Public Goods Referenda without Perfectly Correlated Prices and Quantities

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Short Abstract:
This paper examines the incentive properties of probabilistic referenda. In contrast to earlier research in which prices and quantities are perfectly correlated, we consider uncertain and potentially different outcomes for prices and quantities. We provide a theoretical analysis on incentive compatibility and an induced-value experimental test of this theory to gain new insights. First, our results using a standard design confirm previous findings. Second, our results suggest that moving away from a perfectly correlated design undermines the incentive compatibility result found in other studies. Third, our experimental results are consistent with choices made by risk-averse agents in our theoretical analysis. Our findings would be important for survey design in practice as well as theoretical aspect of CV referenda.

Abbreviations used in this paper: CV, contingent valuation; PR, probabilistic referenda; TOPR, two outcome probabilistic referenda; FOPR, four outcome probabilistic referenda.

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Abstract:

Recent experimental economic studies of the validity of dichotomous choice contingent valuation (CV) indicate that consequentiality of a referendum vote is an important element for making the CV referendum incentive compatible. In these previous studies, possible economic outcomes of a referendum are limited to only two outcomes: (1) the referendum is binding and therefore the good is provided and the payment is collected or (2) the referendum is not binding and neither is the good provided nor is the payment collected. In these experiments, provision and payment are perfectly correlated when there is uncertainty over whether the referendum is binding. While studies to date provide important insights into CV referenda, a fundamentally important feature of CV referenda is overlooked. In instances where we typically need to apply CV referenda, prices (amount paid) and quantities (provision of the good) are rarely, if ever, perfectly correlated. Our research relaxes this assumption in an induced-value experimental setting as well as theoretical analysis and we gain new insights that are contrary to results from studies that utilize a perfectly correlated design. First, we explore the incentive properties of probabilistic referenda with and without a perfectly correlated design. Then, we provide an induced-value experimental test of our theoretical predictions. The results suggest that moving away from perfectly correlated prices and quantities undermines the incentive compatibility result found in other studies. The experimental results are consistent with choices made by risk-averse agents in our theoretical analysis. Our results in standard perfectly correlated induced-value experiments confirm previous findings of probabilistic referenda. Our results also suggest that a negative hypothetical bias possibly occurs even in consequential probabilistic referenda if there are four possible outcomes in respondents' cognitive processes and respondents have concave utility functions, implying that dichotomous choice CV possibly underestimates true values.

Keywords:

probabilistic referenda, incentive compatibility, hypothetical bias, contingent valuation, induced-values

JEL Codes:

C91 (laboratory, individual behavior), H41 (public goods), Q51 (valuation of environmental effects)

1. Introduction

Recent experimental economic studies of the validity of dichotomous choice contingent valuation (CV) indicate that consequentiality of a referendum vote is an important element for making the CV referendum be incentive compatible. Carson and Groves (2007) provide theoretical arguments that a single, binary CV referendum would be incentive compatible if the probability that the referendum vote is binding is positive, that is the referendum is consequential. Carson et al. (2004) and Vossler and Evans (2008) provide related experimental evidence. In these previous studies, possible economic outcomes of a referendum are limited to only two outcomes: (1) the referendum is binding and therefore the good is provided and the payment is collected or (2) the referendum is not binding and neither the good is provided nor is the payment collected. In these experiments, provision and payment are perfectly correlated when there is uncertainty over whether the referendum is binding. While studies to date provide important insights into CV referenda, a fundamentally important feature of CV referenda is overlooked. In instances where we typically need to apply CV referenda, prices (amount paid) and quantities (provision of the good) are rarely, if ever, perfectly correlated. Our research relaxes this assumption in both the theoretical framework and the induced-value experimental setting. Consequently, we gain new insights that are contrary to results from studies that utilize a perfectly correlated design.

As noted earlier, a perfectly correlated design results in two outcomes. However, in real world applications one could also imagine outcomes involving relatively low or high provision of the public good coupled with relatively high or low realized costs. There could be uncertainty over the cost of public projects. For example, consider the cost uncertainty over construction of public buildings like a library or stadium. The costs would depend on oil prices, concrete prices, and so on. In fact, these prices are likely to be variable and uncertain. Likewise, there could be uncertainty over the supply of public projects. For example, consider the supply uncertainty over ecosystem restoration projects. Ecosystem restoration outcomes are often uncertain and indeed, there exist major project failures.

A large body of literature discusses the theoretical consequences of the cost and supply uncertainty as well as empirical evidence in respondents' subjective beliefs about uncertainty over the payment and provision. Recently, Flores and Strong (2007) investigate cost uncertainty by using a simple theoretical model of stated preference responses, while Shafran (2007) theoretically discusses supply-side uncertainty. Empirical evidence from a multiple bounded uncertainty choice study by Cameron et al. (2002) suggests that respondents can have a subjective degree of uncertainty that they would actually pay for the good. In a similar way, Herriges et al. (2007) indicate that respondents can have subjective beliefs about uncertainty of consequentiality that the project will be actually provided. These theoretical suggestions and empirical evidence indicate that respondents to CV referenda might form potentially different subjective beliefs about payment and provision uncertainty. These two subjective beliefs about payment and provision could be independently distributed, since they could respectively vary with the institution that is responsible for providing the good (e.g. government or research institute), the probabilistic nature of specific projects (e.g. construction of buildings or ecosystem restorations) or the good to be valued (e.g. public or private). Now, we can cite two extreme cases from Hoehn and Randall (1987): a case like an opinion survey in which no payment would ever be required but the project will be provided depending on the responses,[1]

[1] In fact, a number of public projects in developing countries have been provided by third parties, like the World Bank or UNDP.

and a case in which respondents distrust government by assuming payment will be required but the project will be provided without regard to the responses.[2] To capture this in a probabilistic referendum framework, we provide a known probability of provision and a known and separate probability of payment. While the random variables public good (Provide or No provide) and payment (Pay or No pay) are independent in our design, they are not perfectly correlated. That is we allow for outcomes where the good is provided at no cost or the good is not provided but subjects still pay. This expands the outcome space from ({Provide, Pay} {No provide, No pay}) to ({Provide, Pay}, {No provide, No pay}, {Provide, No pay}, {No provide, Pay}). For the purposes of comparison, we also consider the perfectly correlated design.

In this paper, first, we theoretically examine the incentive properties of probabilistic referenda with and without a perfectly correlated design. Then, we provide an induced value experimental test of our theoretical predictions. Our results in standard perfectly correlated induced value experiments confirm previous findings of probabilistic referenda. Our results suggest that moving away from perfectly correlated prices and quantities undermines the incentive compatibility result found in other studies. In our induced value experimental design, 60% of respondents should vote yes in this one shot referendum. For probabilities 0.25 or greater we see this for the perfectly correlated design, but not for our alternative design. Our experimental results are consistent with choices made by risk-averse agents in our theoretical analysis.

The remainder of the paper is as follows: The next section presents our theoretical model and

[2] Also, this outcome would be likely to occur in projects with supply uncertainty like ecosystem restoration and global warming mitigation.

leads to its predictions on which our analysis is based. Section 3 provides the experimental design. We show the experimental results and econometric analysis of the data in section 4, followed by conclusions in section 5.

2. Theoretical Framework

In this paper, we explore the incentive properties of probabilistic referenda, where probabilities of the referendum being binding range from zero to one, without perfectly correlated prices and quantities in which there exist four potential outcomes. For the purposes of comparison, we also consider the perfectly correlated two outcome probabilistic referenda. In this section, we begin with definitions of probabilistic referenda and the expected utility of voting. Next, we define the incentive compatibility of probabilistic referenda voting mechanisms. By exploring the incentive compatibility, we develop our model and arrive at theoretical predictions of treatment effects in our experiment.

2.1. Setup

Let b be the cost or bids subjects pay and let v_i be subject i's induced value ($v_i > 0$).[3] [4] In a binding binary referendum with a majority vote implementation rule, if more than 50% of subjects vote yes on the proposition "contribute \$$b$ to receive \$$v_i$," then the referendum has *passed* and therefore the payment is collected (Pay) and the good is provided (Pro). If not, the referendum has *failed* and neither the payment is collected (No Pay) nor is the good provided

[3] If we assume that subject i has a *linear* form indirect utility function, the induced value v_i represents subject i's Hicksian compensating surplus (variation) for the project.

[4] We assume that there is no preference uncertainty in the sense that all subjects know their own values of the project when it is provided. We should note that we consider provision uncertainty as an independent issue from the preference uncertainty.

(No Pro). We can denote the outcome space of the referendum as Ω_R = {Pass, Fail} = {(Pro, Pay), (No Pro, No Pay)}.

Now, let us consider a probabilistic referendum (PR) with a majority vote implementation rule. The PR will be implemented by the "Two-step Referendum Rules[5]," where, Step 1: If more than 50% of subjects vote YES on the proposition "contribute \$$b$ to receive \$$v_i$," then the referendum has PASSED. If not, the referendum has FAILED. Step 2: Given the referendum passes (more than 50% of subjects vote yes), an outcome j, which results in monetary payoff π_j, occurs with probability p_j. Where, p_j denotes a probability that an outcome j occurs in PR and π_j denotes a monetary payoff when an outcome j occurs. For the purpose of simplicity, we omit subscript j here then p is interpreted as a probability that the referendum is binding ($0 \leq p \leq 1$). Likewise, $(1 - p)$ is the probability that the referendum is not binding.

By identifying the outcome space and subject's payoff in each referendum, we define the perfectly correlated two outcome probabilistic referenda (TOPR) and the not perfectly correlated four outcome probabilistic referenda (FOPR). In Step 1 of PR, if the referendum fails, then the outcome and subject's payoff are the same as those in binding binary referenda. That is, the outcome given the referendum fails is that neither the good is provided nor is the payment collected: (No Pro, No Pay). Now, let y denote income or initial endowment ($y > b$).[6] Then, all subjects receive their initial endowment y. On the other hand, if the referendum

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[5] Cumming and Taylor (1998) and Carson et al. (2004) also identify PR as the two step rules.

[6] Though we assume homogeneous income distributions (y) and homogeneous costs (b) for all subjects, these assumptions are not essential and our results regarding the incentive properties do not change.

passes in Step 1, there is a probabilistic nature with respect to payment and provision in Step 2 of the PR. The TOPR that all previous studies have employed has two possible outcomes: (1) the referendum is binding, which occurs with probability p, and therefore the good is provided and the payment is collected or (2) the referendum is not binding, which occurs with probability $(1 - p)$, and neither the good is provided nor is the payment collected. The probabilistic outcomes in Step 2 of the TOPR are given by $j \in \Omega_{\text{TOPR|Pass}}$ = {(Pro, Pay), (No Pro, No Pay)}. Table 1 shows a payoff matrix for Step 2 of the TOPR.

Table 1: Payoff Matrix for the Two Outcome Probabilistic Referenda

TOPR (π_j with p_j)	Pay	No Pay
Provide	$(y + v_i - b)$ with p	-
No Provide	-	y with $(1 - p)$

As mentioned in section 1, in instances where we typically need to apply CV referenda like construction of public buildings, ecosystem restoration projects, or climate change mitigation projects, there often exist uncertainties over cost and supply in the possible outcomes of the referenda for such projects. In addition, the cost uncertainty and supply uncertainty are often independent. This implies that uncorrelated outcomes, (Pro, Not Pay) and (Not Pro, Pay), possibly occur in such projects, or respondents of such referenda might believe that uncorrelated outcomes occur. We relax this restriction and extend the outcome space in Step 2 of PR from two perfectly correlated outcomes to four outcomes. The probabilistic outcomes in Step 2 of our FOPR design are given by $j \in \Omega_{\text{FOPR|Pass}}$ = {(Pro, Pay), (No Pro, Pay), (Pro, No Pay), (No Pro, No Pay)}. While the probabilities of payment and provision are the same in this paper, the outcomes are two distinct and independent random variables.[7] Let p be the probability that the cost is collected and let the same p be the probability that the good is provided. For example, the probability that the outcome (Pro, No Pay) occurs is given by p times $(1 - p)$. Table 2 shows a payoff matrix for Step 2 of the FOPR.

Table 2: Payoff Matrix for the Four Outcome Probabilistic Referenda

FOPR (π_j with p_j)	Pay	No Pay
Provide	$(y + v_i - b)$ with p^2	$(y + v_i)$ with $(1 - p)\, p$
No Provide	$(y - b)$ with $(1 - p)\, p$	y with $(1 - p)^2$

2.2. Voting Decisions

Let $\eta(d_i, D_{-i})$ represent voter i's subjective probability of passing, where $d_i \in \{\text{Yes, No}\} = \{1, 0\}$ is voter i's decision, and $D_{-i} = (d_1, d_2, \ldots, d_{i-1}, d_{i+1}, \ldots, d_N)'$ is the vector containing the decisions of the other $N - 1$ subjects.[8] By the definition of majority rule, we can identify $\eta(d_i, D_{-i})$ as follows:

$$\eta(d_i, D_{-i}) = \Pr\left[\frac{\sum_{k\in N} d_k}{N} > 0.5\right] = \Pr\left[\frac{(d_i + D_{-i}{}' \cdot I_{N-1})}{N} > 0.5\right], \qquad (1)$$

where I_{N-1} denotes an (N, 1) unit vector. Consistent with field applications, we assume that subjects know only their own values. In other words, they do not have any information about the distribution (i.e. neither the range nor the frequency) of values. Thus, for subject i, D_{-i} is

[7] Mitani and Flores (2008) deal with the case in which the probability of payment is not equal to the probability of provision, using a threshold provision mechanism. Their experimental analysis suggests that the relative importance between payment and provision uncertainty plays an important role for the explanation of hypothetical bias.

[8] That is, the message space is binary.

unknown while d_i is his/her own decision. We can treat the scalar $D_{-i}{}' \cdot I_{N-1}$ as a random variable. The variable $D_{-i}{}' \cdot I_{N-1}$ takes an integer value from the range [0, N – 1]. Note that there exists a value of $D_{-i}{}' \cdot I_{N-1}$ for which subject i becomes pivotal, in the sense that subject i's vote is decisive in breaking a tie. Let D_{-i}^* be the others' decision vector such that subject i is pivotal, then $D_{-i} = \{D_{-i}^* \text{ or } \neg D_{-i}^*\}$. If subject i is pivotal, the following holds for D_{-i}^*:

$$\eta(1, D_{-i}^*) > \eta(0, D_{-i}^*), \text{ for } D_{-i}^* \text{ (that is, } \eta_Y - \eta_N > 0). \qquad (2)$$

This implies that subject i's subjective probability of passing when he/she votes YES is greater than that of passing when he/she votes NO, if he/she is pivotal. Next, if subject i is not pivotal, the following holds for all $\neg D_{-i}^*$:

$$\eta(1, \neg D_{-i}^*) = \eta(0, \neg D_{-i}^*), \text{ for all } \neg D_{-i}^* \text{ (that is, } \eta_Y - \eta_N = 0). \qquad (3)$$

Combing these two statements, we have the following lemma:

Lemma 1 (Subjective Probability of Passing) *For all* D_{-i}, $\eta_Y - \eta_N \geq 0$, *where* $\eta_Y = \eta(1, D_{-i})$ *and* $\eta_N = \eta(0, D_{-i})$. *For at least one* D_{-i}^*, $\eta_Y - \eta_N > 0$.

Let us assume that the subject has a continuously differentiable and strictly increasing utility function of the monetary payoff: $U(\pi)$. Now, we define the expected utility given a referendum result. First, the expected utility given the referendum passes (PASS; P) is defined as follows:

$$EU_P = \sum_{j \in \Omega} p_j \, U(\pi_j). \qquad (4)$$

Second, the expected utility given the referendum fails (NOT PASS; NP) is defined as follows:[9]

$$EU_{NP} = U(0). \qquad (5)$$

Then, we can define the expected utility of voting YES and NO, using EU_P and EU_{NP}. The

[9] Without loss of generality, we set $y = 0$ hereafter in this section.

expected utility voting YES is given as follows:

$$EU_Y = \eta(YES, D_{-i})\, EU_P + (1 - \eta(YES, D_{-i}))\, EU_{NP}. \qquad (6)$$

Likewise, the expected utility of voting NO is given as follows:

$$EU_N = \eta(NO, D_{-i})\, EU_P + (1 - \eta(NO, D_{-i}))\, EU_{NP}. \qquad (7)$$

Now, consider the expected utility difference between voting YES and NO. By the definition of the expected utility of voting YES and NO, we have the following:

$$EU_Y - EU_N = (\eta_Y - \eta_N)\,(EU_P - EU_{NP}). \qquad (8)$$

This equation implies that if $\eta_Y - \eta_N > 0$, that is if subject i is pivotal or at least the probability that subject i is pivotal is positive[10], then in dichotomous choice referenda with majority-vote rule the sign of the expected utility difference between voting YES and NO depends only on the sign of the difference between the expected utility given the referendum passes and the expected utility given the referendum fails.

Before defining incentive compatibility, let us review our setting so far. Figure 1 summarizes referendum trees of the TOPR and the FOPR. In the tree, the first branch is the result of voting decisions, whether the referendum results in PASS or FAIL. There is a subjective probability of passing (η). Note that this voting decision rule is the same across all referenda we

[10] As an alternative model, we consider a model where voters form a subjective probability that they are pivotal, similar to the model that Vossler and Evans (2008) employ. Let EU_{di} be voter i's expected utility from voting decision d_i = {YES, NO}. Let η_i^P, $\eta_i^{NP:PASS}$, and $\eta_i^{NP:FAIL}$ be the probability that voter i is pivotal, the probability that voter i is not pivotal and the referendum passes, and the probability that voter i is not pivotal and the referendum fails, respectively. Now, voter i's expected utility from voting decision is given by

$$EU_{di} = \eta_i^P \{ d_i\, EU_P + (1 - d_i)\, EU_{NP} \} + \eta_i^{NP:PASS}\, EU_P + \eta_i^{NP:FAIL}\, EU_{NP}. \qquad (9)$$

Then, we have the following:

$$EU_Y - EU_N = \eta_i^P\,(EU_P - EU_{NP}). \qquad (10)$$

Combing equations (8) and (10), we see that $\eta_Y - \eta_N > 0$ implies $\eta_i^P > 0$.

introduced here: binding binary referenda, TOPR, and FOPR. The second branch will be identified as Step 2 in PR, which has a property like a gamble or lottery. There is another probability that the referendum is binding or not (p). Note that we assume that these two probabilities are independent. In our theoretical model and experimental test, this assumption is not restrictive at all because we employ the two step voting rules, which allows us to deal with these two probabilities as independent.

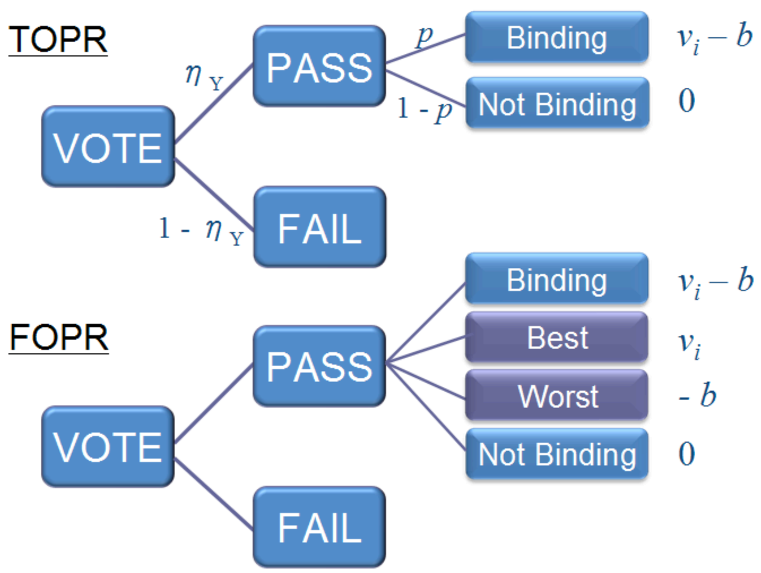

Figure 1. Referendum Tree

2.3. Incentive Properties of Probabilistic Referenda

A voting mechanism for eliciting individual preferences is said to be incentive compatible when the individual's optimal voting decision (e.g. dominant strategy) is to truthfully reveal their preferences. Now, we define the incentive compatibility of probabilistic referenda as follows. First, we consider a situation without uncertainty. A (probabilistic) referendum is *incentive compatible* (*IC1*) if voting yes is optimal for subject i if and only if his/her valuation for the project is greater than the cost he/she pays:

IC1: $v_i > b_i \iff$ subject *i* votes YES.

Then, we need to consider a situation where there exists uncertainty, because of a probabilistic nature in Step 2 of PR. In such a situation with uncertainty, a probabilistic referendum is *incentive compatible* (*IC2*) if voting yes is optimal for subject *i* if and only if the expected utility from voting yes is greater than the expected utility from voting no:

IC2: $EU_Y > EU_N \iff$ subject *i* votes YES.

It is ideal if probabilistic referenda satisfy the first incentive compatibility (IC1) because not only the referendum mechanism guarantees that the referendum result is based on truth revelations but also researchers or policy makers can estimate the distribution of true values using only information about voting decisions (d_i) and the costs (b_i). The probabilistic referenda mechanisms that satisfy only the second incentive compatibility (IC2) are still truth revealing in the sense that no subject has an incentive to lie to reveal his/her preference. However, from the perspective of researchers or policy makers, it is almost impossible to estimate the distribution of true values using only available information for them, voting decisions and the costs, without additional information. We show here that there exist cases that probabilistic referenda satisfy the second incentive compatibility (IC2) but not the first one (IC1), and that subject's risk attitude plays an important role for the alignment of IC1 and IC2. In this case, to estimate the distribution of true values, we would need additional information about subject's individual risk attitude.[11]

[11] Though we treat only the case that the probability of payment (payment uncertainty) is equal to the probability of provision (provision uncertainty) in this paper, if these probabilities are different from each other then we would need to measure these probabilities in addition to subject's risk attitude. In other words, satisfying the first incentive compatibility (IC1) allows us to ignore the influence of the probabilistic nature and subject's risk attitude toward the uncertainty. This implies that it is important for probabilistic referenda mechanisms to satisfy the first incentive compatibility (IC1) from the perspective of eliciting individual preferences for public projects.

Hereafter in this section, we explore the incentive properties of the TOPR and the FOPR and finally show theoretical predictions of experimental treatment effects of uncorrelated design (FOPR) compared to perfectly correlated design (TOPR). First, we have a convenient result to use in examining the incentive compatibility of PR, which all *binary* probabilistic referenda would satisfy. Using equation (8) and Lemma 1, if $EU_P - EU_{NP} > 0$, the following holds:

$EU_Y(D_{-i}) \geq EU_N(D_{-i})$, for all D_{-i}, and (11)

$EU_Y(D_{-i}^*) > EU_N(D_{-i}^*)$, for at least one D_{-i}^*. (12)

Thus, we have the following lemma.

Lemma 2 (Weakly Dominant Strategy in any Binary PR) *Voting YES is a weakly dominant strategy*, *if and only if* $EU_P - EU_{NP} > 0$.

This lemma allows us to focus on investigating whether the inequality $EU_P - EU_{NP} > 0$ holds or not, when exploring the incentive properties of PR. Now, we are ready to examine the incentive compatibility of PR.

Proposition 1 (IC of Referenda) *A binding binary referendum is incentive compatible*, *in the sense that a binding binary referendum satisfies the first incentive compatibility* (***IC1***).

Proof: By the definition of the payoff in CV referenda, $EU_P - EU_{NP} = U(v_i - b) - U(0)$. Since the utility function is differentiable and increasing in the monetary payoff, $\partial U(\pi)/\partial \pi > 0$. Thus, by Lemma 2, for subject i, voting YES is a weakly dominant strategy if and only if $U(v_i - b) - U(0) > 0$ which implies $v_i - b > 0$.[12] This satisfies the **IC1**. □

[12] $v_i - b > 0 \Leftrightarrow U(v_i - b) - U(0) > 0 \Leftrightarrow EU_P - EU_{NP} > 0 \Leftrightarrow EU_Y - EU_N > 0 \Leftrightarrow$ voting

This result is completely consistent with the traditional well-known theorem of Gibbard (1973) and Satterthwaite (1975), which is the starting point in the Carson and Groves (2007) theoretical framework. Also, this is consistent with the result on strategic behavior in CV referenda by Hoehn and Randall (1987).

Proposition 2 (IC of the TOPR) *Suppose that the referendum is consequential* (*i.e. for* $p > 0$), *then the two outcome probabilistic referendum* (*TOPR*) *is incentive compatible*, *in the sense that the TOPR satisfies the first incentive compatibility* (***IC1***).

Proof: Let p represent the probability that the referendum is binding. If $p > 0$, referenda are consequential. By the definition of the payoff in the TOPR, we have the following:

$$EU_P - EU_{NP} = pU(v_i - b) + (1 - p) U(0) - U(0) = p [U(v_i - b) - U(0)]$$

Thus, by Lemma 2, for $p > 0$, voting YES is a weakly dominant strategy if and only if $U(v_i - b) - U(0) > 0$, which implies $v_i - b > 0$. This satisfies the **IC1**. □

This result confirms Carson and Groves (2007) and Carson et al. (2004) who mention that the probability that a CV referendum is consequential does not influence its incentive properties as long as the probability is positive, implying that consequential probabilistic referenda are incentive compatible. Now, we show our main results about the incentive compatibility of the FOPR. We find the result on the incentive compatibility of the FOPR depends on subject's risk attitude. We begin with the risk-neutral agents.

Proposition 3-1 (IC of the FOPR: Risk-neutral Agents) *For* $p > 0$, *if the utility function is linear*

YES.

(*i.e. risk-neutral agents*), *the four outcome probabilistic referendum* (*FOPR*) *is incentive compatible*, *in the sense that the FOPR satisfies the first incentive compatibility* (***IC1***).

Proof (Linear utility function): By the definition of the payoff for the FOPR, we have

$$EU_P - EU_{NP}$$

$$= p^2 [U(0) - U(-\mathrm{b}) - \{U(v) - U(v - b)\}] + p [U(v) - U(0) - \{U(0) - U(- b)\}].$$

Since U is linear, without loss of generality let U take the following: $U(\pi) = \alpha p\pi$, for $\alpha > 0$, $p > 0$. Now, $EU_P - EU_{NP} = \alpha p(v - b)$. Thus, by Lemma 2, for $p > 0$ and $\alpha > 0$, voting YES is a weakly dominant strategy if and only if $v_i - b > 0$. This satisfies the **IC1**. □

For further analysis of the incentive properties of the FOPR, we make use of the *decision function* $f(\mu)$ defined for the difference between subject's valuation and cost (μ) as follows:

$$f(\mu) = EU_P - EU_{NP} \text{ for } \mu = v - b \quad (\text{i.e. } v = b + \mu). \qquad (13)$$

By the definition of the payoff for the FOPR and the definition of $v = b + \mu$, we have

$$f(\mu) = p^2 [U(0) - U(-\mathrm{b}) - \{U(b+\mu) - U(\mu)\}] + p [U(b+\mu) - U(0) - \{U(0) - U(- b)\}]. \ (14)$$

According to the definition, $\mu > 0$ implies $v - b > 0$ and $\mu < 0$ implies $v - b < 0$. Also, $f(\mu) = EU_P - EU_{NP} > 0$ implies that voting YES would be a weakly dominant strategy and $f(\mu) < 0$ implies that voting NO would be a weakly dominant strategy. Now, we have the following lemma about the properties of the decision function.

Lemma 3 (Properties of the Decision Function) *Suppose that* $p > 0$, *then:* ***1***) *The decision function* $f(\mu)$ *is continuously differentiable*; ***2***) $f(\mu)$ *is increasing in the difference* μ, *i.e.* $\partial f(\mu) / \partial\mu > 0$; ***3***) *Also*, *suppose* $1 > p$, *then for* $\mu = 0$, *we have the following*:

(***3-3-a***) *If* U *is concave*, *then* $f(0) < 0$;

(***3-3-b***) *If* U *is convex*, *then* $f(0) > 0$.

Proof: 1) This holds by the definition of the utility function; 2) By the definition of the decision function (14) and Lemma 3-1, we have the following:

$\partial f(\mu) / \partial\mu = (p - p^2)\, \partial U(b+\mu) / \partial\mu + p^2\, \partial U(\mu) / \partial\mu > 0$, for $p > 0$;

3) By the definition of the function (14), we have the following:

$f(0) = (p - p^2)\, [U(b) - U(0) - \{ U(0) - U(-b) \}]$.

For $1 > p > 0$, if U is concave, then $\{ U(b) - U(0) \} < \{ U(0) - U(-b) \}$. Likewise, if U is convex, then $\{ U(b) - U(0) \} > \{ U(0) - U(-b) \}$. □

Lemma 3-2 implies that increase in the difference $\mu = v - b$ has a positive effect on the likelihood of voting YES. Now, utilizing the results of Lemma 3-3, we have the following propositions.

Proposition 3-2 (IC of the FOPR: Risk-averse Agents) *For* $1 > p > 0$, *if the utility function is concave* (*i.e. risk-averse agents*), *the FOPR is NOT incentive compatible*, *in the sense that the FOPR does not satisfy the first incentive compatibility* (*Not **IC1***) *whereas the FOPR satisfies the second incentive compatibility* (***IC2***).

Proof (Concave utility function): Suppose $1 > p > 0$. For concave utility functions, $f(0) < 0$ from Lemma 3-3-a. Now, we take $\varepsilon^* > 0$ such that $\varepsilon^* = | 0 - f(0) |$. By the continuity of $f(\mu)$, there exists some $\delta > 0$ such that $| f(0) - f(a) | < \varepsilon < \varepsilon^*$, whenever $| 0 - a | < \delta$, for any $\varepsilon \in (0, \varepsilon^*)$. Then, we can choose $a^* > 0$ such that $| 0 - a^* | < \delta$ and $f(a^*) < 0$. This implies that for $v - b = a^* > 0$, $f(a^*) = EU_P - EU_{NP} < 0$. Then, by Lemma 2, for $v - b > 0$, voting YES is not a weakly dominant strategy anymore. This does not satisfy the **IC1**. □

Proposition 3-3 (IC of the FOPR: Risk-lover Agents) *For* $1 > p > 0$, *if the utility function is* *convex* (*i.e. risk-lover agents*), *the FOPR is NOT incentive compatible*, *in the sense that the FOPR does not satisfy the first incentive compatibility* (*Not* ***IC1***) *whereas the FOPR satisfies the second incentive compatibility* (***IC2***).

Proof (Convex utility function): Same as Proposition 3-2. □

Proposition 3 suggests that subject's risk attitude would matter considering the incentive properties of the FOPR. Proposition 3-2 implies that it is possible that risk-averse subjects are likely to vote NO even if their valuations are slightly greater than the costs. Likewise, Proposition 3-3 implies that risk-lover subjects are likely to vote YES even if their valuations are slightly less than the costs. Thus, in the FOPR, subjects whose values are close to the bids (costs) possibly fail to vote their true preferences in the sense of the first incentive compatibility (IC1). In other words, when the value is close to the bid (cost), the first incentive compatibility (IC1) of the FOPR is likely to be violated. These results suggest that researchers or policy makers who utilize only information about voting decisions and the costs possibly underestimate or overestimate their true values.

2.4. Experimental Treatment Effect

Now, we set up models for dealing with treatment effects in our experiments. First, we recall the definitions of the expected utility given the referendum passes in the TOPR and the FOPR, respectively. Then, we define the treatment effect in our experimental study. Finally, we provide the theoretical implications of the treatment effects of the FOPR compared to the TOPR.

Using equation (4) and the payoffs for the TOPR and the FOPR, we have the definition of the expected utility given the referendum passes in the TOPR and the FOPR, EU_P^T and EU_P^F, respectively:

$$EU_P^T = p\, U(v - b) + (1 - p)\, U(0), \qquad (15)$$

$$EU_P^F = p^2\, U(v - b) - p(1 - p)[U(v) + U(- b)] + (1 - p^2)\, U(0). \qquad (16)$$

The superscript T denotes the TOPR and the superscript F denotes the FOPR. We omit the superscript for the expected utility given the referendum fails because the expected utility given the referendum fails in the TOPR is equal to that in the FOPR. That is, $EU_{NP} = EU_{NP}^T = EU_{NP}^F$. Now, we define the *treatment effects* (γ) of the FOPR compared to the TOPR as follows:

$$\gamma = EU_P^F - EU_P^T. \qquad (17)$$

Consider a logit (probit) estimation using experimental data in which the dependent variable is voting YES. By Lemma 2, the probability of voting YES in the estimation is given by:

$$\Pr\,[\text{Vote for YES}] = \Pr\,[EU_P - EU_{NP} > 0\,]. \qquad (18)$$

This implies that the difference $EU_P - EU_{NP}$ has a positive effect on the probability of voting YES. Let D^{FOPR} be a treatment dummy variable equaling 1 if the experimental design is the FOPR, 0 otherwise. Now, using this dummy variable, we can rewrite the difference as follows:

$$EU_P - EU_{NP} = EU_P^T - EU_{NP} + D^{FOPR}\,(EU_P^F - EU_P^T). \qquad (19)$$

We can see the treatment effect (17) as a coefficient of the treatment dummy variable (D^{FOPR}). Combining with a logit (probit) estimation-probability (18), we see that the treatment effect (γ) can be estimated using experimental data. Also, equation (19) implies that the treatment effect has a positive effect on the likelihood of voting YES. Now, we achieve the following theoretical predictions.

Proposition 4 (Treatment Effect and Risk Attitude) *Suppose* $1 > p > 0$, *then the relationship* *between the sign of the estimatable treatment effect and the utility function form are given as follows*: ***1***) *No treatment effect of the FOPR* ($\gamma = 0$) *implies that the utility function U is linear and subjects are Risk-neutral agents*; ***2***) *Positive treatment effect of the FOPR* ($\gamma > 0$) *implies that the utility function U is convex and subjects are Risk-lover agents*; ***3***) *Negative treatment effect of the FOPR* ($\gamma < 0$) *implies that the utility function U is concave and subjects are Risk-averse agents*.

Proof: By the definition of the treatment effect, we have the following:

$$\gamma = EU_P^F - EU_P^T = -p(1-p)\,[U(0) - U(-b) - \{U(v) - U(v-b)\}].$$

Suppose $1 > p > 0$, then we have the following: 1) The $\gamma = 0$ implies $EU_P^F = EU_P^T$. This holds if and only if U is linear, i.e. subjects are risk-neutral; 2) The $\gamma > 0$ implies $EU_P^F > EU_P^T$. This holds if and only if U is convex, i.e. subjects are risk-lover; 3) The $\gamma < 0$ implies $EU_P^F < EU_P^T$. This holds if and only if U is concave, i.e. subjects are risk-averse. □

Regarding the first incentive compatibility (IC1) of the FOPR experimental design, once we admit that the TOPR is incentive compatible in the sense that the TOPR satisfies the IC1, Proposition 4 implies that 1) no treatment effect suggests that the FOPR design is incentive compatible in the sense that the experimental data from the FOPR produces the same results as that from the TOPR; 2) positive treatment effect suggests that the FOPR design is not incentive compatible and interpretable as overstating subjects' values when comparing it to the results from the TOPR design; 3) negative treatment effect suggests that the FOPR design is not incentive compatible and interpretable as understating subjects' values when comparing it to the results from the TOPR design. As mentioned above, we can estimate the treatment effect γ by using our experimental data.

3. Experimental Design

The experiments were designed to provide a strict test of our theoretical predictions about the incentive properties of probabilistic referenda. In particular, we focus on examining the treatment effect of the FOPR design compared to the TOPR design. Varying the probability that the referendum is binding as additional experimental treatments in each design, we investigate how subjects' voting decisions change with the consequentiality of referenda.

We employed a between-subjects one-shot induced-value experimental design, which is completely consistent with our theoretical framework. Twelve experimental sessions were conducted with two hundred and thirty subjects at the laboratory for political economy at Waseda University. Subjects were recruited from the general population at the university. The number of subjects in each experimental session is shown in Table 3. Subjects were paid a 1000JPY participation fee (about 10USD). Subjects were assigned to a lab computer with privacy shields; communication was not allowed between subjects. That is, during the experiment, subjects were visually isolated. The Z-tree software (Zurich Toolbox for Readymade Economic Experiments) was used in our experiments. Fifteen to thirty-five subjects in a session were randomly and anonymously assigned into three to seven groups of five subjects for each of the twelve experimental sessions. These controls for anonymity are important to minimize the possible impacts of social networks on the voting decision (List et al., 2004; Vossler and Evans, 2008). Likewise, our experimental design attempts to avoid introducing potential biases due to uncertain values, group size, or other-regarding preferences (Vossler and McKee, 2006; Bohara et al., 1998; Burton et al., 2007).

Induced-values

Before starting the referendum vote, subjects were presented their induced-value in JPY using a value card, which indicates each subject's value for the project if provided. Induced-values across the session members were uniformly distributed over the range of 100JPY to 900JPY, in 200JPY increments (i.e. 100, 300, 500, 700, 900JPY). Experimental instructions were developed parallel to the work of Vossler and McKee (2006) and Taylor et al. (2001). Consistent with field applications, subjects were told that values varied across subjects but were not told the range and the frequency of values. That is, subjects knew only their own values.

Referendum Rules

The instruction and procedure of our experiments with probabilistic natures in referenda followed the two-step referendum rules of Carson et al. (2004) and Cummings and Taylor (1998). The homegrown value setting that the previous studies employed was modified into the induced value setting. We further extended their perfectly correlated design (TOPR) to the four outcome not perfectly correlated design (FOPR). The cost, which subjects have to pay if the referendum passes and is binding, and the probability, that the referendum is binding, were common knowledge in each session. The Two-Step Referendum Rule (TOPR Version) is described as follows:

Two-Step Referendum Rule (TOPR Version)

Step 1: If more than 50% of you vote YES on this proposition ("would you pay the cost 400JPY to provide the project which gives you the value of v_i JPY"), then the referendum has passed. If the referendum passes, then in Step 2 we will determine if the referendum is binding, depending on the pre-announced probability [p] (assigned from {0, 0.01, 0.25, 0.5, 0.75, 1}). If the referendum does not pass, then no one will pay 400JPY or receive your value of the project. Everyone receives 1000JPY.

Step 2: Given the referendum passes, the computer determines whether the referendum result done in Step 1 will be binding depending on the pre-announced probability [p]. If the referendum is binding, all of you have to pay the cost of 400JPY and you can receive your value of the project [v_i]JPY.

Also, the Two-Step Referendum Rule (FOPR Version) is described as follows:

Two-Step Referendum Rule (FOPR Version)

Step 1: If more than 50% of you vote YES on this proposition ("would you pay the cost 400JPY to provide the project which gives you the value of v_i JPY"), then the referendum has passed. If the referendum passes, then in Step 2 we will determine if the referendum is binding, depending on the pre-announced probabilities [p, p] (assigned from {0, 0.01, 0.25, 0.5, 0.75, 1}). If the referendum does not pass, then no one will pay 400JPY or receive your value of the project. Everyone receives 1000JPY.

Step 2: Given the referendum passes, the computer determines whether the cost 400JPY and the provision of the project will be *respectively* (FOPR) binding depending on the pre-announced probabilities [p, p]. The chance of coercive collection is [100p]%, and the chance of secure provision is [100p]%. Your earning will depend both on whether you have to pay the cost of 400JPY and on whether you can receive your value of the project [v_i]JPY.

The two-step referendum rules allow us to deal with the probability that the referendum is binding p as independent events from the subjective probability that the referendum passes η_Y.

Experimental Treatments

The twelve treatments and the number of subjects in each treatment are shown in Table 3. Following the experimental design of early work by Cumming et al (1995), cited by Harrison (2006), there were six possible values for the probability: 0, 0.01, 0.25, 0.5, 0.75, 1. There were three to seven groups of five subjects for each of the twelve experimental treatments.

Procedures

The experimenter provided oral instructions with a front screen and answered any questions. The instructions contained information about a vote for a public project, induced values, uncertainty over the referendum (in the TOPR treatments), uncertainty over payment and provision (in the FOPR treatments), and the two-step referendum rule, in this order. Subjects in groups of five were initially endowed with 1000JPY. In this one shot referendum, the probability that the referendum will be binding was publicly announced; then the subjects made their voting decisions. The experiment concluded with a questionnaire that collected basic demographics including gender and age.

Table 3: Treatments and the Number of Subjects

TOPR (Two Outcomes)		**FOPR (Four Outcomes)**	
Treatments	# Subjects	Treatments	# Subjects
$p = 0.00$	15	$p = 0.00$	15
$p = 0.01$	35	$p = 0.01$	15
$p = 0.25$	20	$p = 0.25$	20
$p = 0.50$	15	$p = 0.50$	20
$p = 0.75$	20	$p = 0.75$	20
$p = 1.00$	20	$p = 1.00$	15
Total #	125	Total #	105

4. Results

The goal of the experiments of this paper is to examine the theoretical predictions concerning the incentive properties of probabilistic referenda. In particular, we focus on investigating the treatment effect of the FOPR compared to the TOPR. We begin our analysis with a quick look at the general patterns at the aggregate level. The individual level econometric analysis is then used to test our fundamental theoretical predictions about the treatment effect.

Figure 2 shows the observed percentage of subjects voting YES in each treatment. Also, Table 4 reports the overall voting results. In the table, the **V** denotes induced values and **B** denotes the cost. For example, the number shown in the column of **Vote for YES** and **V > B** (that is, the third column from the left) represents the number of subjects voting YES whose values are greater than the cost, implying that these voting decisions satisfy the first incentive compatibility (**IC1**). In our induced value design, 60% of subjects should vote YES in this one shot referendum. For probabilities 0.25 or greater, we see that 60% of subjects voted YES for the perfectly correlated TOPR design but not for our alternative FOPR design (see Figure 2). The last column from the left in Table 4 shows the percentage of subjects' voting decisions satisfying the first incentive compatibility (IC1) at each treatment. For the FOPR design, we can see some observations in the sixth column of **Vote for NO** and **V > B**, implying understatements of their values in the sense that the observations violate the first incentive compatibility (IC1). We should note that while the observations that fall into the forth (looks like overstatement) and sixth (looks like understatement) column in Table 4 violate the first incentive compatibility (IC1), for subjects in the FOPR the observations might still be consistent with truth revealing, in the sense of the second incentive compatibility (IC2).

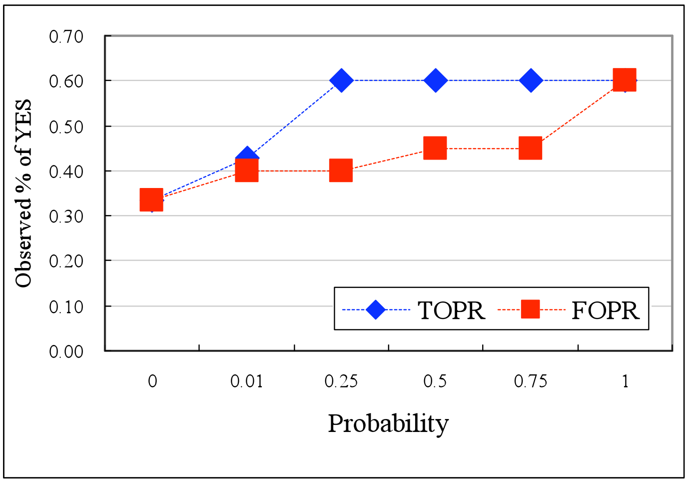

Figure 2: Summary of Results

Table 4: Voting Results

Treatments		Vote for YES			Vote for NO				
Design	**Prob**	**V > B**	**V < B**	**Total**	**V > B**	**V < B**	**Total**	**Total**	**IC1**
TOPR	**0**	5	0	5	4	6	10	15	73%
TOPR	**0.01**	15	0	15	6	14	20	35	83%
TOPR	**0.25**	12	0	12	0	8	8	20	100%
TOPR	**0.5**	9	0	9	0	6	6	15	100%
TOPR	**0.75**	12	0	12	0	8	8	20	100%
TOPR	**1**	12	0	12	0	8	8	20	100%
		65	0	65	10	50	60	125	92%
FOPR	**0**	5	0	5	4	6	10	15	73%
FOPR	**0.01**	6	0	6	3	6	9	15	80%
FOPR	**0.25**	8	0	8	4	8	12	20	80%
FOPR	**0.5**	9	0	9	3	8	11	20	85%
FOPR	**0.75**	9	0	9	3	8	11	20	85%
FOPR	**1**	9	0	9	0	6	6	15	100%
		46	0	46	17	42	59	105	84%

Table 5 presents the logit estimation result in which the dependent variable is vote for yes. The explanatory variables include: 1) the treatment effect dummy of the FOPR (**D_FOPR**) which is equal to 1 if the vote is made in the FOPR treatments; 2) the treatment effect dummies of the probabilities that the referendum is binding (**D_P0**, **D_P1**, **D_P25**, **D_P75**), which are compared to the treatment in which the probability is 1 (i.e. binding binary referenda); 3) subject's induced value (**V**); 4) gender (**GENDER**) which is equal to 1 if subject's gender is male; 5) age (**AGE**); and 6) the dummy variable (**ECON**) which is equal to 1 if the subject is an economics student. Here is our main concern. The treatment effect coefficient (**D_FOPR**) is negative and statistically significant at the 5% level. From Proposition 4 in section 2, this implies that the result is consistent with choices made by risk-averse agents in our theoretical analysis. The estimates of treatment effects of probabilities of being binding suggest that voting results observed for probabilities 0.25 or greater but less than 1 are statistically no different from those observed in a binding binary referendum. This result is consistent with previous findings from studies that employed homegrown-value probabilistic referenda to examine the consequentiality (Carson et al., 2004; Vossler and Evans, 2008). The coefficient of induced values is positive and significant at the 1% level. So, subjects who have higher values are more likely to vote for YES. Also, we did not find any individual effects like gender, age, economics major.

Table 5: Logit Estimation Result

	Coeff.	**Std.Err.**	**P-value**
Const.	-1.636	1.216	0.178
D_FOPR	-0.519	0.232	0.025
D_P0	-1.147	0.372	0.002
D_P1	-0.911	0.334	0.006
D_P25	-0.314	0.353	0.375
D_P75	-0.219	0.343	0.522
V	0.005	0.001	0.000
GENDER	-0.252	0.247	0.308
AGE	-0.010	0.057	0.857
ECON	0.463	0.303	0.126
LL	-82.796		
LRI	0.48		

Our results in standard perfectly correlated induced-value experiments confirm previous findings of PR (Carson and Groves, 2007; Carson et al., 2004). Since all previous studies (Vossler and Evans, 2008; Carson et al., 2004; Cumming and Taylor, 1998) of PR employed homegrown value, our study would be the first induced-value test of PR. The results of the

FOPR suggest that moving away from perfectly correlated prices and quantities undermines the incentive compatibility result found in other studies. The experimental results are consistent with choices made by risk-averse agents in our theoretical analysis.

5. Concluding Remarks

In this paper, we examine the incentive properties of probabilistic referenda. We first extend outcome space from two outcomes to four outcomes. Then, we provide a closer look and theoretical analysis on incentive compatibility of probabilistic referenda. Also, we conduct an induced-value experimental test of our theoretical predictions and we gain new insights that are contrary to results from previous studies. First, our results in standard perfectly correlated induced value experiments confirm previous findings of probabilistic referenda. Second, our results suggest that moving away from perfectly correlated prices and quantities undermines the incentive compatibility result found in other studies. Third, our experimental results are consistent with choices made by risk-averse agents in our theoretical analysis. Our results suggest that a negative hypothetical bias possibly occurs even in consequential probabilistic referenda if there are four possible outcomes in respondents' cognitive processes and respondents have concave utility functions, implying that dichotomous choice CV possibly underestimates true values.

We confirm that if CV referenda are consequential and there are only two outcomes, in other words payment and provision are perfectly correlated, then CV referenda would be incentive compatible. This implies that every CV survey should be designed such that it is consequential. In addition, researchers need to pay attention to the possible outcomes that respondents might have. If respondents think about more than two perfectly correlated outcomes, for example, as the result of the referendum we might have to pay the cost of the project but the policy makers might not conduct the project, or the reverse, then CV referenda are not incentive compatible and possibly underestimate true values. This new perspective will be more important in applications where there exists uncertainty over the cost and/or provision, like ecosystem restoration projects and climate change policy.

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