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Unit-pricing: Minimising Christchurch Domestic Waste

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Unit-pricing: Minimising Christchurch Domestic Waste

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Summary

One economic tool that can aid in the achievement of waste minimisation targets is unit-pricing. Unit-pricing in the waste management sector refers to a pricing system that charges households for their collection and disposal service relative to the amount of waste disposed by the household. This research investigates the potential impact of implementing a unit-pricing policy for domestic waste collection and disposal services in Christchurch. Data is collected using a Contingent Valuation survey. A Poisson Quasi-Maximum Likelihood count model is specified for econometric analysis of demand for Christchurch City Council domestic collection services.

Key words: Demand for domestic waste service, unit-pricing, Contingent valuation methodology, PQML count model.

Christchurch Domestic Waste Services

The Christchurch City Council (C.C.C.) supplies the city's major domestic waste and disposal service to households by way of a weekly kerbside collection. There are also a number of small private suppliers, and they account for approximately 15% of the market. The council service requires waste to be placed in a council approved bag that has a fifty litre, 15 kilogram capacity. Until recently each rateable property was supplied with 52 bags per year. This has now been halved. Collection and disposal of these bags is presently funded by a flat rate of \$43 levied on households as part of general annual rates. Residents can buy as many additional bags as they require in a minimum pack size of 5 for around \$6 a pack from retail outlets. Hazardous waste and liquids are prohibited but anything else can be put in the bag. The council service accounts for 85% of the Christchurch domestic waste collection market, collecting and disposing of approximately 37,818 tonnes in Burwood landfill during 2001 (C.C.C. 2003). This is 17 percent of Christchurch refuse going to Burwood landfill. With 123,000 households, the average Christchurch household disposes of 307 kilograms per year by this service.

The life-span of Burwood landfill, currently Christchurch's only landfill, has exceeded its planned duration and the Council anticipates the opening of a new regional landfill at Kate Valley in the near future. The life span of Burwood has been just over twenty years and Kate Valley is expected to have a comparable lifespan. At this rate potential sites will become very scarce within decades. The Christchurch City Council recognises responsibility for ensuring that Christchurch has a sustainable future and have implemented programmes to help reduce waste going to the landfill including kerbside recycling, composting of some garden waste brought directly to landfill, recycling centres at the Refuse Transfer Stations, and the sorting of refuse at the Transfer Stations (mostly metals and inert material like soil and rubble). In 2001 kerbside collection amounted to 14,374 tonnes, and 31,157 tonnes of green waste was collected at Transfer Stations (C.C.C., 2003).

Figure 1: Composition of refuse in domestic black bags
Source: C.C.C. (2003)

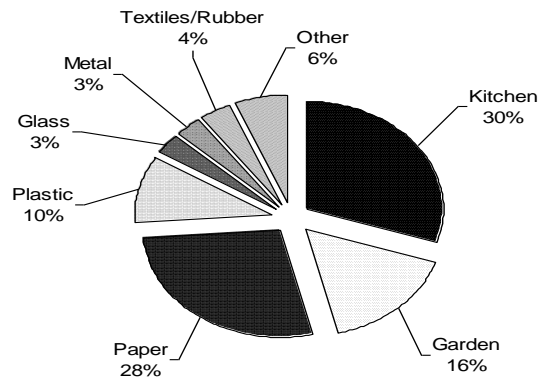


Figure 1 reveals that almost three-quarters (74%) of the contents of an average black bag has the potential to be diverted from landfill. Almost all paper types are now collected from household kerbsides as part of recycling. Kitchen and garden waste make up nearly half of an average bag, even though Christchurch City Council estimates that approximately 60% of households compost at home or take green waste to transfer stations.

Sustainable development in Christchurch

The mandate and plan for Christchurch's domestic waste management is contained in three important documents: the Christchurch City Plan (C.C.C., 1995) which discusses sustainable development and its implications for waste management, the Waste Management Plan for Solid and Hazardous Waste (C.C.C., 1998) which directs current policy, and The New Zealand Waste Strategy (M.F.E., 2002) which aims to coordinate actions and policy nationally. The Natural Environment section of the City Plan emphasizes a strategy of waste minimisation for the city that promotes the sustainable management of resources.

The plan recognises that a primary indicator of sustainable development is the disposal rate of domestic municipal solid waste. Reduction of waste generation will prolong the life of waste management facilities, particularly landfills, and adds to the efficient use of resources. Policy directly applicable to the domestic solid waste sector should be formulated so as to minimise the disposal of waste into the environment. In relation to council provided domestic waste collection and disposal services, the Waste Management Plan for Solid and Hazardous Waste recommends that in order to promote the objectives of this plan, costs must be allocated such that they establish economic incentives to reduce waste and that an element of deterrent pricing for producing excessive waste is included in such a system (C.C.C., 1998).

The New Zealand Waste Strategy comprises of five core policies that form the basis for action, one of these is efficient pricing (M.F.E., 2002). This means creating an incentive structure that encourages households and individuals to minimise waste. This is consistent with Christchurch's waste management plan. Failure to provide

such an incentive structure is untenable in communities that strive to implement modern waste management.

The vision of the Waste Management Plan for Solid and Hazardous Waste is to *minimise the impact of solid waste on the environment*. The reduction target for domestic kerbside waste collection is 80% less than 1994/95 levels by 2010. As the 1994/95 level was approximately 126 kilograms per person per year, this target equates to approximately 26 kilograms per person per year.

Figure 2: Per person domestic waste, recycling and green waste
Source: C.C.C. (2003)

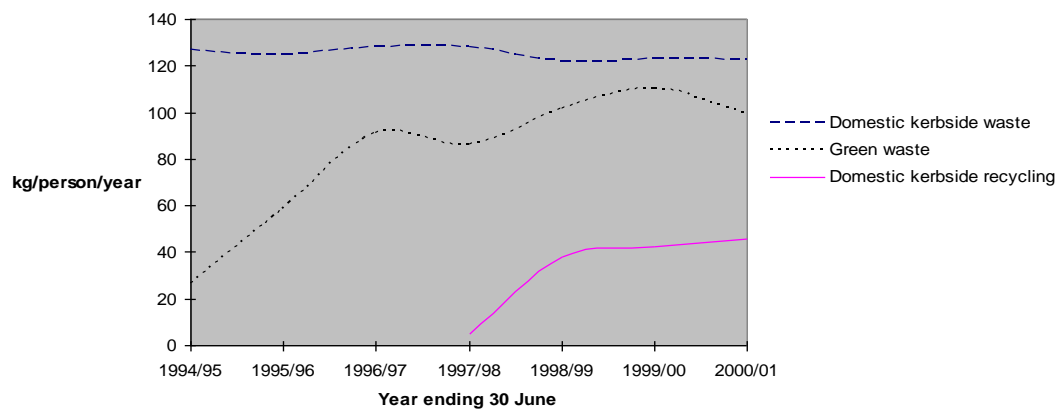


Figure 2 shows current trends for council collected domestic waste and recycling, and green waste at transfer stations. The almost horizontal dashed line at the top shows that domestic kerbside waste per person going to the landfill has remained virtually constant since 1995, with only a very slight downward trend. The introduction of kerbside recycling in 1997 has done little to decrease the quantity of domestic black bag waste going to the landfill. Christchurch City Council (C.C.C. 2003) suggests that this low impact is due to residents finding new bits and pieces to throw out, now that recycling means there is more capacity for the same amount of bags. If this is the case then residents would have had to store waste over some time accumulating a significant amount. As recycling increased households found more and more things to dispose of, so that the amount of waste sent to the landfill remained relatively stable. The zero price for recycling may be a reason. This is because the zero price can create a perverse incentive structure in that households can now purchase larger items or more of an item, for example, if those items can be recycled. They face no increase in disposal costs (directly, that is, recycling must be funded from somewhere and so other services prices may increase) for the increase in volume as they can use the free recycling service. This is the opposite of source reduction, and may be mitigated by charging a positive price for recycling services in the same way as waste service (i.e. unit-pricing). However the recycling service price must be set below the waste service price to decrease the volume of waste going to landfill. Another possible explanation may be that household's have reduced the amount of waste that they take directly to refuse stations themselves.

The introduction of 'green waste' separation at landfill, to be composted, has also done little to decrease the amount of domestic waste entering the landfill via kerbside collection. This may indicate that collection of green waste is not a substitute for

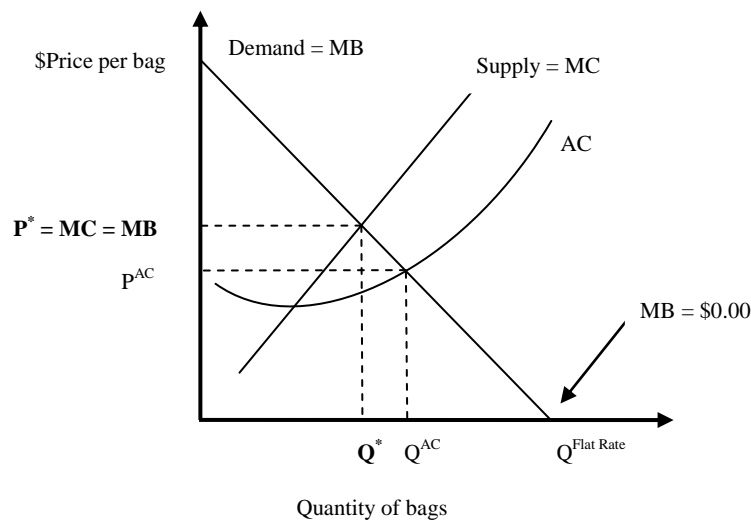
kerbside collection. Implying that the increase in green waste collected can be attributed to separation of waste by households already going to transfer stations.

Flat-rate inefficiency

Many communities have traditionally charged households for their waste service by a flat-rate, as has Christchurch. A flat-rate charge is the price of a service levied in one lump sum, which is the same for all households. The charge does not reflect the amount of waste that a household generates. Flat-rate charging creates a perverse incentive structure that does not motivate sustainable practice and leads to an inefficiently high level of service demanded. The economic argument is relatively straightforward and is illustrated below in Figure 3. This section is adapted from Miranda *et. al.* (1994 pp 683-5). The figure shows demand (marginal benefit) and supply (marginal cost) of council service as measured by the number of black bags. Waste collection services are assumed to be a normal good and so the demand curve is downward sloping. Q^* is the efficient quantity of service since at this quantity the marginal benefit from the last unit consumed is equal to the marginal cost of supplying it. This quantity of service can be achieved with the 'right' price of P^* . In contrast, with a fixed charge households face a cost of zero for each additional unit (bag) of service demanded, that is, the marginal price to users is \$0.00. The result is that households demand service until the marginal benefit of the last unit consumed is also equal to zero, giving quantity of $Q^{\text{Flat Rate}}$. At this level of service the marginal cost of providing the last unit is greater than the marginal benefit obtained from consuming it. If instead of charging a flat-rate a unit-pricing policy is adopted, then setting the unit-price at marginal cost will achieve economic efficiency.

In application it can be difficult to estimate marginal cost and so average cost (AC) pricing is often used instead. This would result in a level of demand greater than Q^* but less than $Q^{\text{Flat Rate}}$. Two-tier pricing can also be applied. Residents are charged two fees, the first fee is flat and covers some minimum level of service. The second fee is unit-based and varies with any additional bags collected. The smaller is the level of service provided by the flat-rate, and the closer the unit-price is set to marginal cost, the closer we come to achieving economic efficiency.

Figure 3: Illustrative MC and MB for domestic waste services



Unit-pricing

Unit-pricing in the waste management sector refers to a pricing system that charges households for their collection and disposal service relative to the amount of waste disposed by the household. At present in the United States of America, over 4,000 communities use unit pricing programs for domestic waste service pricing, which serve over 27 million U.S. residents (Gordon, 1999). This makes America the number one implementer globally. However communities in many nations around the world have adopted the approach. Unit-pricing has been shown to reduce waste generation and disposal, and to increase diversion option such as recycling and composting.

Convincing evidence of the impacts of unit-pricing on a households waste management decisions comes from case studies of communities who have implemented the program. Data on waste flows both before after implementation provide opportunities to make sound comparisons between programs using flat-rate charging and those with unit-pricing. Such studies typically categorise the effects of unit-pricing into five factors: decreased rates of waste generation, decreased rates of waste disposal, increased recycling, increased illegal disposal and increased source reduction behaviour (see for example: USEPA, 1991; Fullerton and Kinnaman, 1994; Miranda et al, 1994; Miranda et al, 1996a; Miranda and Bauer, 1996; Reschovsky and Stone, 1994; Choe and Fraser, 1999)

Contingent Valuation Survey

To gain insight into the possible effect of a unit-price on quantity, demand for domestic waste services is modelled. CVM was incorporated into a self-administered questionnaire sent to Christchurch households in February and March of 2003. The survey instrument was pretested using the cognitive interview method (Dillman, 1998). The intent of this method is for the interviewer to prompt the interviewee to verbalise comments and thoughts that would otherwise go unnoticed. A proportionate-stratified random sample of 1500 Christchurch residents on the electoral role was conducted, the design variable being household income. This sampling procedure was employed because a secondary objective of the study is to

analyse how different income groups react to changes in price. With 121 respondents gone-no-address, and 448 usable responses a 32% response rate results.

The survey consisted of four components, the first is based on substitutes for the council service and asks questions measuring alternative disposal options such as the volume of private service that the household subscribes, and the number of recycling bins put out for collection. The second component is the hypothetical market scenario for rubbish bags. Respondents were asked to indicate the quantity of bags that they would put out, for different prices per bag under a unit-pricing system. The elicitation method can best be described as iterative bidding and is given in figure 4. The third component sought to identify attitudinal motivations for household waste minimisation. Respondents were asked to indicate agreement on a likert scale, with statements representing motivations for waste minimisation such as: ‘concern for the natural environment’. The scale ranges from one (strongly agree) to five (strongly disagree). This data was recoded into a dummy variable for each statement, by including only those that agree or strongly agree with the statement. The fourth component of the survey focused on the generation of waste in the household. This took the form of demographic questions such as the number of adults and children in the household, and if households consider the cost of disposing of a product at the end of its lifetime or disposing of its packaging, in the purchase decision, behaviour known as source reduction.

Figure 4: Willingness-to-pay elicitation

12 Currently in Christchurch, each rateable property is supplied with 52 rubbish bags per year that entitle the household to waste collection and disposal services. These are paid for by an amount in the rates that is the same for every household, regardless of the number of people in the household or the volume of waste put out at the gate, currently this amount is \$43 per year. Any additional bags can be purchased separately from retailers at around \$5 for a pack of 5; a cost of \$1 per bag

The next few questions relate to how the amount of waste put out for collection by your household would change given a certain scenario. The scenario is hypothetical, and there is no suggestion that it will occur in Christchurch.

Imagine that your household had to purchase all of its rubbish bags from a retail outlet at a price per bag, this would mean that no money would be taken out of rates to fund the service. For each additional unit of rubbish disposal needed, the household would purchase another bag. If the household generates very little waste then costs will be low. This is a situation that occurs in many communities around the world.

For each question there is a table provided that will help you to answer. The tables provide information on the total costs of disposal depending on prices per bag, and the number of bags put out for collection each fortnight. Using the first table below for example, if rubbish bags cost \$0.50 each and your household put 4 bags per fortnight out for collection, then the cost to the household would be \$2.00 per fortnight, which is \$52.00 per year.

Please consider each alternative carefully.

A If rubbish bags were to cost \$0.50 each, how much would your households rubbish collection cost? (get figures from table below)

\$0.50 per bag	1 bag per fortnight	2 bags per fortnight	3 bags per fortnight	4 bags per fortnight	6 bags per fortnight
Cost per fortnight	\$0.50	\$1.00	\$1.50	\$2.00	\$3.00
Cost per year	\$13.00	\$26.00	\$39.00	\$52.00	\$78.00

Would this cost mean that your household would change the number of bags put out?

If yes, then how many bags would be put out per fortnight? _____

B If rubbish bags were to cost \$2.00 each, how much would your households rubbish collection cost? (get figures from table below)

\$2.00 per bag	1 bag per fortnight	2 bags per fortnight	3 bags per fortnight	4 bags per fortnight	6 bags per fortnight
Cost per fortnight	\$2.00	\$4.00	\$6.00	\$8.00	\$12.00
Cost per year	\$52.00	\$104.00	\$156.00	\$208.00	\$312.00

Would this cost mean that your household would change the number of bags put out?

If yes, then how many bags would be put out per fortnight? _____

C

If rubbish bags were to cost \$3.00 each, how much would your households rubbish collection cost? (get figures from table below)

\$3.00 per bag	1 bag per fortnight	2 bags per fortnight	3 bags per fortnight	4 bags per fortnight	6 bags per fortnight
Cost per fortnight	\$3.00	\$6.00	\$9.00	\$12.00	\$18.00
Cost per year	\$78.00	\$156.00	\$234.00	\$312.00	\$468.00

Would this cost mean that your household would change the number of bags put out?

If yes, then how many bags would be put out per fortnight? _____

D

If any of your answers to questions 12A – 12C resulted in a reduction in the number of bags put out for collection, then how do you think the household will achieve this?

Data Description

The following table describes the variables used in the modelling procedure.

Table 1: Data description

Dependent variable the number of C.C.C. domestic rubbish bags put out for collection and disposal each fortnight.

Explanatory variables

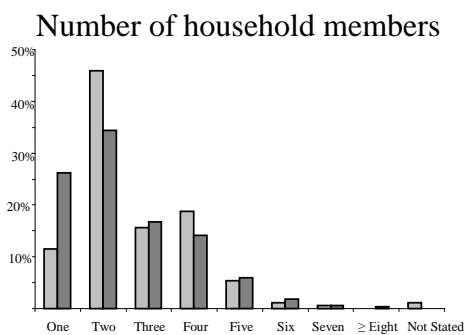
Price per bag	CVM WTP estimates
Adults	the number of people in the household aged 16 years or over
Children	the number of people in the household aged 16 years or under
Compost	dummy variable: 1 if household uses composting to dispose of food waste, 0 otherwise.
Private	the volume (litres) of weekly private service
Source reduction	dummy variable: 1 if practices source reduction behaviour, 0 otherwise
Recycle	fitted values of the number of recycling bins put out for collection fortnightly
Income	Household annual income, in categories 1-9

Attitudinal variables dummy variable: 1 if household agrees or strongly with statement as motivation to minimise waste, 0 otherwise.

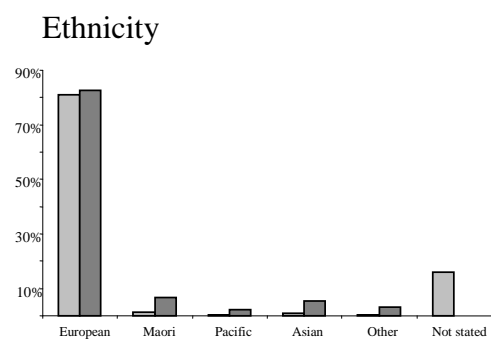
Concern for the natural environment
 Other peoples views of oneself
 Price of waste service
 Time and effort managing waste
 Negative attributes of waste
 Desire for efficiency
 Member of environmental organisation

A chi-squared test is used to test the null hypothesis that there is no association between the distributions of demographic variables of the sample and 2001 Census data, the relevant distributions and p-values are reported in Figures 5. We can see that the null is rejected in all but one case, at a 1 percent significance level. The distribution of age for the sample is skewed towards older age and away from younger age. This results from drawing the sample from the electoral role as this excludes those aged 17 years and under. It is considered that excluding this age group would not bias the results as these individuals would seldom be responsible for decisions on household waste management.

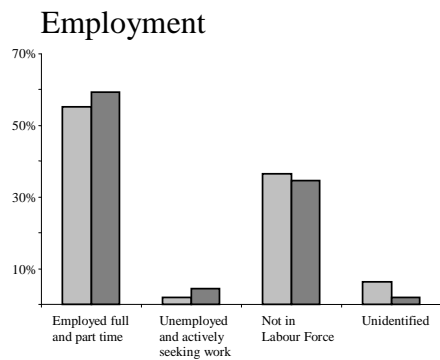
Figure 5: Sample characteristics



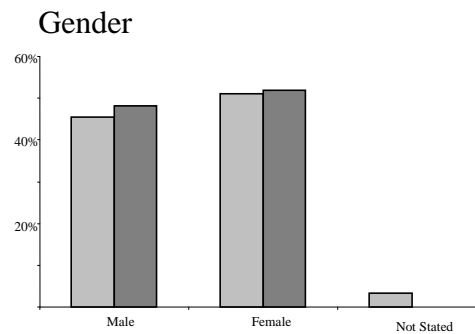
P < 0.001



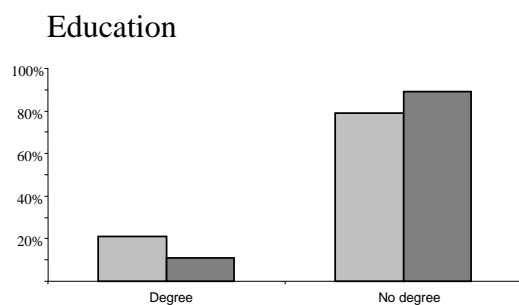
P < 0.001



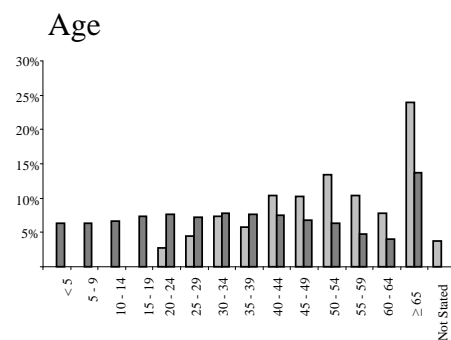
P < 0.001



P < 0.001

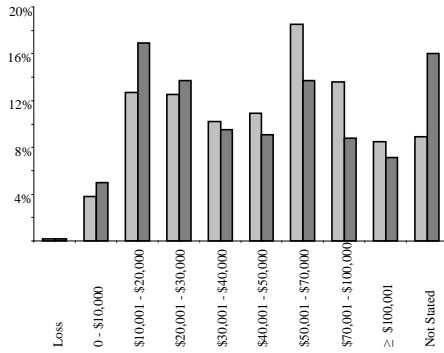


P < 0.001



P < 0.001

Household income



P < 0.001

Model specification

The dependent variable exhibited nonnegative integer properties, to take advantage of this a Poisson count data model was deemed an appropriate specification for the modelling procedure.

For a detailed and comprehensive analysis of count data models see Cameron and Trivedi (1998). The Poisson regression model is the simplest and perhaps most common count data model. The Poisson parameterisation exploits the discrete characteristic of the dependent variable. For a discrete random variable, y_i , with observed frequencies, y_i , $i = 1, \dots, N$, where $y_i \geq 0$, the Poisson regression model specifies that y_i given x_i is Poisson distributed with density

$$f(y_i | x_i) = \frac{e^{-\mu_i} \mu_i^{y_i}}{y_i!}, \quad y_i = 1, 2, 3, \dots \quad (1)$$

The distribution is determined by the single parameter μ , the mean. This parameter is given by the conditional mean function

$$E(y_i | x_i) = \mu_i \quad (2)$$

which is determined by the regression equation.

This study specifies an exponential condition mean function, as is common practice. This mimics the nonnegative nature of the dependent variable, ensuring that none of the fitted values of the model will be negative.

$$E(y_i | x_i) = \mu_i = e^{x_i' \beta} \quad (3)$$

The method of Maximum Likelihood is used to estimate the model. All empirical model estimation is carried out using LIMDEP econometric software. The log-likelihood function takes the following form

$$\ln L(\beta) = \sum_{i=1}^n \left\{ y_i x_i' \beta - e^{(x_i' \beta)} - \ln y_i \right\} \quad (4)$$

The maximum likelihood principle is to choose values of the parameter vector $\hat{\beta}$ that maximises the likelihood function given the sample data (i.e. the vector of parameter values that gives the greatest probability of obtaining the observed data).

The Poisson MLE $\hat{\beta}_p$ is the solution to the first-order conditions

$$\sum_{i=1}^n \left(y_i - e^{(x_i' \beta_i)} \right) x_i = 0. \quad (5)$$

The method for computation of $\hat{\beta}_i$ is the Newton-Raphson iterative method.

Convergence is guaranteed because the log-likelihood function is globally concave

For empirical estimation one of the most important restrictions of the Poisson assumption is the equality of the (conditional) mean and variance

$$E(y_i | x_i) = Var(y_i | x_i) \quad (6)$$

The raw data suggest that there is under-dispersion present, that is, the variance is less than the mean for the dependent variable, however we need to test the conditional mean and variance equality. This restriction, referred to as equi-dispersion, is formally tested using a regression based test proposed by Cameron and Trivedi (1990). The test is based on an auxiliary regression of $e_{oi}^2 - y_i$ on \hat{y}_i^2 where the errors and fitted values are obtained from an initial estimation of the Poisson model. The test statistic is highly significant leading to rejection of the equi-dispersion assumption. In settings of under-dispersion an alternative is to use Poisson quasi-maximum likelihood (PQML). The estimator is like the Poisson MLE in that the Poisson model is used to motivate the first-order condition defining the estimator, but it is unlike the Poisson MLE in that the data generating process used to obtain the distribution of the estimator need not be the Poisson. This means that the same log-likelihood function is used but a different estimator of the covariance matrix is adopted. This study uses the estimator proposed by Huber (1967) and White (1982). Provided the conditional mean function is correctly specified and the conditional distribution of y is Poisson, the PQML $\hat{\beta}$ is consistent, efficient, and asymptotically normally distributed.

Table 2 presents the preliminary estimation as estimation (1) which includes all variables. The explanatory variables collectively are statistically significant in explaining the variation of the dependent variable. None of the attitudinal variables are individually statistically significant although concern for the natural environment, other peoples views of oneself, and price of waste service all have envisaged signs. Neither burning nor illegal disposal are statistically significant. All other variables have the anticipated sign except recycling. The coefficient for recycling is positive, suggesting that the expected number of bags would be increasing in the amount of recycling the household does. The opposite result is theorised.

Table 2: Model estimation

Variable description	Estimation (1)	Estimation (2)	Estimation (3)
Constant	0.59 ^a	0.57 ^a	2.92 ^a
<i>Unit-price proxy</i>			
CVM WTP estimates (\$ per bag)	-0.21 ^a	-0.21 ^a	-0.21 ^a
<i>Questions concerning waste generation</i>			
Adults	0.22 ^a	0.22 ^a	0.96 ^a
Children	0.20 ^a	0.20 ^a	0.49 ^a
Source reduction	-0.26 ^a	-0.27 ^a	-0.24 ^a
Household income	0.02 ^b	0.02 ^b	0.09 ^a
<i>Questions concerning waste diversion</i>			
Recycling	0.16 ^a	0.31 ^a	-2.66 ^a
Private service	-0.01 ^a	-0.01 ^a	-0.01 ^a
Composting	-0.19 ^a	-0.19 ^a	-0.19 ^a
Burning	-0.19		
Illegal	-0.28		
<i>Attitudinal questions</i>			
Concern for the natural environment	-0.11		
Other peoples views of oneself	-0.03		
Price of waste service	-0.01		
Time and effort managing waste	0.05		
Negative attributes of waste	0.06		
Desire for efficiency	0.03		
Member of environmental organisation	0.00		
RsqD	0.21	0.20	0.20
Chi squared	338.00	331.00	323.00
Prob [$\chi^2 > \text{value}$]	0.00	0.00	0.00

^a significant at 99% confidence level. ^b significant at 95% confidence level.

Dropping non-significant variables from the model, yields estimation (2). It was determined that the incorrect sign for the recycling coefficient results from the quantity of recycling being endogenous to the model, and therefore correlated with the error term. A standard approach in cases where right-hand side variables are correlated with the residuals is to estimate the equation using instrumental variables regression. The general idea behind instrumental variables is to find a set of variables, termed instruments, which are both correlated with the explanatory variables in the equation, and uncorrelated with the errors. These instruments are used to eliminate the correlation between right-hand side variables and the disturbances. One technique is to model the variable of concern and use the fitted values of that regression to act as the instrument in the original model. This is the procedure adopted presently. A Poisson ML model is specified for the number of recycling bins put out per fortnight. The regressors are number of adults, number of children and household income. The equi-dispersion assumption is rejected and so Poisson QML estimation is employed. The estimates from this model are given in Table 3. The variables collectively and

individually are highly significant. The fitted values for the dependent variable from this model are used as the instrument.

Table 3: Instrumental variable estimation for recycling

Adults	0.24 ^a
Children	0.10 ^a
Income	0.03 ^a
RsqD	0.10
Chi-squared	68.00
Prob [$\chi^2 > \text{value}$]	0.00

^a significant at 99% confidence level. ^b significant at 95% confidence level

The final model with the inclusion of the recycling instrumental variable is presented as estimation (3) in Table 2. We can see that the use of instrumental variable has corrected the sign of the recycling coefficient. The chi-squared test indicates that the explanatory variables as a whole are significant in explaining the dependent variable. Each explanatory variable is significant individually at the 1% level. All signs of the estimated coefficients are consistent with economic theory. The value of RsqD, the sum of the squared deviance residuals, considered by Cameron and Trivedi (1998) to be the most appropriate measure of fit for this model, could be considered low, however cross-sectional data often suffer from this result.

Interpretation

The marginal effect of a regressor indicates the change in the expected value of the dependent variable, given a unit change in that regressor.

The marginal effect of the j^{th} regressor is

$$\frac{1}{n} \sum_{i=1}^n \frac{\partial E(y_i | x_i)}{\partial x_{ij}} = \frac{1}{n} \sum_{i=1}^n \beta_j e^{x_i' \beta} \quad (7)$$

because the first-order conditions imply $\sum_i e^{x_i' \beta} = \sum_i y_i$ this simplifies to

$$\frac{1}{n} \sum_{i=1}^n \frac{\partial E(y_i | x_i)}{\partial x_{ij}} = \beta_j \bar{y} \quad (8)$$

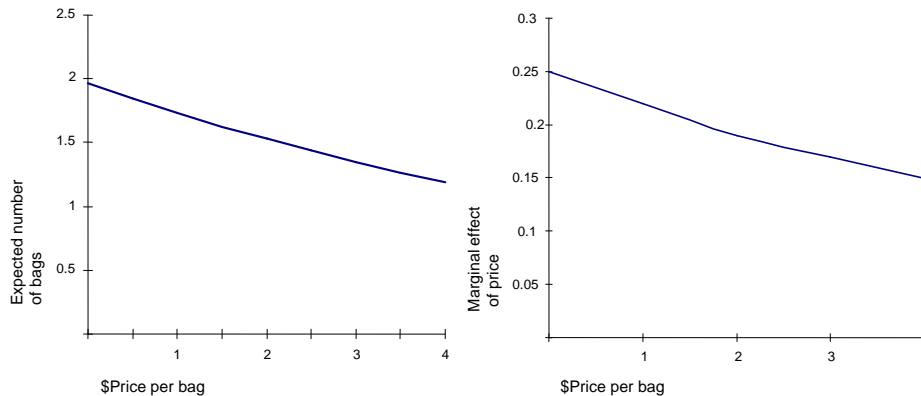
This procedure involves assessing the conditional mean for each observation and then averaging, to yield an average response. The partial derivatives of $E(y | x)$ with respect to each variable are computed at the means of the explanatory variables. This highlights the non-linear nature of the estimation, and as coefficient estimates are sensitive to the values at which they are computed, they are not constant. Interpretation of each explanatory variable in the model follows.

The marginal effect of price in Table 2 is -0.21. This is calculated at the average of all prices (all other variables are at their averages also), which is \$1.64. This is interpreted as a one unit increase in price (i.e. \$1.00), from the average price, leading

to a decrease in the expected number of bags by 0.21 bags per fortnight. To investigate how the marginal effect of price changes across price levels, we can change the value at which the marginal effect of price is computed. First we compute the marginal effect of price, with price set at zero, and all other variable set at their means. This gives the marginal effect of a one unit increase in price from zero dollars. Then we repeat the estimation with higher prices of \$1.00, \$2.00, \$3.00 and \$4.00. Plotting the resulting conditional means against price results in Figure 6. The slope of a tangent to the curve at a given price is the marginal effect of that price, holding all else in the regression equation constant. Figure 6, which is essentially a demand curve, illustrates how the conditional mean falls as price increases and that the marginal effect of price is diminishing as price increases, the curve is steeper at low prices and flatter at high prices. This is more easily seen if the magnitude of the marginal effect is plotted against price as in Figure 7.

Figure 6: Marginal price effects curve

Figure 7: Magnitude of marginal price effect



We can see that the magnitude of the marginal effect of price is decreasing as price increases. Households respond more strongly to initial increases in price than they do to increases once the price is set. The theorised price per bag facing households under flat-rate charging is \$0.00 per bag. This is quite different from the average price at which the marginal effect presented in Table 2 is computed. Table 3 shows that the marginal effect of price at \$0.00 is -0.25, increasing price one unit from \$0.00 leads to a decrease in the expected number of bags by 0.25 bags per fortnight. It is this value of the marginal effect that should be used in assessing reductions in demand for service. Because the mean function is nonlinear, it is theoretically inaccurate to talk of a marginal effect across several units. If we want to look at the effect of increasing price from \$0.00 to a price greater than a one unit increase (*i.e.* \$1.00) then we need to compute an accumulative or total effect. For example, consider an increase from \$0.00 to \$3.00 per bag. Using the conditional means provided in Table 4 the accumulative effect is a decrease in the expected number of bags (conditional mean) of 0.61 per fortnight ($= 1.96 - 1.35$).

Table 3: Marginal price effects

Price	Conditional mean	Marginal effect of price
\$0.00	1.96	-0.25
\$1.00	1.73	-0.22
\$2.00	1.53	-0.19
\$3.00	1.35	-0.17
\$4.00	1.19	-0.15

Consider the following numerical example. For this sample, the status quo average number of bags put out for collection is 2.04 per fortnight for each household. This equates to 53.04 bags a year. If a unit-price of \$1.00 per bag was introduced the model predicts a reduction of 0.25 bags for the average household per fortnight. In Christchurch with approximately 123,000 households this equates to a reduction of 799,500 bags per year. The average weight of a domestic black bag has been estimated at 8.3kg (C.C.C. 2003), indicating a possible weight reduction of around 6,636 tonnes. Given that approximately 37,818 tonnes of waste goes to landfill from council domestic service this equates to a 17.55 percent reduction. Table 4 provides some more examples.

Table 4: Numerical examples of waste reduction

Change in price	Tonnes per year	percent of council domestic service
\$0.00 to \$1.00	6,636	17.55
\$0.00 to \$2.00	11,414	30.02
\$0.00 to \$3.00	16,191	42.81
\$0.00 to \$4.00	20,438	54.04

The marginal effects discussed next, adults, children, private service, and recycling are computed at the means of all variables. For the average household, the effect of the number of adults on the quantity of bags put out is given by 0.964, which indicates that for each additional adult in the household above the average (2.11) the expected number of bags increases by 0.964 bags. Each child contributes approximately half as much waste as each adult. Each child in the household increases the expected number of bags by 0.485 bags. Each litre of private service that the household uses decreases the expected number of bags by 0.0085 bags. This means that if a household subscribes to 140 litres of private service a week then they will put out 1.2 bags less per fortnight on average. Each bin of recycling put out by the household reduces the expected number of bags by 2.656 per fortnight.

For the binary choice variables, compost and source reduction, interpretation is slightly different. The negative coefficients imply that the conditional mean is e^{β_i} smaller when the dummy variable is unity rather than zero. Table 5 shows the results of these computations. If the household uses compost to dispose of food waste then the expected number of bags put out per fortnight falls by 0.83 bags. If the household purchases products with relatively less packaging or otherwise relatively low disposal costs, behaviour referred to as source reduction, then this reduces the expected number of bags by 0.78 bags per fortnight.

Table 6: Binary choice variable coefficient interpretation

	$\hat{\beta}_i$	e^{β_i}
Compost	-0.188	0.83
Source reduction	-0.245	0.78

The marginal effect of household income on the number of bags put out as presented in Table 2 is estimated as 0.086. Again this is computed at the means of all variables. As the income variable is measured in categories, the coefficient estimate is interpreted as an increase in income from one category to the next increases the number of bags put out by 0.086 bags per fortnight.

Do different income groups react differently to changes in price?

Income distribution concerns should be investigated as part of an effort to recognise social sustainability as a requirement for domestic waste management policy. One might expect the marginal effect of price to be greater for lower income groups who face a relatively tighter budget constraint. Analysing this effect could highlight which income groups might reduce their demand more than others. To do this we will compute the marginal effects of varying price levels across different household income groups. First we compute the marginal effect of price, with price set at zero, income set at nine (the highest income category) and all other variables set at their means. This gives us the first marginal effect for the high income group. Then we repeat the estimation with higher prices of \$1.00, \$2.00, \$3.00 and \$4.00. This procedure is then repeated for two other income groups, medium (category 5) and low (category 1). This will reveal whether income affects a household's reaction to the price level.

Figure 8: Marginal price effect curves

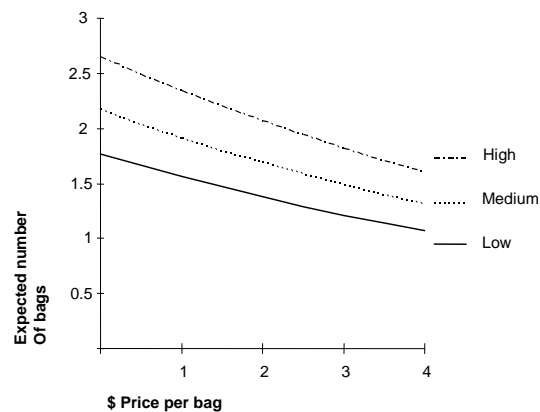
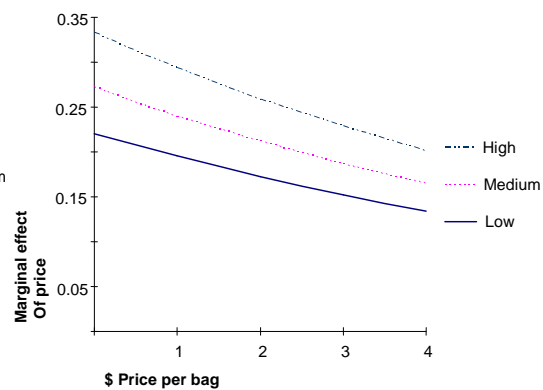


Figure 9: Magnitude of marginal price effect across household income groups



First we can see that the price effect is greatest when moving from a price of zero to \$1.00, and that the effect of price is diminishing as the price per bag increases. This is the same for all income groups. A more interesting observation is the higher income

groups react more strongly to the price, and the price effect is converging between income groups as price increases. This can be more easily seen in Figure 9. The marginal effect at price equal to zero is -0.22, -0.27 and -0.33 for the low income, medium and high income groups respectively. This gives a range of 0.11. When the marginal effect is evaluated at a price of \$4.00 then the effects are -0.13, -0.16 and -0.20, giving a range of 0.07. This suggests that as an autonomous level is reached the ability of a household to reduce waste further is limited. Figure 8 also reminds us that, holding all else constant, higher income groups have a higher conditional mean relative to low income households. That is, holding all else constant, a wealthy household will produce more waste than a relatively low income household. At each price level the high income groups have a relatively greater opportunity to decrease the amount of bags used because the magnitude of their waste is greater. The lower income groups are closer to the autonomous level of waste generation and disposal. They do not generate or dispose of a lot to start with and therefore they do not have as much opportunity to decrease the use of bags.

Reduction achievement

How households achieve any reduction is crucial to the success of the waste management program. The following table gives the options that respondents indicated they would use to achieve the reduction in bags. The survey asked respondents to indicate how they would achieve any reduction in the number of bags put out. The question was open-ended but could be categorised as in Table 7. The percentages given are of the number of households actually reducing the number of bags put out, n = 247.

Table 5: Waste reduction achievement options (n = 247)

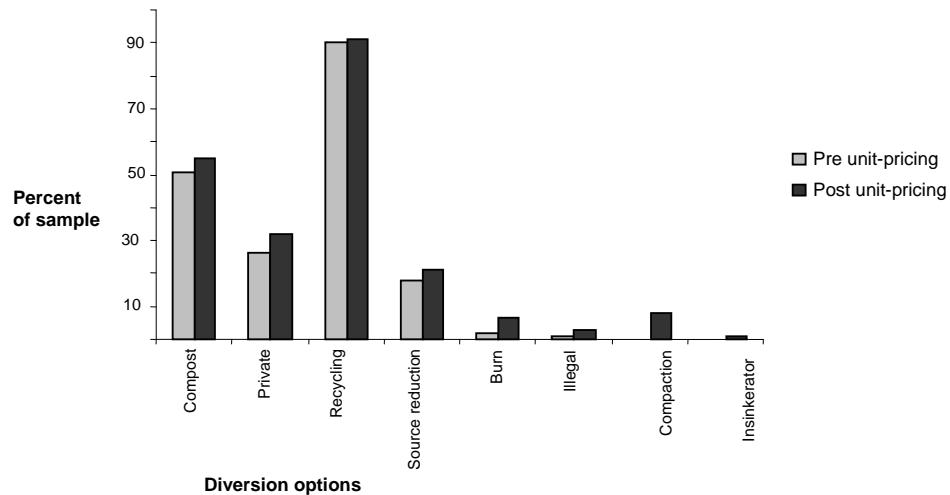
Variable description	Percentage
Private	24.3
Compost	19.8
Compaction	19.4
Recycle	18.2
Burn	12.1
Source reduction	10.1
Illegal	4.9
Can not do any more	5.7
Insinkerator	2.0

The sum of the percentages is more than 100 because some households indicated several options. All households that would reduce indicated at least one option. Subscription to a private service is the most popular option, with almost 25 percent of households choosing this option to help obtain reductions in the number of council bags used. This is perhaps the most serious threat to achieving waste targets in a unit-pricing programme as it results in no reduction in the amount of waste going to the landfill. Composting, compaction and recycling are also major reduction options for households. Compaction reduces the volume of but not the actual amount of waste

and so does not contribute to waste reduction goals. Some households considered that they would decrease the number of bags that their household put out but did not know how they would achieve this. This group is measured by 'can not do any more'. This group of households may be doing all they can to minimise waste.

Has the introduction of unit-pricing increased the number of households using diversion options? This question is answered in the Figure 10.

Figure 10: Increases in household diversion



We can see that there has been a relatively even increase for most diversion options, with no single option being favoured significantly more than others. This highlights the diverse nature of individual household's waste management strategies.

Households did not indicate that they compact waste until after the introduction of unit-pricing, so all compaction behaviour is attributed to the unit-pricing policy. With this in mind, it is burning that has the largest percentage increase compared to the pre-unit-price level.

Conclusions

This research demonstrates that there is a significant opportunity for unit-pricing to decrease the amount of waste that Christchurch households send to landfill. Substitution towards private service and compaction are the greatest threats to the ability of a unit-pricing system to decrease waste going to landfill. Compaction can only successfully be eradicated if the weight of rubbish is measured and used from pricing.

Respondents who practice source reduction are an indication of the growing incentive for manufacturers and producers to take some accountability for the waste component of the goods they sell. In this way the responsibility for minimising waste is not only that of consumers, although it is them that must signal to manufacturers that products with minimal disposal costs will be favoured. This implies a role for policies that explicitly incorporate firms into the management of waste from their products, post sale. Minimum recyclable component requirements and buy-back systems are

examples that need to be investigated as possible tools in a comprehensive waste minimisation strategy.

The major limitations of this research stem from the inability to form a quantitative estimate of respondent's use of diversion options such as recycling post-implementation of a unit-pricing programme. This research is able to present a qualitative measure. To estimate a quantitative response would require data describing observed measurable changes in the levels of diversion options such as the number of recycling bins increasing. This is not usually possible as a unit-pricing programme has not actually been implemented. Some communities have conducted experiments, or trials that can provide the necessary data.

One possible limitation stems from the data collection process. The number of bags put out provides the measure of the level of waste disposed of via council service. However the volume and weight of a council rubbish bag varies across households, but is treated as constant, that is, one bag.

This study has focused on the application of a market based instrument at the household level. Instruments applied at industry level also play an important role in minimising waste generation. Research into the interaction of instruments at this, and the household level in New Zealand, is an essential part of waste minimisation debate that provides ground for future research.

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