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Preference Uncertainty, Preference Refinement and Paired Comparison Choice Experiments

David C. Kingsley
University of Colorado, Boulder

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1 Introduction

A fundamental assumption of neoclassical microeconomic theory is that preferences exhibit transitivity. This intuitive assumption implies that between pairs of items preferences cannot cycle. For example, if a consumer prefers A to B and B to C then it follows that they also prefer A to C. Paired comparison choice experiments are unique because they involve simple binary choices between pairs of items, allowing researchers to test the transitivity axiom. Choices violating this axiom, referred to as inconsistent, can be quickly identified and retested within individual.

Paired comparison research suggests that as respondents progress through a random sequence of paired choices they become more consistent, apparently *fine-tuning* their preferences (Brown et al., 2006). Brown et al. (2006) also find that the proportion inconsistent for choices involving public goods is higher and remains higher throughout the experiment than the same proportion for choices involving private goods. Furthermore, respondents are more likely to reverse an originally inconsistent choice than an originally consistent choice when retested. Peterson and Brown (1998) conclude that although original choices violate the transitivity axiom when given the opportunity the majority of these violations are reversed (Peterson & Brown, 1998). This paper investigates the implications of these results within a model of preference uncertainty allowing for preference refinement.

Random utility models provide a general framework within which researchers investigate individual choice behavior (McFadden, 2001). First developed by Marschak, random utility models assume that the individual always chooses the alternative yielding the highes level of utility (Marschak, 1960). Despite the assumption of well-behaved preferences, utility is described as a random variable in order to reflect the researcher's observational deficiencies (Ben-Akiva & Lerman, 1985). The model that Marschak proposed was an interpretation of an important paper by L.L. Thurstone (1927). Thurstone's Law of Comparative Judgement marks the first known model of

valuation distribution as a measure of preference uncertainty. Increases in

the discriminal dispersion.

preference are assumed transitive while realizations or perceived preferences may exhibit intransitivity. Respondent error creates judgement error which leads to what appear to be inconsistent choices.

Allowing for the existence of uncertain preferences and sources of error beyond researcher error has been considered at least since Bockstael and Strand (1987). Bockstael and Strand look at the effect the source of error has on the estimation of economic values in a framework they called *Random Preferences* (Bockstael & Strand, 1987). More recently Wang (1997) suggested, in order to explain why respondents choose the *Don't Know* option in dichotomous choice contingent valuation studies, that each respondent has an implicit valuation distribution. Respondents answer DCCV questions as if their values follow a distribution (Wang, 1997).

This paper also allows preferences to follow a distribution, however, opposed to Wang (1997) valuations or choices on each choice occasion are realizations from this distribution. As such this paper follows the work of Li and Mattsson closely (Li & Mattsson, 1995). Li and Mattsson assume that respondents have incomplete knowledge of their preferences and thus can give the wrong answer to a dichotomous choice contingent valuation question. First, the implications of respondent uncertainty in a dichotomous choice contingent valuation is discussed, following closely the work of Li and Mattsson (1995).

2.1 Dichotomous Choice Contingent Valuation

In a standard DCCV study respondents are asked to vote *yes/no* to a referendum question such as: Would you be willing to pay t_i dollars to obtain some environmental improvement or resource k? The individuals valuation function will be defined as a follows.

$$u_{ik} = \alpha_k + \varepsilon_{ik} \quad (1)$$

Where u_{ik} is an individuals unobserved utility of item k, the deterministic component of value is represented by α_k and $\,_{ik}$ represent the stochastic component. It is common to express α_k as linear in parameters, $x_i'\beta$, where x_i is a set of variables describing the characteristics of either the individual or the item k. The respondent will vote *yes* whenever $u_{ik} \geq t_i$. Therefore,

$$Pr(yes) = Pr(u_{ik} \geq t_i) = Pr(\,_{ik} \geq t_i - \alpha_k) \tag{2}$$

and

$$Pr(no) = 1 - Pr(yes) \tag{3}$$

Let the stochastic error term, $\,_{ik}$, be normally distributed with mean zero and constant variance σ^2. Then σ represents the standard deviation, referred to as the scale, of the estimated valuation distribution which has mean α_k.

Li and Mattsson introduce preference uncertainty by allowing individual valuations to be realizations from an underlying valuation distribution so that

$$\tilde{u}_{ik} = u_{ik} + v_{ik} \tag{4}$$

combining terms we have the unobserved utility function $\tilde{u}_{ik} = \alpha_k + \,_{ik} + v_{ik}$. Therefore, respondents reply *yes* whenever $\tilde{u}_{ik} \geq t_i$.

$$Pr(yes) = Pr(\tilde{u}_{ik} \geq t_i) = Pr(e_{ik} \geq t_i - \alpha_k) \tag{5}$$

and

$$Pr(no) = 1 - Pr(yes) \tag{6}$$

Where e_{ik} is a composite error term such that $e_{ik} = \,_{ik} + v_{ik}$. Here $\,_{ik}$ represents the stochastic component associated with the researcher arising from omitted variables. On the other hand, v_{ik} represents the stochastic component associated with the respondent arising from preference uncertainty. As discussed in the following section the standard deviation of v_{ik}, σ_v, measures preference uncertainty reductions in which represent preference refinement.

and

$$\tilde{u}_{ic} = \alpha_c + e_{ic} \tag{8}$$

Under the assumption that e_{ik} is a mean zero random variable distributed i.i.d. normal, the choice between item r and c can be written probabilistically.

$$P_{rc} = P(\tilde{u}_{ir} > \tilde{u}_{ic}) = P(\alpha_r + e_{ir} > \alpha_c + e_{ic}) = Pr(e_{ic} - e_{ir} < \alpha_r - \alpha_c) \tag{9}$$

or

$$P_{rc} = \Phi\left(\frac{(\alpha_r - \alpha_c)}{\sqrt{2}\sigma_e}\right) \tag{10}$$

and

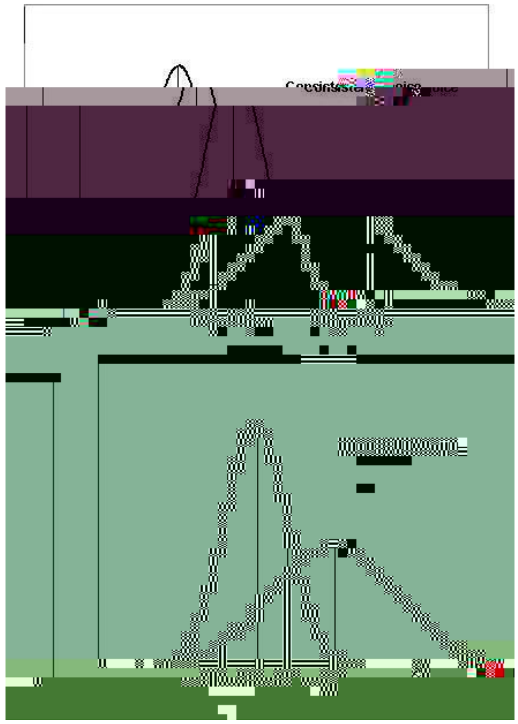
$$P_{cr} = 1 - P_{rc} = 1 - \Phi\left(\frac{(\alpha_r - \alpha_c)}{\sqrt{2}\sigma_e}\right) \tag{11}$$

Where Φ is the standard normal cumulative distribution and $\sqrt{2}\sigma_e$ is the standard deviation of $e_{ic} - e_{ir}$.

Consider the density functions of items r and c depicted in Figure 1. In expectation item r is preferred to item c as $E(u_{ir}) > E(u_{ic})$ or equivalently $\alpha_r > \alpha_c$. If this respondent were certain, or made certain, of his valuation he would always chose item r. The top panel represents a consistent choice, the realization of item r, u_{ir}, is greater (to the right of) u_{ic} the draw on item c, therefore item r is chosen over item c. However, the bottom panel of Figure 1 depicts an inconsistent choice. The realization of item c, u_{ic}, is greater than u_{ir} so on this choice occasion the individual would choose item c.

In psychometric experiments inconsistent choices are easily identified because the expected value of each item is objective. However, in economic valuation studies the expected value must be estimated and inconsistency particularly within individual is not easily identified. Peterson and Brown (1998) develop a method (discussed in Section 4) which identifies a likely set of inconsistent choices within individual.

The expression for P_{rc}



the more narrow the distribution the more likely a consistent choice.

$$\frac{d\Phi\left(\frac{\alpha_{rc}}{\sqrt{2}\sigma_e}\right)}{d\sigma_e} = -\varphi\left(\frac{\alpha_{rc}}{\sqrt{2}\sigma_e}\right)\frac{\alpha_{rc}}{\sqrt{2}\sigma_e^2} < 0 \tag{13}$$

As the scale, σ_e, approaches zero the choice becomes deterministic and increasingly consistent. In the ongoing example item r becomes increasingly likely to be chosen. While as the scale approaches ∞ the choice becomes increasingly random. Therefore, decreases in σ_e imply preference refinement as respondents become more able to discriminate between the alternatives while increases represent respondent fatigue or confusion (Holmes and Boyle 2006). This is the intuition behind preference refinement to which the paper now turns.

3 Preference Refinement

Allowing for preference uncertainty and respondent error one must ask whether the level of uncertainty can be affected by the experimental design. That is, does the task itself (the choice experiment) affect the level of respondent uncertainty. The level of uncertainty, as noted by Thurstone and the above analysis, can be measured by the standard deviation of the distribution.

The relationship between choice consistency and the scale of a random utility model has been investigated since researchers have considered scale as a sign of preference uncertainty (Deshazo & Fermo, 2002; Swait & Adamowicz, 1996). Deshazo and Fermo (2002) consider the impact choice set complexity has on the variance of error term in a heteroscedastic logit model. The variance of the random error term a-3zr cscedastic -234(-234(-2)-1s)-1g3.44(a-t-369(ranee1
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affect the complexity by changing the number of alternatives as well as the number and correlation of the attributes in a conjoint framework. Swait and Adamowicz (1996) consider the difficulty of the choice, referred to as

1)	A meal at a restaurant of the respondent's choice not to exceed $15.
2)	A nontransferable $200 gift certificate to a clothing store of the respondent's choice.
3)	Two tickets and transportation to a cultural or sporting event in Denver estimated at $75.
4)	A nontransferable $500 certificate good for travel on any airline.
5)	A 2,000 acre wildlife refuge in the mountains west of Fort Collins Colorado purchased by the University.
6)	An agreement among Colorado State University, local business and government to improve the water and air quality in Fort Collins
7)	An annual no-cost on-campus weekend music festival open to all students.
8)	A no-fee service providing video tapes of all class lectures in the University library.
9)	An expansion to the parking garage system on campus so that parking was always easy to find and convenient.
10)	An expansion of the eating area in the student center.

Table 1: Items included in Peterson and Brown 1998

across respondent and choice occasion. All respondents see all possible pairs. In a choice set of t items each respondent makes $\frac{t(t-1)}{2}$ choices.

In the Peterson and Brown 1998 experiment all items were economic gains (see Table 1). Respondents were instructed to choose the item they would prefer if they could have either at no cost. The choice sets were drawn from a set of four private goods and six locally relevant public goods along with 11 monetary amounts[6]. Each respondent made 155 choices; 45 between items and 110 between an item and a dollar amount. Items are not paired with themselves and dollar amounts are not compared. Three hundred and thirty students from Colorado State University participated in the study. Three were dropped because of missing data leaving a total of 327 respondents, providing 50,685 individual observations.

[6] Monetary amounts included 1, 25, 50, 75, 100, 200, 300, 400, 500, 600 and 700.

Raw Choice Matrix					
		A	B	C	D
	A	-	0	0	0
	B	1	-	1	1
	C	1	0	-	1
	D	1	0	0	-
Preference Score		3	0	1	2

Table 2: Raw Choice Matrix

4.1 Identification of Inconsistent Choices

After all choices have been made preferences are described using choice matrices. One of these choice matrices, referred to as the raw choice matrix, summarizes the choices and preferences of a single individual. For example, consider a choice set containing only four items A, B, C and D. A choice is made between each pair, in this example each respondent makes 6 choices. A 1 in the matrix implies that the column item was chosen over the row item. Consider Table 2, it can be seen that this respondent's preferences are as follows: A $\succ$ B, A $\succ$ C and A $\succ$ D; D $\succ$ B D $\succ$ C and C $\succ$ B. Summation of the columns provides each items *preference score*. The preference score is simply the number of times the item was chosen over another item in the choice set and provides an ordinal measure of the item's value. An important measure is the *preference score di erence* (PSD) which provides an approximate measure of the di□erence in value placed on the items. For example, the PSD between items A and B is 3 while between A and D it is 1, implying that this respondent prefers A over B more than they prefer A over D.

Next the double sorted choice matrix is formed. This matrix is formed by ranking the items by increasing preference score from left to right, similarly the rows are ranked by increasing row sum bottom to top. Table 3 displays two double sorted matrices. The top half is obtained from the raw choice ma-

Consistent Choice Matrix					
		B	C	D	A
	B	-	1	1	1
	C	0	-	1	1
	D	0	0	-	1
	A	0	0	0	-
Preference Score		0	1	2	3
Inconsistent Choice Matrix					
		B	C	D	A
	B	-	1	1	0
	C	0	-	1	1
	D	0	0	-	1
	A	1	0	0	-
Preference Score		1	1	2	2

Table 3: Double Sorted Choice Matrices

trix in Table 2. Note that the 1's all appear above the diagonal and that each integer between 0 and $t-1$ appears as a preference score. This choice matrix represents perfect choice consistency. The bottom half of Table 3 shows the double sorted matrix if the respondent had chosen B $\succ$ A rather than A $\succ$ B. This inconsistent choice causes a violation of the transitivity axiom: A $\succ$ C, C $\succ$ B but B $\succ$ A. Notice that the preference scores are no longer unique integers with both 1 and 2 being repeated. The important change is the 1 that appears below the principal diagonal. The double sorted choice matrix identifies inconsistent choices by isolating 1's below the diagonal[7]. In this example the choice B $\succ$ A would be identified as inconsistent.

[7] The effectiveness of the double sort algorithm has been extensively examined using simulations (Peterson & Brown, 2006). The details of these simulations are beyond the scope of the current paper. However, it is shown that given a choice set including 21 items (e.g. Peterson and Brown (1998)) and assuming normal error terms approximately 72% of the choices identified as inconsistent are indeed inconsistent. The Peterson and Brown (2006) paper is available at the following web address: http://www.fs.fed.us/rm/value/discpaper.html.

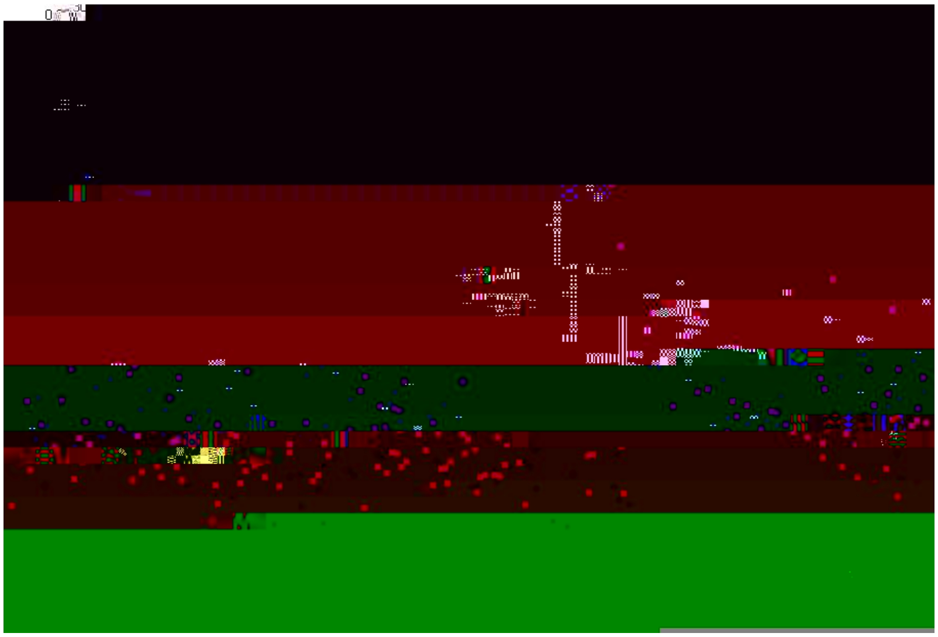

Figure 2: Proportion of Choices Identified as Inconsistent

4.2 Descriptive Results

The Peterson and Brown 1998 experiment, yields several important results. First, the proportion of choices identified as inconsistent drops as the respondents progress through the experiment. Recall that 155 choices were made by each respondent. In Figure 2 *Public* (*Private*) refers to choices between either two public (private) items or a public (private) item and a dollar amount. For both sets of choices a downward trend exists. This process, by which respondents become more consistent has been referred to as *fine-tuning* (Brown et al., 2006).

Furthermore the experimental design included retesting 10 consistent choices and all inconsistent choices made by an individual after the initial 155 choices were made. The respondents did not know that this portion of the experiment had started. Of the 3270 consistent choices retested 290 or

Type of Choice	Inconsistent	Switched	Proportion
Public v. Public	368	216	.59
Public v. Money	1498	974	.65
Private v. Private	153	95	.62
Private v. Money	922	518	.56
Public v. Private	747	453	.61
Total	3688	2256	.61
	Consistent	Switched	Proportion
Public v. Public	257	26	.1
Public v. Money	1313	121	.09
Private v. Private	157	18	.11
Private v. Money	1060	83	.08
Public v. Private	483	42	.09
Total	3270	290	.09

Table 4: Proportion of Choices Switched

8.9% were switched while 2256 of 3688 inconsistent choices or 61.2% were switched (see Table 4). This implies respondents are not simply being consistent with their previous choices but, rather, attempting to express their true preferences.

5 Methodology and Results

The above analysis provides several testable predictions. First, the asserted inverse relationship between choice consistency and the scale of a random utility model is verified. This result is interpreted as preference refinement. Second, the model of preference uncertainty predicts the probability of an inconsistent choice declines with both a greater utility difference between the involved items and a narrowing of the scale.

Further, preference reversals can be investigated with the retested data.

finement with a heteroscedastic probit. Second, the paper considers the likelihood of a preference reversal for both inconsistent and consistent choices when retested.

5.1 Choice Consistency and Scale

Results from the paired comparison choice experiment suggest that as respondents gain experience expressing their preferences they are less likely to commit an inconsistent choice. A heteroscedastic probit model is proposed to test the conjecture that increased choice consistency is associated with a reduction in the scale of the random utility model. Again the valuation function is represented as follows.

$$u_{ijk} = \alpha_k + \quad {}_{ijk}$$

item. Consider a choice between two items.

$$P_{rc} = Pr(u_{ijr} > u_{ijc}) = Pr(\alpha_r + \ _{ijr} > \alpha_c + \ _{ijc}) \quad (16)$$

$$P_{rc} = \Phi((\alpha_r - \alpha_c)/\sqrt{2}\sigma(j)) \quad (17)$$

The choice between an item and a dollar amount.

$$P_{rc} = Pr(u_{ijr} > t_{ijc}) = Pr(\alpha_r + \ _{ijr} > t_{ijc}) \quad (18)$$

$$P_{rc} = 1 - \Phi((t_{ijc} - \alpha_r)/\sigma(j)) \quad (19)$$

As before Φ represents the cumulative distribution function of a normal random variable and $\sqrt{2}\sigma(j)$ is the standard deviation of $\ _{ijc} - \ _{ijr}$. Particular attention must be paid to the functional form of the scale, $\sigma(j) = \lambda + \beta(1/j)$[8]. This function will either decrease to the level of λ with choice occasion or increase depending on the sign of β. Interpretation of these parameters is as follows. Researcher error, λ, is hypothesized to be constant. This parameter will also pick up any error generated by the respondent unrelated to choice occasion. A significant β coecient implies a significant magnitude of preference uncertainty as it represents a significant change in the scale of the model through choice sequence. As no other aspects of the experiment are changing a positive β represents refinement while a negative β represents fatigue or boredom. The hypothesis to be tested is $H_o : \beta = 0$ implying that choice sequence has no aect the scale of the model.

The items are grouped by type, either public or private, so that all items within type are assumed to have a single scale. Grouping the data smoothes the data across choice occasion. Although the data is randomized across

[8]This functional form is chosen by estimating the change and shape of the scale using two common methods. First the ratio of the standard deviation is estimated for dierent subsets of the data (Swait & Louviere, 1993) and second an equivalent method is used to estimate the change between groups of choices. Both methods suggest a function that decreases and levels o over the experiment.

choice occasion for each respondent the data tends to cluster reducing the observations across choice occasion. With this grouping there are five separate contributions to the likelihood function each representing a type of choice. These include public good versus public good, public good v. money, public v. private, private v. private, private v. money. Consider the choice between two public goods.

$$P_{rc} = \Phi((\alpha_r - \alpha_c) \quad \alpha_r$$

	Public	Private	Pooled
λ	370	203	296
	(57.9)	(57.3)	(80.1)
β	334	305	340
	(3.4)	(4.5)	(5.2)

Table 5: Heteroscedastic Probit Parameters

The log likelihood function.

$$lnL(y_{ijk};\alpha_k,\lambda_b,\beta_b,\lambda_p,\beta_p) = \sum_{i}^{n}\sum_{j}^{J}[(1-y_{ijk})lnP_{rc} + y_{ijk}lnP_{cr}] \quad (23)$$

The results in Table 5 are consistent with our expectations. First $\lambda_b = 370$ and $\beta_b = 334$ while $\lambda_p = 203$ and $\beta_p = 305$, all coefficients are significant ($p < .01$) t-statistics are in parentheses. These results were used to create Figure 3, the scale declines and levels off, similar to the proportion of choices which were inconsistent in Figure 1. The positive and significant β in an8F3h17.9an8F3m.84clinesijk

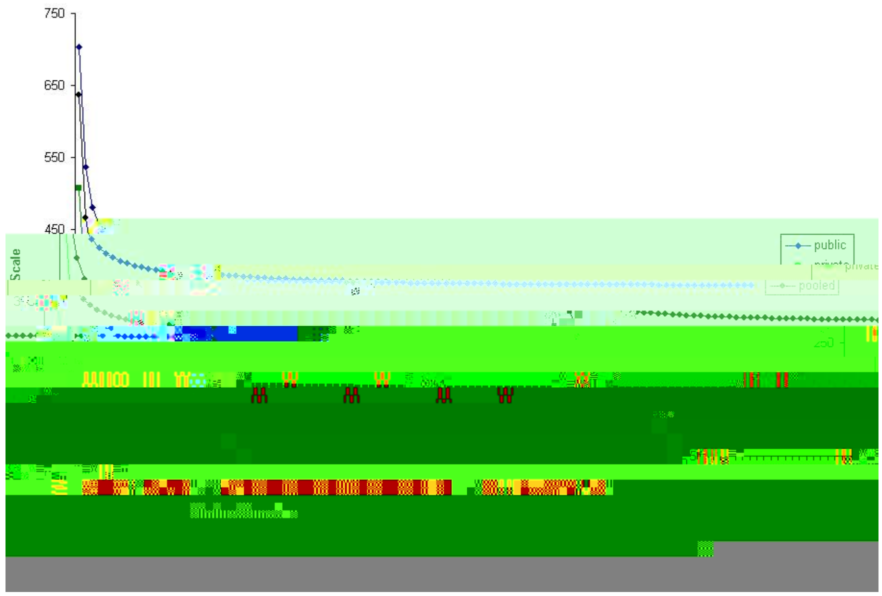

Figure 3: Graphical Representation of Preference Refinement

t-statistics appear in the parentheses. The restricted log likelihood equals $lnL_r = -26,544$ while the unrestricted log likelihood equals $lnL_u = -26,175$. Thus $-2(lnL_r - lnL_u) = 738$, this is compared to the 95% confidence measure for a $\chi^2_6 = 12.59$. Therefore we can reject the restrictions requiring a single parametrization. This suggests a significant difference between the scale of choices involving public goods than those involving private goods as expected.

5.2 Probability of an Inconsistent Choice

The model of preference uncertainty allowing for preference refinement predicts that an inconsistent choice becomes less likely as the scale narrows or the greater is the utility difference between the involved pair. This is tested using a probit model where the dependent variable, y_i, equals 1 if the choice is identified as inconsistent and 0 otherwise. Using the above result choice occasion serves as a proxy for the scale of the model. An increase in choice

	(1)	(2)
Constant	-.36	-.44
	(-15.3)	(-16.6
Choice Occasion	-.002	-.002
	(-8.8)	(-6.9)
Preference Score Difference	-.22	-.22
	(-56.9)	(-56.3)
Public	.05	.05
	(2.4)	(2.2)
Time		.01
		(6.7)

Table 6: Probability of an Inconsistent Choice

occasion represents a reduction in the scale. The preference score difference (PSD) between the items involved is used as an approximate measure of the utility difference. In addition a dummy variable is included indicating that the choice involves a public good. A probit model is developed to predict the probability of an inconsistent choice.

$$Pr(y_i = 1) = \Phi(x_i'\beta) \tag{24}$$

and

$$Pr(y_i = 0) = 1 - \Phi(x_i'\beta) \tag{25}$$

All 50,685 choices are pooled over individuals i and choice occasion j so the log likelihood becomes.

$$lnL(y_i;\beta) = \sum_{i} \sum_{j} [y_i ln\Phi(x_i'\beta) + (1 - y_i) ln(1 - \Phi(x_i'\beta))] \tag{26}$$

Results are shown in Table 6 and support the intuition of the model (t-statistics are in parentheses). Choice occasion is negative and significant reflecting that an inconsistent choice is less likely as the respondents progress

	Public	Private	Pooled
λ	336	175	270
	(66.3)	(64.7)	(91.1)
β	21	20	13
	(.5)	(1.0)	(.5)

Table 7: Retested Heteroscedastic Probit Parameters

through the experiment. A negative and significant preference score difference reflects that inconsistency is less likely the greater the utility difference of the involved items. Additionally choices including a public good, *Public*, are more likely to be inconsistent. The second column of Table 6 also controls for the amount of time taken for the choice, *Time*. The longer the choice took to make the more likely it is inconsistent. The amount of time taken reflects the difficulty of the choice, this may stem from greater uncertainty in the choice or indifference between the items.

5.3 Preference Reversals

Although the above results suggest a model of preference uncertainty allowing for preference refinement the data allow further investigation. All inconsistent choices are retested while 10 consistent choices per respondent are retested. A total of 3688 individual choices were identified as inconsistent (2256 or 61% were switched on retrial) while 3270 consistent choices were retested (290 or 9% were switched on retrial).

First, originally inconsistent choices that are switched when retested can be recycled into the original data set and the relationship between choice consistency and the scale of the random utility model can again be investigated. Recycling choices that were reversed with the benefit of preference refinement ought to reduce the magnitude of respondent error. In particular the scale is hypothesized to be constant across choice sequence. This is tested using a heteroscedastic probit but uses the data set obtained when the 2256

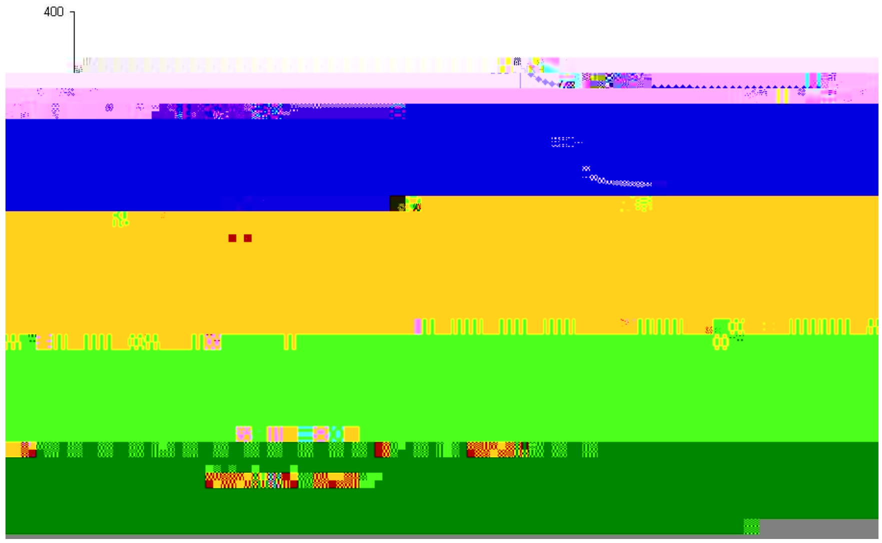

Figure 4: Graphical Representation of Retested Heteroscedastic Parameters

reversed inconsistent choices are in place.

Results are shown in Table 7 and further support preference refinement. Although respondent error is thought to exist within λ it is no longer significantly e□ected by choice occasion, β is no longer significant. Again Figure 4 depicts a graphical representation of these results.

Second, the data show substantial di□erences in the reversal rates of originally inconsistent and consistent choices. Originally inconsistent choices appear more likely to be switched when retested. To test this relationship two probit models are developed. For the inconsistent case the dependent variable, y_i, equals 1 if the inconsistent choice is switched and 0 otherwise. Similarly in the consistent subset the dependent variable equals 1 if the choice is reversed and 0 otherwise. Two exogenous variables are included, the PSD and the public good dummy. The expectation is that choices involving public goods are more likely to be reversed reflecting greater uncertainty. Greater

	Inconsistent	Consistent
Constant	-.09	-1.58
	(-3.3)	(-33.8)
Preference Score Difference	-.11	-.04
	(-23.8)	(-5.7)
Public	.14	.03
	(4.4)	(.29)

Table 8: Probability of a Preference Reversals

PSD is expected to increase the likelihood of reversal for inconsistent choices and decrease this likelihood for consistent choices.

Table 8 displays the results. The consistent subset results are as expected. The greater the preference score difference between the items the less likely an originally consistent choice is switched. However, the results from the inconsistent subset also imply that the PSD has a negative effect on the probability that an originally inconsistent choice is switched.

6 Conclusion and Discussion

Paired comparison choice experiments allow researchers to measure within individual choice consistency and to retest likely inconsistent choices. Using data from Peterson and Brown (1998) this paper supports the inverse relationship between the scale of a random utility model and choice consistency (Deshazo & Fermo, 2002). Within a model of preference uncertainty where preference are realizations from a valuation distribution this result is interpreted as a reduction in respondent error or preference refinement. Furthermore results suggest that choice inconsistency is less likely as the utility difference between the pair of items increases and as the standard deviation of the valuation distribution narrows. These results are consistent with the predictions of the model and intuition.

Preference Refinement is further supported by recycling inconsistent choices that were reversed when retested into the data set. Results, using this

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