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Understanding Preferences for Recycling Electronic Waste in California: A Contingent Ranking Study

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Abstract

Increasing stockpiles of electronic waste (e-waste) combined with low recycling rates are threatening human and environmental health because of the hazardous materials contained in electronics. Little is known, however, about consumers' preferences for e-waste recycling alternatives. Using a mail survey, we find that California households prefer curbside recycling, but drop-off recycling at regional centers is a close second choice. Our contingent ranking analysis indicates that consumers are willing to pay $0.13/(equivalent mile) to increase e-waste recycling convenience. Significant predictors include age, gender, ethnicity, attitudes toward the role of business in protecting the environment, as well as environmental attitudes and behavior.

Keywords: electronic waste, recycling, willingness to pay, contingent ranking, rank-ordered logit

Introduction

Increasing demand for consumer electronics combined with the trend to replace, rather than upgrade, older electronics has led to a new environmental challenge: electronic waste (e-waste). E-waste is a concern for public policy because it contains a wide variety of materials potentially toxic to human and environmental health. In addition to organic chemicals such as brominated flame retardants, consumer electronic devices (CEDs) contain heavy metals such as arsenic, cadmium, chromium, lead, and mercury (Townsend & Musson, 2006). Lead in televisions and computer monitors is of particular concern as cathode ray tubes contain, on average, 4 to 8 lbs of lead. Several empirical studies have examined the hazardous content and landfill leaching potential of CEDs. Lincoln et al. (2006) review this body of research and find that lead levels consistently exceed regulatory thresholds at state, national, and international levels.

The EPA (2003) estimates that approximately 2.2 million tons of e-waste are generated annually in the U.S., yet only 9% are recovered or recycled. One explanation for this low percentage is that consumers who want to recycle their e-waste often face high fees and limited recycling options (General Accounting Office [GAO], 2005). In fact, the GAO cites inconvenience as a major factor discouraging proper end-of-life management of used CEDs.

To deal with e-waste recycling, different programs have been created around the U.S., including permanent collection facilities (often co-located with municipal hazardous waste collection programs), drop-off special events (one- or multiple-day events held at a temporary site), retail collection programs, curbside recycling, and nonprofit or thrift retail collection (see California Integrated Waste Management Board [CIWMB], 2004, for an overview of the pros and cons of each model). To date, however, there does not appear to be any research that explores consumers' preferences for e-waste recycling programs. The cost to set-up and operate these programs is not trivial, so it is important to choose between them with a solid understanding of people's preferences and willingness to pay. This paper seeks to explore this issue through a contingent ranking (CR) study of Californian households' preferences for recycling alternatives and willingness to pay for electronic waste recycling.

Since 2001, when the California Department of Toxic Substances Control designated cathode ray tubes (CRTs) as universal waste, local governments have taken the primary role in diverting these items from landfills because of concerns about the environmental consequences of illegal dumping (CIWMB, 2004) and pressure from BAN and other NGOs to stop exports of e-waste to developing countries.[1] Given their financial situation, however, many municipalities are reluctant to finance the additional costs of managing e-waste. Most municipalities contract with independent recyclers for transporting and processing e-waste. Electronics collectors and recyclers make money from obsolete cell phones (which are often refurbished and re-sold) or older desktop computers (from their metal content), but they often turn down other items such as old TVs without a subsidies. Moreover, electronics recyclers find it typically more profitable to work with large businesses and government than with households because it is more expensive to collect materials from residential areas than from businesses. Indeed, the IAER (2006) estimates that transportation and collection make up 80% of the costs of municipal recycling programs (CIWMB, 2004; International Association of Electronics Recyclers [IAER], 2006).

In this study, we explore consumers' preferences for five hypothetical e-waste recycling alternatives: (1) "Pay As You Throw" where households contact a manufacturer and arrange to return items for a set recycling fee; (2) "Drop-Off Recycling at Regional Collection Centers"; (3) "Curbside Recycling"; (4) Drop-Off Recycling at Retail Locations"; and (5) a "Deposit-Refund

[1] See the Basel Action Network (BAN) at http://www.ban.org/.

Program at Retail Locations." Our results indicate that "Drop-Off Recycling at Regional Collection Centers" is the most preferred alternative. In fact, nearly two-thirds of respondents listed this alternative as either their first or second choice, which suggest that municipalities should seriously consider this option for their e-waste recycling programs. The least popular alternative is the "Pay As You Throw" with more than one-third of respondents identifying this as their fifth choice. Interestingly, respondents are equally divided between selecting the "Deposit-Refund Program at Retail Locations" as their first and least preferred choice.

After analyzing rankings of these recycling alternatives using a contingent ranking model, we find that Californian households are willing to pay $0.13/(equivalent mile) for increased e-waste recycling convenience.[2] Influential individual characteristics include age, gender, ethnicity, attitude toward the role of business in protecting the environment, and two factors summarizing environmental attitudes and behavior.

This paper is organized as follows. We first review briefly the contingent ranking literature, as well as some key household recycling papers from the economics and behavioral psychology literature. We then summarize our survey methodology and data in Section 3. This is followed by a presentation of the contingent ranking methodology and a discussion of our results. Finally, we conclude and present some policy recommendations.

[2] An "equivalent mile" is an estimate of convenience based on the distance a respondent lives from the relevant recycling location for our contingent ranking study (e.g. nearest electronics retailer).

Literature Review

Typically, economists rely on markets to analyze consumer preferences, but markets are often missing for various attributes of environmental quality. Environmental economists have therefore devised techniques to estimate environmental values based on stated preference data. As noted in Calfee et al. (2001), compared to revealed preferences data, stated preferences data offer several advantages: first, they allow exploring options not currently available to consumers; second, they can provide a more complete picture of preferences by asking respondents to rank a complete set of alternatives; and finally, revealed preferences yield explanatory variables with a wider range of variability. Stated preferences, however, may not translate into actual behavior and rankings may not always be consistent with standard microeconomic assumptions.

In this study, we rely on contingent ranking (CR) because of its usefulness in quantifying trade-offs in multidimensional problems and its ability to avoid some of the potential problems associated with contingent valuation (e.g., see Lareau & Rae, 1985; Garrod & Willis, 1998, or Foster & Mourato, 2000).[3] First, CR appears to be less demanding than CV: whereas CV respondents are asked to directly reveal their willingness to pay for a change in environmental quality, CR relies only on stated rankings for different options characterized by various attributes (including cost) in order to elicit willingness to pay. This is important since published research suggests that respondents are better able to rank alternatives than to directly reveal their valuation for these alternatives (Smith & Desvouges, 1986; Mitchell & Carson, 1989; Caplan et

[3] Some excellent references on contingent valuation (CV) include Carson, 1997; Carson et al., 1998; or Hanemann, 1994, 1996. CV may suffer from strategic response bias, starting point bias, and the ability to value only a single, well-defined scenario or attribute (Smith & Desvouges, 1986; Foster & Mourato, 2000). Starting point bias can occur as a result of the interviewer establishing an arbitrary initial value for the environmental good. Rather than indicate their true willingness to pay for the goods, respondents use that starting point to guide their responses, which may bias willingness to pay estimates. Strategic response bias stems from respondents deliberately distorting their true willingness to pay in order to influence the outcome.

al., 2002; Bateman et al., 2006). In addition, substitutes are typically made more explicit and all options are presented upfront in CR studies, which may encourage respondents to explore their trade-offs more in-depth. Irwin et al. (1993) also argue that the prominence of monetary measures in CV may increase the subjective weight of monetary losses compared to CR studies. These factors may partly explain observed differences between willingness to pay estimates obtained by CR and CV (Bateman et al., 2006).

Surprisingly, however, only a handful of CR studies have been conducted and published so far. This may be due to a lack of familiarity or to the need to rely on more sophisticated statistical techniques (Mitchell & Carson, 1989). Contingent ranking was first used to estimate the demand for electric cars (Beggs et al., 1981). Since then, its applications to the environment include water quality (Smith & Desvouges, 1986; Machado & Mourato, 2002; Bateman et al., 2006); diesel odor exposure (Lareau & Rae, 1989); forest biodiversity (Garrod & Willis, 1997); the visual impact of power lines and utility pipelines along recreational canals (Garrod & Willis, 1998); and the recreational values of national parks in Thailand (Isangkura, 1998). Contingent ranking has also been used to estimate health and biodiversity impacts associated with pesticide application (Foster & Mourato, 2000; Mourato et al., 2000) and to value various curbside waste disposal options (Caplan et al., 2002).

In their seminal work, Beggs et al. (1981) extend McFadden's (1974) random utility model to an ordered logit model that can estimate the probability of a complete ordering of preferences. Their findings suggest that consumers are not receptive to electric cars because of their limitations; in fact, they are willing to pay a large premium to overcome these limitations.

In their study of diesel vehicle odors, Lareau and Rae (1989) examine the trade-off between the benefits of reducing diesel odor exposure and their associated costs. They find ethnicity and the presence of children in the household to be statistically significant but not age, gender, and education. Overall, however, the most important variables are the trade-off variables cost and odor; demographic variables only contribute marginally to willingness to pay.

Garrod and Willis (1997) rely on contingent ranking to understand preferences between forest management standards in the UK and the preservation of biodiversity. In another CR study, Garrod and Willis (1998) ask a sample of canal users in the UK to rank different levels of utility service structures (e.g. pipelines, cables, etc.) along canals in order to assess their corresponding loss of amenity. Overall, recreational users are willing to pay approximately $1.2 million for a 1% reduction in the number of structures, but individual willingness to pay estimates ranges only between $0.06 and $0.16 for most respondents.

Environmental decision-making typically involves trade-offs between cost and environmental quality, but also between different dimensions of environmental quality (e.g. environmental improvement in one area could lead to environmental deterioration in another). Foster and Mourato (2000) show that CR can effectively analyze these trade-offs in their study of the impacts of pesticide use in the UK. They report that respondents will only tolerate a small number (7-8) of cases of human illness to save an entire species of farmland bird. Mourato et al. (2000) suggest that this methodology can be used to design a "pesticide tax" based on the aggregate willingness to pay to avoid pesticide damage.

We could not find any study that examines willingness to pay for electronic waste recycling. However, Caplan et al. (2002) rely on contingent ranking to evaluate curbside waste disposal options for households. Due to rising landfill disposal costs, the City of Ogden, Utah, surveyed its residents to understand their preferences for three curbside waste disposal alternatives that varied by price and quantity of material diverted from a landfill. Women, adults under 45 years, new residents, and households with annual incomes under $30,000 were more likely to prefer diverting more material from the landfill, even at a higher cost.

While CR has mostly been used to value environmental goods, it could be applied in principle to any public good. In health economics, conjoint analysis is most commonly used to elicit preferences for health care. This method only explores which option is most preferred by a respondent. Until recently, more complex choice methods have not been utilized. However, Slothuus et al. (2002) apply contingent ranking effectively to measure willingness to pay for health care. Although CR is more computationally involved, the additional information obtained from a complete ranking gives more precise estimates.

A handful of papers compare willingness to pay estimates from contingent ranking and contingent valuation methods (see, e.g. Smith & Desvouges, 1986; Isangkura, 1998; Georgiou et al., 2000). The first published study to specifically compare contingent valuation and contingent ranking is due to Smith and Desvouges (1986), who find that contingent ranking gives estimates three to four times higher than contingent valuation. In a study designed to assess appropriate fee levels for national parks in Thailand, Isangkura (1998) also finds that CR estimates tend to be higher than results from open-ended CV questions; Isangkura also reports that respondents find the ranking process easier to perform than a direct elicitation of their willingness to pay. Georgiou et al. (2000) find evidence consistent with both of these conclusions. They report that non-response is much less of a problem with CR and they conjecture that contingent valuation may create incentives for respondents to understate their true willingness to pay.

Studies on household recycling also provide relevant background information for this paper. The applied behavioral analysis literature identifies several theories to explain recycling (Mannetti et al., 2004). Porter, Leeming, and Dwyer (1995) model individuals as utility maximizers influenced by the costs and benefits associated with recycling. Others focus on individual attitudes and beliefs to explain pro-environmental behavior (Schultz & Oskamp, 1996; Ebreo et al., 1999). Excellent reviews of this body of literature can be found in Hornik et al. (1995), Oskamp (1995), and Schultz et al. (1995). In addition, Saphores et al. (2006) discuss key findings in the behavioral literature on household recycling published since 1990.

One of the goals of this paper is to examine the trade-offs individuals make between the cost and convenience of different e-waste recycling options. Several papers on household recycling emphasize the importance of convenience including Jenkins et al. (2003), Sterner and Bartelings (1999), Jakus et al. (1996; 1997), and Reschovsky and Stone (1994). Recycling convenience often depends on the level of development of the recycling infrastructure. As expected, Sterner and Bartelings (1999) find that a good physical infrastructure facilitates environmentally sound waste management practices.

Survey Description and Results

Data for this study were collected in 2004 through a mail survey to 3,000 randomly chosen California households, stratified by county in order to capture the diversity of the state's population. The overall response rate to our survey was 12.4% (357 returned answers from 2,848 valid households), which is at the low end of similar general population mail surveys (Alreck & Settle, 1995).[4] A possible explanation for our response rate is the length of our questionnaire (12 page), which may have seen demanding. In addition to collecting data for our CR study and information about e-waste stored by households, we wanted to explore the impact of environmental beliefs on people's preferences for e-waste recycling options. These questions

[4] Unfortunately, most environmental CR studies referenced herein do not report a response rate.

were summarized in factors PC1-PC3 described below, and two of these factors turned out to be statistically significant in our analysis, so we feel partly vindicated.

In general, our respondents are older, more educated, have higher incomes, and are less ethnically diverse than the general California population. Therefore, care is warranted when generalizing from our sample results to a larger population. A comprehensive discussion of our survey methodology and an analysis of the characteristics of our respondents can be found in Saphores et al. (2006).

Scenarios for our contingent ranking study were presented in the last section of our four-part survey. This section starts with a brief statement describing the e-waste problem. It then asks respondents to rank five e-waste recycling options characterized by price and level of convenience. We limited our respondents' choices because typically people can only rank four to six alternatives reliably, and they have difficulties with complex options (e.g., see Smith and Desvouges, 1986 or Foster & Mourato, 2002). When they face either of these situations, respondents may just randomly rank alternatives between their most and least preferred options. The five options are: (1) "Pay As You Throw"; (2) "Drop-Off Recycling at Regional Collection Centers"; (3) "Curbside Recycling"; (4) "Drop-Off Recycling at Retail Locations"; and (5) a "Deposit-Refund Program at Retail Locations."

Under Option 1, "Pay As You Throw," consumers would have to directly contact a manufacturer or authorized collector and pay a fixed recycling fee for e-waste. At the time of our survey (January-April 2004), this option was available through several manufacturers, so we consider it our status quo alternative. Option 2, "Drop-Off Recycling at Regional Collection Centers," mandates the collection of an environmental handling charge (EHC) on new retail sales of all consumer electronics. This EHC is used to finance recycling programs at regional recycling centers located throughout the state. We told respondents that these centers are located no more than 25 miles from their dwellings. Option 3, “Curbside Recycling,” would provide monthly curbside pick-up of e-waste for a flat rate. All households would have to pay this fee, regardless of use. Option 4, “Drop-Off Recycling at Retail Locations,” is similar to Option 2, but consumers could return e-waste to nearby retail stores; for our calculations, we used the actual distance between our respondents’ residence and retail stores such as Best Buy. Finally, Option 5, “Deposit-Refund Program at Retail Locations,” is similar to existing bottle and car battery deposit-refund programs. Consumers pay a deposit when purchasing new electronics and receive a refund when they return used CEDs to a retail location for recycling. In order to finance the program, a small EHC is subtracted from the original deposit. A copy of our CR questions is provided in the appendix. A description of the corresponding cost and convenience calculations is available from the authors upon request.

Modeling Willingness to Pay for Electronic Waste Recycling

Principal Components Analysis Methodology and Results

To model responses to our contingent ranking questions, we first perform a Principal Components Analysis (PCA) with varimax rotation to condense twelve survey questions on environmental attitudes and beliefs into a small number of factors (Kline, 1994). For PCA to be effective, intercorrelations between variables must be high enough to limit the number of factors, but if intercorrelations are too high, multicollinearity can be a problem. We use Bartlett’s test for sphericity to check the level of intercorrelation and the Kaiser-Meyer-Olkin (KMO) statistic to examine multicolllinearity. Cronbach’s alpha is used to measure factor reliability.

We develop three factors, normalized between 0 and 1, to reflect respondents' attitudes and beliefs about the environment (see Table 1). Overall, our three factors account for 64.52% of the variance between the individual variables.

Our first factor (PC1) reflects respondents' support for the environment and their willingness to pay higher prices and taxes to protect the environment. The second factor (PC2) captures an individual's attitudes and beliefs about environmental quality at the national, state, and local levels, while the third factor (PC3) synthesizes information on respondents' level of participation in environmental activities and organizations.

Contingent Ranking Methodology

The basis for modeling consumer behavior using contingent ranking is an extension of the random utility model (McFadden, 1974), which was developed by Beggs, Cardell, and Hausman (1981) to take advantage of complete preference rankings. Each alternative has some probability of being selected based on its characteristics, the characteristics of other alternatives, and features of each respondent.

The random utility model assumes that individuals select the alternative that maximizes their utility subject to a budget constraint (Smith & Desvouges, 1986). The utility function can therefore be written

$$U_{ij} = V\left(\boldsymbol{s}_i, q_{ij}, c_{ij}\right) + \varepsilon_{ij} \equiv V_{ij} + \varepsilon_{ij}, \qquad (1)$$

where $i = 1,\ldots,I$ indexes respondents and $j = 1,\ldots,J$ indexes e-waste recycling alternatives. $\boldsymbol{s}_i$ is a vector of demographic and socioeconomic attributes, q_{ij} is the convenience associated with recycling option j for respondent i; c_{ij} is the corresponding recycling cost; and ε_{ij} is a stochastic component. $V\left(\boldsymbol{s}_i, q_{ij}, c_{ij}\right) \equiv V_{ij}$ is the deterministic part of utility. It is commonly assumed to be a linear function of unknown coefficients denoted by β_k that need to be estimated from the data. Following Caplan et al. (2002), Garrod and Willis (1997), and Lareau and Rae (1989), we assume that V_{ij} can be written as a linear function of unknown parameters, as follows:

$$V\left(\boldsymbol{s}_i, q_{ij}, c_{ij}\right) = \beta_0 q_{ij} + \beta_1 c_{ij} + \sum_{m=2}^{M+1} \beta_m \left(q_{ij} s_{im}\right) + \sum_{n=M+2}^{M+N+1} \beta_n \left(c_{ij} s_{in}\right) + \varepsilon_{ij}. \qquad (2)$$

Here, β_m and β_n represent mutually-exclusive sets of parameters based on possibly overlaping sets of demographic and socioeconomic characteristics, $\boldsymbol{s}_m$ and $\boldsymbol{s}_n$. Thus, the two summation terms in Equation (2) represent interaction terms between the respondent's individual characteristics and the convenience of the recycling options, q_{ij}, or their associated costs, c_{ij}.

In Equation (2), we also assume that the error terms ε_{ij} are independently and identically distributed (i.i.d.) extreme value (Weibull) random variables, so for any real number t, we have

$$\text{Prob}\left[\varepsilon_{\text{j}} \le t\right] = \exp\left(-e^{-t}\right). \qquad (3)$$

If the conditional distribution of the utility for each choice is independent of the ranking of other choices (Koop & Poirier, 1994), i.e., if the assumption of the independence of irrelevant alternatives (IIA) holds, Beggs, Cardell, and Hausman (1981) show that the conditional logit specification can be extended to the rank-ordered logit model as follows:

$$\text{Prob}\left[U_{i1} > U_{i2} > \ldots > U_{iH} \text{ for } H \le J\right] = \prod_{i=1}^{I} \prod_{h=1}^{H} \left\{ \exp\left(V_{ih}\right) / \left[\sum_{m=1}^{h} \exp\left(V_{im}\right)\right]\right\}, \qquad (4)$$

where respondent i's ranking of the alternatives is indexed in the numerator by $h = 1,\ldots,H$ and $m = 1,\ldots,h$ indexes her rankings in the denominator of Equation (4). The corresponding log likelihood function is given by

$$L = \sum_{i=1}^{I} \sum_{h=1}^{H} V_{ih} - \sum_{i=1}^{I} \sum_{h=1}^{H} \left[\log \sum_{m=1}^{h} \exp\left(V_{im}\right)\right]. \qquad (5)$$

The primary goal of this study is to estimate people's preferences and willingness to pay for various electronic waste recycling options. Willingness to pay can be seen as the "payment" that makes an individual indifferent between two recycling options. As shown in Caplan et al. (2002), a person's willingness to pay for option $j \neq 1$, c^*_{ij}, is given by:

$$V\left(\boldsymbol{s}_i, q_{ij}, c^*_{ij}\right) - V\left(\boldsymbol{s}_i, q_{i1}, c_{i1}\right) = dV_{ij} \equiv \eta_{ij}, \tag{6}$$

where η_{ij} represents the difference between the error terms, ε_{i1}-ε^*_{ij}.

From Equations (2) and (6), the marginal willingness to pay can then be expressed as

$$E\left(\frac{dc^*_{ij}}{dq_{ij}}\right) = -\frac{\beta_0 + \sum_m \beta_m s_{im}}{\beta_1 + \sum_n \beta_n s_{in}}, \tag{7}$$

where dc^*_{ij} represents the difference between c^*_{ij} and c_{ij}.

A limitation, however, is the assumption of independence of irrelevant alternatives (IIA) which states that the probability of any one alternative being chosen over another alternative is not affected by any other alternatives (Smith & Desvouges, 1986). If there are close substitutes in the choice set, failure of this assumption can lead to inconsistent estimates of the coefficients. To test the IIA assumption, we follow Hausman and Ruud (1987) and compare the log-likelihood from the ranked data model to the sum of log-likelihoods from a series of most preferred alternative (MPA) models. We estimate a logit model for the most preferred alternative from the full choice set. We then estimate MPA models on the choice set that remains after the most preferred alternative from the previous model has been removed. The null hypothesis for the Hausman and Ruud test is that the log-likelihoods should be equal. Under the null hypothesis, the test statistic has a chi-square distribution with degrees of freedom equal to the difference between the number of parameters estimated for each model.

Contingent Ranking Results

From our 357 respondents, 18 did not complete the CR part of the survey, 10 gave us partial rankings, and 58 returned rankings with ties, so we only had 289 questionnaires to work with. Of these, only 164 respondents provided consistent rankings and 145 of them gave us complete responses to all of our socioeconomic, demographic, and environmental belief variables.

The seemingly large number of inconsistent rankings is clearly disappointing, but it is unfortunately not unusual in CR studies: in their excellent study of trade-offs between pesticide use, bird deaths, and the price of bread, Foster and Mourato (2002) actually find that approximately half of their respondents do not provide fully consistent rankings. A thorough analysis of our respondents' rankings reveals that many of the ranking inconsistencies are due to Option 4, "Drop-Off Recycling at Retail Locations." We conjecture that many respondents picked this option ahead of other ones that seemed more convenient simply because they did not plan to make a special trip to an electronics retailer to return obsolete electronics. This highlights the difficulty of designing CR studies with realistic options (which is desirable for exploring policy options), as opposed to more abstract alternatives as in Lareau and Rae (1989) or Foster and Mourato (2002), for example.

Although our sample of 145 respondents is not large, we want to emphasize that it is comparable with published CR studies, for which the number of valid responses ranges from 115 for Slothuus, Larsen & Junker (2002) to 932 for Garrod & Willis (1998). Fortunately, a comparison of the 145 respondents in our reduced sample with all of our respondents shows that they have essentially the same characteristics. In addition, there is no significant difference between the education levels of Californians and that of people in our reduced sample.

Table 2 presents the results from our contingent ranking model. Option 2 ("Drop-Off Recycling at Regional Collection Centers") was selected as the most preferred option by 34% of the respondents. This was closely followed by Option 2 ("Curbside Recycling"), most preferred by 29%. Very few respondents (6%) ranked "Drop-Off Recycling at Retail Locations" at their most preferred recycling alternative. The least preferred option was "Pay As You Throw" (Option 1) ranked last by 31% of respondents. Twenty-five percent ranked Option 5 ("Deposit-Refund Program") last. Option 2 was least likely to be ranked last (it was ranked last by only 2% of the respondents).

We used Stata (StataCorp LP, College Station, TX) to estimate our rank-ordered logit model. Table 3 presents results for three of the specifications we considered. Model A is our basic specification; it includes only the option-specific variables (convenience and cost of the recycling option) with no interactions. The coefficient for the convenience variable is statistically significant at the 0.05 level and the signs of the estimated coefficients for the option-specific variables match a priori expectations. For the convenience variable, respondents value negatively an increase in the distance to a recycling option because it represents an increase in the inconvenience of recycling. Similarly, respondents place a negative value on increases in recycling costs. This is consistent with economic theory: it reflects that people prefer convenience and low cost when it comes to recycling e-waste.

In Model B, we estimate a rank-ordered logit with interactions between the option-specific variables and our survey respondents' demographic and socioeconomic characteristics. These characteristics were selected based on our literature review as likely variables to influence pro-environmental behavior.

Our final specification is Model C. Here we use likelihood ratio tests to eliminate irrelevant variables and include only variables statistically significant at the 0.10 level. A number of previous contingent ranking studies have retained all variables regardless of statistical significance in order to calculate willingness to pay (WTP) levels (e.g., see Caplan et al., 2002 or Lareau & Rae, 1989, among others). Our findings indicate that including statistically insignificant variables in the calculation of willingness to pay can have a large impact (see below).

An important underlying assumption of contingent ranking is the independence of irrelevant alternatives. Surprisingly, only a handful of published contingent ranking studies report testing this assumption (the exceptions are Lareau & Rae, 1989; Foster & Mourato, 2000; and Caplan et al., 2002). Following Hausman and Ruud (1987), we first estimate the most preferred alternative from the full choice set. We then remove the first choice alternative and re-estimate the model with the second choice as the most preferred alternative. We continue through the full choice set and compare the sum of the log-likelihoods from these MPA models to the log-likelihood from the rank-ordered logit estimation. Based on our results, we reject the null hypothesis that the difference between the two procedures is equal. According to Hausman and Ruud (1987), although a misspecified ranked data model could lead to significant differences for the coefficients compared to the MPA model, it does not necessarily impact willingness to pay estimates since these are based on the ratio of coefficients.

Let us now estimate the marginal willingness to pay for e-waste recycling using Equation (7). Here we evaluate trade-offs between the cost and the convenience associated with each recycling alternatives $(\Delta c / \Delta q)$ to assess individual willingness to pay for one additional unit ("equivalent mile") of e-waste recycling convenience. For our final specification (Model C), we find that respondents are willing to pay $0.13/month/eq. mile in order to increase recycling convenience.

To illustrate this result, recall that the two most preferred recycling options in our sample are "Curbside Recycling" and "Drop-Off at Regional Centers." The latter has a lower recycling cost, but curbside recycling is likely more convenient. On average, our respondents live 8.2 miles from the nearest regional recycling facility. Based on this information, our results suggest that, in general, respondents would be willing to pay approximately $13 annually for curbside e-waste recycling as opposed to drop-off at a regional center (8.2 miles $\times$ $0.13/month $\times$ 12).

This compares to $0.44 per equivalent mile for the naïve model with only cost and convenience (Model A), and $0.45 per equivalent mile for Model B, where our calculations of the marginal rate of substitution includes non-significant variables. The discrepancy between Models A and C (our "best" model) can be explained by model misspecification due to omitted variable bias, since a number of variables missing from Model A are correlated with cost and convenience through interaction terms. This is clearly not the problem with Model B: a cursory look at Table 3 shows that Model C parameter estimates are within two standard errors of their Model B values (using Model B values). Unfortunately, Model B estimates of our parameters are known quite imprecisely because it includes many redundant variables.

Evaluating the effect of individual characteristics is more involved due to the interaction terms. In order to examine the overall impact of each characteristic on willingness to pay, we define a baseline respondent and systematically work through Equation (7), changing each binary variable to see how it affects $\Delta c / \Delta q$. Our baseline respondent is a white male between the ages of 36 and 65 years who believes that business plays a major role in protecting the environment. He scores 0.6 for PC1 and 0.5 for PC2. Descriptive statistics for our key variables are shown in Table 4.

Age plays an important role in our model. Compared to our baseline respondent, we find that young adults (ages 18-35) and older adults (over 65 years) are willing to pay more to increase e-waste recycling convenience (+$0.11/eq. mile and +$0.04/eq. mile, respectively). Several possibilities could explain this result. Even though many older adults live on fixed incomes, convenience may be quite important to them. For example, the higher cost of curbside recycling might outweigh the inconvenience of driving to a recycling location. Young adults tend to be major consumers of electronics (Mintel USA, 2005; Enpocket, 2005) so they may be more aware of the potential environmental impacts of CEDs.

Interestingly, we find that non-Whites are willing to pay more for e-waste recycling than Whites (+$0.21/eq. mile holding other variables at baseline values). Although the relationship between ethnicity and willingness to pay for environmental goods or recycling behavior has not been widely analyzed, some studies suggest that Whites are willing to pay more for "green" products and that they are more likely to recycle (Hownestine, 1993; Johnson et al.; Zarnikau, 2003). One possible explanation for our seemingly contradictory result is that non-Whites in our study are far more likely to indicate that the environmental quality had worsened in the past 10 years. Hence, they may be willing to pay higher prices to increase recycling convenience in order to protect the environment.

Our results for gender are consistent with empirical studies indicating that women are willing to pay higher prices for products with an environmental benefit (e.g., see Brown, 2003; Loureiro & Hine, 2002; Lockie et al., 2004). Holding all other variables at their baseline values, women are willing to pay $0.05/eq. mile more for e-waste recycling than men.

For our two factors, PC1 and PC2, we incrementally change their values over their 0 to 1 range and examine the impact on WTP holding all other variables at their baseline values. Results for both factors are consistent with our expectations. As PC2 increases, WTP levels also increase, which indicates that individuals who believe that environmental quality has worsened in recent years are willing to pay higher prices for increasing e-waste recycling convenience. Similarly, as a respondent's PC1 score increases, WTP levels also increase. A higher PC1 score indicates more emphasis on the environment than on economic growth. Thus, as support for the environment increases, respondents are willing to pay more for recycling convenience.

Policy Considerations and Conclusions

End-of-life management of used electronics is a significant concern, particularly for municipal governments with limited budgets. The number of recyclers and recycling programs has increased substantially in the past few years, yet there is still considerable room for improvement (IAER, 2006). Our study sheds light not only on the amount consumers are willing to pay to increase recycling convenience, which we estimate to be approximately \$0.13/(equivalent mile), but also on their preference for different types of e-waste recycling program. Our paper also makes a contribution to the contingent ranking literature by showing that people's environmental beliefs are statistically significant and play a role in their willingness to pay for recycling convenience.

The most popular recycling alternative among our five options was "Drop-Off at Regional Centers," preferred by 34% of our respondents. This was closely followed by "Curbside Recycling," ranked first by 29% of respondents. The status quo alternative, "Pay As You Throw," was the least preferred option, ranked last by more than one-third of our sample.

Although “Drop-Off at Retail Locations” received the fewest votes for first choice, respondents were evenly split between this option and “Drop-Off at Regional Centers” for second choice (approximately 30% of respondents ranked each option second). Results for the “Deposit-Refund Program at Retail Locations” are interesting as this option was ranked most and least preferred by almost the same amount (26% and 29%, respectively).

For policymakers, it appears that developing e-waste recycling programs using regional collection centers may be the best alternative for the majority of Californians. Drop-off recycling programs tend to be less expensive to operate than curbside recycling and our results indicate that the former are preferred by most households (it was ranked first or second by ore than 60% of our respondents). In our contingent ranking scenarios, financing for the “Drop-Off Recycling at Regional Collection Centers” option would be provided through an Environmental Handling Charge imposed on new retail sales of consumer electronics. This would reduce the burden on municipalities and it would decrease the likelihood of illegal dumping since consumers would not face end-of-life fees.

It may also be desirable to organize occasional curbside e-waste pick-ups. Such programs could be implemented in higher density communities with a relatively high number of residents over 65 years or between the ages of 18-35 years since people in these age groups seem willing to pay higher prices for increased convenience.

Finally, since our results are based on a relatively small sample that reflects imperfectly characteristics of California’s population, additional research is needed to confirm our results.

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Table 1: Principal Components Analysis of Environmental Attitudes and Behaviors

Survey Items and Principal Components	Scoring coefficients	% Variance explained v; Cronbach's α; KMO; Bartlett.
PC1 – Money matters and the environment		v = 20.46%
1. "Environmental protection should be a priority, even if it slows economic growth and causes some job losses."	0.329	α = 0.797 KMO = 0.740
2. "I would agree to a tax increase if the extra money was used to prevent environmental damage."	0.602	Bartlett: p<0.001
3. "I would buy things at higher than usual prices to protect the environment."	0.611	
4. "Do you think we're spending too much money, too little money, or about the right amount on environmental protection?"	0.360	
PC2 – Environmental quality attitudes		v = 23.98%
1. "The word environment is used to describe the world around us – land, sea, air, rivers, lakes, climate, etc. Do you feel that the environment has become better or worse in the past 10 years?"	0.433	α = 0.716 KMO = 0.686 Bartlett: p<0.001
2. Environmental quality in the U.S. (very good, good, fair, or poor)	0.391	
3. Environmental quality in California (very good, good, fair, or poor)	0.574	
4. Local environmental quality (very good, good, fair, or poor)	0.448	
PC3 – Environmental activism		
1. "During the last 12 months, have you attended a meeting or signed a letter or petition aimed at protecting the environment?"	0.504	v = 20.08% α = 0.696
2. "During the last 12 months, have you contributed to an environmental organization?"	0.587	KMO = 0.648 Bartlett: p<0.001
3. "During the past 12 months, have you participated in any local environmental activities such as Earth Day, Beach Clean-Up, etc.?"	0.568	

A higher value of PC1 indicates more support for the environment and a greater willingness to pay more to protect the environment. A higher value of PC2 indicates less concern for the environment and a belief that environmental quality has improved recently. A higher value of PC3 indicates more involvement with environmental activities and organizations. Cronbach's alpha indicates how well a set of variables measures a single underlying construct; it is high when inter-item correlations are high. KMO measures sampling adequacy and tests whether partial correlations between variables are small; it should be >0.5 for a satisfactory factor model. Bartlett's test of sphericity checks whether the correlation matrix of the variables differs significantly from the identity matrix; if not, the factor model is inappropriate.

Table 2: Summary of Rankings of Recycling Alternatives

Recycling Alternative	**First Choice** (%)	**Second Choice** (%)	**Third Choice** (%)	**Fourth Choice** (%)	**Fifth Choice** (%)
Option 1: Pay As You Throw	15.0	20.0	15.7	17.9	31.4
Option 2: Drop-Off at Regional Recycling Centers	33.6	30.1	19.6	14.7	2.1
Option 3: Curbside Recycling	29.1	19.1	19.9	15.6	16.3
Option 4: Drop-Off at Retail Locations	6.4	30.0	25.0	30.7	7.9
Option 5: Deposit-Refund Program at Retail Locations	26.1	21.8	10.6	13.4	25.2

Notes. This table is based on 145 consistent rankings with complete demographic and socioeconomic variables of interest. Totals may not sum to 100 due to rounding.

Table 3: Model Estimation Results

Variable	Model A	Specification Model B	Model C
Option-specific attributes			
Convenience of recycling option (in "equivalent miles")	-0.0089** [0.004]	-0.2080*** [0.063]	-0.1089*** [0.026]
Cost of recycling option	-0.0202 [0.052]	-0.8260* [0.425]	-0.3934*** [0.148]
Interactions between option-specific attributes and individual characteristics			
Convenience * PC1 "Money and the Environment"		0.0521** [0.021]	0.0520*** [0.012]
Convenience * PC2 "Environmental Quality Attitudes"		0.0136 [0.026]	0.0369*** [0.012]
Convenience * PC3 "Environmental Activism"		-0.0276 [0.021]	
Convenience * Gender (female = 1)		0.002 [0.011]	
Convenience * Age 18-35 years (yes == 1)		-0.1716*** [0.048]	-0.1043* [0.058]
Convenience * Age > 65 years (yes = 1)		-0.0060 [0.009]	-0.0148** [0.007]
Convenience * White (yes = 1)		0.1479** [0.059]	0.0777*** [0.024]
Convenience * Hispanic (yes = 1)		0.0556 [0.072]	
Convenience * College education (yes = 1)		0.0134* [0.008]	
Convenience * Income <$40K (yes = 1)		0.0035 [0.012]	
Convenience * Income >$80K (yes = 1)		0.0004 [0.009]	
Convenience * Republican (yes = 1)		0.0008 [0.009]	
Convenience * Democrat (yes = 1)		0.0048 [0.011]	
Convenience * Role of individual in protecting the environment (major = 1)		0.0028 [0.0228]	
Convenience * Role of business in protecting the environment (major = 1)		-0.0183 [0.023]	-0.0276*** [0.008]
Convenience * Role of government in protecting the environment (major = 1)		0.0259 [0.016]	
Convenience * Knowledge of toxics in e-waste		0.0041 [0.011]	
Convenience * Knowledge of CA's CRT law (yes = 1)		0.0074 [0.008]	

Cost * PC1 "Money and the Environment"		-0.2209	
		[0.377]	
Cost * PC2 "Environmental Quality Attitudes"		0.4800	0.5020**
		[0.342]	[0.250]
Cost * PC3 "Environmental Activism"		-0.2281	
		[0.241]	
Cost * Gender (female = 1)		0.3587**	0.2556**
		[0.148]	[0.109]
Cost * Age 18-35 years (yes = 1)		-0.5873***	-0.4640**
		[0.149]	[0.221]
Cost * Age >65 years (yes = 1)		0.0440	
		[0.158]	
Cost * White (yes = 1)		0.1532	
		[0.293]	
Cost * Hispanic (yes = 1)		-0.0577	
		[0.335]	
Cost * College education (yes = 1)		0.0983	
		[0.137]	
Cost * Income <$40K (yes = 1)		-0.0242	
		[0.183]	
Cost * Income >$80K (yes = 1)		-0.1061	
		[0.155]	
Cost * Republican (yes = 1)		0.1378	
		[0.187]	
Cost * Democrat (yes = 1)		0.1318	
		[0.160]	
Cost * Role of individual in protecting the environment (major = 1)		0.2612 [0.179]	
Cost * Role of business in protecting the environment (major = 1)		-0.3148* [0.177]	
Cost * Role of government in protecting the environment (major = 1)		0.2273 [0.169]	
Cost * Knowledge of toxics in e-waste		0.1678	
		[0.168]	
Cost * Knowledge of CA's CRT law (yes = 1)		0.1182	
		[0.139]	
Unrestricted log-likelihood	-679.68	-609.44	-679.68
Restricted log-likelihood	-676.34	-571.85	-652.98
Pseudo R^2	0.0049	0.0617	0.0393
Wald Chi-Square	5.14	142.83	50.95
	d.f. = 2	d.f. = 38	d.f. = 11
	p = 0.0766	p <0.0001	p<0.0001
Willingness to Pay	$0.44/eq. mile	$0.45/eq. mile	$0.13/eq. mile

Notes: (1) Number of observations = 725; Number of groups = 145.

(2) Robust standard errors are shown in brackets.
(3) “Equivalent miles” refers to an estimate of convenience based on the distance a respondent lives from the relevant recycling option (e.g. nearest electronics retailer). For the “Pay As You Throw” and “Deposit-Refund” options, five equivalent miles are added to the distance calculation to account for the added inconvenience of contacting the manufacturer for e-waste recycling information and packaging the item for mailing, in addition to wait times at their local post office (for the former option) or electronics retailer (to obtain refund for the latter option).
(4) *, **, *** identify coefficients significant at the 10%, 5%, and 1% levels respectively.
(5) Pseudo R^2 is an alternate goodness-of-fit measure for probabilistic choice models (McFadden, 1974). It is calculated as 1 – (restricted log-likelihood/unrestricted log-likelihood).

Table 4: Descriptive Statistics for Key Variables

Variable	Mean	S.D.	Min.	Max.
Option-specific attributes				
Convenience of recycling option (in "equivalent miles")	10.73	17.78	0	93
Cost of recycling option (in dollars)	1.99	0.94	0.29	3
Individual characteristics				
PC1 "Money and the Environment"	0.60	0.21	0	1
PC2 "Environmental Quality Attitudes"	0.50	0.22	0	1
Age between 18-35 years (yes = 1)	0.11	0.32	0	1
Age > 65 years (yes = 1)	0.21	0.41	0	1
Ethnicity (white = 1)	0.80	0.40	0	1
Role of business in protecting the environment (major = 1)	0.77	0.43	0	1
Gender (female = 1)	0.36	0.48	0	1

Notes: (1) "equivalent miles" refers to an estimate of convenience based on the distance a respondent lives from the relevant recycling option (e.g. nearest electronics retailer). For the "Pay As You Throw" and "Deposit-Refund" options, five additional miles are added to the distance calculation to account for the added inconvenience of contacting the manufacturer for e-waste recycling information and packaging the item for mailing, in addition to wait times at their local post office (for the former option) or electronics retailer (to obtain their refund for the latter option).
(2) PC1 and PC2 are both treated as continuous indexes. They are normalized to be between 0 and 1. All other independent variables are binary (0 or 1) indicator variables.

Appendix: Contingent Ranking Questions

This is the last part of our survey. The other three parts ask questions about: 1) The environment, recycling, and involvement with voluntary organizations; 2) Used electronics and e-waste; and 3) Socio-economic and demographic characteristics. This part was printed on two facing pages so respondents could see the description of all five options when ranking them.

In this final section, please read the following information and then rank the various e-waste recycling options from most preferred (1) to least preferred (5).

The State of California is currently considering different policies to foster the recycling of used electronic products. In 2000, more than 4.6 million tons of consumer electronics and appliances were discarded into landfills or burnt in incinerators. As you may know, many components of consumer electronic devices such as cellular phones, televisions, and computers contain toxic materials that might threaten public health and the environment. According to the U.S. Environmental Protection Agency, 70% of the heavy metals such as mercury and cadmium and 40% of the lead in landfills comes from discarded electronic devices.

Recycling provides many benefits to society: it extends the life of existing landfills, provides jobs in the recycling industry, and improves our overall environmental quality. For these reasons, California recently passed a law that makes it illegal to dispose of cathode ray tubes from televisions and computer monitors in landfills. This legislation also makes it illegal to dispose of many other consumer electronics devices in California landfills after 2006.

To craft better policies for managing e-waste, we would like you to **rank the five options presented below in order of preference from most preferred to least preferred**. The prices listed are average prices; in some cases, they may vary slightly depending on location.

Option A: *Pay As You Throw*

With this option, consumers need to directly contact the manufacturer or an authorized collector to recycle an electronic product. This option is currently offered by companies such as HP, Dell and Sony where consumers mail back used electronics for recycling at a set fee. A sample price list for representative items is shown below. Based on the typical useful product life, the approximate monthly cost for this option is $2.31.

Item	Price ($)
Desktop Computers/CPU (without monitor, keyboard, or mouse)	20.00
Televisions (small/large)	15.00/30.00
Monitors (small/large)	15.00/25.00
Laptop Computers	10.00
Consumer Electronic Devices (small/large)	5.00/15.00

Option B: *Drop-Off Recycling at Regional Centers*

With this option, an Environmental Handling Charge (EHC) is applied to the sale of all new consumer electronic devices. This charge varies by product and is used to pay for recycling programs. Consumers must return used electronics to regional recycling centers. A regional center would be located no farther than 25 miles from your house. Based on the typical useful product life, the approximate monthly cost for this option is $1.76.

Item	EHC ($)
Desktop Computer/CPU (without monitor, keyboard, or mouse)	25.00
Televisions (small/large)	18.00/35.00
Monitors (small/large)	18.00/30.00
Laptop Computers	10.00
Consumer Electronic Devices (small/large)	1.50/4.00

Option C: *Curbside Recycling*

Monthly curbside pick-up of all consumer electronic devices is provided at a flat fee for all households, regardless of whether they use the service or not. The fee is $3.00 per month in addition to the monthly charge for garbage and curbside household waste recycling pick-up. Currently, the average monthly charge for garbage pick-up in California is $15.40 and the average curbside recycling charge for plastics, cans, or newspapers is $2.40.

Option D: *Drop-Off Recycling at Retail Stores*

As with Option C, an Environmental Handling Charge (EHC) is applied to the sale of new consumer electronic devices to pay for recycling programs. While the EHC for this program is slightly higher, consumers are able to return their used electronics to convenient retail locations such as Circuit City or Best Buy. Based on the typical useful product life, the approximate monthly cost for this option is $2.59.

Item	**EHC ($)**
Desktop Computers/CPU (without monitor, keyboard, or mouse)	35.00
Televisions (small/large)	25.00/55.00
Monitors (small/large)	25.00/45.00
Laptop Computers	12.00
Consumer Electronic Devices (small/large)	2.25/6.75

Option E: *Deposit-Refund System*

This option works like bottle or car battery deposit/refund programs. Consumers pay a deposit on the purchase of new consumer electronic devices. This deposit varies by item (see below). Upon returning the product to an authorized retail location such as those in Option D, consumers recover their deposit less a small Handling Charge. Based on the typical useful product life, the monthly average is approximately $2.88 for deposits and $2.59 for refunds.

Item	**Deposit ($)**	*	**Refund ($)**
Desktop Computer/CPU (w/o monitor, keyboard, or mouse)	40.00	*	35.00
Televisions (small/large)	27.50/60.00	*	25.00/55.00
Monitors (small/large)	27.50/50.00	*	25.00/45.00
Laptop Computers	13.00	*	12.00
Consumer Electronic Devices (small/large)	2.50/7.50	*	2.25/6.75

Ranking:

Please rank the five options presented above from most preferred (1) to least preferred (5) based on the different characteristics of the alternatives including costs, program features, etc. There is no correct way to order these options. The best answer is the one that ranks the options in the order that you most prefer. Please make sure to rank each option.

Option	**Your Ranking (Most Preferred=1, Least Preferred=5)**
(A) Pay As You Throw	**Rank** ________________
(B) Drop-Off Recycling at Regional Centers	**Rank** ________________
(C) Curbside Recycling	**Rank** ________________
(D) Drop-Off Recycling at Retail Stores	**Rank** ________________
(E) Deposit-Refund System	**Rank** ________________