Optimal uptake of second-generation genetically-modified crops

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Abstract: The results of a nationwide New Zealand survey into willingness to pay (WTP) for six different genetically modified (GM) food products were used to estimate market-level demand curves for the products. The raw results clearly indicate that different New Zealanders have different WTP for GM food. An estimated sigmoid regression curve showed that, with one exception, the type of GM product offered had little effect on WTP. This estimated demand curve was used to calculate the optimal uptake of GM crops, which is the percentage of total output that should be GM in order to maximise industry revenues.

Keywords: genetically modified food, survey, consumer research, second-generation, New Zealand

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1. Introduction

Using data from a New Zealand survey on public perceptions of biotechnology, we estimate the relationship between production of genetically modified (GM) food and its price. This survey asked respondents about their intentions to purchase and willingness to pay for specific GM products with production and consumer-oriented benefits. These findings were then used to estimate the optimal adoption rate of GM crops – the uptake percentage that would maximise industry revenues.

This research extends prior work in two key ways. First, it considers several specific genetically modified food products with defined productivity benefits and/or defined consumer benefits. Respondents were presented with plausible products that offered specific benefits, such as butter with 50 per cent less cholesterol. The survey therefore represented an improvement over research concerned with undefined 'genetically modified food', as well as greater information on respondents' preferences than single-product surveys. Secondly, the survey was designed to allow a respondent to express acceptance or rejection of each GM food product, and to consider a range of possible prices for the products. The entire range of demand for GM food was therefore present in the data.

This paper discusses consumer reactions to GM food, then presents the empirical analysis. It begins with a brief review of the literature on demand for GM food, presents results from the New Zealand survey on public perceptions of biotechnology, and discusses those results. An analysis of the survey data is included and the results are used to estimate the demand curve and the optimal uptake of GM crops. The paper concludes with a discussion of the results.

2. Literature on Demand for GM Food

Economic research on consumer reactions to GM food has consistently found, on average, either a willingness to pay for non-GM food or a willingness to avoid GM food (Kaye-Blake et al., 2003; Saunders, Kaye-Blake, & Cagatay, 2003). However, using an average willingness to pay obscures this variation in consumer responses. Consumer and public perception research has found that reactions to GM food and biotechnology can be categorised into several different groups (Gaskell et al., 2003). From an economic perspective, there are four different consumer responses to consider: willingness to pay a premium in order to have quality-enhanced GM food, indifference to the issue of genetic modification, willingness to buy GM food at a discount, and refusal of GM food (Noussair, Robin & Ruffieux, 2004). Each response is considered in turn.

Economic research has found that some consumers are willing to pay more for GM food that offers specific benefits. A contingent valuation survey in Beijing, China found that 43.9 per cent of respondents would pay a premium for GM rice with extra vitamins (Li, Curtis, McCluskey, & Wahl, 2002). In a choice experiment survey, respondents who were concerned about their cholesterol levels were prepared to pay $0.83 on average for a GM beer that reduced their cholesterol levels by 20 per cent (Burton & Pearse, 2002). For these consumers, GM technology offers a way to increase the value of food.

Other research has indicated that some consumers are indifferent to the use of gene technology. In an auction experiment at a US university, most students were not willing to

pay a premium in order to have non-GM food (Lusk, Daniel, Mark, & Lusk, 2001). Choice experiment surveys in the U.K. and Australia have found that GM food produced with plant-only gene technology has approximately the same value as non-GM food for most consumers (Burton, Rigby, Young, & James, 2001; James & Burton, 2003). A conjoint analysis survey for pST-treated pork (Halbrendt, Pesek, Parsons, & Lindner, 1994) determined that respondents who were unconcern about the use of pST rated both the treated and untreated pork products similarly. This would suggest indifference to the issue of GM or a similar WTP for both the GM and non-GM products. For products with no consumer-oriented benefits, this indifference should lead to equal prices for GM and non-GM food. For enhanced products, these consumers could be willing to pay higher prices. This group may, therefore, overlap with the group willing to pay a premium.

Willingness to buy GM food at a discount to non-GM food has been the focus of much consumer research. On average, consumers seem to prefer non-GM food. The characteristic 'genetically modified' as separate from other food characteristics has dis-utility; it has negative value for consumers. For example, researchers at Iowa State University found that Midwestern U.S. consumers were willing to pay 14% less on average for GM food (Huffman, Shogren, Rousu, & Tegene, 2001). Consumers in the U.K. were willing to pay a premium of at least 26% for non-GM food when GM food was produced using plant and animal gene technology (Burton, Rigby, Young, & James, 2001). Similar responses were found in Australia (James & Burton, 2003) and France (Noussair et al., 2004)

Not all consumers are willing to purchase GM food, however. A number of respondents refused to choose GM products in choice experiment surveys (Burton et al., 2001; James & Burton, 2003; Onyango, Govindasamy, & Nayga Jr., 2004), or said they were unwilling to purchase GM food regardless of the discount in contingent valuations surveys (McCluskey, Ouchi, Grimsrud, & Wahl, 2001). In a New Zealand choice experiment survey designed to capture unwillingness to pay for GM food, 41 per cent of respondents would not pay for GM food (Kaye-Blake, 2004). Research on consumer attitudes towards GM food confirms the existence of such consumers. Cluster analysis on results of the GM Nation survey in the U.K., for example, found that 47 per cent of the sample were 'Implacably Opposed to GM' (Heller, 2003). Canadian and European research has similarly found sizeable groups of respondents who oppose GM food (Gaskell et al., 2004; Noussair et al., 2004; Sheehy, Legault, & Ireland, 1998). For some of this research, unwillingness to purchase GM food occurred even with the presence of positive consumer benefits, such as health or environmental benefits (Burton et al., 2001; James & Burton, 2003; Kaye-Blake, 2004; Onyango, et al., 2004). This type of consumer response limits the size of the market for GM food.

The complexity of consumer reaction to GM food is generally not captured in econometric models purporting to show the impact of GM crops on the agricultural sector. For example, the model in Sobolevsky, Moschini, & Lapan (2002), an expansion of the well-known GM model in Moschini, Lapan, & Sobolevsky (2000), allows only two consumer responses: weak preference for non-GM food and indifference. It does not account for consumer refusal, demands for steep discounts, or indeed preferences for GM food, all of which are observed in consumer research. Modelling using the Global Trade Analysis Project (GTAP) model has also considered demand for GM food. Although changes in demand have been modeled as preference shifts and governmental bans (e.g., Anderson, Nielsen & Robinson, 2000; Stone, Matysek & Dolling, 2002), they consistently show that regions with negative reactions to GM foods have declines in consumer welfare. If, in fact, some consumers would be infinitely harmed by the introduction GM food – which is what a total refusal of GM food implies – then any modelling scenario that allows such consumers access to non-GM food must represent an improvement in consumer welfare. Thus, an estimate of the market demand for

GM food is important not only in its own right but also as a useful addition to econometric modeling investigating the potential impacts of GM on the agricultural sector.

3. New Zealanders and Biotechnology: a Nationwide Survey

In late 2003, the AERU conducted a nation-wide mail-out survey of public perceptions of biotechnology. A total of 2,000 questionnaires were distributed to randomly selected addresses in New Zealand. There were 701 questionnaires with usable responses returned. Adjusting for undelivered questionnaires, the response rate was 36.3 per cent. The survey was representative in terms of gender but not age, income, number of respondents with university qualifications and ethnicity. Details regarding survey administration, response rate, and representativeness are available in Cook, Fairweather, Sattersfield, & Hunt (2004).

As part of this survey, respondents were asked about their intentions to purchase and their willingness to pay for specific food items that were produced using genetic modification. The questions were designed with several issues in mind: identifying different levels of acceptance and willingness to pay, providing examples of different possible uses of gene technology, and estimating demand for key New Zealand export commodities. The questions are provided in Figure 1.

Identifying levels of acceptance and willingness to pay was approached with two separate questions. First, respondents were asked about their intention to purchase the GM food products. Intentions to purchase have been shown to have reasonable correspondence with actual purchasing behaviour (Conner & Sparks, 1995). Responses were recorded on a Likert scale anchored on Strongly Agree and Strongly Disagree. With this question, respondents could indicate whether they wished to avoid GM food. The second question asked respondents to indicate their willingness to pay for these products. The response scale ran from a 40 per cent discount to a 40 per cent premium in steps of ten per cent. The question was thus a contingent valuation question similar to a payment card format. Respondents could also indicate that they would refuse the products. These two questions were designed to provide a picture of the overall potential market for GM food products.

Respondents were presented with six products representing different modifications that could be achieved with gene technology. A range of modifications was presented to respondents in order to gauge the impact of different benefits on the acceptability and WTP for GM food. To date, the major commercial GM crops have been field crops modified for herbicide tolerance and insect resistance (James, 2003). These input-oriented crops are considered the first generation of GM crops, but the second generation promises modified output characteristics that consumers may find desirable (Caswell et al., 1998; Shoemaker et al., 2001). Second-generation crops may include better-tasting tomatoes, crisper carrots, and more nutritious strawberries (Biotechnology Industry Organization, 2003b). For the survey, three products offered health benefits, such as less fat, less cholesterol, or more nutrition. One product offered an environmental benefit: a reduction in the use of pesticides. A fifth product was cheaper to produce. The last product offered nothing in the way of producer or consumer benefit; it was simply genetically modified.

These products seem to be realistic representations of potential GM products (Information Systems for Biotechnology, 2003; Biotechnology Industry Organization, 2003a). However, these products are not currently commercially available nor are they likely to be in the next

Figure 1
Survey Questions on Intentions Towards and Willingness-to-Pay for GM Food

9. Buying the products of biotechnology

(a) As well as gauging the acceptability of biotechnology we are interested in whether you would purchase products made using biotechnology. Please indicate whether or not you intend to purchase the following products.

Definitely intend not to purchase	Intend not to purchase	No intention to either purchase or not purchase	Intend to purchase	Definitely intend to purchase
1	**2**	**3**	**4**	**5**

Butter from cows genetically modified to produce 50% less cholesterol in their milk	
Meat from sheep genetically modified for 'double-muscling', producing more meat and less fat per animal	
Bread made from genetically modified wheat that is 25% cheaper to grow	
Apples genetically modified to produce twice as much antioxidants, which may help prevent cancer	
Milk from cows that are grown on pastures containing genetically modified clover	
Sweetcorn that has been genetically modified to resist insects so that it requires 50% less than the usual application of pesticides	

(b) Now please indicate the most you would pay for each of the following products. For some products you may be willing to pay more or only consider purchasing if they cost less. For the products you do not wish to purchase please write an **X** in the box.

Pay 40% less	Pay 30% less	Pay 20% less	Pay 10% less	Pay no more or no less	Pay 10% more	Pay 20% more	Pay 30% more	Pay 40% more
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Butter from cows genetically modified to produce 50% less cholesterol in their milk	
Meat from sheep genetically modified for 'double-muscling', producing more meat and less fat per animal	
Bread made from genetically modified wheat that is 25% cheaper to grow	
Apples genetically modified to produce twice as much antioxidants, which may help prevent cancer	
Milk from cows that are grown on pastures containing genetically modified clover	
Sweetcorn that has been genetically modified to resist insects so that it requires 50% less than the usual application of pesticides	

six to eight years. Bringing a GM product to market can take eight years or more (Shoemaker, et al., 2001) and none of these example products is expected to come onto the market within the next six years (Biotechnology Industry Organization, 2003a).

A final consideration in developing these questions was obtaining results for key agricultural commodities. New Zealand produces and exports large amounts of dairy products and meat. The survey questions therefore included butter, milk, and sheepmeat. Sweetcorn is a product that has currently commercialised GM cultivars available, and has been the subject of media scrutiny in New Zealand. Wheat is another product for which GM cultivars have been developed, but they have not yet been commercially released. The sixth commodity included in the survey was apples, which have been the subject of other GM consumer research in New Zealand (Kaye-Blake, 2004; Richardson-Harman, Phelps, Mooney, & Ball, 1998).

The full descriptions of the products in the survey and the type of modification offered are presented in Table 1.

4. Survey Results

Results from these two questions provided information about the extent of rejection of GM food as well as the range of willingness to pay for GM food. These two issues are discussed in turn.

The survey included two questions designed to indicate rejection of GM food. The first was an intention-to-purchase question, results of which are presented in Table 2. A respondent could indicate either a positive or a negative attitude towards purchasing the GM food product. This question was included mainly to determine whether the respondent had a negative intention, that is, whether the respondent would like to avoid purchasing the specific GM food product. The willingness-to-pay question also allowed respondents to indicate refusal of GM food, as shown in Table 3. For that question, a respondent could place an 'X' in the response box rather than indicate some positive willingness to pay (see Figure 1 for the actual survey questions).

The data from the intention-to-purchase question (Table 2), exhibit two interesting patterns. The first pattern is that each product is rejected by a large minority of respondents: for each item, from 36 per cent to 43 per cent of respondents disagree or strongly disagree that they would purchase it. The second pattern is that there is variation in the negative intentions. The percentage opposed to purchasing each product varies, so that some products encounter less resistance than others. Further data analysis found that the percentage of respondents who do not intend to purchase any of the products is 27.8 per cent, but on average the products are rejected by 39.5 per cent of respondents. The difference in these figures suggests that some respondents wish to reject some but not all GM food products.

The second question, regarding willingness to pay, provided two important estimates: a second measure of the extent of product rejection and an estimate of willingness to pay. Rejection in the willingness to pay data (Table 3) follows a similar pattern to the data in the intentions question. For each product, the percentage of respondents refusing the product is approximately the same. However, this percentage includes both a core of total refusers – who do not want any of the GM food products – and a group of respondents who refuse some products but not others. The willingness to pay question also provided data about the percentage of respondents who would purchase the item at each price level (Table 4). For all products, responses (excluding rejection) are concentrated around a nil discount/premium.

For consumers who would purchase an item, most would be willing to pay the same price for the GM product as the non-GM product. About one-half of all respondents would be willing to pay the same price or higher for each of the products, with one exception (bread from GM wheat that was cheaper to grow).

Table 1
Products in the Survey

Product	Type of change	Note
Butter from cows genetically modified to produce 50% less cholesterol in their milk	Health benefit	Impact of GM on the food product is indirect
Meat from sheep genetically modified for 'double-muscling', producing more meat and less fat per animal	Health benefit / Possible environmental benefit	
Bread made from genetically modified wheat that is 25% cheaper to grow	Cost reduction	
Apples genetically modified to produce twice as much antioxidants, which may help prevent cancer	Health benefit	
Milk from cows that are grown on pastures containing genetically modified clover	Merely GM – no benefit	The food product is not modified
Sweetcorn that has been genetically modified to resist insects so that it requires 50% less than the usual application of pesticides	Environmental benefit / Possible cost benefit	

Figure 2 provides another view of the same data. In this figure, the horizontal axis represents the price of the GM food product as a percentage of the non-GM counterpart. Prices to the left of 100% represent discounts for GM food, and prices to the right represent premia. Each ten per cent step represents a different willingness to pay from the range of options provided. The vertical axis is the percentage of respondents who indicated they were willing to pay at least that price for the GM food product. It is therefore a cumulative measure. Several interesting characteristics of the data are apparent in this figure. None of the willingness-to-pay curves rises higher than 62 per cent of the sample; for all products, there was an upper limit to the percentage of respondents who would purchase them. Furthermore, each curve represents a different product, but they are all the same shape and largely in the same position on the diagram. This similarity suggests that the respondents' reactions were about the same for all products.

Table 2
Responses to Intention-to-Purchase Question
(percentage of respondents)

	Definitely intend not to purchase	Intend not to purchase	Neither	Intend to purchase	Definitely intend to purchase
Butter with less cholesterol	19.3%	20.9%	33.3%	23.1%	3.5%
Milk from cows fed GM clover	17.5%	19.7%	40.2%	19.8%	2.9%
Meat from double muscled sheep	21.3%	22.0%	30.2%	23.8%	2.8%
Antioxidant apples	17.6%	20.1%	29.9%	26.5%	6.0%
Bread from efficient wheat	18.5%	23.6%	32.7%	22.3%	2.9%
Insect-resistant sweetcorn	17.6%	18.8%	33.2%	26.8%	3.6%

Table 3
Willingness to Pay Categories
(percentage of respondents in each category)

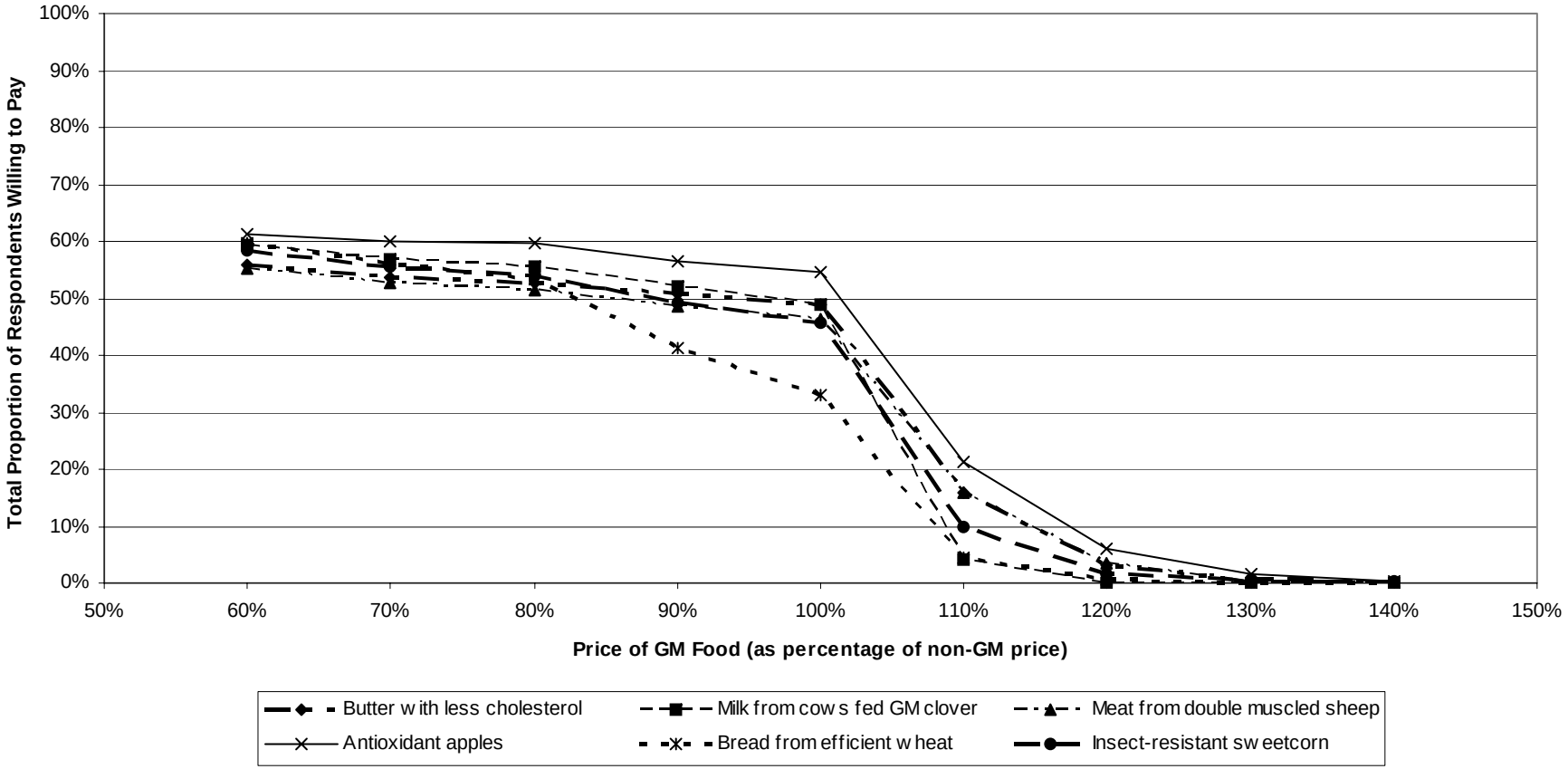
Products	Rejection	Discount	Indifference	Premium
Butter with less cholesterol	44.0%	7.0%	33.0%	16.0%
Milk from cows fed GM clover	40.7%	10.4%	44.8%	4.2%
Meat from double muscled sheep	44.9%	8.7%	30.6%	15.8%
Antioxidant apples	38.8%	6.5%	33.5%	21.2%
Bread from efficient wheat	40.3%	26.8%	28.6%	4.3%
Insect-resistant sweetcorn	41.5%	12.8%	36.0%	9.8%

Table 4
Willingness to Pay for GM Food Products (percentage of respondents)

Products	Willingness to pay (as percentage change from non-GM price)								
	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%
Butter from cows genetically modified to produce 50% less cholesterol in their milk	2.2%	1.0%	2.1%	1.6%	33.0%	12.9%	2.8%	0.0%	0.3%
Milk from cows that are grown on pastures containing genetically modified clover	2.4%	1.5%	3.6%	3.0%	44.8%	4.0%	0.1%	0.0%	0.0%
Meat from sheep genetically modified for 'double-muscling', producing more meat and less fat per animal	2.4%	1.3%	2.8%	2.2%	30.6%	12.4%	3.0%	0.1%	0.3%
Apples genetically modified to produce twice as much antioxidants, which may help prevent cancer	1.3%	0.3%	3.0%	1.9%	33.5%	15.1%	4.6%	1.0%	0.4%
Bread made from genetically modified wheat that is 25% cheaper to grow	3.6%	3.0%	11.9%	8.4%	28.6%	3.7%	0.6%	0.0%	0.0%
Sweetcorn that has been genetically modified to resist insects so that it requires 50% less than the usual application of pesticides	3.0%	1.5%	4.8%	3.6%	36.0%	8.2%	0.9%	0.4%	0.3%

NB: Figures are percentages of valid responses, which excludes non-response. Rows do not sum to 100% because respondents who refused products are not included.

Figure 2
Willingness to Pay for Genetically Modified Foods



5. Estimating the Demand Curve

The willingness to pay diagram (Figure 2) is transformed in Figure 3 into a demand diagram, with price on the vertical axis and quantity on the horizontal axis. Price is again given as a percentage of the non-GM price, making it the relative price of GM to non-GM. Quantity is given as the percentage of respondents who would purchase the GM product at each relative price. It can therefore be interpreted as a market share percentage. The curves for the products are quite steep near the vertical axis – relatively few respondents will purchase GM food at high premia. The demand curve flattens out between relative prices of 110 per cent and 90 per cent of the non-GM price (a premium of 10 per cent and a discount of 10 per cent), which can be read from the vertical axis. Generally, about one-half of respondents express a willingness to pay in this range. At higher discounts, the demand curve is again rather steep. Larger and larger discounts do not entice many more people into the market.

The demand curves in Figure 3 are sigmoid or S-shaped. Such a curve can be represented by a number of functional forms. We chose to use a Weibull distribution, given its tractability. The average demand curve can thus be represented by the following equation:

$$f(Q_G) = \exp(-\exp(g(P_G))),$$

where $f(Q_G)$ is some function of the percent of product that is GM and $g(P_G)$ is some function of the price of GM food. It is necessary to consider the function of quantity and the function of price because the curve does not follow the Weibull distribution exactly. The quantity, for example, does not cover the full interval from 0 to 1 (as the Weibull distribution does), but only reaches at most 0.62 of the survey sample. This yields the function:

$$f(Q_G) = (Q_G) / 0.62.$$

Two aspects to the price function need to be considered. The centre of the function is not where quantity equals zero (as in the unadjusted function), so the true centre needs to be estimated. In addition, the curvature of the function needs to be estimated. These two adjustments can be made by including parameters β_0^* and β_1, respectively. This yields the equation:

$$Q_G / 0.62 = \exp(-\exp((P_G + \beta_0^*) \cdot \beta_1)).$$

Rearrangement of the terms leads to a linear function on the right-hand side:

$$\ln(-\ln(Q_G / 0.62)) = \beta_1 P_G + \beta_0 ,$$

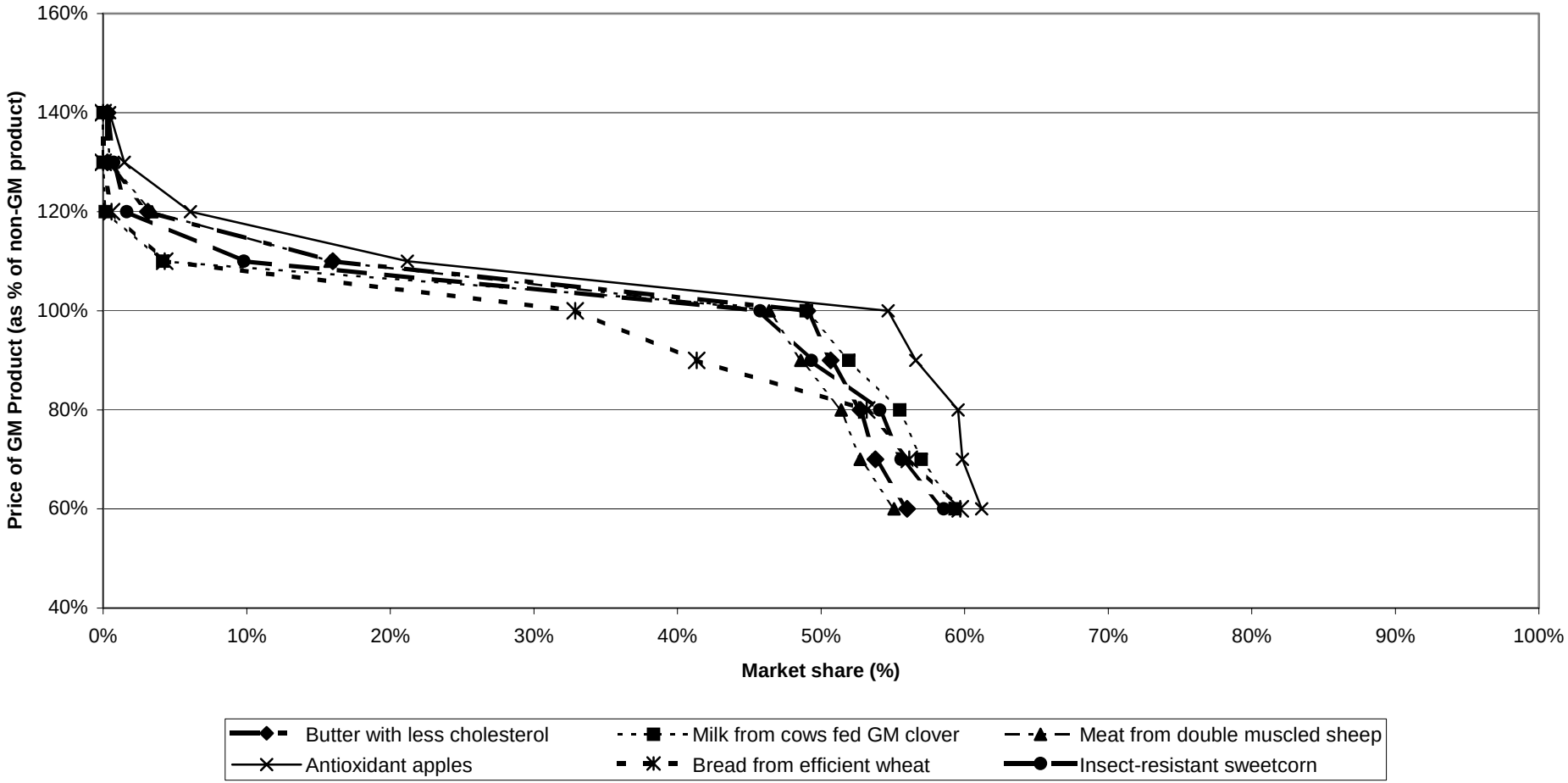
where β_0 is equal to $\beta_0^* \cdot \beta_1$ and β_0 and β_1 are the parameters to be estimated. The dependent variable is calculated from the percentages of respondents who are willing to buy the GM food products at each price level, and price is the independent variable. The parameters can be estimated via OLS regression.

It is also possible to add a vector of dummy variables to this equation to account for differences in reactions by type of product offered. If the type of product affects the placement of the curve and not the curvature, then the dummy variables are simply additive:

$$\ln(-\ln(Q_G / 0.62)) = \beta_1 P_G + \beta_0 + \mathbf{D},$$

where **D** is a vector of five variables, one for each product less one omitted base product.

Figure 3
Demand for Genetically Modified Food Products – Survey Results



From the survey results, we had 54 observations, being the percentage of respondents willing to pay for each product at each price (six products x nine prices = 54 observations). Estimating the full equation with seven variables resulted in 47 degrees of freedom. Three different equations were estimated in Excel using the Regression tool from the Data Analysis menu. The results of the regression analysis are presented in Table 5.

Model one estimated only the parameters β_0 and β_1, so it considered only the impact of price on the percentage of respondents willingness to purchase GM food. It shows that there is a strong relationship between the dependent and independent variables. Furthermore, the high adjusted R^2 suggests that the functional form (the sigmoid curve) chosen for the analysis is correct.

Model two included the vector of dummy variables, so it estimated a different regression intercept term or distribution centre for each product, with the GM sweetcorn as the base product. The dummy variables increase the fit of the model slightly. However, the only one that is significant is the parameter for GM apples. The low t-scores for the other dummy variables suggest that all the products except apples are eliciting similar reactions from the respondents.

This finding for model two led to the specification of model three. It included β_0 and β_1 and one dummy variable, for the GM apples with greater antioxidants. This model seems to represent the survey data best, showing the strong relationship between price and quantity and including the additional impact from the differential reaction to the GM apple product.

The estimated model is plotted in Figure 4. For this figure, percentage of product that is GM was plotted against the estimated price for GM food at that percentage. Two curves were estimated, one for apples and one for all other products. This figure also includes the average raw results from the survey for purposes of comparison. The figure shows that the estimated curves mimic the survey data well. As a result of the good fit of the regression models and the appearance of this figure, we are confident in our estimate of the relationship between price of GM food and the percentage of people willing to purchase it.

We do realise that this analysis of willingness to pay data is somewhat different from the standard treatment of interval contingent valuation data. Standard practice would be to generate a probabilistic function based on whether or not respondents were willing to purchase GM food at each price level. The probability that a respondent would agree to purchase the product would be a function of the relative price, the type of product, and perhaps some socio-demographic variables.

There are two reasons for our treatment of the data here. The first concerns problems with indifference, that is, with a relative price of GM to non-GM food equal to 100 per cent. The large number of respondents who chose an indifferent response suggests that it is important to model this accurately. In an interval treatment, given the data collected, these respondents would be modelled as willing to pay between 100 per cent and 110 per cent of the non-GM price for GM food. That is, we know that they would pay 100 per cent and we know that they would not pay 110 per cent, but we do not know their exact willing to pay within that interval. In future work, it would be better to specify an interval that includes indifference as its midpoint, e.g., willing to pay 95 per cent to 105 per cent of the non-GM price. However, the present work takes the responses from the 100 per cent category to mean that the respondents are truly indifferent, rather than that 100 per cent is a lower bound. It therefore avoids ascribing to respondents a willingness to pay a premium, although as a consequence it might have biased downward the true willingness to pay by 5 per cent overall.

The second reason for the regression estimate of the demand curve rather than a probabilistic estimate of willingness to pay was the importance of including refusal responses. In order to estimate a probabilistic model, one needs to assume the probability distribution of the responses, which, furthermore, needs to be a continuous function and which generally has a central tendency. If one considers only those respondents willing to pay for GM food, then these assumptions are not likely to cause difficulties. If one is concerned with how the entire market for food could react in the presence of these GM food products, then it is important to consider refusal responses, as well. How to include refusal responses in an analysis of willingness to pay based on probability is beyond the scope of this report.

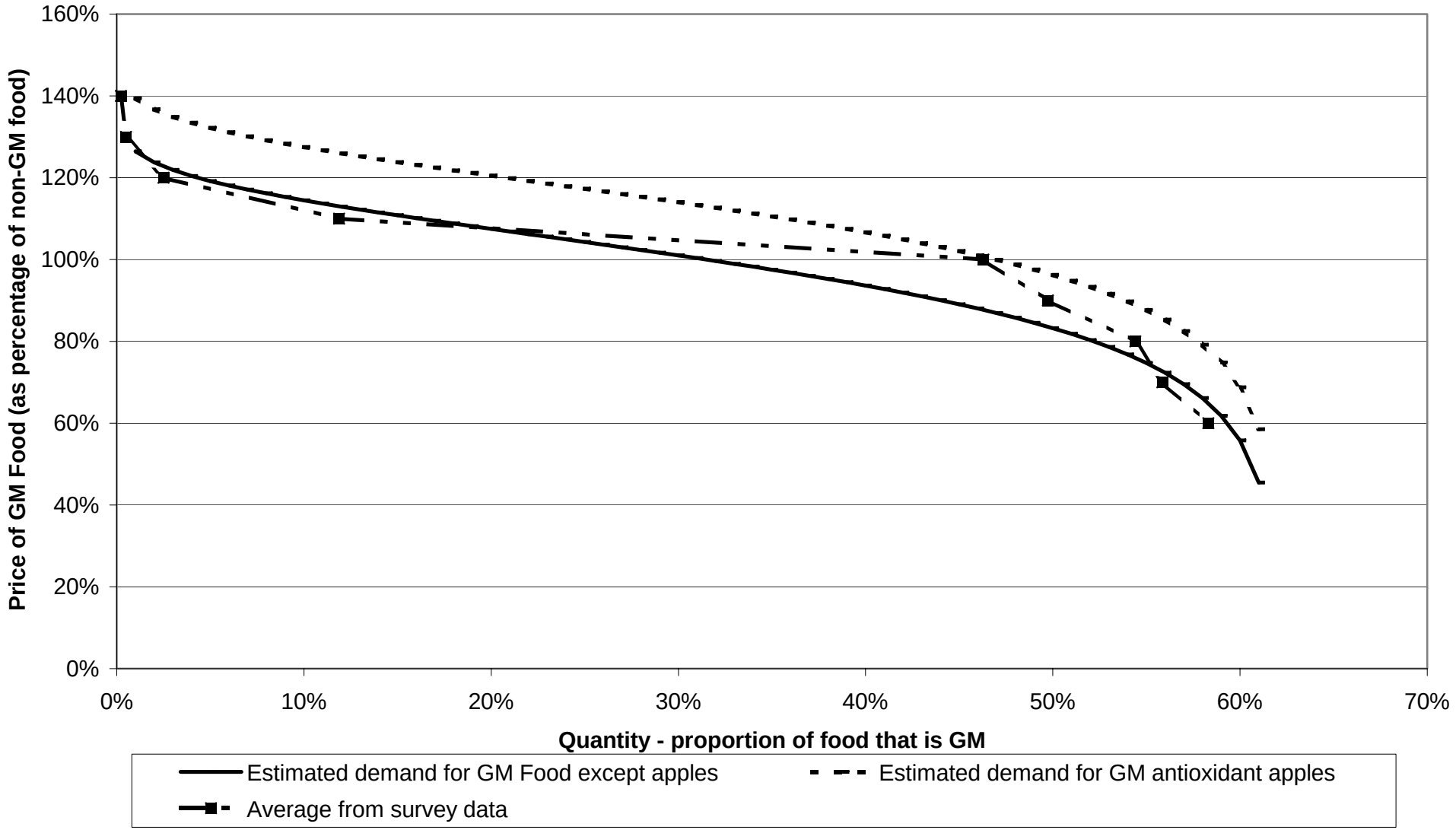
For these reasons, we have opted for the approach described above. The result is an equation that expresses relative demand for GM and non-GM food as a function of their relative price. Obtaining this estimated equation allowed us to take the analysis to its next logical step, as described below.

Table 5
Results of Regression Analysis

	Parameters (*t statistic*)		
	Model 1	**Model 2**	**Model 3**
β_0	-7.38*	-7.36*	-7.23*
	-21.58	*-21.71*	*24.70*
β_1	6.84*	6.84*	6.84*
	20.66	*23.88*	*24.29*
Dbutter		0.034	
		0.134	
Dshpmeat		0.143	
		0.557	
Dwheat		0.115	
		0.449	
Dapples		-0.762*	-0.891*
		-2.973	*-4.563*
Dmilk		0.352	
		1.371	
Dswtcorn		base	
Adjusted R^2	0.889	0.917	0.920

* significant at 1% level

Figure 4
Demand for Genetically Modified Food Products – Results of Model Estimation



6. Optimal Uptake of GM Crops

By transforming the raw willingness to pay data from the survey of New Zealanders into a demand curve that relates market share to relative price of GM food, we are able to extend the analysis further. We can calculate the relationship between industry revenues and percentage adoption of GM crops. This allows us to identify the adoption rate or uptake percentage that maximises industry revenues.

Recall first that total revenue is found by multiplying price times quantity:

$TR = P * Q,$

where TR is total revenue, P is price, and Q is quantity for a given commodity.
In a segmented commodity market, both GM and non-GM commodities would need total revenue calculated separately:

$TR = (P_N * Q_N) + (P_G * Q_G),$

where the subscripts N and G denote non-GM and GM versions of the same commodity, respectively.

We can reduce the number of terms in the equation by fixing the amount of production in the commodity, so that the proportion of a commodity that is non-GM is simply:

$Q_N = 1 – Q_G .$

This simple specification does not make an allowance for greater productivity of GM crops, although that complication can be included by reducing the Q_G term by the productivity gain:

$Q_N = 1 – (Q_G /(1 + gain)).$

This more complex equation is not used further. We can also normalise the prices in the equation, such that the price of the non-GM commodity is set to unity (1). Thus we have:

$TR = (1 - Q_G) + (P_G * Q_G),$
which is essentially an index of total revenue, equal to 1 when all production is non-GM.

The regression models estimated above allow total revenue to be expressed as a function of one variable, Q_G. Using the parameters estimated for model three and excluding the case of GM apples, we have:

$TR = 1 + (P_G * Q_G) – Q_G$

$TR = 1 + Q_G (P_G – 1)$

$TR = 1 + Q_G((1 / 6.84) * (\ln(-\ln(Q_G / 0.62)) + 7.23) –1)$

When some GM crops are adopted and they represent a small fraction of total output, the GM food products can be sold at a premium over non-GM commodities. This is evident in the demand curve shown in Figure X and the underlying survey data. At these small fractions, total revenue is increasing. As the amount of GM product increases, the price must fall in order to clear the market. At some percentage uptake, total revenue stops climbing and starts

to decline. At higher uptake percentages, the prices of GM and non-GM products reach parity and the industry as a whole has no more revenue than it had at a nil uptake of GM crops.

The point at which the industry has maximum total revenue represents the optimal production of GM crops. Evaluation of the above equation at different levels of GM production reveals that the uptake of GM crops that maximises total revenue is 15 per cent. This level of uptake leads to a total revenue index value of 1.0162, which indicates that a 15 per cent uptake of GM crops would lead to an increase in industry revenues of 1.62 per cent. For GM apples with greater antioxidants, the optimal uptake rate is 26 per cent, leading to increased revenues of 4.33 per cent.

The maximum level of total revenue is driven largely by two factors: the percentage of respondents who rejected each GM product and the percentage of respondents who were indifferent to the products. Consumers who refuse GM products limit the potential market share of GM products and, conversely, guarantee a minimum share for non-GM. In this survey sample, the percentage of respondents who refuse each product was about 40 per cent. This is an unsurprising percentage given the literature cited above. Indifferent consumers also affect the total revenue calculations because they limit the possibilities for charging premium prices. For this survey, the percentage of respondents who were willing to pay the same price for GM and non-GM products was 30 per cent to 45 per cent. The net result is apparent in the calculation of total revenue: growers of the most popular GM product, anti-oxidant apples, can charge some consumers a 17 per cent premium to maximise industry revenues. However, they can only charge 26 per cent of the market this price. Once the increased revenue is averaged into the whole industry, total revenues are only 4.3 per cent higher.

The fairly small increases in average industry returns can be increased in several ways, which can loosely be separated into changes in the overall market and changes to New Zealand's position in that market. As should be evident from the above analysis, two broad changes to the market for GM food would improve estimates of total revenue. The first would be to have fewer consumers refusing the product. The more consumers are willing to purchase GM food, the larger the revenues from those crops can be. A second beneficial change would be a decrease in those who are indifferent to the products. The anti-oxidant apples in the survey are a case in point: over 20 per cent of respondents were willing to pay a premium for them, and the increase in total revenue was over twice the average increase.

The impacts of these changes in the market for GM food can easily be analysed with the demand equation generated from the survey data. In the regression analysis, the maximum percentage of the market that could be GM was set at 62 per cent. This figure was based on survey data for the most acceptable GM product. Changing the maximum percentage of consumers willing to buy GM food from 62 per cent to 90 per cent changes the increase in total revenue from 1.62 per cent to 2.35 per cent. This figure is the result of a 22 per cent uptake of GM crops and an 11 per cent premium. Reducing the number of indifferent consumers is not as straightforward. However, the following equation has a higher percentage of consumers WTP for GM food (90 per cent), a smaller region of indifference, and a wider spread of maximum and minimum relative prices than the estimated equation above:

$\ln(-\ln(Q_G/0.9)) = 4.0*P_G - 4.50$.

If this equation is used to evaluate total revenue for agriculture, optimum uptake is 24%, the price premium is 19%, and the increase in total agricultural revenues is 4.67%.

7. Conclusion

In this paper, responses to the New Zealanders and biotechnology survey have been presented, discussed, and analysed. From the responses, we have estimated a demand curve for GM food that accounts for the full range of consumer reactions, from outright rejection to a willingness to pay a premium. Respondents' willingness to pay for GM food exhibited a strongly sigmoid pattern: very few were willing pay a high premium, many were concentrated around an indifferent reaction, and high discounts attracted fewer and fewer respondents. By using an appropriate functional form, we were able to use regression analysis to estimate the impact of the price of GM food on the percentage of respondents willing to purchase the products. This appears to represent the first attempt in the published literature to account for the full range of consumer responses in a single market demand estimate.

This estimated demand curve, in turn, allowed for a calculation of maximum total revenue possible from adopting GM crops. The results indicate that the agricultural sector as a whole can maximise its income from adopting GM crops with an uptake rate of 15 per cent for most crops and 26 per cent in the case of apples with greater anti-oxidants. Although the other five products did not have identical numbers of respondents expressing identical willingness to pay, the variation was not enough to affect the demand curves of the specific products. The analysis of the optimal uptake rate for GM crops found that agricultural revenues could increase by two to four per cent. This idea of the optimal uptake of GM technology, given consumer demand, has not been raised elsewhere, although it is a straightforward extension of a willingness to pay analysis. By moving away from an analysis of average demand or average price for GM food, and by avoiding an all-or-nothing approach, we have been able to provide a more useful estimate: what the agricultural industry can do to make optimal use of GM crops. An important caveat to this analysis is that it assumes that the GM and non-GM products can be segregated in ways acceptable to consumers of both products.

Analysis of this demand curve allows us to draw a few conclusions about the market for GM food. The market is strongly affected by the large minorities who are indifferent to GM food and who refuse to consume GM food. These two groups limit the possibilities of charging a premium for quality-enhanced products, so that the optimal uptake of GM crops for the agricultural industry is less than one-quarter of total production. Reducing the number of consumers rejecting GM food has been shown to increase industry revenues, but only by a small amount. On the other hand, reducing the number of indifferent consumers could have a larger impact on revenues.

Changes to New Zealand's position in the market could increase revenue even more. One possibility is that New Zealand could concentrate on supplying the GM product. In this scenario, New Zealand would have a very high uptake of GM crops, but its contribution to the total world market would be small enough that high premiums could still be maintained. A second possibility is to segment the market so that consumers who are willing to pay more are charged higher premiums. This would require New Zealand to market and price its products effectively. Either strategy has the possibility of increasing revenues for agriculture.

These results also point to areas that require further investigation. An important area for future research is the demand curve for different countries. It is now a commonplace in consumer research on GM food that consumers in different countries have different reactions to GM products. The demand estimate provided here is specific to New Zealand. The general proportions of indifferent and refusing consumers are approximately the same as in some countries, but are likely quite different from others. Given New Zealand's dependence on export markets, more precise estimates of demand for GM food in other countries are desirable. A second important area of research is the impact of different product

enhancements on willingness to pay. In the present research, both the product and the enhancement were varied simultaneously. It is therefore unknown whether consumers have different preferences regarding which food is modified, whether they have preferences regarding the modifications themselves, or whether there is some interactive effect between the specific food product and the enhancement.

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