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30 April 2012

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April 30, 2012

Abstract

Experimental evidence and field data suggest that agents hold two seemingly unrelated biases: failure to account for the fact that the behavior of others reflects their private information ("winner's curse"), and a tendency to value a good more once it is owned ("endowment effect"). In this paper we propose that these two phenomena are closely related: the biases fully compensate for each other in various economic interactions, and induce an "as-if rational" behavior. We pay specific attention to barter trade, of the kind that was common in prehistoric societies, and suggest that the endowment effect and the winner's curse could have jointly survived natural selection together.

Keywords: Bounded Rationality, Endowment Effect, Winner's Curse, Cursed Equilibrium, Evolution.

JEL Classification: C73, D82.

1 Introduction

The growing field of Behavioral Economics has continuously identified and defined differences between the canonical model of rational decision making and actual human behavior. These differences, usually referred to as "anomalies" or "biases," have been identified through

*We thank Itai Arieli, Eddie Dekel, Richard Katzwer, Shawn McCoy, Rani Spiegler, Lise Vesterlund, and various seminar audience for valuable discussions and suggestions.

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controlled experiments in the laboratory, as well as in field experiments.[1] Though some researchers have challenged the existence of some biases, it seems there is a significant body of evidence for systematic biases that depart from payoff-maximizing behavior. Such behavior is puzzling to economists, who are trained to think that competitive forces in our society and economy select optimal over suboptimal behavior.

Two of these biases are the *endowment effect* and the *winner's curse*. The endowment effect refers to the phenomenon where individuals place a higher value on a good once they own it. Kahneman, Knetsch, and Thaler (1990), in a well-known experiment, distributed coffee mugs to half of the students in a classroom. When asked to assess the value of the mug, the mug-owners had on average a much higher valuation than the rest of the students. An example of the economic implication of the endowment effect is the violation of the Coase theorem: the allocation of resources would depend on the assignment of property rights even when costless trade is possible. The winner's curse is the failure of an agent to account for the informational content of other players' actions. The bias was first identified in common-value auctions, where an auctioned item has an "objective" value, but each player receives noisy (and private) information regarding that value. In a symmetric equilibrium of such an auction, the winner of the auction is the player who has the highest estimate and therefore places the highest bid. This player's estimate is likely to overestimate the value of the object. Fully rational players are supposed to take this into account, and decrease their bidding accordingly. However, a large collection of experimental literature (Bazerman and Samuelson, 1983; Kagel and Levin, 1986; Kagel, Harstad, and Levin, 1987; Lind and Plott, 1991) shows that people do not take this into account and overbid instead. Thus, the winner of the auction is most likely to get an object that is worth less than he expected, and may even receive a negative payoff. Hence, the "winner's curse." [2]

We demonstrate that these two seemingly unrelated biases actually compensate for each other in several economic interactions: errors made due to the winner's curse can be *fully corrected* if the agent demonstrates the endowment effect, and vice versa, resulting in an "as-if rational" behavior, i.e., a behavior identical to that of an agent without any of these biases. Specifically, we study the relation between these two biases in the context of bilateral trade. Bilateral trade is an important and meaningful economic interaction and is one of the earliest economic activities that took place in prehistoric societies (Herskovits, 1952; Polanyi,

[1] For a survey of laboratory experiments in economics, see Kagel and Roth (1997). For a recent overview of field experiments in economics, see Harrison and List (2004). For specific examples see the survey below.

[2] This failure is also manifested in other circumstances, where there are no winners (or losers), and the term "winner's curse" is usually used also in these contexts as well (for a more elaborate discussion and references on the endowment effect and the winner's curse see the survey below).

1957). We suggest that these two biases were not driven to extinction by natural selection because they evolved together as a second-best adaptation that resulted in an "as-if rational" behavior in bilateral trade. This also suggests an explanation of how behavioral biases might have evolved as "shortcuts" to rational decision making.[3]

Evidence from anthropology suggests that trade between groups, based on localization of natural resources and tribal specializations, was common in primitive societies (see Herskovits, 1952; Polanyi, 1957; Sahlins, 1972; Haviland, Prins, Walrath, and McBride, 2007). Moreover, "[t]he literature on trade in nonliterate societies makes clear that barter is by far the most prevalent mode of exchange" (Herskovits, 1952, p. 188). We therefore model trade as a game in which each of two traders owns a different kind of indivisible good. The value of each good depends on an unobservable property, which is known to the owner of the good but not to his trading partner. The players' potential gains from trade also depend on additional conditions that result from initial stock, locations, weather, etc. While these conditions are known to both players before the start of trade, we assume that they can change from one instance of trade to another. In this simple version of barter, traders simply decide whether or not to participate, and goods are exchanged if both traders agree.

A trader is "cursed" (Eyster and Rabin, 2005) if he believes that his partner's agreement to trade is independent of the quality of that partner's good. We first show that a cursed trader has a unique dominant strategy, by which he is willing to trade his own good even when its quality is relatively high. This is because traders do not take into account the fact that, conditional on the other trader's agreement to trade, the average quality of the good they get is lower than the unconditional average. Therefore, cursed agents' expected gain is always lower than the actual average gain (this is the "winner's curse"), and there are types who agree to trade their high-quality goods despite an actual negative expected gain from trade. When we solve for a Nash equilibrium, thus assuming that traders form rational beliefs during trade, the result is trade that occurs only for low-quality goods (similar to the case of a "lemon market").

We then proceed to the evolutionary results. We start by presenting a two-stage game. The second stage of this game is identical to the trading game between cursed agents as described above, except that each trader is not only cursed, but is also endowed with a *perception bias* that distorts his signal. In the first stage, denoted the *perception game,*

[3] Samuelson (2005, p. 100) states that a first step for achieving a better understanding of the endowment effect and its economic implications might be "the construction of theoretical models, especially models shedding insight into how and when it might have been evolutionary valuable to condition valuation on ownership." We believe that our model contributes to such an understanding.

two fully rational principals are each associated with a trader and benefit from their trader's second-stage payoff. The principals simultaneously choose a perception bias for their traders, taking into account the outcome of the trading game that follows. Then, given their distorted private signals, the cursed traders play their unique dominant strategy. We characterize the Nash equilibrium of the perception game, and show that this equilibrium is unique, pure, symmetric, dominance solvable, and that it exhibits the *endowment effect*. That is, principals choose a perception bias that leads traders to systematically overestimate the value of their own good. Moreover, we show that in equilibrium, this endowment effect fully corrects for the winner's curse, and traders play the trading game as if they were fully rational traders playing the Nash equilibrium.

The perception game can be interpreted as the product of natural selection, and indeed we show that the endowment effect can evolve in a population of cursed individuals. We assume a population of cursed traders, each having a type that determines some perception bias for its members. If traders are randomly matched at each generation, and payoff from trade serves as fitness, then regardless of the initial distribution of biases, the only result of the replicator dynamics is an entire population that exhibits the same endowment effect found in the perception game.

We further extend this evolutionary insight by presenting a model in which both biases evolve together. We first present partially cursed traders, who underestimate how the behavior of others reflects their private information but do not ignore it completely, and define the appropriate partially cursed equilibrium (Eyster and Rabin, 2005) in the trade game.[4] We then show that for any level of cursedness there is a specific endowment effect that fully compensates for it and leads to an as-if rational behavior. A stronger endowment effect is required to compensate for higher levels of cursedness. Finally, we analyze the equilibrium of the two-stage game and show that principals always choose pairs of biases (cursedness level and endowment effect) that imply as-if rational behavior of their agents. The intuition behind this is the following: principals can always choose rational strategies for their agents; thus they will never choose a strategy that leads to suboptimal behavior. This leads to the following evolutionary result: in the long run, the population of the surviving types is likely to be heterogeneous such that (1) different surviving types have different levels of each bias, (2) there is a perfect correlation between the degrees of the two biases, and (3) all agents exhibit as-if rational behavior in the trading game. This result implies the main falsifiable

[4] We apply Eyster and Rabin's notion of "Cursed Equilibrium" because of its flexibility and tractability. Using, for example, Jehiel's Analogy Based Expectation Equilibrium will lead to results which are qualitatively similar (see Jehiel and Koessler, 2008.)

prediction of our model: there is a substantial positive correlation between the winner's curse and the endowment effect.

The paper is organized as follows. Section 2 briefly reviews the literature on the endowment effect and the winner's curse, and discusses closely related papers from the evolutionary literature. Section 3 presents the trading game, the two-stage game, and the full evolutionary arguments for the simple case in which agents are fully cursed. Section 4 discusses the case in which traders are partially cursed and both biases evolve together. Lastly, a discussion on the predictions of our model and the robustness of the results appears in Section 5. All proofs that are not in the main text appear in the appendix.

2 Related Literature

2.1 Experimental Literature on the Two Biases

In what follows we briefly describe the main experimental findings on the two biases discussed in this paper. The interested reader is referred to Kahneman, Knetsch, and Thaler (1991) for a survey on the endowment effect and to Kagel and Levin (2002, chapter 1) for a survey on the winner's curse.

2.1.1 The Endowment Effect

The *endowment effect* (Thaler, 1980) refers to the phenomenon where individuals value a good much more once they own it. As a result, prices exist where such individuals are not willing to buy the good or sell it if they own it. That is, the price is perceived as too high for buying but too low for selling. Thus people do not trade even when they would benefit from it. The endowment effect was observed in various experimental setups, from a simple trade of mugs and chocolate bars (Kahneman, Knetsch, and Thaler, 1990) to auctions (Knetsch, Tang, and Thaler, 2001). There is also field evidence for its existence, for example in the US housing market (Genesove and Mayer, 2001; Bokhari and Geltner, 2011). Horowitz and McConnell (2002) survey and analyze the findings of over forty experimental and empirical studies of this effect. The main finding of their analysis is that the endowment effect is strongest for non-market goods, second strongest for private goods, and weakest in experimental settings involving money.[5]

[5] There are several studies that argue against the existence of the endowment effect. Evidence from field experiments by List (2003, 2004) support the claim that experienced traders do not manifest the endowment effect. Other authors provide counterevidence (Knetsch, Tang, and Thaler, 2001; Bokhari and Geltner,

2.1.2 Winner's Curse

The *winner's curse* is the failure of an agent to account for the informational content of other players' actions. As discussed above, the bias was first identified in common-value auctions, but it has been observed in a wide range of economic interactions. An example of such a setup is bilateral trade where the seller and/or the buyer have private information about the unknown value of the traded good. In such a case, one or both of the traders should take into account the expected value of the object conditional on the event that the opposite side agrees to trade, and change the bid/ask accordingly. Samuelson and Bazerman (1985) were the first to identify the winner's curse in experiments that resemble bilateral trade. In an experimental design à la Akerlof's "market for lemons," participants took the role of buyers in a trade. They were asked to offer a price for an item of unknown value, knowing the possible distribution of values, and were informed that the seller would only accept the price if the price were below the seller's value. A sophisticated participant in that experiment was supposed to understand that the value of the price conditional on the acceptance of the seller was below the average value, and, given the parameters of the experiment, was supposed to set a price of zero. However, only a few participants did choose a zero price, and the majority of them selected prices that were close to the average value, suggesting that they were "cursed." Ball, Bazerman, and Carroll (1991) and Grosskopf, Bereby-Meyer, and Bazerman (2007) have shown these results to be robust even in repeated trials with feedback.

The winner's curse was also identified in several real-life situations. The bias was originally identified and termed in a paper on auctions on oil rights in the Gulf of Mexico (Capen, Clapp, and Campbell, 1971). Additional examples are US timber-lease sales (Mead, 1967; Hansen, 1985, 1986), corporate takeovers (Roll, 1986), real-estate auctions (Ashenfelter and Genesove, 1992), and markets for free players in professional sports (Cassing and Douglas, 1980; Blecherman and Camerer, 1998; Massey and Thaler, 2010). While some of these field examples were questioned,[6] there is a significant amount of evidence that people are "cursed" in the sense described above.

2011). A series of papers by Plott and Zeiler (2005, 2007, 2011) argue that the endowment effect is not a real phenomenon but merely a by-product of the experimental setup, but see the response by Isoni, Loomes, and Sugden (2011).

[6] For a debate on whether the results from oil rights auctions represent the winner's curse, see Mead, Moseidjord, and Sorensen (1983) and Hendricks, Porter, and Boudreau (1987); for negative evidence in the context of corporate takeovers, see Boone and Mulherin (2008). Some alternative explanations of situations that seemingly display the winner's curse are risk aversion and uncertainty regarding the number of auction participants. For an extensive discussion and references see Kagel and Levin (2002), chapter 1, section 6.

2.2 Evolutionary Literature on Biases

Our paper is related to a broad literature dealing with the evolution of preferences deviating from payoff (or fitness) maximization. This "indirect evolutionary approach" follows the seminal work of Güth and Yaari (1992) (see also Güth and Kliemt, 1998; Dekel, Ely, and Yilankaya, 2007). Under this approach, types, or genes, are represented as preferences that deviate from the maximization of physical fitness. Such a deviation is beneficial (to a certain extent) to the carrier of the gene due to the resulting effect on other player's strategy. Therefore nonrational preferences may survive natural selection in the long run.[7] The analysis of the preferences that will prevail in the population can be done with the help of a two-stage delegation game:[8] at the first stage each principal (representing a genetic type) chooses the preference of an agent that will play on its behalf during the second stage. Recently, Winter, Garcia-Jurado, and Mendez-Naya (2009) presented a related two-stage game where the choice of preferences in the first stage is interpreted as a choice of emotions.

Our paper is also related to the literature that explains how behavioral biases may evolve. Samuelson (2004) studies how natural selection may build relative consumption effects into preferences (see also Nöldeke and Samuelson, 2005). Robson and Samuelson (2007, 2009) and Dasgupta and Maskin (2005) show how "present bias" (dynamic inconsistency) might have evolved. Heller (2011) demonstrates how overconfidence emerges as a tool for risk diversification.

We present a variant of the "indirect evolutionary approach" literature, with the novel feature that natural selection does not select the preferences of the agents, but rather selects their *behavioral biases*: how much attention they pay to the informational content of other players' actions, and how they react to their own private information.

Very few papers deal with the possibility that evolution will create two biases that are significantly different and yet complementary. Waldman (1994), in an early contribution, shows that an evolutionary dynamics with sexual inheritance is generally expected to yield only "second-best" adaptations, which depend on the initial conditions, and do not necessarily attain the optimal solution to the evolutionary problem. In particular, this implies that agents may be endowed with two biases, which only approximately compensate for each other. Waldman (1994) specifically considers the overestimation signal of self-ability and excess disutility from effort. Heifetz, Shannon, and Spiegel (2007a) develop a general framework

[7] Heifetz, Shannon, and Spiegel (2007b) show that under rather general terms, evolutionary dynamics always leads to distortions from payoff maximization.

[8] Delegation games are also applied in various nonevolutionary setups; see, for example, Fershtman, Judd, and Kalai (1991).

in which natural selection may lead to perception biases. They give an example where overconfidence is a result of an (indirect) evolutionary process. This result depends on agents' inability to learn the properties of the environment. They therefore hypothesize as a possible explanation an additional non-Bayesian learning bias to support the results.[9] In a nonevolutionary context, Kahneman and Lovallo (1993) study the relation between risk aversion and the tendency of individuals to consider decision problems one at the time, in a way that isolates the current problem from pending ones and ignores future opportunities. Turning to introspection, Kahneman and Lovallo (1993) then claim that using a broader view of several choice problems as a grand problem will cancel out risk aversion, but they stress that there is no reason to believe that the errors will fully compensate for each other. Recently, Ely (2011) demonstrated that in evolutionary processes improvements tend to come in the form of "kludges" – marginal adaptations that compensate for, but do not eliminate, fundamental design inefficiencies.

Finally, Huck, Kirchsteiger, and Oechssler (2005) and Heifetz and Segev (2004) show that endowment effect may evolve in populations that engage in bargaining. In both papers the endowment effect serves as a "commitment" that prevents an agent from giving up his own object for a small compensation, and thus improves his stand in the bargaining. These results, unlike our model, rely on the assumption that a trader observes (at least partially) the degree of his partner's endowment effect. This explanation complements the mechanism we present in our paper. We further discuss their results in Section 5.2.

3 Basic Model: Fully Cursed Traders

In this section we formulate and analyze our basic model. We assume that all agents are fully cursed and that the evolutionary process influences only their level of endowment effect. In Section 4 we will relax both assumptions: agents will be partially cursed and the evolution process will influence both the level of cursedness and the endowment effect.

3.1 Trade Game

We first present the trade game and analyze its cursed and Nash equilibria. Two agents (traders) $\{1,2\}$ participate in the trade game (each can be interpreted as representing a tribe). Each trader owns a different kind of an indivisible good. Each trader $i \in \{1,2\}$

[9] This intuition is formalized briefly only in an unpublished early version of the paper, Heifetz and Spiegel (2001), Section 3.1.

observes a private signal x_i regarding the unobserved qualities of his own good, where x_1, x_2 are independent uniform[10] random variables over $[L, H]$ where $0 < L < H$. We assume for simplicity that x_i is the value that trader i attaches to his own good. Let $\mu \equiv E(x_i)$ be the expected value of x_i and $\mu_{\leq y} \equiv E(x_i | x_i \leq y)$ be the expected value of x_i, conditional that his value is at most y. In addition, both traders receive a public signal $\alpha > 1$, which is a "surplus coefficient" for trade: the good of agent $-i$ is worth αx_{-i} to agent i.[11] High α represents better general conditions for trade, disregarding the specific qualities of the objects that each trader owns. For example, if both parties have a great need for the commodity they do not own, then α will be high. Given that α captures the conditions for trade aside from fluctuations in product quality, which are captured by x_1 and x_2, we assume that α, x_1, and x_2 are all independent. The coefficient α can have any distribution with support $\left(1, \frac{H}{\mu}\right)$.[12] The agents interact by simultaneously declaring whether they are willing or not willing to trade. The goods are exchanged if and only if both agents agree to trade.

A pure strategy of a player is a measurable set of signals $A \subseteq [L, H]$ (the "acceptance set") for which the agent accepts trade. A threshold strategy $x \in [L, H]$ means that the acceptance set is $[L, x]$. For each $q \in [0, 1]$ let q be the mixed type-independent strategy by which a player agrees to trade with probability q, regardless of his signal. A fully cursed player, as defined in Eyster and Rabin (2005), believes that his opponent uses a type-independent strategy. That is, if his opponent plays A, he plays a best response against the strategy $q(A) = \Pr(A) = \frac{|A|}{H-L}$. A strategy is *fully cursed-dominant* if it is a best response against all type-independent strategies.

The following proposition characterizes the unique equilibrium in fully cursed-dominant strategies of the trade game.

Proposition 1. *The game admits the following unique fully cursed-dominant strategy: trader i accepts trade if and only if $x_i < \alpha\mu$.*

Proof. Each cursed agent mistakenly believes that the other trader uses a type-independent strategy. Thus, each agent i evaluates the other good at its ex-ante value $\alpha\mu$ (without conditioning on the other agent's agreement to trade) and accepts trade if his own good is worth less: $x_i < \alpha\mu$. This strategy is fully cursed-dominant for every type of agent i (and

[10] See Section 5.1.1 for a discussion on the uniformity assumption.

[11] Our results remain qualitatively unchanged in the case where each agent i privately obtains an independent identically distributed surplus coefficient α_i.

[12] The conditions imposed on α are only to make the presentation of the results simpler. Full support over $(1, \frac{H}{\mu})$ is needed for uniqueness. The results are identical in the case where we allow for smaller or higher α's (while the notation becomes cumbersome).

strictly fully cursed-dominant if the other player agrees to trade with positive probability). □

Remark 1. Observe that each cursed trader makes a systematic mistake: he accepts trade even for values that are too high, that is, that generate an expected negative payoff from trade. This is because each trader does not take into account the fact that the expected value of his partner's object conditional on trade is lower than the unconditional one, as types of his partner with high signals do not trade.

We next study the equilibrium when the traders are not cursed. The game admits a Nash equilibrium where both traders never trade. The following proposition characterizes the unique Nash equilibrium of the interaction that also has positive trade probability.

Proposition 2. *For each $1 < \alpha < H/\mu$ the game admits the following symmetric Nash equilibrium: each trader i agrees to trade if and only if $x_i < x^*(\alpha)$ where $x^*(\alpha)$ is the unique solution to the following equation:*

$$x^*(\alpha) = \alpha\mu_{\leq x^*(\alpha)}. \tag{1}$$

Moreover, this equilibrium has the following properties:

1. *It is unique equilibrium with positive trade probability.*
2. *It Pareto-dominates (for all traders' types) the no-trade Nash equilibrium.*

The proof is presented in the appendix. In a Nash equilibrium, traders' expected gain from trade depends on the beliefs they form about the strategy of their partner. Each agent i, with a rational (self-fulfilling) belief, evaluates the other good at a value of $\alpha\mu_{\leq x}$. Thus, eq. 1 describes an agent's indifference condition in a symmetric solution.

3.2 Perception Game

In this subsection we present an auxiliary two-stage game in which principals choose a perception bias for agents that will trade in the second stage. Then we interpret the perception biases as genetic types and the principals as natural selection, and show how the endowment effect evolves as a response to cursed behavior.

The interaction includes two stages: a perception game (stage 1) and a trading game (stage 2). At each stage there are two players: two fully rational principals in the perception game, and two fully cursed agents (traders) in the trading game. The trading game is the same as in the basic model, except that each trader i is endowed with a *perception bias* – a continuous function $\psi_i : [L, H] \to [L, H]$ that distorts trader i's perception of his signal. Formally, trader i with signal x_i misbelieves his signal to be $\psi_i(x_i)$. Each principal in the first stage is associated with one of the traders in the second stage, and he benefits from this trader's second-stage payoff. At the first stage (the perception game), the principals simultaneously choose a perception bias for their agents. Each principal i is allowed to choose a mixed strategy – a distribution $\eta_i \in \Delta([L, H] \to [L, H])$ and a perception bias ψ_i will be chosen for his agent according to η_i. At the second stage, endowed with their perception biases, the traders play the unique fully cursed-dominant strategy (notice that strategy is independent of the perception bias of the partner).

Note that, in the trade game taking place in the second stage, agents are biased and thus best respond with "perceived" strategies. i's perceived best response is to the belief that trader $-i$ plays the type-independent mixed strategy $\Pr\left(\psi_{-i}^{-1}(A_{-i})\right)$. Notice that, although agent $-i$ believes he plays A_{-i}, due to his perception bias he really plays $\psi_{-i}^{-1}(A_{-i})$ and therefore this is the strategy trader i is best-replying to. We refer throughout to the perceived strategies and therefore omit the adjective "perceived" unless otherwise stated.

A pure[13] perception profile $\psi = (\psi_1, \psi_2)$ *presents the endowment effect* if each type of each trader overestimates the value of his own good: $\psi_i(x_i) > x_i$ for each $x_i < H$, $i \in \{1, 2\}$. The perception game has equilibria in which both principals induce extreme endowment effect in their agents and as a result the agents never trade. Such equilibria are counterintuitive, as they induce low types (close to L) to reject trade (a weakly dominated strategy), while such types can only earn from agreeing to trade. In what follows, in order to simplify the analysis and presentation, we exclude such extreme perception biases. We allow the principals to choose only perception biases where the lowest type L agrees to trade for every $\alpha > 1$. That is, for each player i we require that: $\psi_i(L) \leq \mu$.

The following proposition shows that the perception game has a unique dominance-solvable Nash equilibrium that exhibits the endowment effect.

Proposition 3. *The perception game admits a symmetric Nash equilibrium where*[14]

$$\psi^*(x) = \frac{\mu}{\mu_{<x}} x.$$

[13] In a slight abuse of notation, we denote a pure strategy by the bias to which the mixed strategy assigns probability one.

[14] We abuse notation throughout and use the same notation for both the profile and the individual biases in case of symmetric profiles. For example, in the context of a perception profile (ψ_1, ψ_2) such that $\psi_1 = \psi_2 = \psi$, we will denote both the profile and the individual perception biases by ψ.

Moreover, this equilibrium:

1. *presents the endowment effect;*
2. *is dominance-solvable: ψ^* is the unique surviving strategy of iterated elimination of strictly dominated strategies.*

Proof. Observe first that $\psi^*(x) > x$ for each $x < H$ and thus ψ^* exhibits the endowment effect. Next, observe that:

$$\psi^*(x) < \alpha\mu \iff \frac{x \cdot \mu}{\mu_{<x}} < \alpha\mu \iff x < \alpha\mu_{<x}.$$

That is, the perception profile ψ^* induces the cursed traders to *actually behave as if they were fully rational* agents (without biases) who play the Nash equilibrium strategy $x^*(\alpha)$ of the trade game. This implies that ψ^* is a Nash equilibrium of the perception game. We prove dominance solvability in the appendix. □

3.3 Evolutionary Dynamics

We finish this section by presenting an evolutionary interpretation of the perception game, and show that the perception bias of all agents will converge in the long run to ψ^* regardless of the initial distribution.

We assume that all agents in the population are fully cursed (and this bias cannot be influenced by the evolutionary process). In addition, each genetic type in the population generates a perception bias in its carrier. In each generation, agents are randomly matched and each couple plays the trading game (given their perception biases and cursedness). The payoffs in the game determines their fitness, i.e., the number of offspring of each type in the next generation *(replicator dynamics)*.

In order to prove global convergence to ψ^*, we rely on Theorem 1 of Heifetz, Shannon, and Spiegel (2007a), who prove that convergence always occurs in dominance-solvable games. Their result can be summarized in the theorem below:

Theorem (Heifetz, Shannon, and Spiegel (2007a)). *Consider a population that plays, in each generation, a symmetric two-player game with a compact set of (pure) strategies for each player. Assume that the actions of the players are determined by their types, these types* *evolve according to the replicator dynamics,*[15] *and initially the distribution of actions has a full support. If the game is dominance-solvable, then the population converges to a unit mass at the unique dominance-solvable equilibrium.*

Combining the result of Heifetz, Shannon, and Spiegel (2007a) with part two of Proposition 3 immediately yields that in the long run all agents have perception bias ψ^* and therefore exhibit the endowment effect.

Corollary 1. *Any distribution of perception biases (with full support)*[16] *will converge in the long run to a unit mass on* ψ^*.

4 Partial Cursedness and Co-Evolution of Biases

The basic model presented above allows us to show how the endowment effect and the winner's curse fully compensate each other, and to explain why these two psychological biases may have survived natural selection together. This model, however, has two restrictive and unnatural properties. First, we assume that individuals are cursed and show how the endowment effect evolves. This is rather arbitrary, and we would like to have a model where both biases evolve together. Second, in the basic model evolution leads to a homogeneous population, since we assume that agents are "fully cursed." In reality, of course, we see that individuals are not fully cursed, and they only underestimate the informational content in others' actions. In this section we therefore extend the basic model by allowing heterogeneity in the level of both biases and also show how the evolutionary process can shape both the cursedness level and the perception bias of agents.

In the rest of this section we make the appropriate definitions, analyze a generalized version of the model presented in Section 3, and show that, in this general setup as well, the endowment effect and the winner's curse fully compensate for each other. Here is a summary of the results and some intuition behind them. In the following subsection we show that partially cursed traders, i.e., traders who underestimate how the behavior of others reflect their private information, will choose an intermediate threshold between the two extreme cases analyzed in Section 3. We then show that any level of cursedness can be corrected using a specific level of endowment effect: the higher the level of cursedness, the stronger the endowment effect needed in order to compensate. Thus, we obtain a continuum of types

[15] Heifetz, Shannon, and Spiegel (2007a) prove their result in a broader setup that allows for any regular payoff monotonic growth-rate function (where the replicator dynamics is a particular case).

[16] The full support assumption is required because the replicator dynamics does not include mutations (which allow new types to emerge).

that have an as-if rational behavior. We further propose that when principals can choose both biases for their agents, they will choose only pairs of biases that lead to an as-if rational behavior. The intuition is straightforward: a principal can always choose to make his trader rational (i.e., not cursed and without endowment effect). Any agent who does not behave "rationally" will obtain a payoff that is less than or equal to a rational agent. This makes all pairs of biases, except for those where both biases fully compensate for each other, weakly dominated strategies for principals. Lastly, in the evolutionary framework, our results imply that if natural selection leads to a steady state, then in the long run the entire population will exhibit the endowment effect and the winner's curse at levels that fully compensate for each other.

4.1 Partial Cursedness and Best Response

We begin by defining partial cursedness as in Eyster and Rabin (2005). A partially cursed agent underappreciates the relation between his opponent's strategy and type, but does not ignore it completely More formally, agent i is χ_i-cursed ($\chi_i \in [0,1]$) if he best responds to the belief that with probability χ_i his opponent uses a type-independent mixed strategy $\Pr(A_{-i})$ (defined in Section 3.1), and with probability $1-\chi_i$ his opponent plays the type-dependent pure strategy A_{-i} . When $\chi_i = 1$ the agent is fully cursed as in the previous section, and when $\chi_i = 0$ the agent is fully Bayesian.[17]

Since in our framework agents have the additional perception bias, we need to modify, as we did in the previous section, the definition of a best reply. Consider the case where each trader i is χ_i-cursed and has a perception bias ψ_i. Now, let trader $-i$ play the pure strategy A_{-i}. In such a case, trader i's cursed-biased best response is to the belief that trader $-i$ plays the type-independent mixed strategy $\Pr\left(\psi_{-i}^{-1}(A_{-i})\right)$ with probability χ_i and the pure strategy $\psi_{-i}^{-1}(A_{-i})$ with probability $1-\chi_i$. Notice that, although agent $-i$ believes he plays A_{-i}, due to his perception bias he really plays $\psi_{-i}^{-1}(A_{-i})$ and therefore this is the strategy trader i is best-replying to. The same holds for agent i.

4.2 Two-Stage Game with Cursed-Biased Traders

Next, we extend the perception game presented in the previous section to allow each principal to determine the perception bias but also the cursedness level of his agent. Each principal

[17] We interpret this behavior in the common "as-if" fashion. Each agent does not properly introspect about how his opponent uses his private information, but it seems he is playing as-if he believes his opponent is playing a strategy which the actual opponent's strategy biased towards the type independent strategy.

i simultaneously chooses a pair of biases (χ_i, ψ_i) for his agent, where $0 \leq \chi_i \leq 1$ is the cursedness level and $\psi_i : [L, H] \to [L, H]$ is the perception bias as defined in Section 3. In order to simplify the analysis and the presentation of the results we limit the space of possible perception biases to include biases ψ that are (1) continuous and strictly increasing[18] in x, and (2) satisfy $\psi(L) \leq \chi_i \mu + (1 - \chi_i) L$. The second condition implies (see Proposition 4) that lowest type (L) always agree to trade for every α. The principals are allowed to choose mixed strategies, i.e., a distribution ζ_i over the pairs (χ_i, ψ_i).

Given the mixed-strategy profile $\zeta = (\zeta_1, \zeta_2)$, the traders play a ζ-trade game: both agents learn the realization of α, each agent i is privately and randomly awarded with a pair of biases (χ_i, ψ_i) according to ζ_i, and each agent i observes the true value of his good x_i but mistakenly believes it to be $\psi_i(x_i)$. Each trader i then plays a best reply to ζ_{-i}. A *cursed-biased equilibrium* of the ζ-trade game is thus a profile in which for every private realization of biases, each agent i plays a cursed-biased best response to ζ_{-i}.

Remark 2. Note that each trader i does *not* observe the perception bias and the cursedness level of his opponent; instead, agent i plays a best response against the aggregate behavior that is induced by the distribution of biases ζ_{-i} and the strategy of his opponent. In the evolutionary setup, this assumption implies that genetic types of other agents are unobservable. In the fully cursed case, the equilibrium strategy of each trader is independent of his partner's bias, and so our result in that case holds for both observable and unobservable biases. In the partially cursed case, a trader's equilibrium strategy depends on his partner's bias. Assuming observability allows principals to use the perception bias as a commitment device. Such a use would complicate the analysis, and as a result, no pure strategy profile would be stable (see a related analysis of observable and unobservable preferences in Dekel, Ely, and Yilankaya, 2007).

The following proposition shows that every ζ-trade game admits a pure cursed-biased equilibrium.

Proposition 4. *A ζ-trade game admits a pure cursed-biased equilibrium. Furthermore, in every such equilibrium and for every realization of χ_i, every trader i plays a threshold strategy with a threshold strictly larger than $\chi_i \mu + (1 - \chi_i) L$.*

A ζ-trade game may have more than one pure strategy equilibrium. For each such game, we arbitrarily fix one of these equilibria and assume that both traders follow the fixed equilibrium (the results below hold for any equilibrium selection).

[18] Monotonicity is assumed so that ψ^{-1} is well defined.

We next prove uniqueness and characterize the unique equilibrium in a special case that will be of importance. For each $0 \leq \chi \leq 1$ consider the specific perception bias

$$\psi_{\chi}^{*}(x) = \chi \cdot \psi^{*}(x) + (1-\chi) \cdot x = \frac{(\chi\mu + (1-\chi)\,\mu_{\leq x})}{\mu_{\leq x}} \cdot x. \qquad (2)$$

Notice that $\psi_{\chi}^{*}(x)$ presents the endowment effect for all χ, and that the endowment effect is strictly increasing in χ. The following proposition characterizes the unique equilibrium of the ζ-trade game when the support of each ζ_i is $\Gamma = \left\{\left(\chi, \psi_{\chi}^{*}\right) : \chi \in [0,1]\right\}$. In other words, if principals choose a cursedness level of χ for their agents they must also give them a perception bias $\psi_{\chi}^{*}(x)$. This shows that in such equilibrium all agents behave as if they were fully rational (that is, without any biases).

Proposition 5. *Assume that the support of each ζ_i is a subset of Γ. Then, the ζ-trade game admits a unique, pure, cursed-biased equilibrium in which both traders behave as if they were rational traders who play the Nash equilibrium of the trade game. That is, they trade if and only if $x < x^{*}(\alpha)$, as defined in Proposition 2.*

4.3 Perception Game and Evolution

As in the previous section, we here use the perception game to study the evolution of biases. We assume that each genetic type in the population generates both a cursedness level and a perception bias in its carrier. In each generation, agents are randomly matched and each couple plays the trading game (given their perception biases and cursedness level, and without observing their partner's type). The payoffs in the game determines their fitness, i.e., the number of offspring of each type in the next generation *(replicator dynamics)*. Stable profiles in this evolutionary dynamics correspond to symmetric Nash equilibria of the perception game (as evolution in a single population can only induce symmetric profiles). The following proposition characterizes the symmetric Nash equilibria of the perception game as the set of profiles with a support in Γ.

Proposition 6. *A symmetric profile ζ is a Nash equilibrium of the perception game if and only if its support is a subset of Γ.*

Finally, we can also write the evolutionary interpretation of the results. Assume that each genetic type in the population determines the level of cursedness and the perception bias if its carrier. As before, we assume that in each generation agents are randomly matched and each couple plays the trading game (given their perception biases and cursedness). The payoffs in the game determines their fitness, i.e., the number of offspring of each type in the next generation *(replicator dynamics)*. The following corollary of Proposition 6 shows that the population can converge in the long run only to a subset of Γ.

Corollary 2. *Assume that the initial distribution of biases has full support, and that it converges in the long run to distribution ζ. Then the support of ζ is a subset of Γ.*

Observe that in each generation fully rational types get a weakly best payoff, and thus they cannot be eliminated and must be in the support of ζ. For ζ to be a stable profile, all types in its support must have the same payoff. This implies (similar to the proof of the previous proposition) that all types in the support of ζ must play as if they were rational traders, and that the support of ζ is a subset of Γ.

The set Γ is a surface in the space of $[0,1] \times [L,H] \times [L,H]$. This is demonstrated in Figure 1 (for $L = 1$ and $H = 2$). In the long run, all the surviving types in the population will be inside Γ, and all these types will induce the same observable behavior and have the same payoff. Thus, in our model there are no substantial evolutionary forces to distinguish between pairs of biases in Γ, and the population is likely to be heterogeneous. This result suggests a strong positive correlation between the level of the endowment effect and the level of the winner's curse. Some agents are fairly rational (low level of both biases), while others display a high level of both biases. In the next section we informally discuss indirect evolutionary forces among the different pairs in Γ through their influence in other interactions.

5 Discussion

5.1 Robustness

Our model includes various simplifying assumptions. In what follows, we discuss a few ways to relax or change these assumptions, and their influence on our results.

5.1.1 Non-Uniform Signal Distributions

The only time we make use of the the uniform distribution assumption for private signals is in the uniqueness part of Proposition 4. Uniqueness holds due to the concavity of ψ^*, and implicitly due to the concavity of $\frac{x}{\mu_{<x}}$. The latter property is sufficient to obtain the results.

A distribution that does not satisfy this condition may induce many Nash equilibria in the trade game, even in the basic model. In any such equilibrium, rational traders use strictly lower thresholds than cursed traders. This multiplicity of equilibria in the trade game results

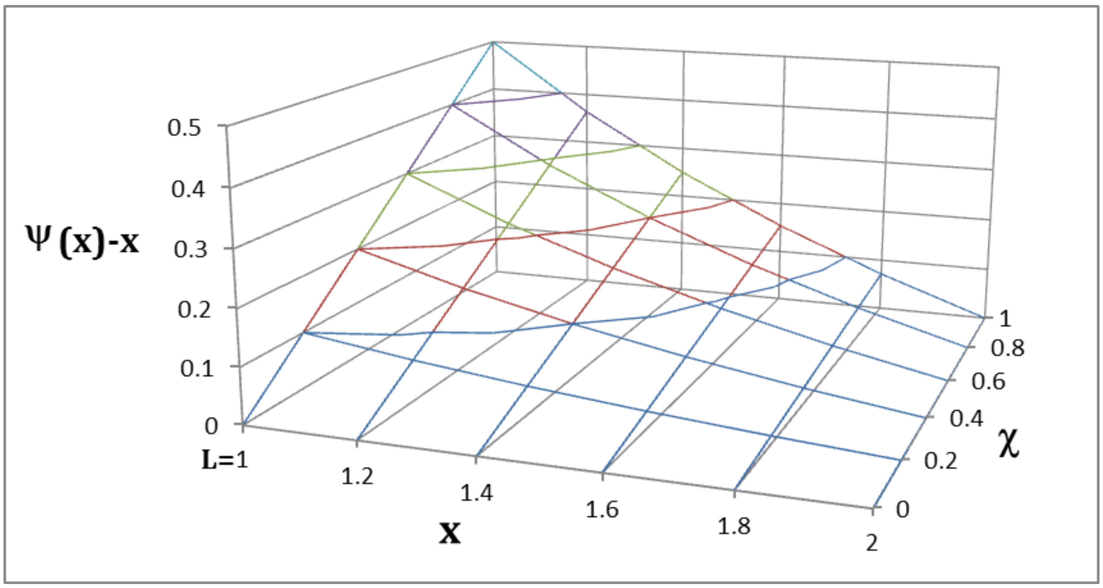

Figure 1: *An example of* Γ*. The figure depicts the set of surviving types: for every level of cursedness* χ *there is a perception bias function* $\psi^*(x)$*. The net bias* $\psi^*(x) - x$ *is plotted as a line on the X-Z plane. As can be seen, the perception bias presents the endowment effect, and therefore all values are positive. The perception-bias function fully compensates for the cursedness level, and therefore high cursedness (*χ *closer to one) is associated with a greater endowment effect (steeper slope for the function and higher values). This figure was calculated assuming* $x_i \sim \mathrm{U}[1, 2]$*.*

in a multiplicity of Nash equilibria in the perception game. In each of these equilibria, agents exhibit the endowment effect ($\psi^*(x) > x$ for each $x < H$), but they may use different levels of the endowment effect in different equilibria. Perception biases that do not induce the endowment effect ($\psi(x) < x$ for a positive-measure set of types) are strictly dominated, and will be excluded from the population throughout the evolutionary dynamics. Thus, our qualitative result still holds in this more general setup: evolution would induce all agents to exhibit an endowment effect. However, contrary to the case where the signals are uniformly distributed, there is no unique prediction for the degree of the induced bias.

5.1.2 Other Trade Mechanisms

Our assumption that each trader evaluates his partner's good as α times the partner's evaluation may seem artificial in some trade setups. However, we checked several alternatives to this surplus coefficient α, and our results seem robust to the exact assumptions according to which each trader evaluates his partner's good. In particular, we analyzed the case in which each agent values his good in accordance with his private signal, but values the other's good in accordance with the average of the other's signal and the good's expected value (reflecting the fact that the trader finds his partner's signal less relevant than his own signal due, for example, to differences in tastes). Note that in this model at the *ex-ante* stage, both traders evaluate both goods the same. All of the results of our paper remain qualitatively unchanged in this variant.

5.2 Main Prediction

The main new falsifiable prediction of our model is that there would be a relatively strong positive correlation between the intensity of endowment effect and the cursedness level that an individual exhibits. We are not familiar with any existing theory that implies this correlation or any experiment that tests for it, and indeed we plan to test it in future research.

One might argue that our model has a different prediction: that people will have neither of these biases. The model (Section 4) shows that all bias-pairs in Γ will have similar success in simple bilateral trade interactions. This implies that the evolutionary choice among the pairs in Γ will be determined by their success in other interactions, which we leave unmodeled. One may be tempted to think that a rational type (with no biases) will always have an advantage over a type with both biases in other interactions, and that as a result only rational types will survive in the population due to their advantage in non-barter interactions. This conclusion ignores two important points. First, these behavioral biases may have additional benefits. As was discussed earlier (in Section 2.2), several authors have claimed that an observable endowment effect may serve as a commitment device and induce credible toughness in bargaining (Heifetz and Segev, 2004; Huck, Kirchsteiger, and Oechssler, 2005). The winner's curse may also be beneficial in some interactions. For example, it can reduce the risk of creating information cascades.[19] Second, there are significant "complexity costs" for developing fully rational thinking. Aumann (2008), among others, argues that natural selection may "find" it more cost-effective to use simpler heuristics rather than full rationality, which bears high cognitive costs. We thus conclude that, though our model does not address all the implications of having these two biases, its natural prediction is that different levels of endowment effect and winner's curse did survive natural selection together.

A Proofs

This appendix includes the proof of Proposition 2 from Section 3 and the proofs of all the propositions of Section 4.

A.1 Proof of Proposition 2

Proof. The expected payoff of each trader i, $\alpha E\left(x_{-i}|A_{-i}\right) - x_i$, is decreasing in x_i, and therefore any equilibrium strategy is monotone: if trader i agrees to trade for signal x, he agrees to trade for any signal $x_i < x$. Thus, without loss of generality we assume that each trader i uses a threshold strategy $x_i^*\left(\alpha\right)$. Assume first that $1 < \alpha < \frac{H}{\mu}$. If there is positive trade probability then $L < x_i^*\left(\alpha\right)$. Observe that $x_i^*\left(\alpha\right) < H$ as the type with the highest signal can never earn from trading. This implies that each a $x_i^*\left(\alpha\right)$-type trader is indifferent to trading when

$$x_i^*\left(\alpha\right) = \alpha\mu_{\leq x_{-i}^*\left(\alpha\right)}.$$

The fact that $\mu_{\leq x}$ is strictly increasing in x_{-i}^* implies that both thresholds are equal, $x^*\left(\alpha\right) = x_i^*\left(\alpha\right) = x_{-i}^*\left(\alpha\right)$, and this implies that

$$x^*\left(\alpha\right) = \alpha\mu_{\leq x^*\left(\alpha\right)}. \tag{3}$$

[19] Bernardo and Welch (2001) show how an evolutionary process can induce agents to underestimate information that is revealed by the actions of others; they interpret it as overconfidence, but this could be equivalently interpreted as the winner's curse.

Let $G(x,\alpha) = x - \alpha\mu_{\leq x}$. Observe that: (1) $G(L,\alpha) < 0$, (2) $\alpha \leq \frac{H}{\mu} \Longleftrightarrow G(H,\alpha) \geq 0$, (3) $\frac{\partial}{\partial x}G(x,a) > 0$ (due to our assumption that x has a uniform distribution), and (4) $\frac{\partial}{\partial \alpha}G(x,\alpha) < 0$. These observations imply that Equality (3) has a unique solution for each $1 \leq \alpha \leq \frac{H}{\mu}$ (and no solution for larger α's), and that this solution is strictly increasing in α. It is immediate to see that if $\alpha \geq \frac{H}{\mu}$, then there is no adverse selection and all types choose to trade so $x^* = H$, and that if $\alpha \leq 1$ then all types choose not to trade. In addition, observe that any type of any trader (except the threshold type) strictly prefers to follow this equilibrium. This implies strictness of the equilibrium. Finally, observe that both traders earn a positive expected payoff (because $\alpha > 1$), and this implies Pareto-dominance compared to not trading at all. □

A.2 Proof of Proposition 3 (Part 2)

Proof. In part (2) of the proposition we have to show that ψ^* is the unique surviving strategy of iterated elimination of strictly dominated strategies. The first iteration deletes all perception biases that do not result in a monotone behavior. To see this assume a perception bias $\psi(x)$ that leads to a non-monotone strategy A for its trader, i.e., there exist three signals $x < x' < x''$ such that the trader agrees to trade for x and x'' ($x, x'' \in A$) but refuses to trade for x' ($x' \notin A$). This perception bias is strictly dominated by a perception bias that induces a threshold strategy (i.e., monotone strategy) $\tilde{A}$, with the same total probability of agreeing to trade (that is, $|A| = |\tilde{A}|$). Therefore, we can first eliminate all perception biases that result in non-monotone behavior, i.e., where the induced strategy of the traders is not a threshold strategy.

Given that only undominated perception biases are now used, we can eliminate additional strategies using the following recursive argument. For any α it is always strictly better for an agent to accept trade whenever $x \leq \alpha L$ and reject trade whenever $x \geq \alpha\mu$, regardless of the strategy and the perception bias of his trading partner. Thus, biases that do not satisfy these inequalities are strictly dominated strategies for the principals. Let Ψ_0 be the set of undominated biases, i.e., the set of biases that always induce the agent to accept trade when $x < L_1 \equiv \alpha L$ and reject trade when $x > H_1 \equiv \alpha\mu$. Assuming that both principals use undominated perception biases (biases in Ψ_0), it is always strictly better to accept trade if $x \leq \alpha\mu_{\leq L_1}$and reject trade if $x \geq \alpha\mu_{\leq H_1}$. Let $\Psi_1 \subseteq \Psi_0$ be the set of biases that always satisfy these conditions (against an opponent who uses strategies from Ψ_0). All strategies outside Ψ_1 are eliminated at the second iteration. Define by induction $L_n = \alpha\mu_{\leq L_{n-1}}$and $H_n = \alpha\mu_{\leq H_{n-1}}$. In the n-th iteration, it is strictly better to accept trade if $x \leq \alpha\mu_{\leq L_{n-1}}$ and reject trade if $x \geq \alpha\mu_{\leq H_{n-1}}$. Let Ψ_n the set of biases that always satisfy these conditions (assuming the opponent's strategy is from Ψ_{n-1}). Observe that, $(L_n)_n$ $((H_n)_n$) is an increasing (decreasing) sequence and let L^* (H^*) be its limit. Both these limits are characterized by the unique solution to the equation $x^* = \alpha\mu_{\leq x^*}$. Let Ψ^* be the limit of the sequence of serially undominated sets $(\Psi_n)_n$. The above argument implies that $\Psi^* = \{\psi^*\}$. □

A.3 Proof of Proposition 4

Proof. As in Proposition 2, we can assume without loss of generality that each trader uses a threshold strategy; that is, trader i agrees to trade if and only if his biased signal $\psi_i(x)$ is below threshold $y_i^*(\alpha, \chi_i)$. If there is a positive trade probability then accepting trade is strictly dominant for type $\psi_i(x) = L$ and strictly dominated for type $\psi_i(x) = H$. This implies that for each realization $(\chi_{i,}\psi_i)$ of ζ_i, trader i is indifferent to trade if and only if the perceived value of his good $y_i^* = y_i^*(\alpha, \chi_i)$ satisfies, for every α and χ_i, the equality

$$y_i^*(\alpha, \chi_i) = \alpha\left[\chi_i\mu + (1-\chi_i)\,\mathbf{E}_{\zeta_{-i}}\left(\mu_{\leq\psi_{-i}^{-1}\left[y_{-i}^*(\alpha,\chi_{-i})\right]}\right)\right].$$

In particular, for $\chi_i = 0$,

$$y_i^*(\alpha) \equiv y_i^*(\alpha, 0) = \alpha\mathbf{E}_{\zeta_{-i}}\left(\mu_{\leq\psi_{-i}^{-1}\left[y_{-i}^*(\alpha,\chi_{-i})\right]}\right). \tag{4}$$

This implies that for every cursedness level χ_i,

$$y_i^*(\alpha, \chi_i) = \alpha\chi_i\mu + (1-\chi_i)\,y_i^*(\alpha). \tag{5}$$

Thus, the value perceived threshold for non-cursed traders $y_i^*(\alpha)$ immediately determines the perceived threshold for cursed traders $y_i^*(\alpha, \chi_i)$. Using (5) to modify (4) we get

$$y_i^*(\alpha) = \alpha\mathbf{E}_{\zeta_{-i}}\left(\mu_{\leq\psi_{-i}^{-1}\left[\alpha\chi_{-i}\mu+(1-\chi_{-i})y_{-i}^*(\alpha)\right]}\right),$$

and using (4) once again to revise the R.H.S of this equality gives us an implicit function of $y_i^*(\alpha)$:

$$y_i^*(\alpha) = \alpha\mathbf{E}_{\zeta_{-\mathbf{i}}}\left(\mu_{\leq\psi_{-i}^{-1}\left[\alpha\chi_{-i}\mu+(1-\chi_{-i})\left(\alpha\mathbf{E}_{\zeta_i}\left(\mu_{\leq\psi_i^{-1}\left[\alpha\chi_i\mu+(1-\chi_i)y_i^*(\alpha)\right]}\right)\right)\right]}\right). \tag{6}$$

Observe that the R.H.S is greater than L when we set $y_i^*(\alpha) = L$ and less than H when we set $y_i^*(\alpha) = H$. Continuity implies that equation(6) admits at least one solution strictly between L and H. Any such solution induces an equilibrium strategy (for a given α) in the ζ-trade game. Equation (5) implies that this equilibrium satisfies $y_i^*(\alpha, \chi_i) > \alpha\chi_i\mu + (1-\chi_i)L > \chi_i\mu + (1-\chi_i)L$. $\square$

A.4 Proof of Proposition 5

Define a threshold strategy with a perceived threshold $y^*(\alpha,\chi) \equiv \alpha\chi\mu + (1-\chi)\alpha\mu_{\le x^*(\alpha)}$, where $x^*(\alpha)$ is the Nash threshold of Proposition 2, that is, the unique solution to $x^*(\alpha) = \alpha\mu_{\le x^*(\alpha)}$. Notice that (1) $y^*(\alpha,\chi)$ is the (perceived) best reply of a χ-cursed trader who faces a partner that is using the Nash threshold $x^*(\alpha)$, and (2) any χ-cursed trader with perception bias ψ_χ^* who uses a threshold $y^*(\alpha,\chi)$ is behaving as a fully rational trader that uses threshold $x^*(\alpha)$. (1) is immediate from the definition of χ-cursed behavior. To see (2), observe that the expected value of this trader's object conditional on trade equals

$$\begin{aligned}
\mu_{\le\psi_\chi^{*-1}[y^*(\alpha,\chi)]} &= \mu_{\le\psi_\chi^{*-1}\left[\alpha\chi_i\mu+(1-\chi_i)\alpha\mu_{\le x^*(\alpha)}\right]} \\
&= \mu_{\le\psi_\chi^{*-1}\left[\frac{\alpha\mu_{\le x^*(\alpha)}}{x^*(\alpha)}\frac{\left(\chi_i\mu+(1-\chi_i)\mu_{\le x^*(\alpha)}\right)}{\mu_{\le x^*(\alpha)}}\cdot x^*(\alpha)\right]} \\
&= \mu_{\le\psi_\chi^{*-1}\left[\frac{\left(\chi\mu+(1-\chi_i)\mu_{\le x^*(\alpha)}\right)}{\mu_{\le x^*(\alpha)}}\cdot x^*(\alpha)\right]} \\
&= \mu_{\le\psi_\chi^{*-1}\left[\psi_\chi^*(x^*(\alpha))\right]} \\
&= \mu_{\le x^*(\alpha)}.
\end{aligned}$$

From (1) and (2) it follows that the symmetric strategy profile $y^*(\alpha,\chi)$ is an equilibrium for a ζ-trade game if the support of each ζ_i is $\Gamma = \left\{\left(\chi, \psi_\chi^*\right) : \chi \in [0,1]\right\}$.

Next, we prove that this equilibrium is unique. Note that for every χ the function ψ_χ^* is strictly concave (and thus $\left(\psi_\chi^*\right)^{-1}$ is strictly convex). This means that, for a fixed α, the R.H.S. of equation (6) is a strictly convex function of $y_i^*(\alpha)$ when the supports of both $\zeta_i's$ are in Γ (assuming a positive probability for $\chi_i < 1$; uniqueness in the case of $\chi_i = 1$ is immediate). In addition, for the extreme value L (H) the R.H.S. is strictly greater than L (strictly less than H). This implies that there must be a unique solution to equation (6).

A.5 Proof of Proposition 6

Proof. The proof of Proposition 5 shows that any mixed distribution over Γ induces all agents to play as if they were playing the Nash equilibrium of the trade game without biases. This immediately implies that any such mixed distribution is a Nash equilibrium of the perception game (applying the same arguments as in Proposition 3). We are left with proving that any symmetric equilibrium ζ has a support in Γ. Observe that each principal can play a best reply against ζ by choosing a fully rational type. Moreover, any bias that induces a trader to use a different threshold for some value of α would obtain a strictly smaller payoff. Thus, it must be that any bias in the support of ζ induces the trader to use the same threshold (as a function of α) against the profile ζ. This implies that each bias should induce the trader to play as if he were fully rational when playing against another fully rational agent. That is, all biases induce the traders to use the threshold $x^*(\alpha)$. The proof of the previous proposition shows that any bias $\left(\chi, \psi^*_\chi\right)$ satisfies it. Observe that any other bias (χ, ψ) where $\psi \neq \psi^*_\chi$ induces a different threshold against x^* for some α and this completes the proof. $\square$

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