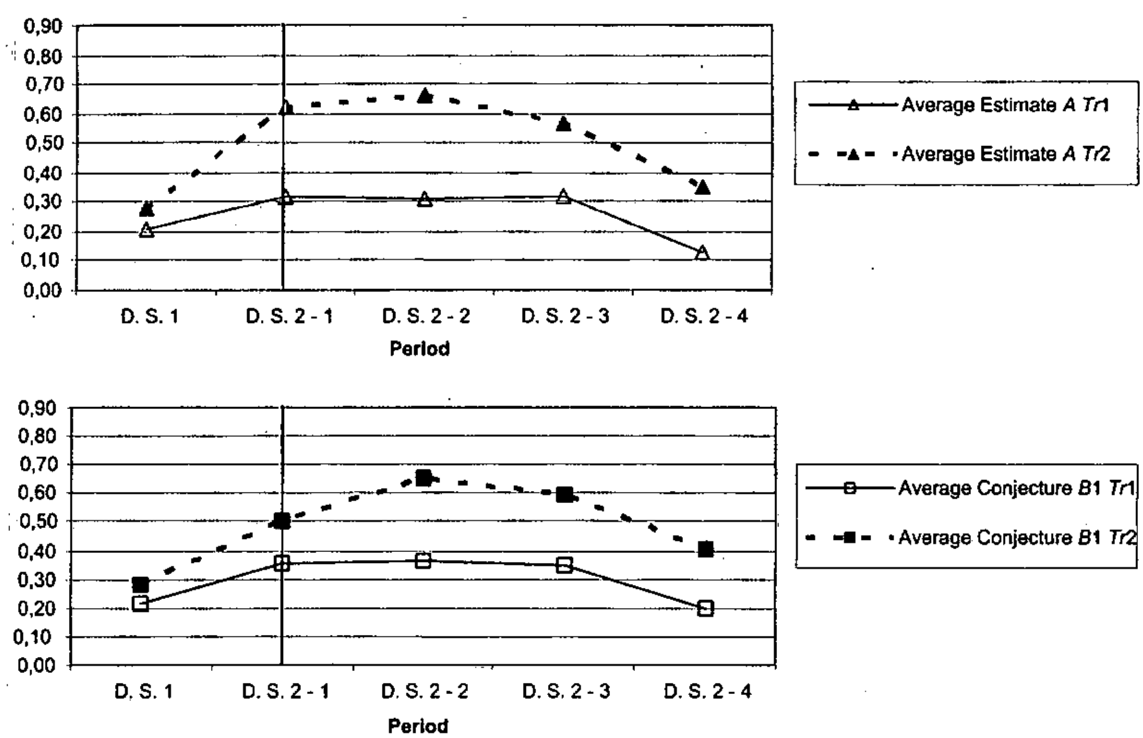

Table 7. Average first- and second-order beliefs of Share in ST ($Tr1$) and in QTT ($Tr2$)

2.4.2 Actions and beliefs: dynamic analysis of their relationships

In this second subsection dedicated to the analysis of the experimental results, we want to show a couple of results concerning the *dynamic relation between actions and beliefs.* Our goal in this subsection is twofold: we want to check whether *reaction* and *projection* theories apply in our experimental setting. In case of an affirmative answer, we want to detect if belief-dependent motivations (feelings) are able to influence both actions and beliefs.

The first null hypothesis is about the relations between B's choice in period t and A's guess on B's choice in period $t+1$.

H5 *(First-order beliefs monotonicity): In a repeated trust game, if in a certain stage t of the repeated game player A expects that player B will choose Share with probability α_t and B effectively chooses Share (Take), then $\alpha_{t+1} \geq \alpha_t$ ($\alpha_{t+1} \leq \alpha_t$), i.e. next period A's guess that Share will be chosen again does not decrease (increase) if this action is (is not) chosen in the period in play.*

This null hypothesis is a direct application of projection theory, i.e. behavior causes expectations (see Section 2.1). However, experimental evidence suggests that in the last period(s) of a repeated game there is a strong distortion towards subgame perfect equilibrium play. Hence, even though B has chosen *Share* in the first three periods of the repeated game, A could lower his guess about B choosing *Share* in period 4, because he anticipates that in the last period B will choose *Take*, in line with the subgame perfect equilibrium. This feature of A's beliefs formation in the last period is again consistent with projection theory.

Our experimental results allow in ST to accept H5 in the first three periods of the repeated game and to reject it in the transition from period 3 to 4. H5 is instead accepted in QTT in *all* periods of the repeated game (so also in the transition from period 3 to 4). It's important to notice that in ST, from period 3 to 4, only 42% of observations [24] are coherent with H4, while in QTT, from period 3 to 4, 79% of observations respect H5. This result stresses again the relevance of the psychological payoffs (belief-dependent motivations) still in the last period of the repeated game.

The second null hypothesis is about the relations between B's choice in period t and B's statement of A's guess on B's choice in period $t+1$.We think the same beliefs monotonicity requirement introduced in H4 could hold for B's second-order beliefs, even though conditionally on A's choice in t: [25]

H6 *(Second-order beliefs "conditional" monotonicity): if in a certain stage t of the repeated game player B states that player A expects she will choose Share with probability*

[24] *(B's choice in period 3, A's first-order beliefs in period 4)*

[25] It works only when the action profile chosen in the period in play is (*Dissolve, Take*) or (*Continue, Share*). It does not hold when the action profile chosen in the period in play is (*Dissolve, Share*) or (*Continue, Take*).

β_t, *B chooses Share (Take) and A chooses Continue (Dissolve), then* $\beta_{t+1} \geq \beta_t$ ($\beta_{t+1} \leq \beta_t$).

In other words,

H6a - *next period B's statement of A's guess that Share will be chosen does not decrease if (Continue,Share) is the action profile of the period in play;*

H6b - *next period B's statement of A's guess that Share will be chosen does not increase if (Dissolve,Take) is the action profile of the period in play.*

Our experimental results allow to accept H6b in all periods of the repeated game (independently from the treatment); H6a is instead rejected in ST in the transition from period 3 to 4, while in QTT it is accepted in *all* periods of the repeated game (so also in the transition from period 3 to 4). It's important to notice that in ST, from period 3 to 4, only 32% of observations [26] are coherent with H6, while in QTT, from period 3 to 4, 76% of observations satisfy H6. This result stresses again the relevance of the psychological payoffs (belief-dependent motivations) still in the last period of the repeated game.

See next subsection for the psychological game theory explanation for the acceptance of both H5 and H6a from period 3 to 4 in QTT (in comparison to the rejection of both from period 3 to 4 in ST).

2.4.3 Behaviour of Bs' behaviour according to their different feelings sensitivity

Let us now concentrate on the interpretation of the psychological payoffs ,"revealed" by Bs once filling their HPS.

This analysis can be divided in three steps.

Step 1. We first concentrate on the interpretation of the elicited feeling sensitivities (psychological payoffs) of Bs in the questionnaire stage in QTT and in QNT.

Step 2. After having classified each B according to his/her HPR, we want to understand if B players showing different belief-dependent motivations behave in different ways during the repeated game.

Step 3. In case different "types" of Bs behave differently, we want to check if their behaviour is coherent with our theoretical previsions, built using the tools of psychological game theory. This last step is developed in Section 5.

[26] (*B's choice in period 3, B's second-order beliefs in period 4*)

During the questionnaire stage, once all HPS have been filled, we ask each player B to explain (in a comments sheet) the reasoning he followed to insert the values in her own HPS. [27] By analyzing the reasoning processes (explained in the comments sheet) and the filled HPS, we classify each player B's belief-dependent motivations into 5 categories: *guilt aversion*, *reciprocity*, *mixture of reciprocity and guilt aversion*, *self-interest* and *other* (random values, no pattern). More specifically,

- for a HPS non-decreasing in A's assessment of *Share*, we state that the correspondent player is motivated by *guilt aversion*. In other words, a guilt-averse B thinks: "the more my co-player trusted me when choosing *Continue*, the more guilty I feel when choosing *Take*; hence, the more I want to give him back of my 4€";

- for a HPS non-increasing in A's assessment of *Share*, we state that the correspondent player is motivated by *reciprocity*. In other words, a reciprocity-sensitive B thinks: "when my co-player chooses *Continue* even though he does not trust me too much, it means he has been kind with me; hence, the less he trusted me, the more kind he has been by choosing *Continue*, then the more I want to give him back of my 4€";

- for a HPS non-decreasing in A's assessment of *Share* until $x\%$ and non-increasing from $(x+10)\%$ onward, with $x \in (0, 100)$, we state that the correspondent B player is motivated by both *guilt aversion & also reciprocity*: the stronger feeling is the first one, reciprocity emerges only for high values of A's assessment of *Share*, by curbing the pay back in correspondence of those beliefs;

- for a HPS non-increasing in A's assessment of *Share* until $x\%$ and non-decreasing from $(x+10)\%$ onward, with $x \in (0, 100)$, we state that the correspondent B player is motivated by both *reciprocity & also guilt aversion*: the stronger feeling is the first one, guilt aversion emerges only for high values of A's assessment of *Share*, by expanding the pay back in correspondence of those beliefs;

- for a HPS equal to zero independently from A's assessment of *Share*, we state that the correspondent B player is motivated by (only) *self-interest* (she does not assign any weight to any particular feeling);

- for a HPS not belonging to any of the patterns described above, we state that the values has been *randomly* inserted or that the B player has chosen according to a reasoning *other* than belief-dependent motivations. For example, if B's HPS is equal to 2 independently from A's assessment of *Share*, than we state he is motivated by *fairness*

[27] Notice that, contrarily to Charness and Dufwenberg (2004), in our experimental setting participants play the constituent game one time before feelings are (directly) elicited. That makes B players more sure of what they feel when filling the rows of their own HPS and helps A players understand better the meaning of the values in the filled HPS transmitted to them.

(that is not dependent on B's beliefs).

In Table 8, we sum up the different types of Bs players in each treatment, according to their elicited feelings sensitivity, both in the questionnaire stage and in the final questionnaire.

	Treatment 1 (final questionnaire)	**Treatment 2 (questionnaire stage)**	Treatment 2 (final questionnaire)	Treatment 3 (questionnaire stage)	Treatment 3 (final questionnaire)
*G*uilt *A*version	23	21	20	12	1.1
*R*eciprocity	10	8	8	4	4
Mixture of *GA* & *R*	4	8	8	2	2
*F*airness	0	1	1	0	0
*S*elf-*I*nterest (only)	3	2	3	2	3
Total	40	40	40	20	20

Table 8. Classification of Bs' feelings according to their HPS in each treatment

Looking at experimental results of the questionnaire stage of QTT, we find that, according to our class scheme, 52,5% (21/40) of B subjects show guilt aversion, 20% (8/40) of B subjects show reciprocity, 20% (/40) of subjects show both reciprocity and guilt aversion, 2,5% of subjects (1/40) show fairness, 5% of subjects (2/40) show self-interest only. It's important to notice that nobody inserts values randomly.

Analyzing our experimental design (Section 3), one could reasonably object that among those B subjects showing guilt aversion, reciprocity or a mixture of both, there could be some Bs using their HPS as a "false" signal to their new co-player A, thus allowing him a generous potential *pay back scheme*, even though not motivated in their economic choices by feelings other than self-interest.

Hence, our next null hypothesis is the following one:

H7 *(signaling issues)*

B players use their filled HPS as a "false" signal; in other words, B players show some feelings' sensitivity only because they know their filled HPS will be transmitted to some randomly chosen player A. [28]

[28] See Section 3.2 for instructions concerning filling and transmission of HPS in $Tr2$.

Even though this objection would seem reasonable at a first sight, our results show it is without foundation in our experimental setting: H7 is strongly rejected. Let us explain why.

Looking at our experimental design, one can notice that in the final questionnaire after Decision Stage 2:

- in *ST*, we ask *B* players to fill *HPS*, knowing that it will not be transmitted to anyone.

- in *QTT*, we ask *B* players to fill again *HPS*, this time knowing that it will not be transmitted to anyone.

- in *QNT*, we ask *B* players to fill again *HPS*, again knowing that it will not be transmitted to anyone.

HPS filled at the end of *ST* lead to these feelings' sensitivities percentages: 57,5% (23/40) of *B* subjects show guilt aversion, 25% (10/40) of *B* subjects show reciprocity, 10% (4/40) of subjects show both reciprocity and guilt aversion, 7,5% of subjects (3/40) show self-interest only. Again, nobody inserts values randomly. They do not differ too much from those filled in the questionnaire stage of *QTT*.

The same conclusion holds for *QNT*, both in the "questionnaire stage" and in the "final questionnaire" stage

Finally, *HPS* filled during the final questionnaire of *QTT* differ from those filled during the questionnaire stage only for 6/40 *B* subjects (15%). Among these,

- 3 (7,5%) changed their *HPS* in order to incorporate a higher feeling sensitivity (i.e. allowing a more generous *pay back scheme*, even though it maintains the same "form" of the previous one);

- 2 (5%) changed their *HPS* in order to incorporate a lower feeling sensitivity (i.e. allowing a less generous *pay back scheme*, even though it maintains the same "form" of the previous one);

- 1 of them (2,5%) changed her *HPS* to show only self-interest, stating in her relative comments sheet that the reason for this change was public anonymity.

Thus, only 1/40 (2,5%) player *B* has exploited the questionnaire stage in *QTT* to give a false signal to her new co-player, in order to increase her own payoffs in Decision Stage 2.

Let us now concentrate on the *HPS* filled *and transmitted* during the questionnaire stage in *QTT*.

We quote them from the experimental results in Table 9.

Dominant feeling:
Guilt Aversion

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	0,00	0,00	0,50	1,00	1,50	2,00	2,00	2,50	3,00	3,50	4,00
2	0,00	0,50	0,70	0,90	1,20	1,60	2,00	2,50	3,00	3,50	4,00
3	0,00	0,00	0,50	0,75	0,75	1,00	3,00	3,20	3,40	3,60	4,00
4	0,00	0,50	0,50	1,00	1,80	2,00	2,00	2,50	2,50	2,50	2,50
5	1,20	1,30	1,40	1,50	1,60	1,70	1,80	1,90	2,00	2,00	2,00
6	0,00	0,40	0,80	1,20	1,60	2,00	2,00	2,00	2,00	2,00	2,00
7	0,05	0,10	0,15	0,30	0,90	1,00	1,10	1,30	1,60	1,80	2,20
8	0,00	0,50	0,70	0,80	0,90	1,00	1,20	1,40	1,60	1,80	2,00
9	0,00	0,50	0,70	0,80	0,90	1,00	1,20	1,40	1,60	1,80	2,00
10	0,00	0,20	0,40	0,60	0,80	1,00	1,60	1,70	1,80	1,90	2,00
11	0,00	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60	1,80	2,00
12	0,00	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60	1,80	2,00
13	0,00	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60	1,80	2,00
14	0,00	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60	1,80	2,00
15	0,00	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60	1,80	2,00
16	0,00	0,10	0,25	0,40	0,80	1,00	1,10	1,25	1,40	1,80	2,00
17	0,00	0,00	0,00	0,00	0,00	1,00	2,00	2,00	2,00	2,00	2,00
18	0,00	0,00	0,00	0,00	0,00	1,00	1,00	2,00	2,00	2,00	2,00
19	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00
21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	1,00

Table 9.a. HPS filled by Bs showing Guilt Aversion

Dominant feeling:
Guilt Aversion &
also Reciprocity

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	0,00	2,00	2,00	1,75	1,50	1,00	0,50	0,50	0,50	0,50	0,50
2	0,00	0,10	0,50	1,00	1,25	1,50	1,75	1,87	2,00	2,50	0,01
3	0,00	1,00	1,00	2,00	2,00	2,00	2,00	2,00	2,00	1,00	1,00
4	0,00	0,00	0,00	0,50	1,00	1,00	3,00	3,00	2,00	0,00	0,00
5	0,00	0,00	0,00	0,00	0,50	1,00	2,00	2,00	0,00	0,00	0,00

Dominant feeling:
Reciprocity &
also Guilt Aversion

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	4,00	3,00	2,00	1,00	0,50	0,00	0,50	1,00	2,00	3,00	4,00
2	3,50	3,00	2,50	2,00	0,00	0,00	0,00	0,00	0,00	2,00	2,50
3	1,00	0,90	0,80	0,70	0,60	0,50	0,60	0,70	0,80	0,90	1,00

Table 9.b. HPS filled by Bs showing different mixtures of Guilt Aversion and Reciprocity

Dominant feeling: Reciprocity

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	4,00	3,50	3,00	2,50	2,00	1,50	1,25	1,00	0.75	0,50	0,00
2	4,00	3,80	3,20	2,90	1,50	1,00	0,90	0,70	0,20	0,05	0,00
3	4,00	3.75	3.50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	2,00	2,00	2,00	2,00	2,00	2,00	1,60	1,20	0,80	0,40	0,00
5	2,00	1,80	1,60	1,40	1,20	1,00	0,80	0,60	0,40	0,20	0,00
6	2,00	1,80	1,60	1,40	1,20	1,00	0,80	0,60	0,40	0,20	0,00
7	2,00	1,80	1,60	1,40	1,20	1,00	0,80	0,60	0,40	0,20	0,00
8	2,00	1,80	1,60	1,40	1,20	1,00	0,80	0,60	0,40	0,20	0,00

Table 9.c. *HPS* filled by *B*s showing Reciprocity

Dominant feeling: Fairness

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00

Dominant feeling: Self - Interest (only

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 9.d. *HPS* filled by *B*s not showing belief-dependent motivations

Our last null hypothesis is about the absence of effects of different *B*'s filled *HPS* in *QTT* both on her own behaviour and on the behavior of her co-paired *A*.

H8 *(different HPS, same pair's behaviour).*
In QTT, when receiving their co-paired B's filled HPS, A players do not mind about the "form" of the pay back; they consider only the fact that the pay back is positive for some assessments of Share. Hence, given that this condition is satisfied, their behaviour in the repeated game is independent from the "form" of the received HPS. Anticipating that, B players transmitting different feelings behave in the repeated game in the same way.

The experimental results we have obtained in *QTT* indicates that H8 is strongly rejected. In the repeated game played during Decision Stage 2 in *QTT*,

- Among the 8/40 pairs cooperating from $t = 1$ to $t = 4$:

- 7/8 *B*s are motivated by *guilt aversion*;
- 1/8 is motivated by *guilt aversion & also reciprocity.*

Those 8 pairs are underlined with a yellow color in Tables 9.a and 9.b.

• Among the 23/40 pairs in which there is a B motived by guilt aversion,
- 20/23 (87%) cooperate in $t = 1$;
- 12/23 (52%) continue to cooperate until $t = 3$;
- 7/23 (30%) cooperate from $t = 1$ to $t = 4$.

• Among the 8/40 pairs in which there is a B motived by reciprocity,
- 2/8 (25%) cooperate in $t = 1$;
- 0/8 go on cooperating in $t = 3$.

Thus, experimental results of QTT allow us to conclude that different B types (in terms of belief-dependent motivations) lead to a different behavior of the pairs they belong to.

Bringing together the results of this subsection with those exposed in the previous one (look at H5 and H6), we can demonstrate how both projection and reaction theory hold in our experimental setting, once recognizing the role of belief-dependent motivations incorporated in the psychological payoffs: different B's belief-dependent motivations (feelings) have a different impact on the psychological part of B's payoff function. When this process is made public information during the questionnaire stage, transmitting to A a HPS showing that his co-paired B is motivated by guilt aversion would change dramatically the subsequent behaviour of the pair with respect to the case we would transmit a HPS showing that the same B is motivated by reciprocity.

According to this logic, the acceptance of both H5 and H6a from period 3 to 4 in QTT (in comparison to the rejection of both from period 3 to 4 in ST) can be summarized as follows: B's belief-dependent motivations have a direct (psychological) impact on B's payoffs.

In case B is sensitive to *guilt aversion*, this drives her to carry on choosing *Share* if (*Continue,Share*) has been the action profile actually played in each of the three previous periods. This is common knowledge among players. [29] As a consequence,

(i) A's guess on B playing *Share* in the last period does not decrease with respect to the same kind of guess in period 3 (coherently with H4);

(ii) B's statement of A's guess that *Share* will be chosen in the last period does not decrease with respect to the same kind of guess in period 3 (coherently with H5a).

In case the transmitted feeling is *reciprocity*, this drives B to choose $Take$ if (*Continue,Share*) has been the action profile actually played in each of the three previous periods. This is common knowledge among players. [30] As a consequence,

[29] During Decision Stage 2 of $Tr2$, A can in each moment have a look to his co-player B's filled HPS.
[30] During Decision Stage 2 of $Tr2$, A can in each moment have a look to his co-player B's filled HPS.

(*i*) *A*'s guess on *B* playing *Share* in the last period does not increase with respect to the same kind of guess in period 3 (contradicting H4);

(*ii*) *B*'s statement of *A*'s guess that *Share* will be chosen in the last period does not increase with respect to the same kind of guess in period 3 (contradicting H5a).

It is not a surprise that in each pair respecting both H5 and H6 from period 3 to period 4 of the repeated game in *QTT*, there is a player *B* who is motivated by (and has transmitted her) guilt aversion during the previous questionnaire stage. In none of these pairs, there is a *B* player who who is motivated by reciprocity (alone) during the previous questionnaire stage.

This result is unpredictable by traditional game theory. Nonetheless, it allows to interpret *psychological game theory* as a particular *reaction theory*, where individuals choose actions to react not only to their beliefs, but also to their belief-dependent motivations: the direct (psychological) impact of beliefs on preferences over terminal histories of the repeated game of trust makes the choice of cooperation in the presence of the expectation of cooperation an optimal one.

2.5 Theoretical Interpretation

The experimental results we have summed up in Section 4 show that eliciting and transmitting the psychological payoffs and letting the two players playing the *complete information* (repeated) game of trust leads them to behave in a visibly different manner (with respect to their behavior in the corresponding *incomplete information* game setting). More precisely, the *public information* of the psychological payoffs in the (repeated) game of trust results in players' perception of feelings like guilt aversion and/or reciprocity which otherwise would be underestimated. That in turn ends in a more cooperative behavior for both players. Moreover, our experimental results on the repeated psychological game demonstrate how feelings' sensitivity elicitation and transmission (needed to measure and communicate experimentally the psychological payoffs) enhance cooperation more than the traditional repeated-game reputation building explanation would suggest: reputation building arguments would ensure cooperation until a couple of periods from the end of the repeated game. Guilt and/or reciprocity concerns incorporated in the psychological payoffs frequently lead to trust and cooperation until the *last* stage of the repeated game.

We suggest a theoretical interpretation to our experimental results, that makes a large use of psychological game theoretic tools.

Traditional game theory admitting monetary preferences with self-interested players suggests the *unique subgame perfect equilibrium* of the repeated game of trust is given by the repetition of the action profile $(Dissolve, Take)$ in each of the four periods of playing.

Our theoretical framework, which is an application of Battigalli and Dufwenberg (2005) theory to repeated *psychological* games (with complete and incomplete information) allows instead for several sequential (psychological) equilibria for the repeated game.

Let's indicate B's guilt sensitivity with $\theta \geq 0$ and his sensitivity to reciprocity concerns with $\gamma \geq 0$. They both enter B's payoff function through its psychological part.

In the setting with complete information, θ and γ are known to both player B and A: we call $\hat{\theta}$ and $\hat{\gamma}$ the true values of B's guilt sensitivity and of B's reciprocity sensitivity, respectively. The values we elicit and transmit during the *complete information treatment* represent a good approximation of these two feelings sensitivities. Hence, in that treatment it is like they are public information among the two players.

In the setting with incomplete information (the one we represent experimentally through the *incomplete information treatment*), both parameters are not known to any of the two players: we suppose each of them is drawn from a different uniform distribution. Thus, players do not know the true values of θ and γ, but have a common prior on each of the two.

Let us first concentrate on the equilibrium predictions for the repeated psychological game with *complete information.*

We distinguish two subcases according to the two main feelings B players could be sensitive in the proposed trust game:

• in case $\theta > 0$ and $\gamma = 0$ (B is sensitive to guilt aversion, but not to reciprocity concerns), for "high enough" values of θ the following *sequential psychological equilibrium (in beliefs)* exists: in each of the four periods of the repeated psychological game,

- A chooses *Continue*, believing with certainty that B is choosing *Share* and that B believes with certainty that she is choosing *Continue*, and so on;

- B chooses *Share*, believing with certainty that A is choosing *Continue* and that A believes with certainty that he is choosing *Share*, and so on.

Let us call this equilibrium as the *trust equilibrium in beliefs.*

• in case $\gamma > 0$ and $\theta = 0$ (B is sensitive to reciprocity concerns, but not to guilt aversion), the same *trust equilibrium in beliefs* does not exist $\forall \gamma > 0$.

These two theoretical predictions match exactly our experimental results, where different B types lead to different behaviour of the pairs they belong to. More specifically, among the 8/40 pairs cooperating from period 0 to 4, 7/8 Bs are motivated by guilt aversion (alone) and 1/8 is motivated by guilt aversion & reciprocity. On the contrary, among the 8/40 pairs in which there is a B motived by reciprocity (alone), 6/8 do not cooperate in $t = 1$ and 2/8 cooperate from t=1 to t=2 and then they do not cooperate any more.

Let us now compare the *complete* with the *incomplete* information case in terms of equilibrium predictions: intuitively, it is not difficult to conclude that, in case $\theta > 0$ and $\gamma = 0$, the higher $\hat{\theta}$ (the true value of guilt sensitivity in the complete information case), the higher the probability to find the *trust equilibrium in beliefs* in the complete information case. In particular, we calculate a threshold $\bar{\theta}$ such that for each $\hat{\theta} \geq \bar{\theta}$, the *trust equilibrium in beliefs* is more likely to come out in the repeated psychological game with complete information than in the correspondent game with incomplete information.

Also this last theoretical prediction matches our experimental results: in the *complete information treatment*, among all B players showing sensitivity to guilt aversion and no sensitivity to reciprocity (21/40), in 85% of cases $\hat{\theta}$ we infer (by means of the questionnaire each B fills) is higher than theoretical threshold $\bar{\theta}$. For that reason, in the *complete information treatment*, where B's feeling sensitivity is public information among players, the frequency of (*Continue*, *Share*) play in each of the four periods of the repeated game is higher with respect to the *incomplete information treatment*. Moreover, in the *complete information treatment*, 58% of pairs cooperate in $t = 1$ (in each of these pairs there is a B player motivated by guilt aversion); there is also a significant percentage of pairs (20%) playing (*Continue*, *Share*) in all periods of the repeated game; in the *incomplete information treatment*, 18% of pairs cooperate in $t = 1$ (again, in each of these pairs there is a B player motivated by guilt aversion) and no pair play (*Continue*, *Share*) in all periods.

The key point of this theoretical reasoning is in the interpretation of the *incomplete information treatment*: the fact that feeling sensitivities are not elicited and transmitted before the game is played does not allow to conclude that players' payoff functions are only "material", i.e. do not contain a psychological part. Rather, in this treatment, players play a game in which the psychological payoffs are part of their payoff function, but are not common knowledge among them. According to this interpretation, our experimental results show that, in a repeated game of trust, making public information the results of the feeling sensitivities elicitation has a dramatic impact on behavior, substantially enhancing trust and cooperation among players in every period, especially in those pairs in which B has transmitted his "guilt aversion" to his co-paired A.

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Chapter 3

Strategically sophisticated bidding in first-price auctions

3.1 Introduction

This chapter focuses on first-price auctions with private or interdependent valuations and independent or correlated signals. Our goal is design experiments to test the assumption that bidders' conjectures are *strategically sophisticated* (hence consistent with a careful introspective analysis of the game), but not necessarily *correct.*

The analysis of simultaneous bidding games generally builds upon the notion of (Bayesian) Nash equilibrium, in which are implicit the assumptions that players are rational and hold *correct* conjectures about the bidding behavior of their opponents. Battigalli and Siniscalchi (2003) make a first step forward in the analysis of simultaneous bidding games: they do not assume equilibrium behavior in first-price sealed-bid auctions and show theoretically that although strategic sophistication of bidders' conjectures has nontrivial implications for bidding behavior, it is consistent with a wide range of non-equilibrium beliefs. Hence, introspection alone does not provide a justification for equilibrium analysis.

One may argue that, even if bidders initially hold heterogeneous non-equilibri-um beliefs, a learning process should nevertheless lead to an equilibrium. This argument, however, is subject to important qualifications: first, it applies only to situations where bidders repeatedly play similar auction games with different competitors; second, whether convergence to an equilibrium occurs at all, as well as the speed of convergence, crucially depends on how much feedback each player obtains about the decision rules adopted by his competitors in previous plays. In auction games, this feedback is typically poor: only the actual bids, and not the private information that induced such bids, can typically be observed (for example, in a Dutch action, whose reduced normal form is like a first-price auction, only the winning bid is observed). These considerations suggest that it may be interesting to test experimentally the extent to which the predictions of standard auction theory are dependent on the assumption that bidders' conjectures are correct.

What we expect to show through experiments, is that even if bidders are strategically sophisticated (a very strong assumption) there are no compelling reasons to assume approximate equilibrium behavior in the short run. For example, one may think at the fact that, in recent years, many novel auction designs have been implemented in practice: when faced with such "novelties", bidders cannot be expected to have learned the shape of each other's valuation functions, each other's signal distribution, and so on. In such situations, we find the case for an analysis based on strategic sophistication alone, particularly compelling.

3.2 Experimental Evidence and Literature

Experimental evidence shows significant and persistent deviations from the risk-neutral Nash equilibrium (RNNE) in first-price auctions (see Kagel (1995)). There are (at least) three "stylized facts" emerging from the experimental studies on first-price auctions with independent private values, which we find relevant:

- *Overbidding* (a large majority of subjects show a persistent tendency to bid above the RNNE);
- *Decreasing Proportional Deviations* (deviations from RNNE are proportionally larger for subjects with smaller valuations);
- *Heterogeneity* (bidding behavior is heterogeneous across subjects).

In the next two subsections, we present the main theoretical explanations of deviations from RNNE in first-price auctions; we summarize and separate the related literature into two subgroups, according to the fact that the correctness of bidders' conjectures about their competitors' bidding rules is assumed or not.

3.2.1 "Correct" equilibrium beliefs

The large majority of the theoretical and empirical papers that try to explain such deviations from the RNNE maintain the assumption that each bidder holds correct conjectures about the bidding rules of her competitors:

- in a series of papers, Cox, Smith and Walker try to explain the data with a family of models featuring bidders with heterogeneous degrees of (constant relative) *risk aversion*. In such models, equilibrium bidding functions are linear (like the RNNE function) except for the largest valuations, but have heterogeneous slopes and are steeper than the RNNE (e.g. Cox et al., 1988, 1992). The problem is that the risk-aversion explanation of Overbidding is controversial; moreover, it leaves Decreasing Proportional Deviations largely unexplained;

- Goeree, Holt and Palfrey (2002) suggest as an alternative explanation the fact that subjects may perceive incorrectly their probability of winning the auction. Armantier and Treich (2005) conduct an experiment to test whether *probability misperception* may be a possible alternative theoretical feature able to explain Overbidding. The experimental outcomes indicate that subjects underestimate their probability of winning the auction, and indeed overbid. Yet, when provided with feed-back on the precision of their predictions, subjects learn to predict their probability of winning correctly, and to curb-down significantly overbidding. Their structural estimation of different behavioral models suggests that subjects tend to best-respond to their beliefs, and that risk aversion appears to play a lesser role than previously believed. However, probability misperception alone is not able to explain Decreasing Proportional Deviations.

- Ockenfels and Selten (2005) propose an equilibrium explanation of data concerning repeated first-price auctions in which feedback on the loosing bids is provided to all bidders. Their equilibrium concept (*Impulse Balance Equilibrium*) is very different from the RNNE one; it focuses on the concept of weighted impulse balance that is in turn based on a simple principle of ex-post rationality similar to Selten and Stoecker's (1986) *learning direction theory*. It seems to explain the "stylized facts" listed above quite well, both qualitatively and quantitatively, even though it does not fit the data in auctions where this feedback is not allowed.

3.2.2 Relaxing some assumptions

There are (at least) two theoretical papers that try to explain experimental results in first-price auctions, not relying on NE as solution concept: Battigalli and Siniscalchi (2003a, from now on BS) and Dekel and Wolinsky (2003, from now on DW) [1].

They both use in their theoretical analysis (different) concepts of rationalizability: BS use interim rationalizability as solution concept; DW's solution procedure is closely related to the (strong) $\Delta-rationalizability$ analyzed in Battigalli and Siniscalchi (2003b) [2].

BS consider first-price auctions with (both) private (and common) values and with n (not necessarily large) players and assume that the sets of valuations and bids are continuous. DW concentrate on first-price auctions with private values and with many players and assume that both the set of valuations and the set of allowable bids are finite.

There are other specific features characterizing bidders' "knowledge":

[1] Also Chung and Ely (2000) may be included in this group of theoretical papers: they show that in two-person auctions iterated deletion of *ex post* weakly dominated strategies selects the efficient equilibrium of a Vickrey-Clark-Groves even when values are interdependent.

[2] $\Delta-rationalizability$ is an iterated procedure eliminating strategies (bids) that are not best response to any "allowable" conjecture. A conjecture is "allowable" when it satisfies the exogenous restrictions and assign positive probability only to strategies (bids) surviving the iterated elimination.

- BS do not assume correctness of bidders' conjectures: different subjects have different beliefs about the bidding behavior of their competitors, and the limited feedback they get from the outcomes of previous auctions prevents them from approaching the equilibrium sufficiently fast (see, e.g., Friedman, 1992). Nonetheless, they assume that even if subjects do not hold equilibrium beliefs, they may be sophisticated enough to take into account that their competitors' behavior satisfies some rationality restrictions and, possibly, that also their opponents' beliefs conform to analogous assumptions.
BS theoretical analysis is qualitative consistent with Overbidding and Decreasing Proportional Deviations, even though it does not offer an explanation of the asymmetry in subjects' deviations from RNNE (i.e., the tendency to bid above the RNNE), nor does it explain why very small bids are so rare for subjects with intermediate or high valuations. Nonetheless, their nonequilibrium explanation of the experimental findings seems worth exploring by experimental methods.

- DW non-equilibrium analysis relaxes the assumption that the distribution of bidders' types is common knowledge. They show that in large auctions bidders bid (almost) their true valuation when it is common knowledge only that players are rational and that the joint distribution of the valuations satisfies a certain condition [3].
Hence, according to DW theoretical results, with many bidders (in their discrete environment) the object goes to the bidder with the highest valuation (efficiency), and almost surely the price is (almost) the highest valuation, even without imposing the equilibrium assumptions.

3.3 Research questions

In the theoretical analysis of standard auctions there are no strong reasons to assume that each player holds correct conjectures on the behavior of (each of) his opponent(s). When we turn to experimental economics, if players do not know exactly their opponents' behavior (as in reality effectively happens) there are no enough repetitions of the same experimental session (or treatment) able to ensure the possibility of learning, in order for each player to form correct conjectures before the end of the experiment.

For that reason, we use as a starting point of our analysis the paper of BS on rationalizability in auction theory: we follow their intuition of adopting the notion of (interim) rationalizability to capture strategic sophistication and we regard nonequilibrium (but

[3] This condition is satisfied, for example, if the distribution of the valuations is conditionally independent and the likelihood of every valuation in each state is bounded above zero.

strategically sophisticated) bidding as a potential explanation of experimental findings.

Strategic sophistication is defined in BS as the conjunction of the following assumptions about beliefs:

(*i*) bidders expect positive bids to win with positive probability;

(*ii*) bidders are certain that their opponents are rational and certain of (*i*);

(*iii*) bidders are certain that their opponents are certain of (*ii*) and so on.

Let us now describe in detail (step by step) the theoretical process leading to the notion of *interim rationalizability*, in order to better explain why it is able to capture strategic sophistication:

- the requirement of *rationality* constrains bidders to choose best responses to their conjectures but does not restrict those conjectures;

- *common belief in rationality* imposes a consistency requirement upon players' conjectures about others' bids;

- by assuming that the players' rationality is common belief, we can justify the *iterated elimination of strictly dominated bids*: bids which do not survive this process of elimination cannot plausibly be chosen when the rationality of the bidders is common belief;

- a similar, and weakly stronger, process— the *iterated elimination of bids which are never best responses*—leads to the solution concept of *rationalizability* [4]; rationalizability has been defined by Bernheim (1984) and Pearce (1984) for *complete information* games;

- *static incomplete information* games (as first-price sealed bid auctions) can always be represented in extensive form by a move of nature, followed by simultaneous action choices; applying Pearce's notion of extensive form rationalizability to that game gives *interim rationalizability*. BS's use of the term "rationalizability" refers to *interim* rationalizability, where different types of the same player are allowed to hold different beliefs about the bidding behavior of his opponents.

BS thus characterize interim rationalizability in symmetric first-price auctions. Our goal is to test BS' conclusions on the set of interim rationalizable bids via the implementation of well-designed experiments.

[4] Rationalizability and iterative weak dominance are indeed equivalent if one also considers dominance by mixed strategies.

3.3.1 *Research question* 1: BS's qualitative consistency with experimental data

First of all, we want to understand whether their theoretical analysis is *qualitatively consistent* with the existing experimental findings. BS identify the least upper bound on bids of strategically sophisticated, risk neutral bidders with heterogeneous beliefs: all rationalizable bids must fall below this bound, and anything below this bound can be rationalized. The upper bound is above the RNNE and concave (by contrast, the RNNE bidding function is linear in the standard model with uniformly distributed valuations). Numerical computations suggest that in typical auction games three or four iterations of the solution procedure are sufficient to obtain a very close approximation to the upper bound on rationalizable bids.

The theoretical prediction derived by BS is a whole interval of possible bids for each valuation: the low endpoint is zero, the high endpoint is an increasing and concave function of the valuation. We gather as many experimental data sets on first-price auctions as possible, in order to:
- check how well BS set-theoretic prediction matches the experimental data;
- compare BS' theoretical analysis with all other main theoretical models aiming to explain deviations from RNNE [5].

3.3.2 *Research question* 2: Beliefs Heterogeneity *vs* Bounded Rationality

We think it is plausible that deviations from RNNE are in part due to *bounded rationality* considerations. Formulating a conjecture about the bidding behavior of the opponents and computing the best response is not an easy task: even in second-price auctions with private values, where bidding one's own valuation is dominant, experimental subjects deviate somewhat from the optimal bid.

Our aim is to design an experimental setting able to minimize the impact of bounded rationality, in order to see how much of the deviations from the RNNE can be explained by the heterogeneity of beliefs allowed by strategic sophistication. In other words, we want to produce in the laboratory a "*decision support system*" that allows bidders to focus on guessing the behavior of their competitors (as a function of their valuations)

[5] BS' explanation of the deviations from RNNE can also be integrated with risk-aversion, as shown in Battigalli and Siniscalchi (2000).

without having to worry about the problem of computing the optimal response to their conjecture.

In such experimental setting, one could check whether BS's theoretical analysis explains observed bidding behavior both qualitatively and quantitatively, i.e. if all bids fall below the least upper bound and there is a good dispersion of valuation-bid observations below the least upper bound derived by BS.

3.4 Research methodology

In this section, we describe the metodology used to answer each of the research questions, proceeding according to the order introduced in the previous section.

3.4.1 *Research question* 1: BS's qualitative consistency with experimental data

We have found data on first-price auctions experiments by looking at previous research, experiments, working papers and journal articles, every time asking the corresponding authors for them[6].

We first plot the observed bids against valuations for each of these experiments.

Then we compute the BS' least upper bound in order to define the set of rationalizable bids.

Finally, we check through a scatter plot diagram if actual bids (from the different first-price auction experiments) belong to this set.

To calculate the upper bound, we use a computer program written for SCILAB (an open source version of MATLAB) that Marciano Siniscalchi (Northwestern University) kindly provided us. The upper bound is calculated solving the following equation:

$$B(s_i;k) = s_i - \pi^*(s_i; B(s_i;k-1))$$

where

$$\pi^*(s_i; B(s_i;k-1)) := \max_{b\geq 0} (s_i - b) \Pr[s_j : B(s_j;k-1) \leq b]$$

and, for each step $k \in \{1, 2, 3, ...\}$, $B(s_i;k)$ is the least upper bound of the bids for a player with valuation s_i.

[6]We gratefully thank J. Kagel for having sent us data from Dyer, Kagel and Levin (1986) and A. Ockenfels for data from Ockenfels and Selten (2005)

It can be easily proved that $B(s_i;k) \leq B(s_i;k-1)$. Therefore the limit $B(s_i;\infty)$ is well defined. BS prove that the set of interim rationalizable bids for type s_i is an interval with interior $(0, B(s_i;\infty))$.

We know that BS analyze the case where the bids and valuations are not on a grid (thus, any number in $[0,1]$). In most experimental settings, bids are discrete because there is a (possibly only implicit) minimum increment δ (e.g., a cent), so that the set of bids is $\{0, \delta, 2\delta, ..., k\delta, (k+1)\delta, ...\}$. BS analysis of rationalizable bids provides an acceptable approximation if the number of players is not very large and δ is small.

In all the experiment where BS's continuous approximation is not appropriate, we should rely on the analysis of DW: they consider the case of a large population of players and a nonnegligible minimum increment δ in a independent and private values setting. In their setting we have to determine an upper bound and a lower bound for rationalizable bids for each valuations and for each step of their procedure. Unfortunately, we need a completely different code (with respect to that of BS) that solve a collection of linear programming problems.

3.4.2 *Research question* 2: Beliefs Heterogeneity *vs* Bounded Rationality

The first main technical contribution is how to design an experimental setting in which the impact of bounded rationality can be clearly identified and isolated.

We should design two experimental treatments. In the first one, we would let bidders play a standard first-price auction with independent private values; in the second one, we would let bidders play the same standard first-price auction with the help of a *decision support system*. This system, created to minimize the impact of bounded rationality in players' bidding, works in this way: before bidding, each participant provides as inputs his valuation and his conjecture (e.g. in the form of a graph of the competitors' bidding function) and the system gives him back as output the corresponding best reply. Hence, the decision support system does not suggest to a player what he has to think about her competitors' behavior, it only suggests the optimizing bid given her valuation and conjecture. With the introduction of the decision support system, we think bidders could be helped to make two or three steps of the iterative deletion procedure: this involves the iterative deletion, for each possible type, of bids that cannot be justified by beliefs consistent with progressively higher degrees of strategic sophistication.

A second main technical contribution is to provide a more efficient implementation of interim rationalizability in the setting under consideration.

It may be argued that during the experiment rational bidders *should* form their beliefs about the competitors and make plans before they are told their valuation; this kind of behavior, involving each rational player putting himself in the shoes of his opponents before receiving his private information, would suggest *ex-ante* rationalizability as a more appropriate solution concept (with respect to the *interim* one) in an experimental context [7]. However, this reasoning has two problems: first of all, we cannot be certain that each rational bidder will actually behave in that way; moreover, there is no characterization of ex-ante rationalizable bids in the literature. Hence, we have to evaluate the opportunity to organize the experimental setting (in each of the two treatments) in order to incorporate the features of interim rationalizability: in each session, we communicate to each participant his valuation; then, we randomly form pairs of two bidders to play a two-person first price auction. In this situation, each bidder knows he is playing the auction with a well-defined type, but he does not know the opponent he is in front of. Therefore, it makes sense to ascribe different conjectures to different types of the competitor.

3.5 BS's qualitative consistency with experimental data: some results

Our starting point is analyzing previous experiments on first-price auctions resembling the assumptions used in BS.

In the following figures, we plot the observed bids against valuations for such experiments and we report the upper bounds derived in BS, in order to check whether and how BS set-theoretic prediction match the experimental data.

In each figure, the first four bounds for the two-bidder uniform IPV model are shown (dashed line); further bounds are not shown because they do not differ significantly from $B(s_i;k)$. The RNNE function is represented by the continuous line. Observed pairs (*valuation*, *bid*) are represented by cue-balls: the bigger the diameter of a cue-ball, the higher the relative frequency of such observation.

The first data set is taken from Dyer, Kagel and Levin (1989, DKL henceforth). This article reports the results of a series of laboratory experiments on first-price, sealed-bid

[7] For a comparison between *ex ante* and *interim* dominance see Fudenberg and Tirole (1991).

auctions with independent private valuations and uncertainty regarding the number of bidders.

In DKL there are two main experimental treatments, that they run one after the other in the same session. We are interested only in the first one (we call it "contingent bids treatment"), because it is the only one resembling the assumptions used in BS. We describe it below.

In the "contingent bids treatment", six subjects act as bidders; each period consists of either two small ($n = 3$) or one single large ($n = 6$) market. Each bidder is randomly assigned a private valuation for the item; valuations are randomly drawn from a uniform distribution defined on [\$0.00, \$30.00]. New valuations for the item are assigned each period and bidders have no knowledge of each other's valuations.

Each bidder, prior to bidding, does not know the size of the market in which he is competing. He is told that it is equally likely that he will participate in one of the two markets specified above. However, he will be allowed to submit two bids, one contingent on $n = 3$ and one contingent on $n = 6$. He knows also that only the bid corresponding to the actual number of bidders will be used.

After each bidder has submitted is vector of bids, the actual size of the market is randomly determined [8]; then, the bids are opened and posted; profits are calculated according to the standard rules of first-price sealed-bid auctions [9].

It seems plausible to classify players' bidding behaviour in DKL's experimental setting according to the size of the market (number of bidders). When a bidder submits his two contingent bids, it is like he is bidding on two similar items sold in two auction markets differing only for the number of bidders (3 in the first auction, 6 in the second one). We admit there could be some forms of correlation between the two markets, since each bidder knows that his two "potential" opponents in the small market belong to the set of his "certain" opponents in the large market. However, looking at DKL's paper, one can notice that the effects of this correlation on their experimental results are unimportant.

Now, having classified DKL's experimental results according to the size of the market, in each period of playing we have two observations for each bidder, one for the first-price auction with $n = 3$ and one for first-price auction with $n = 6$.

[8] Furthermore, if the event $n = 3$ would occur, the composition of the markets (i.e. which three subjects would be in each small market) would also be randommly determined.

[9] In the other treatment, called "contingent and noncontingent bids treatment", another bidding procedure is introduced: in addition to the two contingent bids, each bidder also submits a single bid, being in effect regardless of the number of active bidders (noncontingent bid). We do not want to go into the details of this procedure, since it is far from resembling the assumptions in BS.

In Figure 1.a we plot the observations $(valuation_i, bid3_i)$ for $i = 1, 2, ..., 6$ in all periods of playing under the "contingent bids treatment"; $bid3_i$ stands for player i's bid contingent on $n = 3$.

In Figure 1.b we plot the observations $(valuation_i, bid6_i)$ for $i = 1, 2, ..., 6$ in all periods of playing under the "contingent bids treatment"; $bid6_i$ stands for player i's bid contingent on $n = 6$.

As anticipated above, the dashed lines represents BS's first four bounds for the uniform independent and private values model.

Several considerations follow from the comparison between the actual bids and the set of interim rationalizable bids:

• both in case $n = 3$ and in case $n = 6$, all [10] observations lie in the set of interim rationalizable bids;

• in case $n = 6$, observations are even closer to the upper bounds, with respect to the case $n = 3$; this result is unpredictable when relying on RNNE as solution concept: according to this latter explanation, players have to approach RNNE from below as the number of opponents increase. The problem here is that almost all the types of each player are bidding above the RNNE already in case $n = 3$. Nonetheless, a crucial result is that in case $n = 6$ all interim rationalizable bids are very close to the least upper bound;

• there is not a good dispersion of valuation-bid observations below the least upper bound, as instead predicted by BS. We have stated that, according to their theoretical findings, for every bidders' type arbitrarily small but positive bids are interim rationalizable [11]. Experimental evidence on first-price auctions suggests that it is unusual to find bidders with high valuations choosing very low bids. This is also confirmed by DKL's experimental data we have plotted in Figure 1.a and Figure 1.b: as the valuation increases, bids near the $x-$axis disappear. DKL's experimental results show a good dispersion below the upper bound only for low valuations. We could however "internalize" these experimental findings into BS interim rationalization procedure, by exogenously specifying a *lower bound* L on the set of possible opponents' bids. A preliminary analysis of the consequences of the further assumption that (it is mutual belief that) players do

[10] Apart one outlier, in case $n = 3$.

[11] We told before that BS's analysis of rationalizable bids provides an acceptable approximation of discrete auction settings if the number of players is not very large and the minimum increment δ is small, as in the experimental setting we are analyzing. BS's lower bound is equal to 0 for all types apart $s_i = 0$ (for which 0 is excluded), in case of continuous set of valuations and bids. When at least one of these two sets is discrete (given that δ is small) we guess that the lower bound has to be positive, colser to the x-axis and slightly increasing in the valuation.

not expect their opponents to bid below L may be found in Battigalli and Siniscalchi (2000), where it is shown that the upper bounds obtained with this modified solution procedure are similar to those found in BS.

The second data set is the output of Ockenfels and Selten (2005, OS henceforth) experimental setting.

The model underlying their experiment is a symmetric two-bidders sealed-bid first-price auction with private values.

The values s_1 and s_2 of the two bidders 1 and 2, respectively, are uniformly and independently distributed over the interval $[0, 100]$. Actually, values are decimal numbers with at most two digits after the decimal point.

In order to avoid losses, bids above the value are not permitted (of course, such bids would be dominated in the game theoretic sense), but otherwise no restrictions are imposed on bids. After each round, each bidder is informed about whether he has won the auction, the price, and his payment for that auction.

There are two treatments. Under treatment NF no additional feedback is given, while under treatment F feedback on the opponent's bid is supplied to the winner of the auction. Altogether eight sessions with 12 subjects each have been run for 140 rounds with one auction in each round. The subjects of one session belonged to two independent subject groups of six participants each.

In Figure 2.a we plot the observations $(valuation, bid)$ for each of the 12 subjects (divided in 6 groups) in all periods of playing under treatment NF; in Figure 2.b we plot the same kind of observations in all periods of playing under treatment F.

Only some considerations on the comparison between the actual bids and the set of interim rationalizable bids:

• treatment NF replicates in the laboratory the standard first-price auctions setting; it matches perfectly all the assumptions from which BS start to build the set of interim rationalizable bids. Among all the experimental data sets we have explored until now, it represents the better test-bed for BS's theoretical findings. From the analysis of Figure 2.a, one may notice that all the valuation-bid observations fall into the BS's set of rationalizable bids and a lot of them lies on the least upper bound. The fact that, by construction, bids above own valuation are not permitted surely represents a distortion towards this result. Nonetheless, there is a good dispersion of the observations below the least upper bound, even though, as the valuation increases, small but positive bids disappear, contrarily to BS's prediction (this is the same feature emerging from DKL's experimental results).

• treatment F adds a feature (feedback on the opponent's bid supplied to the auction's winner) which is not included in the standard framework that BS uses. However, it has to be underlined that:
- the fact that in each round of the auction the winner in such round knows his opponent's bid should help him to better understand his opponent's feasible bidding strategies. Hence, "strategic sophistication" of the winner would be fostered.
- by comparing Figure 2.b to Figure 2.a, one can notice that the distribution of the valuation-bid observations in the two graphs is quite the same. Even though this statistical similarity could be given to the high number of rounds and to the very high number of observations (around 6000), it seems to prove that the "feedback effect" on the bidding behaviour is quite null. However, by looking only at bids in the last 10 rounds of each treatment (Figure 3.a and Figure 3.b, respectively), an important difference seems to emerge: under treatment F, bidders with high valuations (≥ 50) bid more frequently below the RNNE, while under treatment NF the same types of bidders bid more frequently above the RNNE. This is because under treatment F the bidder who wins the auction at round t knows, before playing round $t+1$, his opponent's bid at round t. Hence, any time he finds out that his bid at round t was much higher than the one of his opponent at the same round, he tends to underbid at round $t+1$.

3.6 Beliefs Heterogeneity *vs* Bounded Rationality: expected results

The second research question has still to be answered. We expect that the experimental results will tell us that one part of the deviation from the RNNE is due to bounded rationality and that another part (possibly the largest one) is due to the fact that even very sophisticated bidders have no reasons to think that their opponents behave as the RNNE function would suggest. Hence, their conjectures do not respect the RNNE previsions of correctness.

Moreover, in our experimental setting, we will consider the effect of increasing the number of bidders (say, from 2 to 4 or 5) using both a very fine grid of possible bids (e.g. in tenths of euros from 0 to 10) and a very coarse grid (e.g. 0, 1, 2,..., 10 euros). This way we should be able to test DW: as anticipated above, they consider discrete versions of first-price auctions and present a rather condition on beliefs about players' valuations such that, with any fixed finite set of possible bids and sufficiently many players, only bids close to one's own valuation are interim rationalizable. On the contrary, in BS (where the set of possible bids is continuous) when the number of bidders goes to infinity, one's least upper bound tends to the true valuation from below, but the lower bound still contains bids arbitrarily close to zero, hence the set of rationalizable strategies in their model does not approach the RNNE when the number of bidders becomes large. Thus, BS's theoretical results stand in sharp contrast to those of DW. An experimental setting of the kind described above could be able to reveal us which of the two theoretical predictions better matches bidders' behaviour in reality.

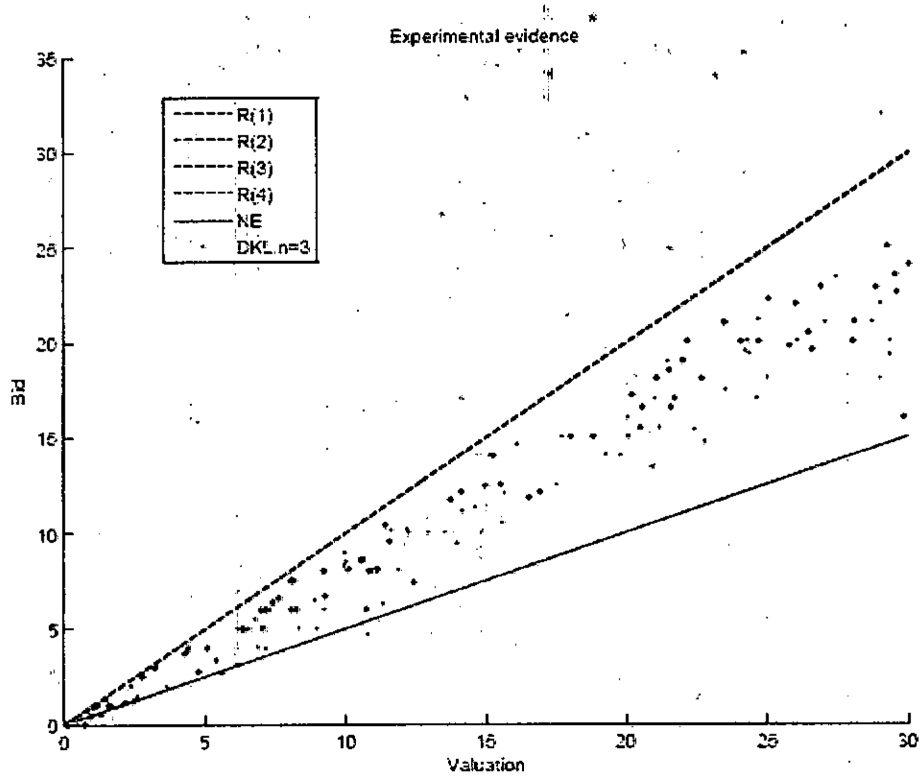

Figure 1.a. DKL: bidding behaviour in the "small" market ($n = 3$)

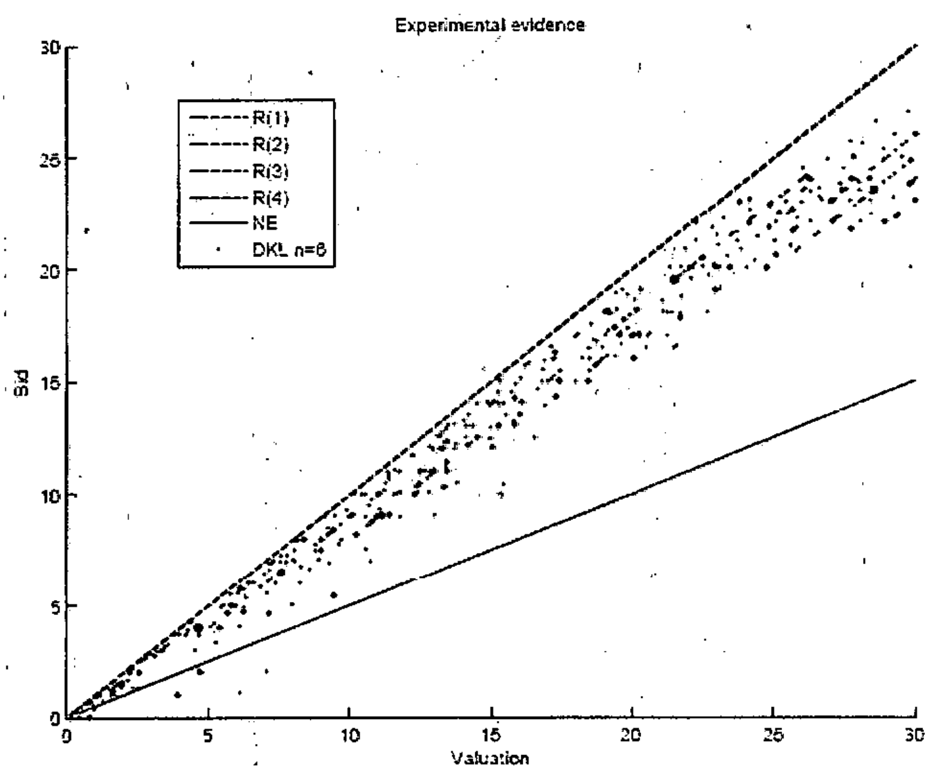

Figure 1.b. Bidding behaviour in the "large" market ($n = 6$)

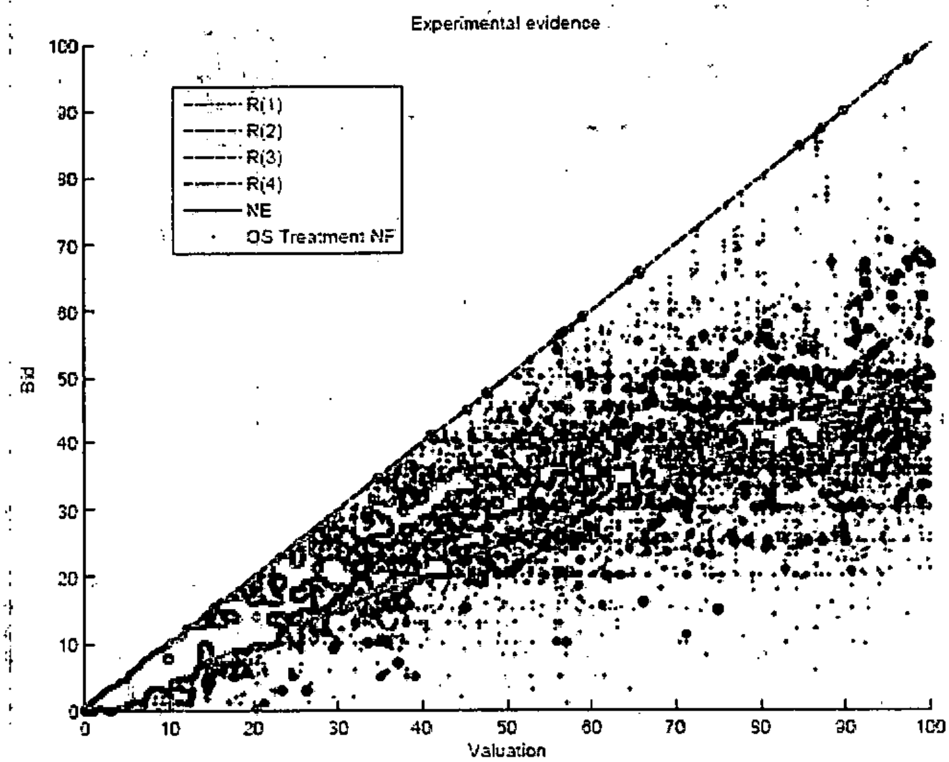

Figure 2.a. OS: bidding behaviour under the No Feedback treatment

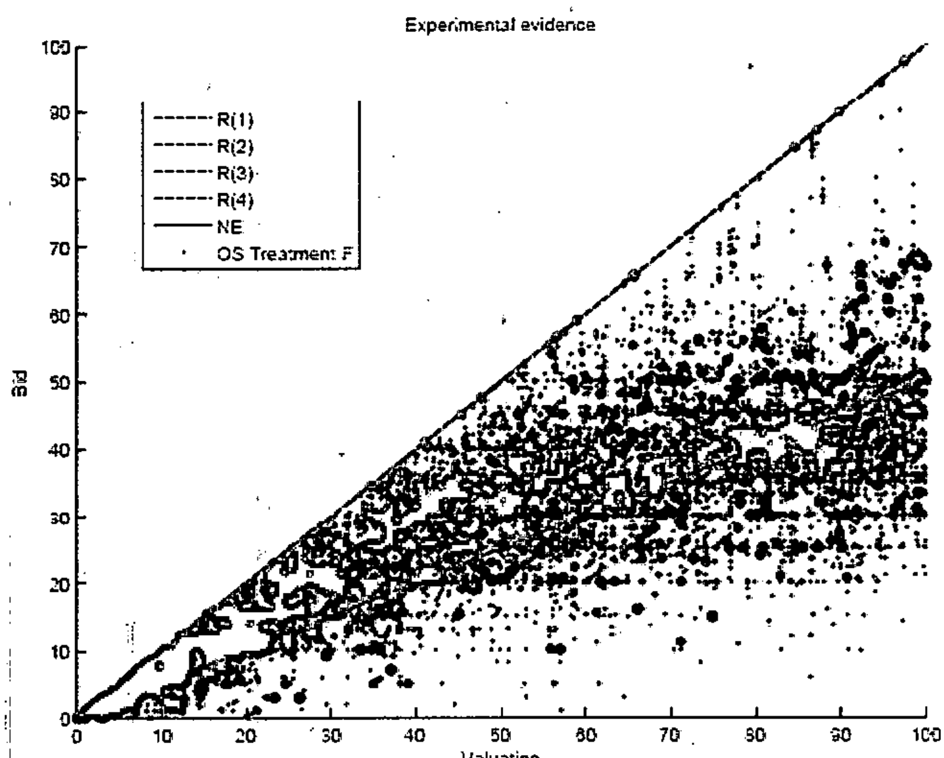

Figure 2.b. OS: bidding behaviour under the Feedback treatment

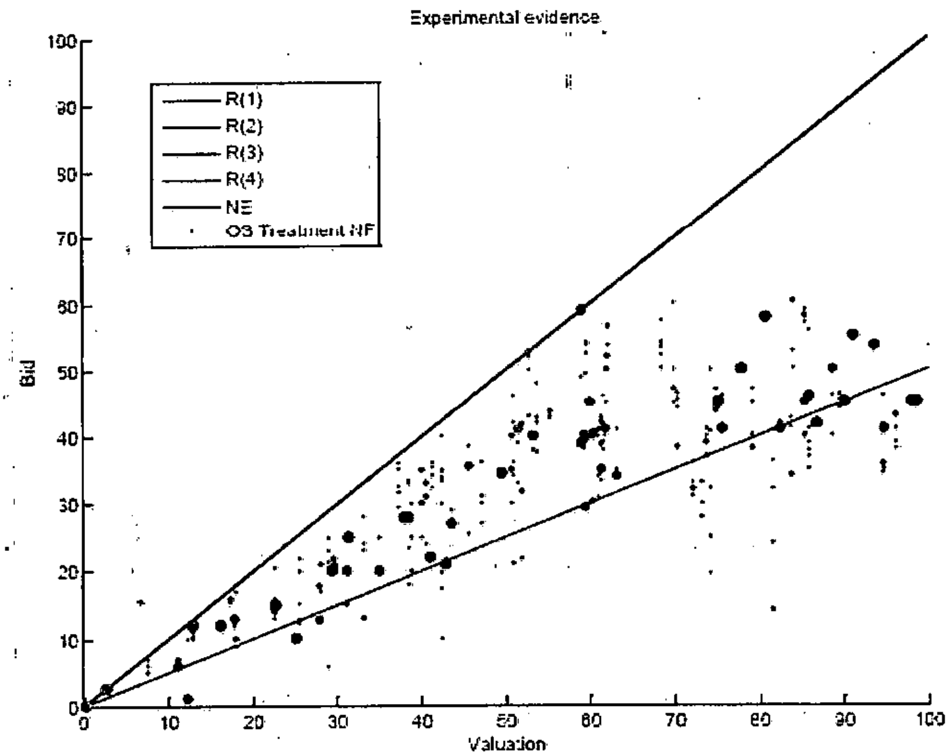

Figure 3.a. OS: last 10 rounds under the *N*o *F*eedback treatment

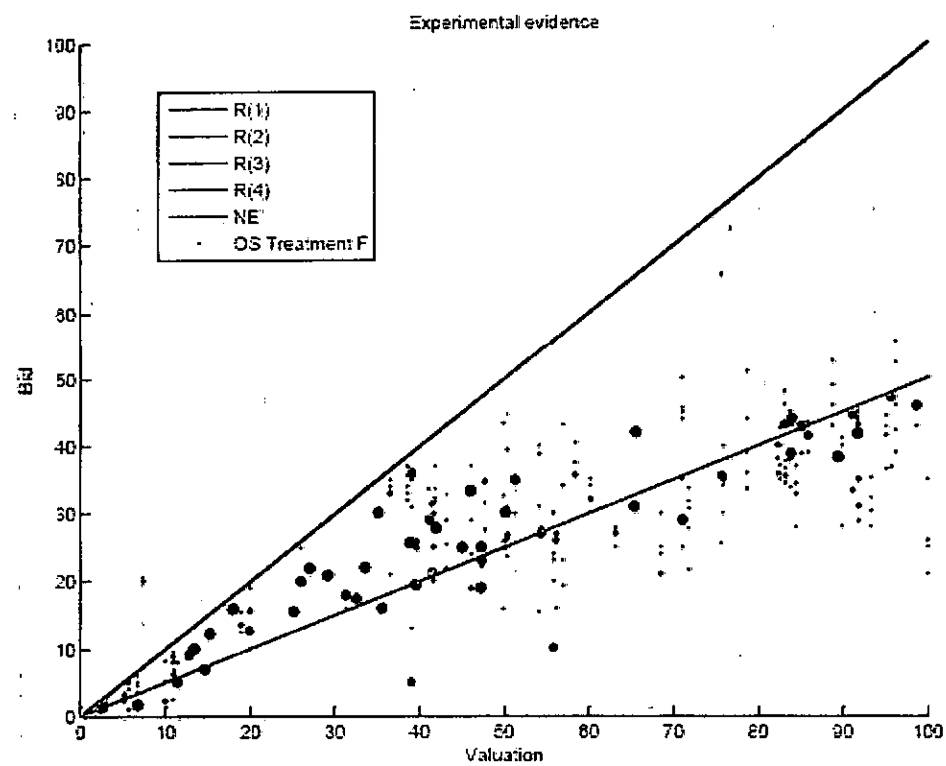

Figure 3.b. OS: last 10 rounds under the *F*eedback treatment

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