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# Private Valuation of a Public Good in Three Auction Mechanisms

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# Private Valuation of a Public Good in Three Auction Mechanisms

Arnaud Z. Dragicevic and David Ettinger

## Abstract

We evaluate the impact of three auction mechanisms—the Becker-DeGroot-Marschak (BDM) mechanism, the second-price auction (SPA), and the random nth-price auction (NPA)—in the measurement of private willingness-to-pay and willingness-to-accept for a pure public good. Our results show that the endowment effect is lower with the BDM mechanism. In this market mechanism, the effect disappears after a few repetitions. Yet, on a logarithmic scale, the random nth-price auction yields the highest speed of convergence towards equality of welfare indices. We also observe that subjects value public goods in reference to their private subjective benefit derived from their public funding.

**KEYWORDS:** WTP-WTA disparity, auction mechanisms, public goods, private provisions

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"I have never known much good done by those who affected to trade for the public good." Adam Smith

## 1. Introduction

The environment provides a large number of goods and services to economic agents. The authorities need to estimate their value in order to budget for public policies. While the environment has value, it does not have a price. Therefore, how do we justify the public expenditure for its management and the extensive funding of public goods? Economic valuation permits us to compare benefits and costs, which makes it an important decision tool for policy assessment and legislation. It meets a double aim: first, to set up a monetary order of magnitude, so that items are inducted in the public decision-making in respect to their fair value or perceived utility; second, to take account of the agents' preferences in regulation (Dragicevic 2009).

The experimental private provision and thus valuation of a public good is principally conducted in the framework of public goods games. Otherwise, contingent valuation is used to value non-market resources such as health, safety or the environment. Its techniques measure the Hicksian indices, which are the willingness-to-pay (WTP) or the price at which an individual is ready to buy a commodity and the willingness-to-accept (WTA) or the price at which an individual is ready to sell the same commodity. By using contingent valuation techniques, our motivation is to study how subjects reveal preferences over public goods in market mechanisms such as the auction processes. This research objective comes from the fact that public goods are neither traded on markets nor have a market price. In case subjects do want to trade public goods on markets, which fair value will they reveal given the negligible private utility derived from their consumption? Microeconomic theory stipulates that in case of informational efficiency and rational preferences, fair value and market price are equal. Market price should then reflect the public good's value. However, estimating the market value from a non-market fair value is laborious, for subjects reveal behavioral biases during their valuation. Put differently, subjects tend to act irrationally. Market price is then not necessarily reflective of the subject's fair value.

Economists bind value to utility or preference satisfaction. The amount an agent is willing to spend on a good to satisfy her preferences reflects her value of the good. This conduct enables us to apply the principles of welfare economics from whence comes the benefit-cost analysis. Economists then calculate the rate at which the agent is willing to substitute a good for another. This substitution rate can be captured by means of stated preferences (Bateman et al. 2002). The weakness of stated preferences comes from the fact that they contain behavioral biases. As a result, the absence of market incentives in form of budget constraints



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and substitutes' availability produces disputable data. Agents do not have the incentives to mobilize adequate cognitive efforts when they formulate their declarations. Yet, economists need to reveal truthful values in order to conduct benefit-cost analyses and estimate the effects of a public policy (Boardman et al. 2005). Why not measure these values by the auction mechanisms? Indeed, preferences revealed from experimental auctions have been studied for some time now: Bohm (1972), Brookshire and Coursey (1987), Hoffman et al. (1993), Shogren et al. (1994), Shogren et al. (2001), Rozan et al. (2004), Lusk et al. (2007).

The rationale is that economic value comes from exchange and experimental auctions put the agents in the context of exchange. Auction mechanisms are capable of both palliating the weakness of stated preferences and creating an exchange. Their incentive-compatibility induces a disincentive cost to deviate from truthful preferences. The match of demand (WTP) and supply (WTA) then uncovers the market price which represents the economic value. Since the market price is a reflection of demand and supply, any WTA/WTP disparity from the public good valuation produces an economic value irrelevant for decision-making.

Another issue surrounding public goods relates to property rights. To own a public good, agents have to buy it. Conversely, they have to own the public good before they sell it. The WTA/WTP ratio comes into play while assigning the property rights, since the difference between WTP and WTA becomes one of valuing property rights. Therefore, any disparity measures the consequence of assigning a property right to public goods one way or the other (Horowitz and McConnell 2002). Property rights remain difficult to establish or legitimate in public policies, whereas in a market the price signals the value of resources on which to base the public decisions (Sinclair-Desgagné 2005).

Neoclassical theory postulates that with null income effect and close substitutes, WTP and WTA are equal (Randall and Stoll 1980, Hanemann 1991), i.e. WTA/WTP = 1, which is in accordance with Coase (1960). If a good is available at market price on an active market, WTP and WTA should be similar. Yet, experimental research has found disparities, i.e. WTA/WTP > 1. The endowment effect, or loss aversion, as a behavioral feature is often invoked to explain the disparity. It occurs when people offer to sell a commonly available good in their possession at a substantially higher rate than they would pay for the identical good not in their possession. The other effect, promoted to explain the disparity, is imperfect substitutability between the goods. Two remedies help remove the initial disparity. The first corresponds to market settings. Market institutions serve as social tools that induce and reinforce individual rationality (Smith 1991). Gode and Sunder (1993) assert that an auction market exerts a powerful constraining force on individual behavior. Cherry et al. (2003) suggest

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that a dynamic market environment with repeated exposure to the process is necessary to achieve rationality. When they act rationally, individuals refine their statements of value. List (2003*a*) provides evidence consistent with the notion that experience in bidding with an incentive-compatible auction can remove the WTA/WTP disparity. The second remedy corresponds to market repetition. The motive for repeating auctions that are incentive-compatible is that individuals require experience to understand that sincere bidding is the dominant strategy (Coppinger et al. 1980) and to realize their true valuation of unfamiliar products (Shogren et al. 2000). When agents perfectly know their valuations, they submit bids close to their valuations (Kagel et al. 1987, McCabe et al. 1990). Even though subjects may not instantly understand that sincere valuing is rational, we choose to focus on repetition from the behavioral standpoint.[1]

Indeed, Plott (1996) advances a discovered preference hypothesis argument, positing that responses reflect a type of internal search process in which subjects use practice rounds to discover their preferences. The experience they gain is reflected in their bidding behavior. Hence, the imperfect substitutability effect disappears when the value of the unfamiliar good is perfectly revealed. We believe that subjects experience the sentiment of ownership after each round. It enables them to better understand preference satisfaction and thus to divulge their values of the good. The iterated adjustments of randomly allotted buyers and sellers reveal their true values, means of which converge to a single market value. As Horowitz and McConnell (2002) point out, if the ratio were to fall with practice, the implications in environmental and public policy decisions would be important, because familiarity and practice and thus rationality are likely absent. Thereby, is there an auction mechanism capable of reducing the initial gap between WTP and WTA and hence revealing the economic value of public good?

Kahneman et al. (1990) report experimental evidence of the endowment effect. They perform a hypothetical telephone inquiry, trading environmental improvements and preparedness for disasters. To elicit value estimates, they use the Becker–DeGroot–Marschak (BDM) mechanism and find that randomly assigned owners of an item require more money to separate from their possession than random buyers are willing to pay to acquire it. According to their results, preferences are dependent on endowments, even in market settings. Shogren et al. (1994) assert that the experiment conducted by Kahneman et al. creates artificial scarcity. They find no evidence of the endowment effect on trading candy bars, for the values converge over time. But, in the contaminated food experiment – a good with imperfect substitutes that can be considered as non-marketed – they show that the discrepancy remains significant after iteration. While the authors

[1] In addition, we suggested to the subjects that truthful bidding is a weakly dominant strategy at the beginning of each experiment.

support the idea of a low substitution elasticity of the non-market good, they do not advocate an institution capable of valuing non-market goods. Later on, Shogren et al. (2001) test the BDM mechanism, the Vickrey's (1961) second price auction (SPA) and the random *n*th-price auction (NPA) to exchange candy bars and mugs, and suggest that the type of auction mechanism accounts for contrasting observations in experiments. They show that the early disparity is not to be called into question. However, the gap ebbs away under SPA and NPA while it lasts under BDM. Therefore, Plott and Zeiler's (2005) claim that results differ from unsound experimental procedures is incomplete. Only List (2003*b*) gives credit to the use of the random *n*th-price auction in valuing non-market private goods, but he does not state whether his results carry over to public goods.

Horowitz (2006*a*) states that the BDM framework could be used to assess public WTP for public projects, with the distribution of costs equal to the project costs; and that other valuation mechanisms should be used if the behavioral evidence shows that outcomes are equivalent whatever the mechanism. Lusk and Rousu (2006) suggest that NPA is preferable to BDM if the researcher is looking for true valuation above all. Lusk et al. (2007) conclude that both provide relatively strong incentives for truthful bidding for all individuals.

We aim to study market valuation of a public good without direct substitutes, so we put the carbon offset, which can be attained *via* tree planting, into auctioning. Public goods have two defining characteristics: non-excludability and non-rivalry. Offsetting carbon emissions helps prevent the effects of climate change; it is considered a public good because, once provided, everyone can enjoy the benefits without adversely affecting anyone else's ability to do the same.[2] Rather than compulsory carbon trade, we institute voluntary trade to approach truthful valuation on both the bidder's (buyer's) and the offerer's (seller's) sides. On account of the common bias of *nescience*[3] in valuing unfamiliar or public goods, we remind the subjects that they are part of the socio-economic setting. This makes them indirectly and partly accountable for the current level of greenhouse gases, as they solicit industries to produce goods they are willing to consume at an environmental cost. We are interested in paper and energy consumed by students to achieve their education.[4] Our experiments differ from the early auction mechanisms for discrete public goods based on the Lindahl equilibrium by Smith (1979), which require that subjects unanimously agree to the public good quantity and cost shares according to their marginal benefits, otherwise no public good is provided.

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[2] We ensured the public good characteristic by providing an email feedback on the aggregate offset achievement to every subject after a few weeks.

[3] It reflects the absence of knowledge or the consideration that things are unknowable.

[4] The money released from trading (buying and non-selling) was sent to a non-governmental organization that launched a plantation of 1,404 Mangrove trees in Sumatra, Indonesia.

Our results show that the initial disparity can be removed by means of repetitive auction mechanisms, i.e. WTA/WTP → 1. Nevertheless, we obtain different results from Shogren et al. (2001). The only mechanism able to remove the gap between bids and offers and to fully reveal the public good market value is BDM. SPA and NPA do not succeed in eliminating the disparity. Still, when we conduct an exponential regression, we find that NPA yields the highest speed of convergence towards equality of welfare indices, suggesting that it contains strong incentives for rational behavior and market valuation. As a final point, we observe that subjects are strongly motivated by the subjective private benefit from funding the public good (either due to warm-glow[5] or to the concern for being formally identified as a contributor of the public good).

The remainder of this paper proceeds as follows. Section 2 describes the experimental design. Section 3 presents results and the analysis of data with standard and novel statistical tools. Section 4 discusses the differences between auction mechanisms and their relations with existing work, and presents a new line of reasoning. We clarify the difference between public and private motivations for the public good funding in Section 5 and conclude with Section 6.

## 2. The experimental framework

We want to evaluate the impact of three incentive-compatible auction mechanisms in the measurement of WTP and WTA for a public good without close substitutes. Our experiments were conducted during three sessions at the École Polytechnique ParisTech. Different subjects took part in each of the three sessions (three auction mechanisms). A total of 102 participants were divided into three groups of subjects, which in turn were arbitrarily divided into two subgroups of buyers and sellers. Each subject received an identification number she filled in on each bid or offer, enabling her to be tracked whilst preserving her anonymity. The initial endowment distributed to the buyers was put forward to fund tree planting. Each buyer received EUR 15 and was asked to state her bid for a certificate of one ton of carbon offset (≤ EUR 15). If she won the bid, trees were planted in her name (this was acknowledged by a certificate which was publicly given to the buyer). Each seller was given a certificate of one ton of carbon offset she could either keep, in which case trees were planted in her name, or sell. If she decided to sell the certificate on the offer she stated (≤ EUR 15), no trees were planted. Subjects ignored that the cost of offsetting one ton of carbon in a five-year period was EUR 15, which enabled them to plant 36 trees[6].

[5] Utility derived from warm-glow (see Andreoni 1990) arises when the act of giving generates utility. It contrasts with the usual case in public economics where the individual only cares about the total amount of public good.

[6] Thus in accordance with the system of reference applied by the non-governmental organization.



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| **Market environment** | **BDM** | **SPA** | **NPA** |
|---|---|---|---|
| Auctioned goods | $CO_2$ offset certificate | $CO_2$ offset certificate | $CO_2$ offset certificate |
| Initial endowment | EUR 15 | EUR 15 | EUR 15 |
| Sellers' bound | EUR 15 | EUR 15 | EUR 15 |
| Number of trials | 10 | 10 | 10 |
| Retail price information | Not provided | Not provided | Not provided |
| Optimal responses explained | Suggested | Suggested | Suggested |
| Practice round performed | Pooled | Pooled | Pooled |
| Subject participation | Voluntary | Voluntary | Voluntary |
| Number of subjects | 37 | 34 | 31 |

The parameters of the experiments are the following: (*i*) 31 to 37 subjects participated per experiment; (*ii*) subjects were recruited among volunteering students from the École Polytechnique ParisTech[7]; (*iii*) the good put up for auctioning was a certificate of one ton of carbon offset; (*iv*) no information on the market-price of the good was provided; (*v*) buyers received an initial balance of EUR 15 and sellers a certificate of one ton of carbon offset as an endowment; (*vi*) in each trial, even though the seller's and the buyer's market sides were independent, bidders and offerers operated simultaneously; (*vii*) ten trials per experiment were unfolded, one of which was randomly selected as the binding trial; and (*viii*) BDM, SPA and NPA auction mechanisms were tested.

Our goal is to question the auction mechanisms' influence on the WTA/WTP gap, not to divulge the gap itself, for we consider it as an established fact. Thus, we decided to put an upper-bound on the sellers' choices in order to monitor which of the three market settings best responds to the early disparity. The bounds and endowments definitely create an anchoring effect, but there is no reason that it affects the three incentive-compatible mechanisms differently. Then, we publicly suggested to the subjects that revealing truthful preferences is a dominant strategy and that they cannot increase their utility payoff following a different strategy. At last, we pooled all performed rounds in the measurement of the gap.

[7] Multi-cultural elite students in science and engineering, who are considered in France as highly rational. They are salaried by the French Government. Their curriculum includes courses in economics.

*The Becker–DeGroot–Marschak mechanism*

Becker et al. (1964) introduce a mechanism under which buyers (sellers) simultaneously state the highest (lowest) amount they are willing to pay (accept) for the good. In our experiment, each buyer and seller was asked to give, for each of the ten trials, independently and privately, her WTP or WTA by marking an "x" on a recording sheet that listed price intervals, such as in the following table. The price intervals ranged from EUR 1–15, in increments of EUR 0.5. After collecting recording sheets from buyers and sellers, the monitor randomly selected one price from the list. If a buyer was willing to pay at least the random price for the certificate of one ton of carbon offset, she bought the item at that price. Otherwise, she did not buy the item. If a seller was willing to accept a price lower than or equal to the random price for the certificate of one ton of carbon offset, she sold the item at that price. Otherwise, she did not sell the item.

| | I will buy (sell) | I will not buy (sell) |
|---|---|---|
| If the price is EUR 0.0 | – | – |
| If the price is EUR 0.5 | – | – |
| If the price is EUR 1.0 | – | – |
| If the price is EUR 1.5 | – | – |
| … | … | … |
| If the price is EUR 14.0 | – | – |
| If the price is EUR 14.5 | – | – |
| If the price is EUR 15.0 | – | – |

The random price, all bids and offers, and the number of buyers and sellers willing to buy and sell at the random price were made public after each trial. At the end of the experiment, one of the trials was randomly selected as the binding trial for the take-home pay.

*The second-price auction mechanism*

Buyers were asked to record, for each of the ten trials, privately and independently, the price they were willing to pay for the certificate of one ton of carbon offset. In this case, buyers wrote simultaneously a numerical value on the recording sheet. The monitor collected values and, after each trial, made all bids public, as well as the identification number of the highest bidder, and the market-clearing price: the second highest bid. For each trial, sellers wrote simultaneously a selling price for the certificate. After each trial, the monitor publicly disclosed all offers, the identification number of the lowest offerer and the market-clearing price, the second lowest offer. As with BDM, after the tenth trial, the monitor randomly selected one of the trials as the binding trial for the take-home pay for both buyers and sellers.

*The random* n*th-price auction mechanism*

The random *n*th-price auction is conducted as follows: (*i*) for each trial, each bidder submits a bid or an offer on a recording sheet; (*ii*) all bids are ranked from lowest to highest, all offers are ranked from highest to lowest; (*iii*) the monitor selects a random number $n \in (2, N]$ with $N$ the number of bidders; (*iv*) the $n-1$ buyers who made the highest bids buy the certificate of one ton of carbon offset at the *n*th-price and the $n-1$ sellers who made the lowest offers sell the certificate of one ton of carbon offset at the *n*th-price. The value of *n*, all bids and offers, the buying and selling price, and the number of buyers and sellers willing to buy and sell at the random price, are made public after each trial. Once again, after the tenth trial, the monitor randomly selects one of the trials as the binding trial for the take-home pay for both buyers and sellers.

BDM, SPA and NPA are incentive-compatible. It is not in a buyer's interest to understate her WTP; if the random buying price falls between the stated WTP and the true WTP, the buyer foregoes a beneficial trade. It is neither in a buyer's interest to overstate her true WTP; if the random buying price is greater than the true value but less than the stated value, the buyer is required to buy the good at a price greater than her true WTP. The reasoning is identical for the seller. A complementary remark on NPA can be made. Contrary to SPA, subjects perceive that they still have a non negligible probability to win the auction, even after having observed that they are not making one of the most attractive bids or offers. Because of the randomness of *n*, off-margin bidders can be among the winners in NPA while they would be excluded from the active part of the market in SPA. As well, the endogenously determined market-clearing price (dependent on *n*) prevents bidders and offerers from using the random market-clearing price as an indicator.

## 3. Results and statistical analysis

Table 1 presents the summary statistics of the experimental results in BDM, SPA and NPA. In all experiments, the bidding behavior in the initial trial does not contradict the endowment effect: (WTA)[8] is significantly greater than (WTP).[9]

[8] The brackets signify mean value.
[9] This is also confirmed by the analysis of the medians.

Still, in BDM, (WTA) decreases and (WTP) increases[10] with subjects' experience gained through repetitive auctioning. The (WTA)/(WTP) ratios thus decline throughout the ten trials falling from 1.70 in trial 1 to 0.94 in trial 10 (Fig. 1), which corresponds to a (WTP) increase of 39% and a (WTA) decrease of 23%. Concerning variances, we notice that the dispersion around the mean increases for both WTP (42%) and WTA (245%) from trial 1 to trial 10. In trials 4–10, a *t*-test shows that we cannot reject the null hypothesis that (WTP) and (WTA) come from the same distribution at the $p < 0.05$ level. In BDM, the disparity fades away.

In NPA and SPA, the mean selling price exceeds the mean buying price for all ten trials. This also holds for the median bids. We observe similar starting and ending values of the welfare indices in both auction mechanisms. The (WTA)/(WTP) ratios remain above one, ranging from 1.35 to 2.71 in NPA, and from 1.28 to 3.07 in SPA (Fig. 1). Bids respectively increase by 69% and 90%; offers decrease by 13% in both experiments. The dispersion around (WTP) follows a different path in NPA and SPA. The dispersion around (WTA) amplifies in both auction mechanisms from trial 1 to trial 10 (NPA: 103%; SPA: 86%). On the contrary, the dispersion around (WTP) remains quasi-stationary in SPA (4%) but decreases in NPA (–21%), which suggests a degree of homogenization between the bids. In all trials, we reject the null hypothesis that (WTP) and (WTA) are equal at the 5% level of a *t*-test. However, we point out that ratios decrease over time, approaching the indices' equality in latter trials. Further, the hypothesis of the equality of means between SPA and NPA is verified in all ten rounds, given the *p*-value. These results are unsurprising in consideration of the likeness of the two auction mechanisms.

Let us now take a closer look at our results and those of the mug experiments from Shogren et al. (2001). At first sight, we obtain contradictory results. In our experiment, the gap disappears in BDM, whereas in theirs, BDM is the only mechanism unable to remove the early gap. Our findings show that repetitions in the BDM mechanism can remove the endowment effect, as long as it steers subjects' behavior. Likewise, they suggest that the auction mechanism *per se* can account for the conflicting observations, as we clearly observe different paths of equalization of (WTP) and (WTA). We introduce a new tool to study the path of the gap removal: the exponential regression on the (WTA)/(WTP) ratios.

[10] Though they never reach the outside market price, i.e. the upper bound of EUR 15, such as in Bohm et al. (1997).

**Table 1. Summary statistics of the BDM, SPA and NPA mechanisms**

| | Value measure | | Trials | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **BDM** | WTP | Mean | 6.18 | 7.11 | 7.82 | 8.11 | 8.29 | 8.66 | 8.39 | 8.71 | 8.82 | 8.61 |
| | N=19 | Median | 5.00 | 5.50 | 6.50 | 6.50 | 7.00 | 7.00 | 7.00 | 7.50 | 7.50 | 7.50 |
| | | Variance | 12.51 | 15.52 | 15.39 | 15.43 | 15.09 | 15.86 | 15.27 | 14.62 | 14.37 | 17.74 |
| | WTA | Mean | 10.53 | 9.47 | 9.56 | 8.42 | 8.92 | 8.69 | 9.53 | 9.19 | 8.67 | 8.06 |
| | N=18 | Median | 10.00 | 10.00 | 10.00 | 8.75 | 9.50 | 9.75 | 10.00 | 10.00 | 9.75 | 8.25 |
| | | Variance | 6.07 | 12.34 | 18.03 | 18.60 | 20.95 | 21.53 | 19.75 | 16.86 | 17.79 | 20.97 |
| | Mean WTA/WTP | | 1.70 | 1.33 | 1.22 | 1.04 | 1.08 | 1.00 | 1.13 | 1.06 | 0.98 | 0.94 |
| | *t*-test of means | | –3.85 | –1.46 | –0.83 | 0.27 | 0.06 | 0.46 | –0.39 | 0.09 | 0.58 | 0.91 |
| **SPA** | WTP | Mean | 3.47 | 3.91 | 4.69 | 5.43 | 5.68 | 5.71 | 6.01 | 6.50 | 5.46 | 6.59 |
| | N=17 | Median | 3.00 | 4.10 | 5.00 | 5.60 | 5.80 | 6.05 | 7.00 | 7.00 | 7.00 | 7.00 |
| | | Variance | 9.64 | 6.68 | 5.52 | 5.42 | 6.15 | 7.71 | 8.86 | 14.50 | 12.56 | 10.04 |
| | WTA | Mean | 10.66 | 8.74 | 8.47 | 9.07 | 8.59 | 9.82 | 9.40 | 8.32 | 9.52 | 9.23 |
| | N=17 | Median | 10.00 | 9.00 | 8.00 | 9.00 | 7.00 | 10.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| | | Variance | 16.60 | 19.56 | 14.03 | 22.27 | 20.72 | 29.45 | 29.44 | 32.86 | 26.44 | 30.86 |
| | Mean WTA/WTP | | 3.07 | 2.23 | 1.81 | 1.67 | 1.51 | 1.72 | 1.57 | 1.28 | 1.75 | 1.40 |
| | *t*-test of means | | –5.28 | –3.41 | –3.06 | –2.35 | –1.78 | –2.30 | –1.78 | –0.59 | –2.21 | –1.20 |
| **NPA** | WTP | Mean | 3.97 | 3.98 | 4.77 | 4.93 | 4.77 | 5.19 | 6.18 | 6.12 | 6.85 | 6.72 |
| | N=15 | Median | 2.50 | 4.00 | 5.00 | 5.12 | 5.14 | 5.01 | 7.00 | 6.50 | 7.00 | 7.26 |
| | | Variance | 12.67 | 6.92 | 4.83 | 4.30 | 5.40 | 6.33 | 5.81 | 6.54 | 7.77 | 10.03 |
| | WTA | Mean | 10.75 | 10.52 | 10.29 | 10.22 | 9.86 | 9.05 | 9.17 | 9.14 | 9.23 | 9.37 |
| | N=16 | Median | 10.50 | 10.00 | 9.74 | 9.65 | 8.77 | 8.50 | 8.49 | 8.35 | 8.09 | 8.50 |
| | | Variance | 10.19 | 6.99 | 6.32 | 9.46 | 10.31 | 13.75 | 16.67 | 13.30 | 14.08 | 20.64 |
| | Mean WTA/WTP | | 2.71 | 2.64 | 2.16 | 2.07 | 2.07 | 1.74 | 1.48 | 1.49 | 1.35 | 1.39 |
| | *t*-test of means | | –5.06 | –6.45 | –6.21 | –5.17 | –4.60 | –2.87 | –1.90 | –2.10 | –1.40 | –1.33 |

$H_0$: Mean WTP – Mean WTA = 0; $H_1$: Mean WTP – Mean WTA < 0 ; *t*-test: reject $H_0$ at the 5% level

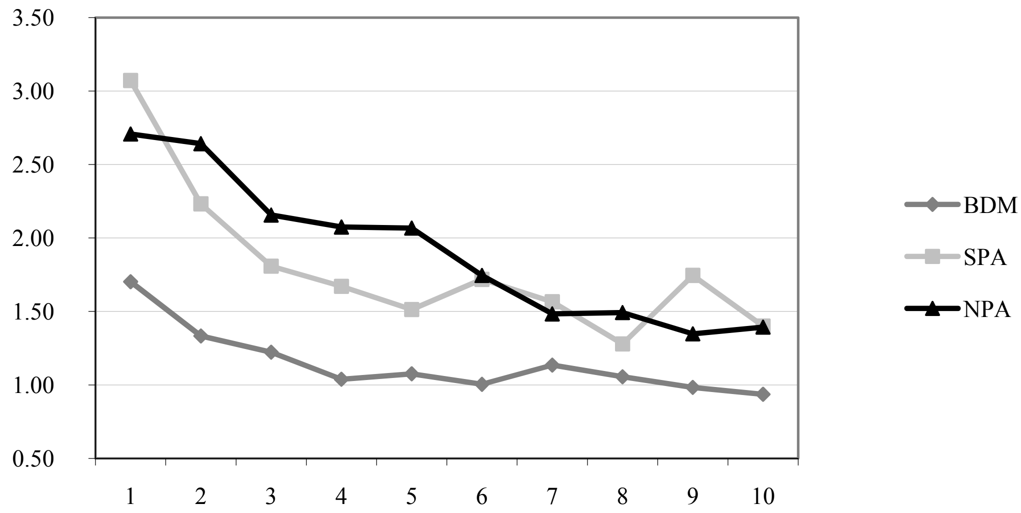


**Fig. 1. (WTA)/(WTP) disparity from trial 1 to trial 10**

An exponential regression is of a form

$$y = b e^{a x} . \tag{1}$$

with $x$ the variable along the $x$-axis, $y$ the regressed values of (WTA)/(WTP), $a$ the amplitude of the decrease (speed of convergence to equality) and $b$ the $y$-intercept of regression. The function is based on a linear regression, with the $y$-axis logarithmically scaled. $R$-square gives information on the extent of the exponential relationship between ratios. We apply this method both to the certificate (Fig. 2) and mug (Fig. 3) experiments.

The exponential regression is used for two reasons: first, it allows observing phenomena with rapid variations which we observe in both experimental series; second, it allows observing the decreasing ratio up to equality. We try to reveal the mechanism that is the source of a quick decrease, independently of the initial ratio. We can thus consider the fastest decreasing coefficient as the highest speed of convergence to the equality of welfare indices (Table 2).

Our data from BDM provide an exponentially decreasing relationship between the sequential ratios, whereas the data used by Shogren et al. (2001) do not. Although the $y$-intercept of the regression starts with the same value (both $a = 1.5$ ), the gap disappears in our experiment (the speed of convergence amounts to $a = -0.04$) but stays stationary in the mug experiment (no acceleration to convergence).

We find in both experiments that NPA provides the best exponential relationship between ratios ($R^2 = 0.95; R^2 = 0.96$) and the highest speed of convergence ($a = -0.08$; $a = -0.12$) towards equality in time. In SPA, the exponential relationship between ratios ($R^2 = 0.61; R^2 = 0.63$) and the speed of convergence to equality of indices ($a = -0.06$; $a = -0.09$) are significant but lower.

**Table 2. Exponential regression statistics**

| Auction | Regression statistics | Our experiments | Mug experiments by Shogren *et al.* |
|---|---|---|---|
| BDM | Speed of convergence (*a*) | –0.04 | –0.00 |
| | *y*-intercept of regression (*b*) | 1.5 | 1.5 |
| | *R*-square | 0.69 | 0.00 |
| SPA | Speed of convergence (*a*) | –0.06 | –0.09 |
| | *y*-intercept of regression (*b*) | 2.5 | 1.9 |
| | *R*-square | 0.61 | 0.63 |
| NPA | Speed of convergence (*a*) | –0.08 | –0.12 |
| | *y*-intercept of regression (*b*) | 2.9 | 2.8 |
| | *R*-square | 0.95 | 0.96 |

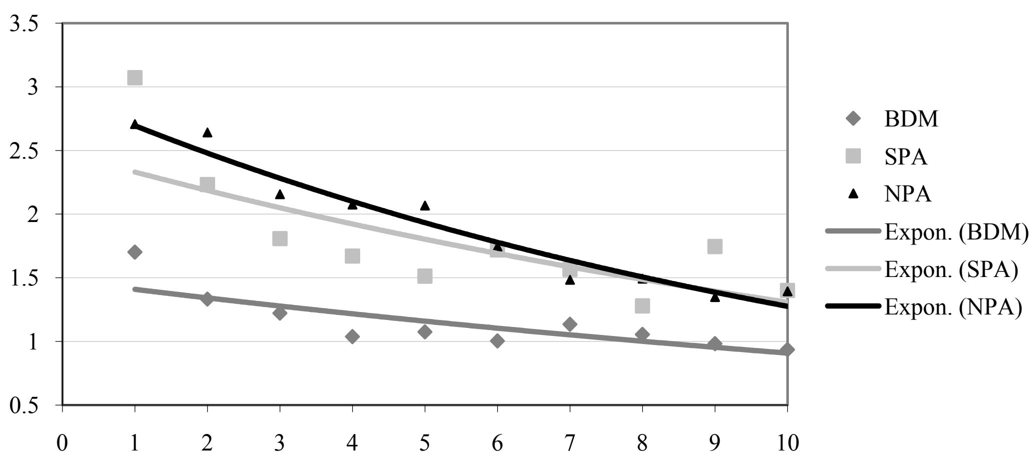


**Fig. 2. Exponential regression of (WTA)/(WTP) disparity**

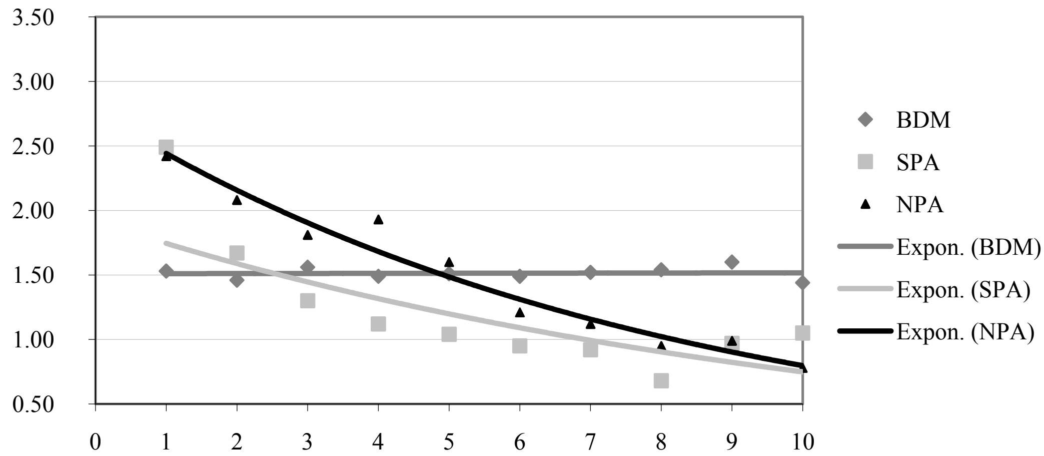


**Fig. 3. Exponential regression of (WTA)/(WTP) disparity from mug experiments by Shogren et al. (2001)**

Sudden leaps of increase of the (WTA)/(WTP) ratio in SPA – believed to be due to off-margin bidders – explain the differences in $R^2$ in comparison with NPA. It is also worthwhile noticing that SPA comes out as the "worst" active market mechanism even though it is frequently used in experiments to reveal agents' preferences. In BDM, our experiment and the mug experiment both obtain the lowest results in terms of exponential relationship[11] and speed of convergence towards equality. Therefore, the orderings of convergence rates in our experiments and those of Shogren et al. (2001) are alike.

We then study the convergent sequence of fitted values (Table 3) to test the consistency of our previous results. A sequence converges at rate $\mu$ with order $q$ such that

$$\lim_{t\to\infty} \frac{|[(\mathrm{WTA})/(\mathrm{WTP})]_{t+1} - 1|}{|[(\mathrm{WTA})/(\mathrm{WTP})]_t - 1|^q} = \mu . \qquad (2)$$

The parameter $q$ represents the acceleration rate, that is, the impulse to the welfare indices' equality. Provided that our time length is short ($t < \infty$), $q$ embodies the true convergence speed and thus the robustness control parameter. By rewriting $\mu$, we can bring out the acceleration rate in form of

[11] The low exponential factor with the BDM is partially explained by the initial smaller difference between WTP and WTA.

$$q = \frac{\ln[|[(\mathrm{WTA})/(\mathrm{WTP})]_{t+1} - 1|]}{\ln[\mu|[(\mathrm{WTA})/(\mathrm{WTP})]_{t} - 1|]}. \quad (3)$$

The rates of convergence, seen from the perspective of a sequence approaching its limit, are in the same order of magnitudes as those previously obtained (NPA > SPA > BDM). The only difference hails from the mug experiments where the acceleration rate is marginally higher in SPA ($q = 1.31$) than NPA ($q = 1.28$). Both the convergence and acceleration rates confirm that our comparative rates are robust.

**Table 3. Sequence convergence**

| Auction | Convergence parameters | Our experiments | Mug experiments by Shogren et al. |
|---|---|---|---|
| BDM | Convergence rate ($\mu$) | 0.69 | 0.99 |
| | Acceleration rate ($q$) | 0.99 | 0.99 |
| SPA | Convergence rate ($\mu$) | 0.87 | 1.49 |
| | Acceleration rate ($q$) | 1.05 | 1.31 |
| NPA | Convergence rate ($\mu$) | 0.83 | 0.95 |
| | Acceleration rate ($q$) | 1.10 | 1.28 |

## 4. Discussion on the differences between mechanisms

Our experimental results enable us to derive recommendations regarding the choice of the auction mechanism in the context of public good funding. If the initial gap between WTP and WTA is due to the choice of the market mechanism, then the choice of BDM is appropriate, for it produces the smallest initial gap. However, if the auction mechanism is needed to rapidly deflate an excessive initial (WTA)/(WTP) gap in a market setting, we suggest the use of NPA.

Now, the differences observed between auction mechanisms require further attention. Let us consider two possible explanations for our results: disappointment aversion and affiliation. Horowitz (2006*b*) relates that in BDM a bidder may report a higher value than the true one, simply because she is more disappointed from not receiving the good than from receiving it at a higher price, which induces her to increase the chance of winning the auction and to report an overpriced bid. This argument could explain the high (WTP) observed in BDM. However, it also applies to SPA and NPA, so disappointment aversion cannot explain the difference between BDM and SPA/NPA. Following Milgrom and Weber (1982), we may also consider that common uncertainty about the value of a good creates affiliation between private values, especially in case of unfamiliar goods. However, it is not clear how affiliation could explain the gaps. Besides, the increasing variances of WTP and WTA in time contradict this interpretation. If values were affiliated and information across rounds was gathered, these variances should decrease.

As a result, we focus on the features of auction mechanisms, particularly those of BDM. As compared to SPA and NPA, two major elements are specific to BDM: (1) individual bids do not affect market-clearing prices, which are determined by an external random process; (2) the bidder's outcome is not affected by others' bids. The mechanism works as if each bidder were bidding against an apparatus which randomly draws a market price. The first element could explain why, even during the early rounds, the difference between (WTP) and (WTA) is lower with BDM. Indeed, in this quasi-market mechanism, it appears useless to submit a higher (lower) bid (offer) than the true one. The clearing price being exogenous, subjects can understand that their personal acceptability of prices is what matters most. In some sense, it is easier for a subject to learn how BDM works and to assimilate that submitting her true value is best. With SPA or NPA, it is less straightforward to understand that the price she pays does not depend on her bid; understanding these auction mechanisms is less obvious. Moreover, real-life buyers are used to thinking that lowering the value of a good is profitable[12]. The second element may explain why the convergence process is slower with the BDM mechanism. The outcome being independent from other bidders' or offerers' strategies, subjects have less incentive to pay attention to what others bid or offer and to react to their moves. This induces a delay in the convergence of indices.

Finally, SPA and NPA are very similar. This similarity could explain the resemblance between behaviors observed in both mechanisms. Yet, in SPA, after the practice rounds, the bidder or offerer can observe whether she is an off-margin bidder or offerer and thus unlikely to win the auction. If that is the case, she has no incentive to fully revise her bids or offers. Given the randomness of the number of winning trades in NPA, this argument does not hold, and this surely induces a more rapid convergence of indices. With regard to this difference between SPA and NPA, we should have expected even larger differences in experimental data. Unexpectedly, a high number of subjects did revise their valuations in SPA, even when they were extremely unlikely to be the part of the winning trades.

[12] Aside from online auctioneers, subjects are more often buyers than sellers in real life. We know that the gap is due to a low WTP the valuation of which is certainly more affected by life habits than the WTA valuation.

## 5. Public and private motivations in the public good funding

Some points regarding the specificity of the pure public good also need to be clarified. Let us first focus on this aspect relative to the auction mechanism. In SPA and NPA, the number of traded tons of carbon offset in a period is independent of the bids and offers submitted by the subjects. In any case, in SPA, one ton of carbon offset is bought and sold; in NPA, $n-1$ tons of carbon offsets are traded. As a result, in these mechanisms, an extreme form of free-riding is likely to occur, since a subject's bid cannot affect the total public good provision while it affects her payment: buying a certificate has a cost. On the contrary, in the BDM mechanism, subjects' choices can affect the total provision of the public good. If a seller chooses a minimum selling price higher than the randomly selected price, she will keep her certificate and one more ton of carbon will be offset. The same reasoning applies for buyers. Put differently, subjects know they can influence the amount of carbon offset in BDM, because their probability of winning the right to buy one certificate is independent of other bidders: the higher the private bid, the higher the chances that a ton of carbon is offset. It is the only auction mechanism in which the level of the public good can be determined by the subjects.

This difference between BDM on the one side and SPA and NPA on the other side allows identifying two distinct motivations in the public good funding. First, there is the (selfless) public good motivation to fund the public good, which translates the motivation to buy or keep a certificate for the sake of all. Second, there is the (self-interested) private good motivation of the public good funding, which translates the motivation to buy or keep a certificate because the subject wants to own a certificate and be associated to the offsetting even though it does not modify the number of tons of carbon offset; through the private public good funding, she wants to derive a significant private utility from warm-glow, social status or guilt alleviation, etc.

Despite the free-rider incentive, individuals often provide more public goods than traditional economic theory predicts. Public goods are then considered as impure public goods, which are products or services that combine both public and private benefits from the public good. Thus, from the funding perspective, our good becomes an impure public good.

In BDM, both motivations for funding the public good are present, whereas in SPA and NPA, only the private good motivation exists, since subjects cannot affect the total provision of the public good. Now, let us consider $\overline{g}$, the mean value of all bids (WTP) and offers (WTA). After its computation over the ten rounds, we observe that $\overline{g}$ is strictly higher with BDM (8.57) than with SPA (7.26) or NPA (7.63). If we take the BDM value of $\overline{g}$ as a benchmark value of the public good, we can reasonably consider its surplus against SPA and NPA to reveal the value of the public good motivation. The surplus lies in the interval [0.94, 1.31]. The interval indicates that the private good motivation highly exceeds the public good motivation, *i.e.* subjects are mainly paying for enjoying warm-glow, being identified as contributors of the carbon offsetting or to alleviate their feelings of guilt. These results are consistent with the microeconomic analysis, where the private benefit governs the decisions of rational economic agents.

Contrary to the observations where repeat-play public goods games produce declining contributions over time (Andreoni 1988), $\bar{g}$ increases in our experiments. As a matter of fact, if we regress $\bar{g}$ over the number of periods, we obtain a small but strictly positive correlation coefficient (BDM: 0.18; SPA: 0.13; NPA: 0.15). In standard public goods games, the diminution is motivated by free-riding and discouragement of high-type players to alone pursue the provision of the public good. We propose two explanations for the increase we observe. First, the funded public good does not only concern the subjects that take part in the experiment but also the population "outside." Therefore, the free-riding attitude of some subjects cannot completely alter other subjects' motivations since they do not specifically contribute for these free-riders, whereas they do in regular public goods games. Second, as already mentioned, the private good motivation outperforms the public good motivation, which also explains the absence of the usual decline in subjects' bids.[13] Nevertheless, these findings do not challenge the difference in experimentation on mugs and certificates. Even if our experiments gave novel prominence to the private good motivation in the public good funding, subjects always traded goods with the attribute of a pure public good.

## 6. Concluding remarks

We examined three market mechanisms that could rectify the initial gap between WTP and WTA in the valuation of a public good. From simple observations of the (WTA)/(WTP) disparities, we observe different results from Shogren et al. (2001). We can either conclude that their findings – which suggest the validity of SPA and NPA in valuing private goods – are local, or that the public goods are subject to a different bidding behavior.

We think that in quasi-market settings such as the BDM mechanism, subjects understood that they could decide on the aggregate level of the public good and behaved accordingly. In active markets with endogenous market-clearing prices such as NPA, no subject could influence the level of the public good. This acted as a disincentive to bid higher for the public good. In standard

[13] One could argue that bids increased because of the *house money effect*. However, Clark (2002) finds no evidence of it in a public good experiment.

public goods games, it would have augmented its provision. Despite the fact that only BDM fully revealed the public good market value, our results show that the (WTA)/(WTP) disparity dropped with repetition in all three mechanisms, signifying that the economic theory of rationality within maturing markets operates. These results match those of Brookshire and Coursey (1987) who conclude that the market-like elicitation makes values for the public good more consistent with traditional economic notions. And yet, the theory implies a perfect equality between WTP and WTA, which seems not to be guaranteed without exception when funding a public good[14], i.e. (WTA)/(WTP) $\geq 1$.

We suggest that more experimental research on private and public values of a public good be conducted. For example, we could more accurately identify the private good and public good motivations by explicitly insisting on the fact that bids cannot affect the size of the public goods in SPA and NPA. As well, we could conduct experiments where subjects would be purposely deprived of any proof of having financed the public good and where each subject could only observe her final outcome; that way, we could distinguish between the desire to finance the public good and the desire to be identified by others as a generous contributor to the public good.

In terms of public policy, we can ascertain that the main advantage of auction mechanisms when valuing a public good is that they reveal the economic value of public good and whether subjects derive any public good motivation from the funding. If they do, they submit superior bids and offers with BDM than with NPA. If not, which then suggests equal bids and offers between BDM and NPA, the public good does not have a clear public good motivation. In the first case, market settings make it possible for the public authority willing to financially support the public good production to estimate the optimal level of taxation from the market value. In the latter case, the public authority is made aware of the undervaluation of the public good’s usefulness and the overvaluation of the private utility derived by the subjects. It should subsequently credit individuals to fund the public good themselves. We actually observe such a policy for various public goods associated with a high level of social prestige or recognition, that is, public goods whose funding contains a high private good component. At a higher level, the lack of public recognition of the firms’ private efforts could explain why voluntary environmental agreements between public authority and industries have failed (see OECD 2003).

[14] A natural explanation could lie in the lack of direct substitutes to the carbon offset market, that is, the substitution effect.

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## Appendix

### GENERAL INSTRUCTIONS (translated from French)

You are about to participate in an experiment about decision making. You are not allowed to speak to your neighbors during the experiment.

All human activities release greenhouse gases, including $CO_2$, that provoke global warming. This warming endangers the planet, its inhabitants, its ecosystems and biodiversity. One way to fight against global warming is to plant trees. The key elements are the following: the forested surfaces are a carbon trap; young forests store much more carbon than old forests, for trees absorb $CO_2$ as they grow; forests preserve plant and animal biodiversity.

An NGO has launched a project of carbon offsetting by funding reforestation projects. The purpose is to offset carbon emissions by buying off your own emissions. The compensation is acknowledged by a certificate of one ton of carbon offset.

During your education at the École Polytechnique ParisTech, you have received and printed, and will certainly do it again in the future, number of documents required for your schoolwork; it is also the case with your consumption of energy (such as light, heating, power supply for computers, etc.). Because you are contributing to the emissions through your consumption of paper and energy *via* your indirect demand for their manufacturing and distribution, we want to value your willingness to buy off your $CO_2$ emissions.

To this end, we will use a mechanism of purchasing and selling certificates of one ton of $CO_2$ offset, such as the ones we currently hold in our hands.

In couple of weeks, we will get in touch with you by email to inform you about the number of offset tons of $CO_2$ according to your decisions.

We will now conduct an experiment. As you came into the class, some of you were designated as sellers while others were designated as buyers. Indeed, each of you randomly drew a number which decided between buyer and seller. Please keep this number until the end of the experiment: it will serve us to track you on the information cards. In the end of the experiment, during the imbursement, please give us back your numbers.

Only one trial will be binding. We will repeat the experiment ten times. After the tenth trial, the youngest person in the room will randomly draw a number between 1 and 10, which will designate the binding trial.

Please feel free to nterrupt us and ask any question you might have in mind.

Without further delay, we are going to read you the instructions concerning the conduct of the experiment. Let us start with those of you who are buyers.



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**BDM MECHANISM**

**Buyers**

You own EUR 15. You can now participate in an auction in order to buy a certificate of one ton of $CO_2$ offset. If that is your wish, please submit a bid. The bid you submit can range between EUR 0 and EUR 15. If you decide to buy the certificate, trees which are planted on your behalf (acknowledged by your name on the certificate) will compensate one ton of $CO_2$.

**To submit a bid, please fill in the following table and mark an "x" for each price at which you are (and are not) willing to buy the certificate.**

Rules: your maximum bid is ranked among all bids. Bids are classified in ascending order. We randomly select one price from the price list, which becomes the displayed price. You buy a certificate if your bid is higher than or equal to the displayed price.

Example: We randomly draw EUR 6. Since your bid is higher than or equal to EUR 6, you buy the certificate and pay EUR 6.

| | I will buy | I will not buy |
|---|---|---|
| If the price is EUR 0 | x | |
| If the price is EUR 0.5 | x | |
| If the price is EUR 1.0 | x | |
| … | … | |
| If the price is EUR 8.5 | x | |
| If the price is EUR 9 | x | |
| If the price is EUR 9.5 | | x |
| … | | … |
| If the price is EUR 14.0 | | x |
| If the price is EUR 14.5 | | x |
| If the price is EUR 15.0 | | x |

*Nota bene*: the higher your bid, the higher your chances of buying the certificate. Since you ignore the displayed price *ex ante*, giving your own value of one ton of $CO_2$ offset enables you to buy the certificate if your value is higher than the displayed price, and prevents you from buying otherwise.

**Sellers**

You own a certificate of one ton of $CO_2$ offset. You can now participate in an auction in order to sell your certificate. If that is your wish, please submit an offer. The offer you submit can range between EUR 0 and EUR 15. If you decide to sell the certificate with your name on, no ton of $CO_2$ will be offset.

**To submit an offer, please fill in the following table and mark an "x" for each price at which you are (and are not) willing to sell the certificate.**

Rules: your minimum offer is ranked among all offers. Offers are ranked in descending order. We randomly select one price from the price list, which becomes the displayed price. You sell a certificate if your offer is lower than or equal to the displayed price.

Example: We randomly draw EUR 10. Since your offer is lower than or equal to EUR 10, you sell the certificate and earn EUR 10.

| | I will sell | I will not sell |
|---|---|---|
| If the price is EUR 15.0 | x | |
| If the price is EUR 14.5 | x | |
| If the price is EUR 14.0 | x | |
| … | … | |
| If the price is EUR 5.0 | x | |
| If the price is EUR 4.5 | x | |
| If the price is EUR 4.0 | | x |
| … | | … |
| If the price is EUR 1.0 | | x |
| If the price is EUR 0.5 | | x |
| If the price is EUR 0.0 | | x |

*Nota bene*: the lower your offer, the higher your chances of selling the certificate. Since you ignore the displayed price *ex ante*, giving your own value of one ton of $CO_2$ offset enables you to sell the certificate if the displayed price is higher than your value, and prevents you from selling otherwise.



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**RANDOM *N*TH-PRICE AUCTION**

**Buyers**

You own EUR 15. You can now participate in an auction in order to buy a certificate of one ton of $CO_2$ offset. If that is your wish, please submit a bid. The bid you submit can range between EUR 0 and EUR 15. If you decide to buy the certificate, trees which are planted on your behalf (acknowledged by your name on the certificate) will compensate one ton of $CO_2$.

**To submit a bid, please specify on the information card the price at which you are willing to buy the certificate.**

Rules: your bid is ranked among all bids. Bids are classified in ascending order. We randomly select a number between 2 and $n$ ($n$ being the total number of bids). In other words, we randomly draw one of the bids and look at its rank. If your bid is contained in $n$–1 highest bids, you buy a certificate at the displayed price: the $n$th price.

Example: twenty bids are submitted. We randomly draw seven, that is, the seventh-highest bid in the increasing order. You buy a certificate at a displayed price (seventh-highest bid) if your bid is contained in the six highest bids.

*Nota bene*: the higher your bid, the higher your chances of buying the certificate. If your bid is randomly drawn, your bid becomes the displayed price imposed to the $n$–1 highest bidders. Since you ignore the displayed price *ex ante*, giving your own value of one ton of $CO_2$ offset enables you to buy the certificate if your value is higher than the displayed price, and prevents you from buying otherwise.

**Sellers**

You own a certificate of one ton of $CO_2$ offset. You can now participate in an auction in order to sell your certificate. If that is your wish, please submit an offer. The offer you submit can range between EUR 0 and EUR 15. If you decide to sell the certificate with your name on, no ton of $CO_2$ will be offset.

**To submit an offer, please specify on the information card the price at which you are willing to sell the certificate.**

Rules: your offer is ranked among all offers. Offers are ranked in descending order. We randomly select a number between 2 and $n$ ($n$ being the total number of offers). In other words, we randomly draw one of the offers and look at its rank. If your offer is contained in $n$–1 lowest offers, you sell a certificate at the displayed price: the $n$th price.

Example: twenty offers are submitted. We randomly draw six, that is, the sixth-lowest offer in the decreasing order. You sell your certificate at a displayed price (sixth-lowest offer) if your offer is contained in the five lowest offers.

*Nota bene*: the lower your offer, the higher your chances of selling the certificate. If your offer is randomly drawn, your offer becomes the displayed price imposed to the $n$–1 lowest offers. Since you ignore the displayed price *ex ante*, giving your own value of one ton of $CO_2$ offset enables you to sell the certificate if the price is higher than your value, and prevents you from selling otherwise.

**SECOND-PRICE AUCTION**

**Buyers**

You own EUR 15. You can now participate in an auction in order to buy a certificate of one ton of $CO_2$ offset. If that is your wish, please submit a bid. The bid you submit can range between EUR 0 and EUR 15. If you decide to buy the certificate, trees which are planted on your behalf (acknowledged by your name on the certificate) will compensate one ton of $CO_2$.

**To submit a bid, please specify on the information card the price at which you are willing to buy the certificate.**

Rules: your bid is ranked among all bids. Bids are classified in ascending order. If your bid is the highest, you buy a certificate at a displayed price: the second-highest bid.

Example: ten bids are submitted. The highest bid is EUR 13. The second highest bid is EUR 11. The bidder who proposed EUR 13 buys the certificate and pays EUR 11.

*Nota bene*: the higher your bid, the higher your chances of buying the certificate. Since you ignore the displayed price *ex ante*, giving your own value of one ton of $CO_2$ offset enables you to buy the certificate if your value is higher than the displayed price, and prevents you from buying otherwise.



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**Sellers**

You own a certificate of one ton of $CO_2$ offset. You can now participate in an auction in order to sell your certificate. If that is your wish, please submit an offer. The offer you submit can range between EUR 0 and EUR 15. If you decide to sell the certificate with your name on, no ton of $CO_2$ will be offset.

**To submit an offer, please specify on the information card the price at which you are willing to sell the certificate.**

Rules: your offer is ranked among all offers. Offers are ranked in descending order. If your offer is the lowest, you sell a certificate at a displayed price: the second-lowest offer.

Example: ten offers are submitted. The lowest offer is EUR 5. The second lowest offer is EUR 7. The seller who proposes EUR 5 sells her certificate and earns EUR 7.

*Nota bene*: the lower your offer, the higher your chances of selling the certificate. Since you ignore the displayed price ex ante, giving your own value of one ton of CO2 offset enables you to sell the certificate if the displayed price is higher than your value, and prevents you from selling otherwise.

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