Measuring Part-Whole Bias: Some Evidence from Crop Biotechnology

Michele C. Marra and Nicholas E. Piggott

The authors are Professor and Associate Professor, Department of Agricultural and Resource Economics, P.O. Box 8109, North Carolina State University, Raleigh, NC 27695-8109 USA. Corresponding author contact details: nick_piggott@ncsu.edu; Phone: 919-515-4668.

Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

Measuring Part-Whole Bias: Some Evidence from Crop Biotechnology

Introduction

The purpose of this paper is to propose an improvement in measuring the value of non-pecuniary characteristics embodied in a crop biotechnology when using stated preference methods are used to elicit them. Since evidence of farm-level net benefits from these biotech crops is available from many countries now, and a growing number of policy-making bodies are taking this evidence into account, this work is particularly useful and timely. Producing better measures of the total benefits will lead to better decision making for both policy makers and innovators.

The Farmer's Choice Problem

The farmer has two choices of technology to employ in the production of a final output; a conventional seed variety and a biotech seed variety. In the short run the farmer has a fixed amount of acres, A, across which he allocates each of the seed varieties—A_B for biotech acres and A_C for conventional acres. Because of the potential for non-pecuniary benefits, the non-separable agricultural household production model is appropriate.

Let the household utility function, U, be defined over consumption of a market good x and M non-pecuniary amenities, q_m comprising $\mathbf{q}$.[1] Suppose further that the level of each non-pecuniary amenity is determined by the choice of A_B acres planted using the biotechnology [i.e., $\mathbf{q}(A_B) = q_1(A_B), ..., q_M(A_B)$]. The utility function is given by $U[x,\mathbf{q}(A_B)]$, where the marginal utility derived from an additional acre of biotechnology is the sum of the product of the marginal utility of the non-pecuniary amenity and the marginal change in the amenity from a change in A_B, i.e., $\frac{\partial U}{\partial A_B} = \sum_{m=1}^{M} \frac{\partial U}{\partial q_m}\frac{\partial q_m}{\partial A_B}$. Technology in the production of the final output is given by $f[A_B$,

[1] We use one market good for ease of exposition. It is straightforward to generalize the problem to N market goods.

A_C, z_B, z_C], where z_B and z_C denote the quantities of other inputs associated with the two technologies. The farm household's maximizing problem can be expressed as

$$\max_{x, A_B, z_B, z_C} U[x, \mathbf{q}(A_B)] \qquad (1)$$

subject to

$$p^o f\left[A_B, A_C, z_B, z_C\right] - r(A_B + A_C) - w_B z_B - w_C z_C \geq p_x x - e\,,$$

where p^o is output price, r is the land rental rate, w_B and w_C are the prices of other inputs associated with each technology, p_x is the price of the market good, and e is endowment income. Hence, the optimization problem can be restated as the Lagrangean:

$$\max_{x, A_B, z_B, z_C} L = U[x, \mathbf{q}(A_B)] + \lambda\left\{e + p^o f\left[A_B, A_C, z_B, z_C\right] - r(A_B + A_C) - w_B z_B - w_C z_C - p_x x\right\}, \qquad (2)$$

where λ is the Lagrange multiplier. The solution to this problem consists of optimal levels of the market good, x, the technology adoption decision (A_B), the variable inputs employed, z_B and z_C, and the marginal utility of an additional dollar of profit or endowment, λ.

The value of the amenities associated with choice of A_B is similar, but not strictly analogous, to the willingness to pay (WTP) amount elicited from contingent valuation (CV) studies. The difference is that farmers' choices of A_B affect their total expected income, whereas the CV paradigm assumes income is exogenous. Since we elicit the farmers' valuation of the non-pecuniary amenities through survey questions, we call the farmers' responses "stated marginal values" (SMV).

Non-pecuniary Characteristics of Crop Biotechnologies

The non-pecuniary aspects of a good are sometimes embedded within a characteristic that has both pecuniary and non-pecuniary components. For crop biotechnologies, these include potential increased human (farmer and worker) safety, environmental improvement, and their relative convenience compared to their alternatives. Convenience includes potential time and equipment cost savings but also increased "ease and simplicity" and less worry because of a wider window of opportunity for pest control. These crops also may be viewed as less risky. Producers often judge the additional value of these characteristics based on their preferences and assessment of the relevant alternatives, as modeled above, when making technology adoption decisions.

Measurement Issues

While there are a number of measurement issues in stated preference studies, we focus on the error that can occur when the value of the characteristics of a good are elicited separately and/or in addition to the total value of the same set of characteristics. This phenomenon has not yet been studied in the context of stated preferences in technology adoption, but has been examined somewhat in the CV literature.

This type of part-whole bias can be defined as

$$\sum_{m=1}^{M} \phi(q_{jm}) > \phi\left(\sum_{m=1}^{M} q_{jm}\right), \tag{3}$$

where ϕ is the function that maps the *m*th characteristic or the sum of m characteristics into the value placed on it by individual *j*. The sum of the value of each of the parts is greater than the value of the whole. Numerous reasons have been proposed in the literature for this "part-whole bias." Mitchell and Carson (1989) lay out a typology of the potential biases that can occur with the CV method. They place part-whole bias as a subset of a broader class, "scenario misspecification", a sub-category of which is "amenity misspecification bias," which is defined as "where the perceived good being valued differs from the intended good." Part-whole bias has two potential sources within misspecification bias: (i) "Where a respondent values a larger (or a smaller entity) than the researcher's intended good," or (ii) "benefit part-whole bias," as "where a respondent includes a broader or a narrower range of benefits in valuing a good than intended by the researcher" (Mitchell and Carson 1989, p. 235).

Within their typology, Mitchell and Carson (1989) also list "incentives to misrepresent responses" as another broad class of potential biases. Two sub-categories are of interest. They are (i) strategic bias which is said to be caused by "a respondent giving a WTP amount that differs from his or her true WTP amount (conditional on the perceived information) in an attempt to influence the provision of the good and/or the respondent's level of payment for the good," and (ii) under the sub-category of compliance bias, "Sponsor bias, where a respondent gives a WTP amount that differs from his or her true WTP amount in an attempt to comply with the presumed expectations of the sponsor (or assumed sponsor)." (Mitchell and Carson 1989, p. 235). Some have considered the case where a respondent values the whole and the sum of the parts equally as a test of "internal consistency" of WTP results (Diamond 1996). However, others have shown that this would be internally consistent only if the goods (or a good's characteristics) were perfect substitutes. Otherwise, the whole should be expected to be less than the sum of the individual parts for goods (or a good's characteristics) that are imperfect substitutes (Kopp and Smith 1997).

Following on from (3), we define v_j as the ratio of the stated value of the total to the sum of the stated values of the *m* parts:[2]

$$v_j = \frac{\phi(\sum_{m=1}^{M} q_{jm})}{\sum_{m=1}^{M} \phi(q_{jm})} = \frac{t_j}{\sum_{m=1}^{M} p_{jm}} = \frac{t_j}{s_j} \ , \tag{4}$$

[2] Notice this measure is the inverse ratio, or the whole/part ratio. This ratio better serves to illustrate the points we want to make in the sections that follow.

where t_j is the stated value of the total bundle of M characteristics, and s_j is the sum of the separately-valued parts p_{jm} for the jth respondent. There may be an empirical distribution of ratios from the sample of respondents in a stated preference study. This may contain behavioral information useful for an innovator attempting to price a product or a policymaker trying to value a set of public projects. Further, the value of each component part relative to the values of the other parts in the bundle conveys useful information.

Consider the set of values for t_j, s_j, and v_j in Table 1. $\mathbf{c^1}$ is the set of respondents who are giving protest zeros, a kind of strategic bias. The only other explanation is that the respondents place no value on any of the characteristics of the good, which is highly unlikely. The respondents in $\mathbf{c^2}$ show evidence of a strategic bias in that they relate the total value to the price they may have to pay for the product and wish to misrepresent the true value they place on the product. In $\mathbf{c^3}$, both t_j and s_j are positive but t_j is less than s_j. The respondents in $\mathbf{c^3}$ conform to the predictions of utility theory, as laid out by Hoehn (1991), and conform to the utility maximization problem laid out earlier. Strategic misrepresentations or other anomalies are not expected to be present in $\mathbf{c^3}$. Therefore, it should be viewed as the category that is most representative of the underlying value. $\mathbf{c^4}$ is a type of sponsor bias where the respondent wants to appear "internally consistent" to the sponsor of the survey. Responses in $\mathbf{c^5}$ imply the benefit part-whole bias form of amenity misspecification bias. $\mathbf{c^6}$ is an extreme form of benefit part-whole bias where none of the characteristics asked about have value to the respondent, but one or more left-out characteristics do.[3]

Survey Evidence

[3] In all of the studies considered here, the "total" valuation question was asked specifically and exclusively about the set of characteristics the respondents were asked to value individually.

The empirical evidence is based on three, computer-aided telephone surveys conducted by Doane Market Research. The first survey, conducted in early 2001, had 601 responses) and elicited U.S. corn farmers' opinions of Yieldgard Rootworm® technology, which was introduced commercially the following year (Alston, et al. 2002). The second survey, taken in 2002, had 610 responses and elicited U.S. soybean farmers' valuation of Roundup Ready (RR) soybeans, introduced in 1996 (Marra, Piggott, and Carlson 2004). The third survey was of North Carolina crop farmers, had 293 responses, and was conducted in 2003 to elicit their valuation of herbicide-tolerant crops (mostly RR). The main crops sampled were corn, cotton, and soybeans (Marra, Piggott, and Sydorovych, 2005).

Questions were asked in each survey about how much value the respondent would place on improved operator and worker safety, increased environmental safety, and additional convenience of the new technology. All valuation questions were open-ended questions because U.S. farmers are familiar with the technologies and regularly evaluate the trade-offs between biotech and conventional crops. Survey example questions are available from the authors.

Thus far, CV researchers have reported only the overall means of the empirical part-whole bias in their work (Bateman et al. 1997 or Boyle et al. 1994, for example). This section takes up the matter of part-whole bias in measurement of these non-pecuniary values and introduces a method of correcting the problem. The surveys provide three different sample distributions of the part-whole ratio, or what we refer to as v_j. First, we are interested in the distribution of v_j over all categories, for which v_j is defined ($\mathbf{c}^1 - \mathbf{c}^5$), as a general measure of dispersion. Second, we are interested in the distribution of v_j for $\mathbf{c}^3$ respondents. This distribution characterizes the re-scaling factor to be used for the *j*th individual and the amount of part-whole "bias" in this category.

The sample properties of v_j are shown in Table 2. First, notice that the proportion of respondents in $\mathbf{c}^3$ is the highest of all the categories in each survey, although the proportion varies. The national soybean survey has the smallest proportion of respondents in $\mathbf{c}^3$, with about 39 percent, while almost 77 percent of the respondents in the corn rootworm survey fall into $\mathbf{c}^3$. Table 2 reveals that the mean estimate of v_j for $\mathbf{c}^1 - \mathbf{c}^5$ ranges from 0.391 for the national soybean survey to 0.639 for the NC herbicide-tolerant survey. Each of the surveys exhibits significant positive skewness over all categories, with skewness coefficients ranging from 0.919 for the NC herbicide-tolerant survey to 2.198 for the national soybean survey. The range of the median reveals that the overall central tendencies of v_j in the surveys are even more diverse than the means reveal, ranging from 0.167 for the national soybean survey to 0.500 for the NC herbicide-tolerant survey.

Consideration of only the most representative estimates ($\mathbf{c}^3$) reveals remarkably similar properties of the distributions of the part-whole biases across surveys. All three surveys exhibit positive skewness for the respondents falling in the $\mathbf{c}^3$ category, ranging from 0.377 for the corn rootworm survey to 0.591 for the NC herbicide-tolerant survey. The medians for v_j are 0.383, 0.357, and 0.333 for the corn rootworm survey, the national soybean survey, and the NC herbicide-tolerant survey, respectively. These estimates indicate that the sum of the parts for the majority of the respondents should be rescaled downward *by more than 60 percent.*

We now demonstrate the practical importance of the decomposition of the ratio of the whole to the sum of its parts into the different categories, each representing different respondent behavior. First, we use only data from $\mathbf{c}^3$, which we believe contains the most representative information. Within $\mathbf{c}^3$ each individual's component values were rescaled as follows:

$$\tilde{p}_{jm} = v_j \cdot p_{jm} , \qquad (5)$$

where $\tilde{p}_{jm}$ is the re-scaled, "true" value of the *m*th characteristic by the *j*th respondent. This re-scaling ensures that the re-scaled sum of the "true" values of the part-worths for each respondent equals the stated total value t_j. This re-scaling was performed for each respondent. We report the descriptive statistics, including the means for comparison, of the rescaled values for each non-pecuniary characteristic and each survey in Table 3. We also report the share of each characteristic. Notice that, as with the v_j's, the distribution of *each* characteristic value is positively skewed. The corn rootworm survey exhibits the highest degree of skewness for the sum of the parts. The degree of skewness for the sum of the parts in the other surveys is less than half that of the corn rootworm survey. The standard deviation of the sample distribution is greater than both the mean and the median values for most individual characteristics in each survey. The exceptions are the mean value of total convenience in the national soybean survey and the mean of each characteristic in the NC herbicide-tolerant survey. The standard deviation of the sum of the parts is greater than the median value in all surveys. This implies that the dispersion of the values cannot be ignored in any pricing or R&D decisions using these surveys.

The rescaled median characteristic values range from \$5.00/acre/year for total convenience in the NC herbicide-tolerant survey to \$0.21/acre/year for environmental safety in the corn rootworm survey. Farmers valued the risk reduction achieved, as a result of a more consistent stand of corn in the Yieldgard Rootworm corn relative to conventional corn, more highly (\$0.80/acre/year) than each of the other non-pecuniary characteristic changes from the new technology. The value of this characteristic is over 30 percent of the total value in the corn rootworm survey. Total convenience value is over 50 percent of the total value in each of the other surveys. The value of each characteristic is highest in the NC herbicide-tolerant survey with a total value twice as high as the national soybean survey. This is because three herbicide-tolerant crops are considered in the North Carolina survey (corn, cotton, and soybeans) and the values for cotton are higher than those for corn or soybeans. Overall, the median total value of the characteristics ranges from $3.00/acre/year for the Yieldgard Rootworm technology to $10.00/acre/year for the herbicide-tolerant crops in North Carolina.

Conclusion

In the case of a good with several dimensions that people value separately, information about important biases is masked if one considers only the overall mean part-whole bias of the sample. We argue here that $\mathbf{c}^3$ respondents give the most representative responses. We must rescale the values of the individual parts to reflect the true total value represented by the value of the whole, but at the same time, retain each part's relative importance in the bundle by using information from this category. From these rescaled numbers, innovators can price a new technology to reflect accurately the additional value placed on it by potential consumers, or government can allocate future project proposals according to their true benefit-cost rankings. Innovators also can use the relative values of the component parts (the shares in Table 3) to help decide in which directions to take future research and development.

Several questions and results from this chapter motivate further work. First is the empirical finding made for the idea that there are multiple categories of respondents within the population of respondents to stated valuation surveys. Each category implies a difference in how the individuals respond to valuation questions and the bias that might be introduced as a result. An investigation of why that difference exists is needed. Second is the result that the most representative category, $\mathbf{c}^3$, appears to have a distribution of v_j that is positively skewed with a median value of around 0.34–0.38. Further investigation of other survey results should shed light on the robustness of these findings. We have not investigated if the magnitude of the rescaling factor is similar in general for goods of this nature or if choice of stated preference method matters. The final item to be investigated further is the reasonableness and accuracy of the re-scaled parts as estimates of the “true” value of the individual characteristics they represent. Although we have hypothesized and provided some empirical support for the notion that the rescaled values are expected to be close to “the truth,” more testing of this hypothesis is needed.

References

Alston, J., J. Hyde, M. Marra, and P. Mitchell. 2002. An Ex Ante analysis of the benefits from the adoption of corn rootworm resistant corn. Agbioforum 5(3): 71–84.

Bateman, I., A. Munro, B. Rhodes, C. Starmer, and R. Sugden. 1997. Does part-whole bias exist? An Experimental Investigation. The Econ. J. 107(441): 322–332.

Boyle, K., W. Devousges, F. Johnson, R. Dunford, and S. Hudson. 1994. An investigation of part-whole biases in contingent-valuation studies. J. of Envir. Econ.and Mgmt. 27(1): 64–83.

Diamond, P.A. 1996. Testing the internal consistency of contingent valuation surveys. J. of Envir. Econ.and Mgmt. 30(3): 337–347.

Hoehn, J. 1991. Valuing the multidimensional impacts of environmental policy: Theory and methods. Am. J. of Agric. Econ. 73(2): 289–299.

Kopp, R.J., and V.K. Smith. 1997. Constructing measures of economic value. In: R.J. Kopp, W. Pommerehne, and N. Schwarz, eds., Determining the Value of Non-Marketed Goods: Economic, Psychological and Policy Relevant Aspects of Contingent Valuation. Boston: Kluwer Academic Publishers.

Marra, M.C., N.E. Piggott, and G. Carlson. 2004. The Net Benefits, Including Convenience, of Roundup Ready® Soybeans: Results from a National Survey. Technical Bulletin No. 2004-3, National Science Foundation Center for Integrated Pest Management, Raleigh, NC.

Marra, M.C., N.E. Piggott, and O. Sydorovych. 2005. "The impact of herbicide tolerant crops on North Carolina's farmers." NC State Economist, NC Cooperative Extension and Dept. of Ag. and Res. Economics, NC State University, Raleigh, NC (March/April).

Mitchell, R., and R. Carson. 1989. Using Surveys to Value Public Goods: The Contingent Valuation Method. Resources for the Future, Washington, D.C., 463 pp.

Table 1. Respondent Valuation Categories

Category	t_j value	s_j value	v_j	Behavioral Implications/Source of Bias
$\mathbf{c^1}$	0	0	0	1. A protest zero response *(strategic bias)*. 2. The person places no value on the non-pecuniary characteristics (unlikely).
$\mathbf{c^2}$	0	> 0	0	Person thinks of the parts as having value, but places a protest zero on the total for *strategic* reasons.
$\mathbf{c^3}$	> 0	> 0 and $t_j < s_j$	< 1	Person displays diminishing marginal utility in the characteristics and the characteristics are substitutes in valuation. *The most representative case*.
$\mathbf{c^4}$	> 0	> 0 and $t_j = s_j$	= 1	Person displays *sponsor bias* in that he wants to appear to be consistent to the evaluator or the sponsor.
$\mathbf{c^5}$	> 0	> 0 and $t_j > s_j$	> 1	Person is valuing more characteristics in the whole than he was asked about separately in the parts. *Amenity misspecification bias/benefit part-whole bias.*
$\mathbf{c^6}$	> 0	0	undefined	Person places no value on the characteristics asked about, but places some value on other characteristic(s). *Amenity misspecification bias/benefit part-whole bias.*

Table 2. Sample Properties of the Ratio of Total Value and Sum of the Parts (v_j)

Categories	J	w_j	Mean	Std. Dev.	Skewness	Median
			Corn Rootworm Survey			
$\mathbf{c}^1: t_j = 0;\ s_j = 0;\ v_j = 0$	0	0	0	0	--	0
$\mathbf{c}^2: t_j = 0;\ s_j > 0;\ v_j = 0$	51	0.107	0	0	--	0
$\mathbf{c}^3: t_j > 0;\ s_j > 0;\ v_j < 1$	**367**	**0.768**	**0.422**	**0.260**	**0.377**	**0.383**
$\mathbf{c}^4: t_j > 0;\ s_j > 0;\ v_j = 1$	21	0.044	1	0	--	1
$\mathbf{c}^5: t_j > 0;\ s_j > 0;\ v_j > 1$	39	0.082	1.672	0.638	1.143	1.429
$[\mathbf{c}^1 - \mathbf{c}^5]$	**478**	**1**	**0.504**	**0.489**	**2.150**	**0.385**
$\mathbf{c}^3/[\mathbf{c}^1 - \mathbf{c}^5]$			0.837	0.532	0.176	0.996
			National Soybean Survey			
$\mathbf{c}^1: t_j = 0;\ s_j = 0;\ v_j = 0$	97	0.34	0	0	--	0
$\mathbf{c}^2: t_j = 0;\ s_j > 0;\ v_j = 0$	35	0.122	0	0	--	0
$\mathbf{c}^3: t_j > 0;\ s_j > 0;\ v_j < 1$	**113**	**0.394**	**0.417**	**0.222**	**0.483**	**0.357**
$\mathbf{c}^4: t_j > 0;\ s_j > 0;\ v_j = 1$	13	0.045	1	0	--	1
$\mathbf{c}^5: t_j > 0;\ s_j > 0;\ v_j > 1$	29	0.101	1.795	0.601	1.055	1.667
$[\mathbf{c}^1 - \mathbf{c}^5]$	**287**	**1.00**	**0.391**	**0.585**	**2.198**	**0.167**
$\mathbf{c}^3/[\mathbf{c}^1 - \mathbf{c}^5]$			1.066	0.380	0.220	2.143
			North Carolina Herbicide-Tolerant Survey			
$\mathbf{c}^1: t_j = 0;\ s_j = 0;\ v_j = 0$	0	0	0	0	--	0
$\mathbf{c}^2: t_j = 0;\ s_j > 0;\ v_j = 0$	0	0	0	0	--	0
$\mathbf{c}^3: t_j > 0;\ s_j > 0;\ v_j < 1$	**52**	**0.732**	**0.401**	**0.228**	**0.591**	**0.333**
$\mathbf{c}^4: t_j > 0;\ s_j > 0;\ v_j = 1$	6	0.085	1	0	--	1
$\mathbf{c}^5: t_j > 0;\ s_j > 0;\ v_j > 1$	13	0.085	1.426	0.255	0.781	1.380
$[\mathbf{c}^1 - \mathbf{c}^5]$	**71**	**1**	**0.639**	**0.466**	**0.919**	**0.500**
$\mathbf{c}^3/[\mathbf{c}^1 - \mathbf{c}^5]$			0.628	0.489	0.643	0.666

Notes: t_j = stated total value, s_j = sum of stated characteristic values, $v_j = t_j/s_j$, and w_j = the proportional weight of the individual category in the total.

Table 3. Stated Values and Re-scaled Values and Relative Contributions of Parts

	Value of the Change in the SMV					
		Re-scaled[b]				
	Un-scaled Median[a]	Median	Mean	Std. Dev.	Skewness	Share[c] (%)
Characteristic	($/acre/year)					
	Corn Rootworm Survey: $\mathbf{c}^{3}$ **:** $\boldsymbol{J}$ **= 367**					
Time savings	1.500	0.588	0.997	1.390	4.047	23.86
Equipment savings	1.000	0.400	0.724	0.969	3.087	17.51
Operator and worker safety	1.000	0.429	0.991	1.623	3.670	17.12
Environmental safety	1.000	0.208	0.787	1.565	4.606	10.88
More consistent stand	2.000	0.800	1.773	2.862	4.111	30.63
Sum of the parts	**9.400**	**3.000**	**5.272**	**6.222**	**3.263**	
Total	**3.000**					
	National Soybean Survey: $\mathbf{c}^{3}$ **=** $\boldsymbol{J}$ **= 113**					
Operator and worker safety	3.000	0.913	1.660	2.026	1.367	20.97
Environmental safety	3.000	1.304	1.961	2.201	1.257	24.89
Total convenience	10.000	3.333	4.158	3.690	1.114	54.14
Sum of the parts	**17.000**	**5.000**	**7.779**	**6.026**	**1.266**	
Total	**5.000**					
	North Carolina Herbicide-Tolerant Survey: $\mathbf{c}^{3}$ **:** $\boldsymbol{J}$ **= 52**					
Operator and worker safety	6.500	2.361	2.923	2.783	0.884	23.91
Environmental safety	5.000	1.666	2.720	2.660	0.955	20.45
Total convenience	15.000	5.000	7.793	7.818	2.588	55.63
Sum of the parts	**28.500**	**10.000**	**13.437**	**10.612**	**1.608**	
Total	**10.000**					

[a] Median of stated value over all observations in the sample. [b] Median and sample moments of re-scaled parts where each respondent's stated value of the part is re-scaled by their individual v_j. [c] Shares are sample means calculated at every data point.