An Application of Mixed Logit Estimation in the Analysis of Producers' Stated Preferences

Gorm Kipperberg
Assistant Professor
Department of Agricultural and Resource Economics
Colorado State University
Ft. Collins, CO 80523-1172
Ph: (970) 491-0887
Fax: (970) 491-2067
gorm.kipperberg@colostate.edu

Craig A. Bond*
Assistant Professor
Department of Agricultural and Resource Economics
Colorado State University
Ft. Collins, CO 80523-1172
Ph: (970) 491-6951
Fax: (970) 491-2067
craig.bond@colostate.edu

Dana L. Hoag
Professor
Department of Agricultural and Resource Economics
Colorado State University
Ft. Collins, CO 80523-1172
Ph: (970) 491-
Fax: (970) 491-2067
dana.hoag@colostate.edu

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Abstract:

This paper analyzes Colorado Corn producers' preferences over both private- and environmental public-good production system attributes. Current production practices are characterized by intensive water and chemical use, resulting in non-point source pollution to water bodies as well as soil erosion problems. Data from a stated preference survey are employed to analyze key attributes of experimentally configured irrigation systems, proposed as alternatives to current practices. Panel mixed logit estimations find positive preferences for profit, risk reduction, and, importantly, systems with less environmental impact in terms of nitrate leaching and soil erosion. The results also find presence of significant preference heterogeneity and a complementary relationship between the two environmental attributes. Analysis of this kind can be used by policy makers to predict behavioral responses associated with introduction of new technologies, or to assess welfare implications of agricultural policy changes and stricter environmental regulations.

Keywords: Agricultural production, profit-maximization, environment, mixed logit, stated preference, attribute part-worth, nitrate leaching, soil erosion, risk

Econlit Subject Areas: C10, D62, Q12, Q15, Q51

* Corresponding author.

1. INTRODUCTION

Do producers care about their environmental impacts? The canonical microeconomic model of the firm would suggest "no" by assuming strict profit maximization. However, multiple strands of economic literature have challenged this view (Johnson, 1966; Baumol, 1967; Furubotn and Pejovich, 1972; Court and Woods, 1970; Lin, Dean, and Moore, 1974; Navarro, 1988; van Kooten, Weisensel, and Chinthammit, 1990; Foltz et al., 1995). A broader and more realistic view of the firm permits consideration of multiple management objectives or production system attributes.[1] Many non-profit objectives or attributes may have dynamic implications for future profits, whereas for other ones, this may not be the case. For example, some producers may contemporaneously maximize sales such as to increase market shares or market power, with expectation of positive impacts on future profits (Williamson, 1966). Another example is *green* production, where the supply of more environmentally-friendly products into markets can either command future price premiums, or be a way for a producer to build social capital for the purpose of attaining an overall favorable standing with consumers (Innes, 2006; Moraga-Gonzalez and Padron-Fumero, 2002; Akerlof and Kranton, 2000; Andreoni, 1990; Nyborg and Rege, 2003).

[1] In this paper the terms "objective" and "attribute" or "feature" are used interchangeably. The term *attribute* is typically used in the literature on consumers' preferences for marketed and non-market economic goods that can be viewed as an attribute bundle (Lancaster, 1971). Similarly, agricultural production can be viewed from a multi-attribute or multi-production objective perspective, with each attribute of the production process carrying some weight in the farmer's management decisions.

In other cases, profit inertia is not so obvious. For instance, if the distinction between owners, shareholders, and management is blurred or overlapping, decision-making agents may bring personal motivations into the firm management processes, such as a desire to contribute to public goods, conform to social norms (e.g., to avoid social stigmatization as socially irresponsible)**,** attain social status, and other non-pecuniary motivations proposed in consumer choice contexts (Andreoni, 1990; Akerlof and Kranton, 2000; Brock and Durlauf, 2001; Brekke, Kverndokk, and Nyborg, 2003; Nyborg and Rege, 2003). In the case of agricultural production, it is likely that both fully privately appropriable benefits and costs, and attributes of production with social and environmental implications (impacting quasi-public goods such as soil and water) are being considered by farmers. In addition to the impacts on profit or risk, the concern over these attributes may be triggered by increased self-awareness as well as public scrutiny regarding negative externalities associated with modern agriculture (Foltz et al., 1995; van Kooten, Weisensel, and Chinthammit, 1990; Hayashi, 2000; Moran, et al., 2007).[2]

The overall goal of this paper is to provide an empirical contribution to the literature on multiple producer objectives by analyzing the extent to which agricultural producers incorporate environmental considerations into their management decisions. Towards this goal, the paper presents an analysis of the preferences of a particular sub-set of agricultural producers (Colorado corn farmers), with a focus on the salient environmental public-good attributes of their production

[2] Multiple-objectives in agricultural production are studied in, for example, Foltz et al. (1995), Rehman and Romero (1993), Hayashi (2000), Brodt, Klonsky, and Tourte (2006), Poe (1999), and Basarir and Gillespie (2006).

practices. Specifically, corn production is characterized by intense water and chemical usage, resulting in water pollution problems as well as soil erosion that can severely damage natural aquatic-environments (Page, 1997).[3] The data employed come from a stated preference survey that elicited contingent ratings of experimentally configured irrigation systems, proposed as alternatives to current practices. These alternative systems were framed in terms of four explicit attributes - *per acre profits*, *crop-loss risk*, *nitrate leaching*, and *soil erosion* - with the former two considered strictly private attributes and the latter two intended to capture environmental attributes within the empirical context.[4]

Stated preference methods have their origins in the environmental valuation, marketing, and transportation literatures, and are based on the theoretically-consistent random utility model (Luce, 1959; McFadden, 1974; Louviere, Hensher, and Swait, 2000). The novelty of these methods is their ability to generate estimates of the value of goods and their attributes about which markets produce imperfect (or no) *revealed preference* information. In this paper's empirical context, these methods are particularly useful as the choices farmers make with respect to non-profit aspects in actual management decisions are not directly observable, nor is it likely that revealed preference data would, if available, exhibit sufficient quasi-experimental variation in production attributes. By using a stated preference

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[3] Agricultural producers may care about environmental aspects of production for a variety of reasons, including potential profit inertia, through the non-pecuniary motivations mentioned above, or simply by deriving utility from the environmental quality of the farm.

[4] Detailed discussions of the environmental impact of Colorado corn production can be found in Dennehy, et al. (1998), USDA-NRCS (1996), and Sprague, Kimbrough, and Ranalli (2002).

approach, however, this paper is able to identify the trade-offs between private and quasi-public objectives. Furthermore, because of the central importance of irrigation usage in corn production, it is possible to frame the experimental elicitation of preferences in a realistic and unambiguous way; to wit, through hypothetical changes in irrigation systems, while holding constant management aspects that in actuality could be confounding or endogenous (e.g., as such input usage choices).[5] Lastly, since the goal is to investigate the existence of multiple production objectives, it is natural to adopt the same random utility model framework employed in consumer choice analysis, which degenerates to strict profit maximization, if per acre profits is the only attribute found to be of significance.

While stated preferences methods are common in analyses of consumer preferences for both new (or re-configured) market good and non-market goods and services, these methods have not been widely utilized in producer studies. A few exceptions are Hudson and Lusk (2004) who perform an experiment related to producer contracting, Birole, Smale, and Gyovai (2006) who use choice experiments to estimate Hungarian farmers' preferences for agro-biodiversity, and Siikamaki and Layton (2006) who study Finish forest owners' willingness to participate in biodiversity conservation programs. Hence, a major contribution of this paper is to offer a rare example of the usefulness of employing a stated preference approach in producer choice settings.

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[5] Experimental *framing* is one of the most important challenges in stated preference survey design. At the same time, the ability to experimentally hold constant things that are not of primary research focus is one of the major advantages of stated preference methods relative to revealed preference methods (Louviere, Hensher, and Swait, 2000; Ajzen, Brown, and Rosenthal, 1996).

As such, the research objectives and concomitant contributions to the economics literature of this paper are to: 1) analyze producer preferences over multiple production system attributes, 2) investigate the extent to which agricultural producers have preferences for reducing their environmental impacts, and 3) illuminate the usefulness of stated preference methods in producer analysis. Furthermore, the analysis implements the most advanced discrete choice econometric technique, namely, the panel mixed logit model with correlated parameters (Train, 2003). Lastly, by recovering the monetary part-worth of attributes, their implied trade-offs, and quantifying preference heterogeneity, the results should be of great interest to policy makers who wish to investigate the impacts of voluntary or mandated adoption of new technologies through agricultural policy changes or stricter environmental regulations.

The rest of the paper proceeds as follows. The next section describes the empirical context and the survey data. Subsequently, the conceptual framework and empirical models are presented, followed by a section discussing econometric results. The last section offers concluding remarks, points out limitations of the analysis, and suggests extensions for future research.

2. EMPIRICAL SETTING AND THE STATED PREFERENCE DATA

The study area, namely the South Platte River Valley Basin and the Irrigated Plains, is characterized by diverse soil types, land uses, and other natural and human-modified features such as streambanks and vegetation, which likely influence environmental impacts of agricultural production (Dennehy, et al., 1998). Nevertheless, a large percentage of water quality degradation is a result of agricultural production, and pesticides, nitrate, and sediment have been detected in both surface and groundwater (USDA NRCS, 1996; Dennehy, et al., 1998). Siltation of stream beds is strongly related to soil erosion, and reduces surface water quality through a combination of sediment deposition and nutrient loading (USDA NRCS, 1996). Contaminated areas are typified by irrigated corn monoculture on well to excessively well drained soils (USDA NRCS, 1996).

In light of these considerations, this study includes nitrate leaching and soil erosion as environmental attributes in the definition of hypothetical irrigation systems used in the stated preference survey. Specifically, multiple irrigation systems consisting of four attributes each (profits, risk, nitrate leaching, and soil erosion) were defined using an incomplete six block orthogonal fractional-factorial design obtained from the software *SAS* (see Louviere, Hensher, and Swait, 2000 for experimental design methods). Each attribute was defined as one of three possible levels (low, medium, or high) for each system, developed in conjunction with experts in the Soil and Crop Science and Agricultural and Resource Economics departments at Colorado State University, and respondents were randomly assigned to a block corresponding with a unique survey. For the private attributes, profits (*P*) was described as dollar increases on returns per acre over cost, while the risk (*R*) was defined as the percentage chance that at least half of the corn crop would be lost. For the environmental attributes, nitrate leaching (*N*) was described in pounds per acre, whereas the soil erosion (*E*) was defined in terms of tons of soil per acre. Details on the experimental design are summarized in Table 1.

Relative preferences for the hypothetical irrigation systems were elicited through a contingent rating format.[6] Respondents were presented with six alternative irrigation system configurations, and asked to rate each of them relative to their current situation. The rating scale went from 1 (signifying strong preference for the current situation) to 10 (implying strong preference for the hypothetical system). In providing their ratings, the participants were asked to assume a current profit level of $100 per acre, which correspond approximately to the mean profit level at the time. However, pre-testing the survey questionnaire suggested that it was not feasible to assume average baseline levels for the non-profit attributes. Furthermore, pre-testing also suggested that it would not be meaningful to elicit these baseline levels from each farmer. As a result, the main analysis presented below does not use the current system as an alternative. Instead, the results are *conditional* on a system change, that is, they represent the farmers preferences provided changes to current practices had to be made (e.g., through agricultural policies changes or new environmental regulations). Basic background information, such as socioeconomic, management, and institutional variables, including acres of corn irrigated, farming experience, soil type, irrigation water source, education level, and credit availability, was also collected.

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[6] A choice experiment approach was initially considered, but deemed too time-consuming in a producer survey. The contingent rating approach has the advantage of generating more preference information with fewer questions, with the draw-back that responses must be re-interpreted to be consistent with true economic choices.

Data was collected in a mail-mode survey targeted to center-pivot irrigated corn farmers in Northeastern Colorado (Page, 1997). The sampling frame consisted of 344 possible center pivot irrigated farm operators who grow corn, with addresses obtained from the Colorado Department of Agriculture. The survey was implemented according to the Total Design Method (Dillman, 1978), and resulted in a response rate of approximately 33%, after accounting for invalid addresses.

Summary statistics are presented in Table 2. Briefly, the average farmer had close to 500 acres, making a profit of about $100 per acre, with a yield of 160 bushels per acre. Most respondents were farm owners (88%) with significant farming experience (about 30 years of farm work and 27 years of irrigation practice, on average). About half of the respondents held at least a high school degree and most (80%) stated they had access to at least some credit. The most commonly indicated soil types were mixed sand-loam or loamy soil. The average reported well-depth was 118 feet.

3. CONCEPTUAL FRAMEWORK AND ECONOMETRIC MODEL

The empirical analysis converts the contingent ratings into ordinal pair-wise preference comparisons, or so-called pseudo-choice observations. With six ratings, this data-reconstruction yields a maximum of fifteen informationally non-redundant observations per respondent.[7] The ratings, and resulting pair-wise comparisons, are

[7] These are called *pseudo-choices* since the survey did not actually ask respondents to make choices between pairs of irrigation systems. Instead, it is assumed that the same ordinal preference revelations would result from such an exercise. See MacKenzie (1993), Swallow

assumed generated from a conditional indirect utility function that depends explicitly on the four attributes included in the stated preference survey:

$$U = v(P, R, N, E), \tag{1}$$

where the reader is reminded that *P*, *R*, *N*, and *E* represent profits, crop-loss risk, nitrate leaching, and soil erosion, respectively.[8] Utility is expected to be increasing in profits, decreasing in risk, and potentially decreasing in the environmental attributes, and it is assumed that the respondent prefers the system that offers maximum overall utility. The model is made operational by choosing a linear first-order functional form approximation to the true function and recognizing unobservable factors with an additive error term.[9] This leads to a random utility model that can be stated formally as:

$$U_{njk} = \beta_{1n}P_{njk} + \beta_{2n}R_{njk} + \beta_{3n}N_{njk} + \beta_{4n}E_{njk} + \varepsilon_{njk}, \tag{2}$$

where U_{njk} is total utility to farmer *n* from irrigation system *j* in comparison *k*, which has a deterministic component $v_{njk} = \beta_{1n}P_{njk} + \beta_{2n}R_{njk} + \beta_{3n}N_{njk} + \beta_{4n}E_{njk}$ and a random component ε_{njk} assumed to be independent and identically distributed (IID) type I extreme value. The *n* subscript on the coefficients recognizes that different farmers are likely to place different weights on the attributes. To account for this heterogeneity in estimation, a density function $g(\beta \mid \theta)$ will be specified, where

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Opaluch, and Weaver (2001), Siikamaki (2000), and Layton and Lee (2003) for different ways to use rating data in estimation.

[8] Here, we treat risk as a non-monetary attribute. Appendix 2 presents the results of a model in which implied expected profits and variance of profits variables are assumed as covariates.

[9] In the empirical results section, we discuss other specifications that were explored.

$\beta = (\beta_1, \beta_2, \beta_3, \beta_4)$ and θ is a vector of parameters that characterizes this function (typically coefficient means, variances, and possibly co-variances).[10]

The distributional assumption on the random component leads to a binary logit expression for the probability that alternative 1 is preferred to alternative 2 in the pairwise comparison (since the error difference $\varepsilon_{n1k} - \varepsilon_{n2k}$ has a logistic distribution):

(3) $$P_n(1 \mid \beta_n) = \frac{e^{v_{n1k}}}{e^{v_{n1k}} + e^{v_{n2k}}}.$$

Furthermore, let $y_n = (y_{n1}, ..., y_{nK_n})$, represent the sequence of preferred alternatives (1 or 2) by farmer *n* across the K_n pair-wise comparisons. These observations are independent conditional on individual-specific utility coefficients β_n, so their joint probability can be expressed as a product of probabilities:

(4) $$P(y_n \mid \beta_n) = P(y_{n1} \mid \beta_n) \cdot ... \cdot P(y_{nK_n} \mid \beta_n).$$

In practice, these coefficients are of course unknown so that it will be necessary to integrate (4)over all possible coefficient values using the specified density function $g(\beta \mid \theta)$, which yields the canonical panel mixed logit probability (Train, 2003):

(5) $$P(y_n \mid \theta) = \int P(y_n \mid \beta) \cdot g(\beta \mid \theta) d\beta.$$

[10] Given the generic, experimental nature of the irrigation systems presented in the survey, there is no need to include alternative-specific constants in the estimations.

Since (5) does not have closed-form solution it must be approximated through simulation, which is achieved by taking R draws of β from $g(\beta \mid \theta)$ and computing the mean joint probability:

(6) $$\tilde{P}(y_n \mid \theta) = \frac{1}{R}\sum_r P(y_n \mid \beta^r).$$ [11]

The mixed logit model is implemented by giving specific structure to the function $g(\beta \mid \theta)$. First, coefficients to be estimated as random must be chosen. Second, statistical distributions must be specified for these coefficients (Train 2003; Hensher and Greene 2003). A full random coefficient specification is virtually unidentified (Ruud 1996). As such, it has become typical to keep the money coefficient fixed, in our case, the coefficient on per acre profit P (see, for example, Revelt and Train, 1998, Layton and Brown, 2000, Goett, Hudson, and Train, 2002; and Hensher, Shore, and Train, 2005). This practice is not restrictive when the ultimate interest lies in identifying heterogeneity in the marginal monetary value, also called "part-worth", of non-monetary attributes, as opposed to heterogeneity in the utility coefficients per se. Furthermore, it makes it easy to interpret the implied part-worth distributions.

With regard to coefficient distributions, the most common practice is to assume coefficients are distributed independently normal. Normality is flexible in that it permits attributes to be both positively and negatively valued. While one would typically expect the non-profit attributes (risk, nitrate leaching, and soil

[11] Specifications issues, simulation procedures, and model properties, are discussed fully in Train (2003) and Hensher and Green (2003). The parsimonious mixed logit exposition given here loosely follows that of Hensher, Shore, and Train (2005).

erosion) to be non-positively valued by the farmers, we let the estimation predict the distribution mass in anticipated sign-region for each of these attributes, as an informal data validity test.

In the next section, models with and without independence between the random coefficients are presented. In the more flexible case that allows correlations between attribute weights, the following symmetric covariance matrix is specified:

(7)
$$\Omega_\beta = \begin{bmatrix} \sigma_R^2 & \sigma_{R,N} & \sigma_{R,E} \\ \sigma_{R,N} & \sigma_N^2 & \sigma_{N,E} \\ \sigma_{R,E} & \sigma_{N,E} & \sigma_E^2 \end{bmatrix}.$$

Note that when all elements of Ω_β are zero, the model becomes the standard fixed coefficient logit. This special case is very restrictive in that it imposes independence of irrelevant alternatives (IIA), ignores preference heterogeneity, and fails to account for the panel nature of the data (Train, 2003). Furthermore, when the off-diagonal elements of the matrix are zero, the random coefficients are independent, which, in our case, means the weight a farmer places on any one non-profit attributes is independent of preferences for the other attributes. This restriction might be unrealistic in our context. Since nitrate leaching (*N*) and soil erosion (*E*) both represent environmental impacts of corn production, one might expect that a farmer who cares more about one of these attributes also cares more about the other. The sign of the correlation between risk and the environmental variables, however, is an empirical question.[12]

[12] Preference relationships between attributes can also be explored through the use of interaction variables. Unfortunately, our stated preference survey was not developed to ensure identification of coefficients on such variables. Nevertheless, we were able to

Estimation of the covariance matrix is achieved through a Cholesky decomposition of the form $\Omega_{\beta} = \Gamma\Gamma'$, where Γ is a lower triangular Cholesky matrix. Specifically, in simulating (6), random draws for β are taken as $\beta = \bar{\beta} + \Gamma e,$ where $\bar{\beta}$ is the mean vector of the multivariate normal coefficient distribution $MVN(\bar{\beta}, \Omega_{\beta})$ and e is a vector of standard normal covariates. The lower triangular Cholesky matrix for (7) is therefore

$$\Gamma = \begin{bmatrix} S_{11} & & \\ S_{21} & S_{22} & \\ S_{31} & S_{32} & S_{33} \end{bmatrix}, \tag{8}$$

which is estimated along with $\bar{\beta}$ through the simulation procedure.[13]

4. ECONOMETRIC RESULTS

Primary Results

Results using the specification in (2) are reported in Table 3. Model 1 is a fixed coefficient logit, whereas Model 2 is a mixed logit with uncorrelated normally distributed random coefficients, and Model 3 is a mixed logit with multivariate normal coefficients. The non-profit attributes were entered negatively (multiplied by -1) such that their expected coefficient signs are now positive. In addition, the profit

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estimate some model specifications with a fixed coefficient interaction term for nitrate leaching and soil erosion, which we discuss in the next section and report in appendices.

[13] The panel mixed logit models in the next section were estimated by simulated maximum likelihood procedures in NLOGIT 4.0 using 500 Halton draws. The advantages of using Halton draws instead of random draws are discussed in Train (2003).

and nitrate leaching variables were re-scaled (by factors of 1/10 and 1/100, respectively) to facilitate easier convergence of the simulated maximum likelihood routine.

As the three models are naturally nested, one can test the various restrictions of (7) using standard likelihood ratio tests. As expected, the fixed coefficient logit model, which does not account for preference heterogeneity and multiple observations per respondent, is vastly inferior to the random parameters models, with a test statistic of 125.67, distributed chi-squared with three degrees of freedom. Furthermore, the test between the two mixed logit models suggests that permitting correlated coefficients yields superior statistical results, with LR test statistic of 12.39 exceeding the $\chi^2_{0.05}(3)$ critical value of 7.82. Thus, we conclude that there is preference heterogeneity across respondents.

The first four rows of parameters in Table 3 represent the mean of preferences across all individuals in the sample. The estimates are positive and highly significant in all three models, suggesting that farmers, on average, obtain positive utility from profit, dislike risk, and prefer irrigation systems with less nitrate leaching and soil erosion, all else equal. In the mixed logit models, the estimated diagonal Cholesky matrix parameters (S_{11}, S_{22}, and S_{33}) are all statistically significant, which suggest that preferences for the non-profit attributes vary across farmers. In Model 3, the off-diagonal Cholesky elements (S_{21}, S_{31}, and S_{32}) are jointly significant (as indicated by the LR test between Model 3 and Model 2 described above). However, while S_{32} is strongly significant, it should be noted that S_{31} is only marginally significant and S_{21} is insignificant. The signs of these parameters give the directions of preference coefficient dependence. The negative sign on S_{31} indicates that farmers with relatively high risk tolerance tend to dislike soil erosion more, and vice-versa. The positive sign on S_{32} indicates that nitrate leaching and soil erosion, the two production attributes with environmental public good implications, are preference complements in the sense that preference intensities for these attributes across farmers move in the same direction. Relative magnitudes of these correlations can be seen in Table 4, which reports the implied covariance and correlation matrices. As seen in the latter, the negative relationship between risk and soil erosion is relatively modest (a correlation of -0.46), whereas the positive relationship between nitrate leaching and soil erosion is more pronounced (correlation of +0.64).[14]

The monetary part-worth for a non-profit attribute is given by the ratio of its coefficient to the coefficient on profit, where the latter represent marginal utility of money. For example, the mean part-worth for risk reduction is given by β_2 / β_1 (after appropriately accounting for the re-definition and re-scaling of the attribute variables described above). Given that the profit coefficient was maintained as fixed, the part-worth distribution for an attribute has the same characteristics as the distribution of the attribute's utility coefficient.

[14] The signs and significance levels of the diagonal Cholesky parameters are stable across different number of random draws and the methods of taking these draws (random versus Halton). In contrast, the off-diagonal parameter estimates are less robust across such variations (but more stable when more than 300 Halton draws are used), and should therefore be cautiously interpreted.

Table 5 reports mean and standard deviation of the marginal values of reducing risk by one percent (in per acre terms), a one pound reduction in nitrate leaching, and a one ton reduction in soil erosion. Using Model 3, the part-worth of a 1% reduction in risk is $0.50 at the mean, and has a standard deviation about $0.45. This estimate seems reasonable. The average farmer in the sample had about 500 acres of productive land. An average profit of $100 per acre, would suggest total profits of $50,000. A 1% probability of loosing half the crop on this land size implies expected profits of $49,750, a difference of $250, or $0.50 per acre (which matches the estimated mean value of reducing risk by 1%).

Turning to the two environmental public good attributes, reducing nitrate leaching has a mean value of $0.31 per pound and a standard deviation of $0.25, whereas a 1 ton reduction in soil erosion has a mean value and standard deviation of $7.06 and $4.38, respectively. Note that the standard deviations imply significant heterogeneity in the sample. Nevertheless, as can be seen in Table 6, the implied probabilities of having preferences in line with a priori expectations (a positive valuation of less risk, and non-positive valuations of nitrate leaching and soil erosion) are high, and serves as an informal validation of the survey. Model 3 results suggest that 87% prefer less risk, 89% prefer less nitrate leaching, and 95% prefer less soil erosion, all else equal and using the *unconditional* coefficient results. T

This finding is reinforced from the *conditional* (or individual-specific) coefficient results. These coefficients can be extracted by applying a Bayesian procedure that utilizes parameter estimates and all available data, including choice information (see Hensher and Greene, 2003 for details). This leads to the prediction that 92% like less risk and virtually everyone like less nitrate leaching and soil erosion (approximately 97% in both cases).

The part-worth discussion above is based on *point estimates* of preference distribution parameters produced by the econometric estimation. But as is well known, models estimated by maximum likelihood are non-linear which means the statistical error of any one parameter estimate is correlated with the statistical errors of all other parameter estimates. A robust full-information characterization of the part-worth distributions can be obtained through simulation procedures described in Hensher and Greene (2003).[15] For completeness, Table 7 reports full-information simulation results for the statistically superior Model 3.

Alternative Model Specifications and Robustness Checks

Several other model specifications were estimated as part of preliminary data examination and robustness checks for the models reported in Table 3.

First, the survey collected background information, which has the potential for enriching the empirical model specifications. For example, one may expect that larger land-holders would be more sensitive to the type of financial risk described, and possibly also to profits. One may also expect that secondary (off-farm) income would be associated with less sensitivity to these private attributes. Other hypotheses could be formulated as well. Several specifications were therefore explored that permitted background variables to be either interacted with attributes or shifting the

[15] This method is similar to the method for simulating elasticities described in Krinsky and Robb (1986).

mean of random coefficient distributions. Unfortunately, these estimations did not improve statistical properties or yield additional insights.

Second, models were estimated wherein one or several of the random coefficients were specified as log-normally distributed (instead of normally distributed), based on a priori expectations about the qualitative effects of attributes on utility. These specifications did not change qualitative findings, nor did they significantly affect the part-worth analysis.[16]

Third, models where attribute levels entered the utility function piece-wise linearly, a flexible way of testing for non-linearity, were estimated (Layton and Brown, 2000). Results from these models were more difficult to interpret and generally weaker in terms of generating insights into the farmers' preferences.[17]

Fourth, models were explored with attribute interaction terms. In general, these models did not perform well, most likely because the experimental design was non-orthogonal with respect to identification of interaction effects.[18] However, Model 3 was extended to include a fixed coefficient interaction variable for nitrate leaching and soil erosion (see Table A1 of Appendix 1). The results are qualitatively similar, and re-enforce the complementary relationship between the two

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[16] Log-normal coefficient distribution would restrict risk, nitrate leaching, and/or soil erosion, respectively, to be strictly negatively valued. The shape of a part-worth distribution with log-normal coefficient on a non-profit variable is itself log-normal (with fixed profit coefficient).

[17] Specific alternative model estimations can be reproduced and made available upon request.

[18] See Louveiere, Hensher, and Swait (2000) for optimal experimental design.

environmental public good attributes, as both the interaction term and the Cholesky parameter are positive and significant.

Finally, an attempt was made to address the structural and related nature of the profit and risk attributes of the contingent rating – stated preference experiment. Specifically, given the nature of the risk attribute (probability of half crop loss), it is possible to turn the profit – risk attributes into an expected profit – variance of profit equivalent, by utilizing the respondent-specific information on farm size. Again, because the experiment was not designed with this purpose in mind, these constructed variables turned out to be too highly correlated to permit identification of separate parameters in the linear indirect utility function specification. Instead, results from a model that only utilizes the expected profit variable, in addition to the two environmental public-good variables, and their interaction term, are reported in Table A2 of Appendix 2. As can be seen, expected profit enters positively in the estimated model, whereas nitrate leaching, soil erosion, and their interaction terms enter positively, consistent with the findings reported in Table 3 and Appendix 1.

5. CONCLUDING REMARKS

This study used a stated preference experiment to identify the preferences of corn producers in Northeastern Colorado with respect to profit, risk, nitrate leaching, and soil erosion attributes. While these first two are fully privately appropriable (and variables which are commonly assumed to explain producer behavior), the latter two have public good aspects in addition to potentially affecting farmers' bottom-lines. The results suggest that most producers do, in fact, value reductions in soil erosion and nitrate leaching in that they are willing to accept an irrigation system associated with less profit (or more risk) in order to reduce the levels of these attributes.

The results generated through this stated preference experiment speak directly to the welfare implications of technological innovations, policy changes, and/or environmental regulation facing Colorado producers. By identifying not only the mean/median willingness to trade off environmentally damaging attributes with profits, but also the distribution of these magnitudes, this paper provides information that could be used to target production research and market alternative production systems, as well as predict the size of potential adoption populations; predict the response of farmers to various agri-environmental policy changes (such as the Conservation Reserve Program or various command and control policies related to soil erosion and/or nitrate leaching); or calculate the welfare changes/necessary compensation required to maintain farmers' welfare in the face of such changes. As Poe (1999) points out, "such comparisons are not isolated academic musing, but instead have long been an essential component of federal policymaking" (p. 573).

These results confirm the conclusions of previous studies that attributes vary across even a relatively small subset of producers (see, e.g., Foltz, et al., 1995), and that expected profit maximization is not always behaviorally appropriate when, say, choosing production or irrigation systems. Furthermore, it is shown that there are potential complementarities between the goals of public environmental policy and the goals of many farmers. Future research is needed to determine the extent that these effects are motivated by expectations over future environmental policy, altruism, building of social capital, or some other reason.

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Table 1. Experimental Design of the Contingent Rating - Stated Preference Experiment

		Survey Version					
Irrigation System	Attribute	V1	V2	V3	V4	V5	V6
1	P	40	30	40	40	15	30
1	R	0.1	0.3	0.1	0.5	0.5	0.5
1	N	14.5	39.5	72.5	14.5	72.5	14.5
1	E	1	1	3	3	1	2
2	P	15	15	30	30	15	15
2	R	0.5	0.1	0.5	0.1	0.3	0.3
2	N	72.5	72.5	14.5	39.5	72.5	14.5
2	E	1	2	2	1	2	2
3	P	30	40	30	30	40	40
3	R	0.3	0.3	0.3	0.1	0.1	0.1
3	N	72.5	14.5	72.5	72.5	14.5	72.5
3	E	3	1	1	2	3	1
4	P	40	40	40	15	30	15
4	R	0.3	0.5	0.5	0.5	0.1	0.1
4	N	14.5	39.5	39.5	14.5	39.5	72.5
4	E	2	2	2	1	3	1
5	P	15	15	15	15	40	40
5	R	0.5	0.1	0.3	0.3	0.5	0.3
5	N	39.5	14.5	39.5	39.5	39.5	39.5
5	E	3	3	3	2	1	3
6	P	30	30	15	40	30	30
6	R	0.1	0.5	0.1	0.3	0.3	0.5
6	N	39.5	72.5	14.5	72.5	14.5	72.5
6	E	2	3	3	3	1	3

Note: *P* = Profit in $ per acre above $100, *R* = Risk: Probability of losing at least half of crop, *N* = Nitrate Leaching in pounds per acre, and *E* = Soil Erosion where 1 is 2-3 tons of soil/acre/year.

Table 2. Summary Statistics For Farm/Farmer Characteristics

Variable	Description	Mean	St. Dev.	Min	Max
ACRE	Irrigated Corn Acres	489.68	59.46	22	4000
PROF	Profit, $/acre	99.47	4.68	5	350
YIELD	Bushels/acre	163.44	2.43	85	239
OWN	% of respondents owning their land	0.88	0.03	0	1
YEXP	Years of experience farming	29.54	1.16	1	65
YIRR	Years of experience irrigating	26.71	1.06	1	50
EDU_H	% of sample with high school degree	0.52	0.05	0	1
WORK	% of sample with off-farm job	0.21	0.04	0	1
CREDIT_Y	% of sample with credit available	0.66	0.05	0	1
CREDIT_S	% of sample with some credit available	0.13	0.03	0	1
SOIL_S	% of sample with Sandy soil	0.11	0.03	0	1
SOIL_SL	% of sample with Sandy-loam soil	0.41	0.05	0	1
SOIL_L	% of sample with Loam soil	0.21	0.04	0	1
SOIL_LC	% of sample with Clay-loam soil	0.14	0.03	0	1
SOIL_C	% of sample with Clay soil	0.06	0.02	0	1
W_DEPTH	Average Well Depth	118.50	10.37	10	780

Table 3. Econometric Results, Psuedo-Choice Models

Parameters	Model 1 (MNL)	Model 2 (Mixed Logit, No Correlations)	Model 3 (Mixed Logit, Full Correlations)
Profit[a]	0.8959***	1.1709***	1.1691***
	(0.0605)	(0.1038)	(0.0687)
Risk (reduction)[b]	3.3549***	5.6323***	5.7900***
	(0.3560)	(0.9034)	(0.9596)
Nitrate Leaching (reduction)[a,b]	2.2025***	3.3256***	3.5736***
	(0.2437)	(0.5286)	(0.6063)
Soil Erosion (reduction)[b]	1.2252***	2.0025***	2.0637***
	(0.0775)	(0.2296)	(0.2541)
S_{11}		5.3626***	5.2343***
		(1.0701)	(0.8985)
S_{22}		3.1971***	2.8642***
		(0.6665)	(0.6478)
S_{33}		1.4660***	0.7431**
		(0.2145)	(0.3116)
S_{21}			0.1555
			(0.8548)
S_{31}			-0.5935*
			(0.3470)
S_{32}			0.8590***
			(0.1780)
LL	-486.3467	-423.5108	-417.3177
LL(0)	-867.8203	-867.8203	-867.8203
# of Observations	1252	1252	1252
# of Individuals	98	98	98

Notes: Std errors in parentheses.
Models 2 and 3 estimated in NLOGIT 4.0 using 500 Halton draws.
Statistical significance at the 1%, 5%, and 10% levels is indicated by ***, **, or *, respectively.
a The profit variable P has been re-scaled by a factor of 1/10. N is re-scaled by a factor of 1/100
b The non-profit variables (R, N, E) are entered negatively (multiplied by -1).

Table 4. Model 3 Preference Covariance and Correlation Matrices

ESTIMATED COVARIANCE MATRIX		
Risk Reduction	Nitrate Leaching Reduction	Soil Erosion Reduction
27.40		
0.81	8.23	
-3.11	2.37	1.64
ESTIMATED CORRELATION MATRIX		
Risk Reduction	Nitrate Leaching Reduction	Soil Erosion Reduction
1.00		
0.05	1.00	
-0.46	0.64	1.00

Table 5. Marginal Part Worth Values for Non-Profit Attributes

	Model 1	Model 2		Model 3	
Attribute	Mean	Mean	St. Dev.	Mean	St. Dev.
1% reduction in risk (per acre)	$0.37	$0.48	$0.46	$0.50	$0.45
1 lbs reduction in nitrate leaching	0.25	0.28	0.27	0.31	0.25
1 ton reduction in soil erosion	5.47	6.84	5.01	7.06	4.38

Note: Columns give part worth based on estimated model parameters only.

Table 6. Sample Share with Positive Non-Profit Attributes Preferences

	Model 2		Model 3	
Attribute	*Uncond.*	*Cond.*	*Uncond.*	*Cond.*
Less risk	85%	92%	87%	92%
less nitrate leaching	85%	95%	89%	97%
less soil erosion	91%	97%	95%	97%

Table 7. Full-Information Simulation of Part Worth Distribution (Model 3, Full Correlations)

Attribute	10tile	25tile	50tile	75tile	90tile
1% reduction in risk (per acre)	$-0.26	$0.14	$0.44	$0.86	$1.66
1 lbs reduction in nitrate leaching	-0.14	0.09	0.28	0.53	1.01
1 ton reduction in soil erosion	-0.75	2.96	6.33	11.39	21.58

Note: Columns give 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile simulated part worth using all parameter uncertainty in Model 3.

APPENDIX 1 – Environmental Interaction Results

Table A1. Estimation Results with Nitrate Leaching – Soil Erosion Interaction

	Model 3	Model 4
Profit	1.1691***	1.1396***
	(0.0687)	(0.0697)
Risk (reduction)	5.7900***	6.3101***
	(0.9596)	(1.0360)
Nitrate Leaching (reduction)	3.5736***	6.9014***
	(0.6063)	(1.2527)
Soil Erosion (reduction)	2.0637***	2.7687***
	(0.2541)	(0.3246)
Nitrate Leaching *x* Soil Erosion		1.3859***
		(0.4234)
S_{11}	5.2343***	5.5812***
	(0.8985)	(1.1223)
S_{22}	2.8642***	3.0599***
	(0.6478)	(0.6719)
S_{33}	0.7431**	1.2679***
	(0.3116)	(0.2477)
S_{21}	0.1555	0.3633
	(0.8548)	(0.9618)
S_{31}	-0.5935*	0.3150
	(0.3470)	(0.3287)
S_{32}	0.8590***	0.6248***
	(0.1780)	(0.2463)
LL	-417.3177	-413.3859
LL(0)	-867.8203	-867.8203
# of Observations	1252	1252
# of Individuals	98	98

Note: Both the fixed coefficient on the interaction term and the Cholesky parameter S_{32} are statistically significant in Model 4.

APPENDIX 2 – Results Incorporating Expected Profits

$$E(Profit)=[(100+P)\cdot Acre\cdot(1-R)]+(100+P)\cdot(Acre/2)\cdot R]$$
$$V(Profit)=[(100+P)\cdot Acre-E(Profit)]^2\cdot(1-R)+[(100+P)\cdot(Acre/2)-E(Profit)]^2\cdot R$$

Table A2. Estimation Results with Expected Profits – Variance of Profits

Attribute	Par. Est.	St. Error
E(Profit)[a]	0.1473***	0.0076
V(Profit)[b]	---	---
Nitrate Leaching (reduction)	7.1857***	0.7248
Soil Erosion (reduction)	2.7809***	0.1883
Nitrate Leaching x Soil Erosion	1.5334***	0.2216
S_{22}	4.0122***	0.5930
S_{33}	1.3565***	0.1472
S_{32}	0.4804**	0.2234
LL	-491.6271	
LL(0)	-867.8203	
# of Observations	1252	
# of Individuals	98	

[a] In $1000
[b] Coefficient not separately identified due to multicolinearity.