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Managing Household Waste in Ireland: Behavioural Parameters and Policy Options

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Abstract: Ireland has signed up to ambitious targets for diverting municipal solid waste from landfill. These targets are likely to be very difficult to meet without substantial changes to the way household waste is collected and managed. Data on household waste management behaviour in Ireland is scarce, and policymaking could benefit from improved data and market analysis. In this paper we use data from the EPA and CSO to estimate econometric models of household waste collection in Ireland, providing national estimates of income elasticities of demand, price elasticities where unit charges are in place, effects of imposing weight-based charging and effects of other important changes to service characteristics. These results are then used in a simulation model to illustrate the likely effects of some current policy options.

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* Environmental Protection Agency, Ireland. The opinions contained within are personal to the authors and do not necessarily reflect the policy of the Environmental Protection Agency.

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1 Introduction

Ireland continues to generate increasing quantities of municipal solid waste (MSW), most of which is sent to landfill. Recent projections suggest that the government will have great difficulty meeting EU limits on landfilling of biodegradable municipal waste over the next few years (Fitz Gerald *et al*., 2008 and EPA, 2008). Continued growth in – and landfilling of – MSW poses risks to the exchequer, which could face fines due to non-compliance with EU directives, and more importantly to the environment, since waste sent to landfill can give rise to emissions of methane (a greenhouse gas) and a range of other disamenities, e.g. visual, odour, dust and liquid pollutants.

Market failures in waste collection and management imply that there is a significant role for government in regulating these services. Households and businesses tend not to face the full social costs of the waste they generate, so taxation and regulatory measures may be required to bring social and private costs into line. Waste collection is subject to economies of density, which can pose difficulties for competitive provision of these services. State provision or franchising may address this problem. In addition, the economics of waste collection vary significantly across localities due to differences in social and economic conditions, so it may not be efficient to apply uniform collection and processing arrangements across the whole country.

In practice, waste policy in Ireland is applied at both national and local levels, and Ireland has adopted many policy instruments with wide local variations. However, regardless of whether the system applies a greater or lesser degree of centralisation or makes more or less use of private sector service provision, policymakers need information about demand and supply parameters to make optimal decisions as to the mix of instruments to be used.

Past research and international experience offer a range of collection and processing options that might be applied to the management of MSW, including pay by use pricing, two- and three-bin collection systems, encouragement of home composting, deposit and refund schemes, landfill taxes, direct regulation of disposal behaviour and various forms of support for post-collection processing of waste. Indeed, many of these options have already been tried in at least some parts of Ireland. However, identifying the most efficient mix of options for a given area requires an understanding of the likely effects and costs of each option under local economic, geographical and social conditions; interactions between options (they may be substitutes or complements); and estimates of the baseline quantities of waste that will arise in future years if no further action is taken.

In short, we need to know in some detail how much waste is being generated, what collection methods are applied, how much influence specific behavioural factors have on the growth in arisings, and what effects particular policy measures would have if they were widely adopted. Progress has been made on the first of these questions, through the vehicle of periodic National Waste Reports by the EPA. Eunomia Research *et al.* (2007) argue that the quality of data available on waste management in Ireland is improving, but that existing waste projections suffer from a lack of "coherent analysis".

However, we suggest that the problem is not simply a deficit in analysis: there are still significant gaps in the information available about what drives waste generation and how policy options might change outcomes. Better data could allow a considerably improved understanding of household waste management behaviour and the likely effects of different policies for reducing waste generation and encouraging diversion of waste from landfill.

In this paper, we focus on the household component of MSW in Ireland. We exploit existing data to produce new estimates for a range of key behavioural and policy parameters, illustrate how these sorts of parameters may inform the policy debate, and highlight some key shortcomings in the available data. This paper also describes key parameters used in the waste component of the ISus model and reports applications from this model to scenario and policy analysis. ISus is a satellite model of the ESRI's Hermes macroeconomic model, and it has been developed by the ESRI to project environmental pressures into the future. Other parts of the ISus model are described in O'Doherty and Tol (2007) and Fitz Gerald *et al*. (2008).

In the next section of the paper, we provide a snapshot of the current situation in Ireland. Section 3 presents new empirical findings on the drivers of household waste generation and disposition in Ireland. In Section 4 we examine the effects of selected policy options, and Section 5 concludes the paper.

2 Background to household waste policy in Ireland

To provide context for our subsequent discussions of behavioural parameters and policy options, this section outlines the current position and projected trends in household waste generation and disposition. We then set out key features of the current policy environment.

2.1 Current position and projected trends

Household waste constitutes almost 60 per cent of total MSW, with the balance primarily from the commercial sector. Household waste generation exhibited a positive trend up to almost 2 million tonnes in 2006, after which an apparent reclassification of some waste from residential to commercial reduced the residential waste total to 1.8 million tonnes in 2007. An estimated 8 per cent of the household waste stream was not collected for treatment within conventional waste management systems in 2007 and represents an estimate of the scale of illegal waste disposal, which includes both backyard burning and illegal dumping. This implies that the scale of illegal household waste disposal has declined dramatically in recent years, with the estimate as high as 17 per cent in 2003. Landfill is the predominant management option for household waste, with almost 70 per cent landfilled in 2007 and about 24 per cent recycled/recovered. Table 1 shows the trends in household waste generation and management since 2001.

Table 1: Household Waste Generation and Management 2001-2007 (Thousand Tonnes)

	2001	2002	2003	2004	2005	2006	2007
Generated	1,469	1,679	1,705	1,728	1,746	1,979	1,761
Landfilled	1,255	1,294	1,231	1,215	1,199	1,379	1,200
Recycled	75	133	186	286	345	394	425
'Uncollected'	139	252	288	227	203	205	136

Source: EPA National Waste Reports

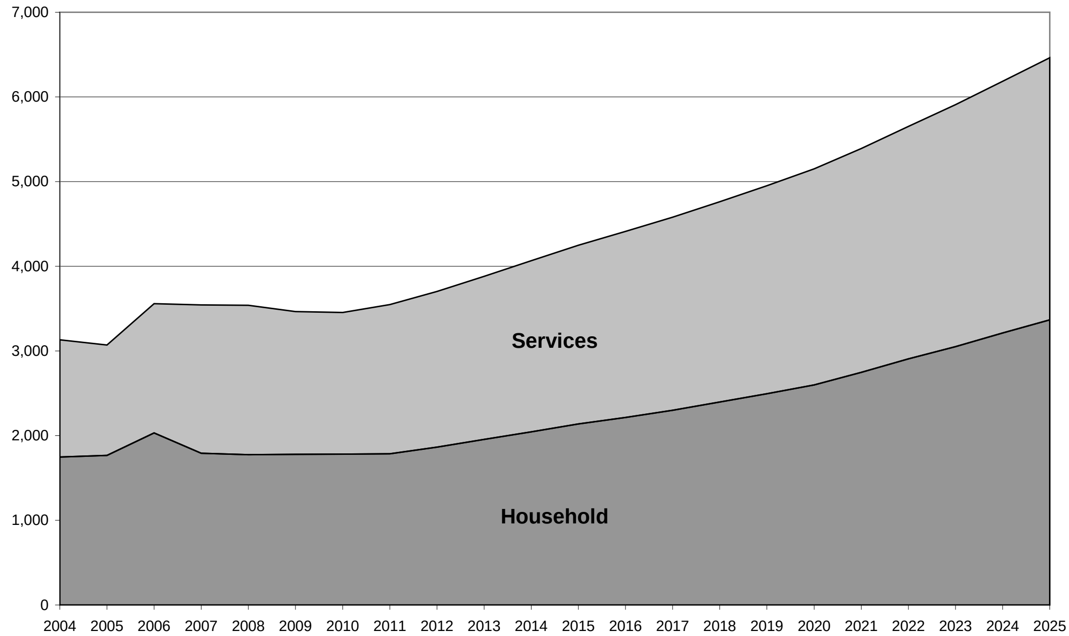
The composition of waste in the household waste stream, especially in landfilled waste, has changed substantially in the 2001-2007 period. Increased recycling of paper and cardboard has reduced its share in household waste landfilled, whereas the relative share of organic household waste landfilled has increased. Organic waste accounts for the largest share of household waste landfilled accounting for 34 per cent in 2007.

Waste collection services in Ireland are provided on a commercial basis both by the private and public sectors. In some local areas private and public collection services compete for market share, whereas elsewhere the local authorities have completely withdrawn from waste collection services. A survey by O'Callaghan-Platt and Davies (2007) found that 18 out of 34 local authorities relied exclusively on private sector collection services in 2006, while 2 provided all services themselves and the remaining 14 were mixed public-private.

The nature of household collection services varies widely. The majority of services collect waste from contractor provided wheeled bins, though in some areas pre-paid (tagged) bagged refuse is collected. Households are billed for collection service in a number of ways including by bin volume, by collection, by weight, by flat fee, as well as in some instances a flat fee for provision of service.

MSW generation in Ireland increased by about 30% between 2002 and 2007, although growth moderated towards the end of the period and the recession may be expected to limit growth further in the short term. Among the factors driving the growth in waste generation is a growing, more affluent population, increasing household numbers, as well as changing consumer preferences towards products and services with greater associated waste generation. Projections from the ISus model, which models the effect of socio-economic activity on environmental parameters, suggest that household waste generation will grow about 3 per annum over the next 15 years. At that level of growth an additional 1 million tonnes of household waste will be generated per decade, doubling existing waste generation by 2025, as shown in Figure 1.

Figure 1: Projected municipal solid waste generation in Ireland to 2025 (actual data up to 2007)



Source: analysis using the ISus model

Continued growth in MSW arisings, together with tightening regulatory restrictions on how waste is managed, present a difficult challenge for the waste management industry to develop sufficient waste management infrastructural capacity. At present, recycling and landfill are the only management options used for MSW (including household waste) in Ireland. Household waste recycling is dominated by paper, cardboard and glass, whereas considerable scope still exists for expanding capacity for recovery of other streams, in particular organics, plastics and textiles. Several MSW incineration projects are currently in the development pipeline, but it is unclear at date of writing how much capacity will be operational over the next few years.

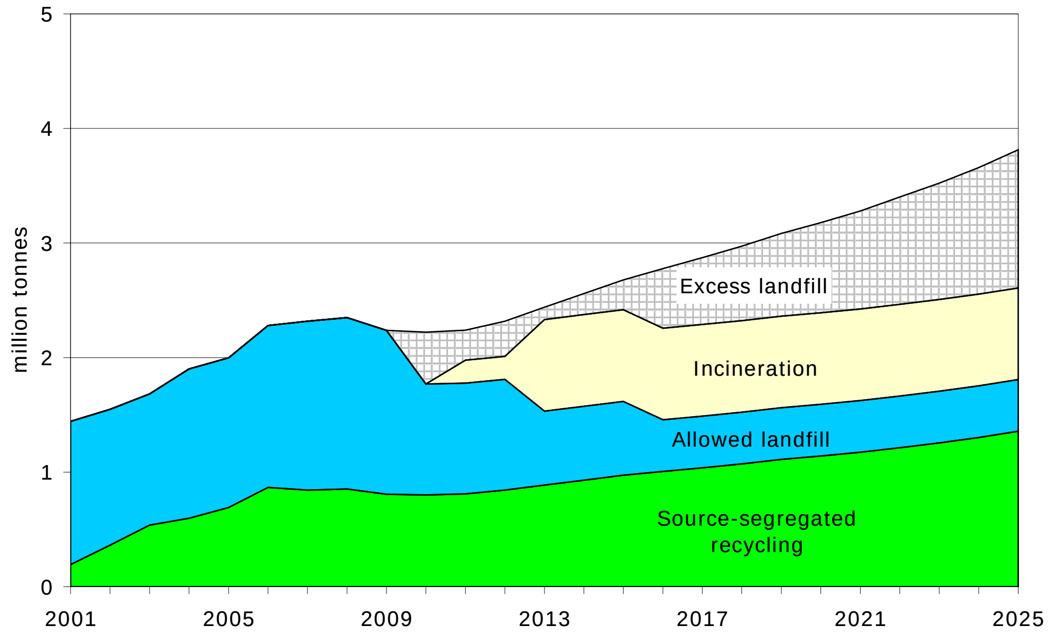
2.2 Policy environment

The most economically significant regulatory constraint relating to MSW arises from the EU Landfill Directive,[1] which imposes limits on the fraction of biodegradable municipal waste (BMW) that may be sent to landfill from 2010 onwards, including

[1] Directive 1999/31/EC.

waste from both residential and commercial sources. This is illustrated in Figure 2 below. Here we project separate series for material segregated by households and thus readily available for recycling (at the bottom) and material collected as mixed waste. The latter is then divided into the quantity that is allowed to be landfilled under EU rules, the quantity that could be incinerated assuming that facilities with existing planning permissions come into service, and a residual (at the top). Current projections from the ISus model suggest that, in the absence of any new policy changes, BMW sent to landfill will substantially exceed the EU limits, even if one assumes that incineration is rolled out in line with current planning permissions.

Figure 2: Projected disposition of biodegradable municipal waste in Ireland to 2025 (actual data up to 2007)



Source: analysis using the ISus model with a macroeconomic scenario based on the 2008 Medium Term Review adjusted for the effects of the recession

As of the mid-1990s, many households in Ireland were charged flat fees for waste collection or were not charged directly for these services at all (Barrett and Lawlor 1995). The prevalence of pay-by-use charging has risen over time, and the government set a target that volume- or weight-based charges should be in place nationally from the start of 2005 (EPA, 2004). However, subsequent to this date some collectors (particularly private sector ones) continued to offer flat rate tariffs, and considerable variations remained in the quality of pay-by-use tariffs employed across the country. Some service providers still offer tariffs that link charges to volume or weight in only a very tenuous way (O'Callaghan-Platt and Davies, 2007).

3 Modelling the determinants of household waste generation and disposition in Ireland

There is a voluminous international literature on household waste management behaviour; surveys are provided in Jenkins (1993), Choe and Fraser (1998) and Kinnaman (2003). Generation of household waste and demand for waste disposal/recycling services are partly derived from demand for complementary goods such as food, packaged products and gardening activities, but they are also affected by each household's waste processing choices, e.g. between reuse, segregation and transport of recyclables, composting, legal disposal and illegal disposal. Thus we should expect that drivers of demand for complementary goods, such as number and size of households, income/expenditure, and other socioeconomic factors, should have important effects on generation and disposition of waste. Also, however, household waste choices will depend upon supply and demand factors affecting the relative attractiveness of different waste management options: availability and costs of disposal and recycling services; the opportunity cost to the household of each form of waste management (e.g. time spent segregating recyclables or driving to bring banks); and household attitudes towards the environment.

In this section, we provide new estimates of selected household waste parameters using data from successive EPA National Waste Reports and surveys of collection arrangements in Ireland's counties and urban boroughs. These models are an imperfect substitute for research using household-level microdata. However, in the absence of such data for most of the country, they at least allow us to arrive at working assumptions as to the levels of the main parameters driving household waste volumes.

The intuition behind these models is that the quantity of waste presented for disposal or recycling in a given area (say, a county) is the sum of volumes presented by households in that area, and the main drivers of waste volumes in the area may be inferred from the average characteristics of households and service offerings that are present there. In effect, we describe a "representative household" with average characteristics and access to an average mix of services, and evaluate how its disposal and recycling behaviour would be affected by changes in potential drivers of demand for waste services.

Two main approaches are employed in this section. One is econometric analysis, which applies statistical techniques to estimate behavioural parameters from historical data. These parameters are useful for predicting future waste flows and analysing policies that change the prices faced by households. We use the second approach, extrapolation from average effects, to illustrate the possible effect of extending three-bin collection systems to the whole country. There is insufficient historical evidence to allow the use of regression analysis in this case.

3.1 Econometric models of total household waste, black bin and green bin collection

In this sub-section, we focus on explaining total waste generated by the household sector and the two biggest components of household waste disposition: segregated presentation of waste for disposal in mixed waste "black" bins and for recovery of dry recyclables in "green" bins.

3.1.1 Model structure and data

Annual data on household waste quantities are available by local authority area for 1998 and 2001-6 from the EPA's National Waste Reports. These data cover too few years to allow meaningful time series analysis at national level, but by exploiting the regional dimension we have sufficient observations to allow statistically-significant parameters to be estimated.

Our econometric model is summarised in Equation 1 below.

$$\frac{W_{it}}{H_{it}} = f\left(\frac{Y_{it}}{N_{it}}, \frac{N_{it}}{H_{it}}, \mathbf{A}_{it}, \mathbf{P}_{it}\right) \qquad (1)$$

For county *i* and year *t*, the dependent variable in all models is the average quantity of waste per household $\frac{W_{it}}{H_{it}}$ in tonnes. The explanatory variables in our models are average persons per household $\frac{N_{it}}{H_{it}}$, real income per capita $\frac{Y_{it}}{N_{it}}$, and indicators concerning the availability and price of waste collection services $\mathbf{A}_i$ and $\mathbf{P}_i$ respectively. We expect persons per household and average real income to have positive coefficients in all regressions, reflecting the positive association between waste demand and demand for goods, which is in turn related to income and number of persons. Availability of recycling services should reduce mixed waste demand, while prices of mixed waste services should have negative coefficients in models of mixed waste demand and positive ones in models of recycling demand (since recycling and mixed waste disposal are substitutes for a significant proportion of waste items).

The service availability and price variables are the most problematic as they are not available in official statistics. We estimate two different sets of models that are tailored to the available data. Both of types of models have limitations, but each can reveal aspects of consumer demand. Also, because they employ quite different analytical approaches, we should have greater confidence in the resulting parameters when both approaches give consistent results.

The first set is a group of cross-sectional models for the year 2006 using data collected in the preparation of O'Callaghan-Platt and Davies (2007). These data provide the most complete national picture of collection arrangements currently available, with details drawn from waste collection firms in all local authority areas.

However, these data have significant limitations for the type of model we are estimating here. Since they cover only one point in time, it is not possible to include them in a model that also controls for unobserved area-level effects on waste disposal behaviour. In addition, the data capture only what pricing options were offered by each firm in each area, not how many households or how much waste was associated with each option or firm. Nevertheless, it is possible to use the data on service availability and price in models estimated at local authority level. We have aggregated the data to this level by the use of simple rules: our availability variables capture whether *any* service provider offered a given type of tariff in an area, and for the price of each tariff type we use an arithmetic average of tariffs offered by service providers in the area.

The service availability and price variables in this dataset include an indicator of whether kerbside recycling was offered in each area, which we expect to be negatively correlated with mixed waste quantities and positively with recycling quantities; whether pay-by-weight services were offered, and if so, how much they cost; and availability/price of tag-based (i.e. volume-based) services. We expect availability and price of both pay-by-use charging methods to be negatively associated with mixed waste quantities and positively with recycling quantities. The variables used in these models, together with sources and descriptive statistics, are listed in Table 2 below.

Table 2: Variables and descriptive statistics for cross-sectional models; 31 observations for 2006; variables are average values by county

Variable	Description	Source	Mean	Std. Dev.	Min	Max
Total waste per household	Total waste per household (tonnes per annum)	Analysis of NWR data and linearly interpolated census data on households	0.764	0.160	0.461	1.11
Mixed waste per household	Mixed (black bin) waste per household (tonnes per annum)	*Ibid.*	0.579	0.148	0.380	0.934
Green bin waste per household	Segregated dry recyclable (green bin) waste per household (tonnes per annum)	*Ibid.*	0.130	0.0415	0.0463	0.194
Real disposable income	Real disposable income per capita (€ per annum at December 2006 prices)	Analysis of CSO data	20,900	1,780	17,800	24,500
Persons per household	Average persons per household	Analysis of CSO data	2.80	0.131	2.50	3.03
Kerbside recycling	=1 if kerbside recycling offered in area, 0 otherwise	Analysis of survey discussed in O'Callaghan-Platt and Davies (2007)	0.710	0.461	0	1
Pay by weight offered	=1 if pay by weight charging offered in area, 0 otherwise	*Ibid.*	0.226	0.425	0	1
Pay by weight price	Price of pay by weight services averaged across suppliers in area (€/Kg)	*Ibid.*	0.0442	0.104	0	0.460
Tag-based offered	=1 if tag-based charging offered in area, 0 otherwise	*Ibid.*	0.839	0.374	0	1
Tag price	Price of tag-based services averaged across suppliers in area (€/tag)	*Ibid.*	3.04	3.26	0	13

The second set of models uses more years of data and allows use of panel data techniques, but it relies on less satisfactory proxies for the prices of services and lacks information on service availability. Prices in this case are drawn from local authorities only, because it was possible to obtain these prices over a span of years. In effect these models assume that changes in local authority prices are a reasonable proxy for changes in service prices generally.

More observations are available for modelling total waste quantities, summarised in Table 3 below, than for modelling mixed waste and dry recyclables separately, described in Table 4 below.

Table 3: Variables and descriptive statistics for total waste panel data models; 195 observations for 2003-2006; variables are average values by year and county

Variable	**Description**	**Source**	**Mean**	**Std. Dev.**	**Min**	**Max**
Total waste per household	Total waste per household (tonnes per annum)	Analysis of NWR data and linearly interpolated CSO census data on number of households	0.891	0.295	0.340	2.52
Real disposable income	Real disposable income per capita in area (€ per annum at December 2006 prices)	Analysis of CSO data; County Incomes and Regional GDP reports and CPI	19,600	2,000	15,700	24,500
Persons per household	Average persons per household	Analysis of linearly interpolated CSO census data	2.90	0.149	2.50	3.26
Volume-based charge	Local authority charge per lift for collecting 240 litre bin (mixed waste); zero if not offered	Local authorities	0.927	2.23	0	8.00
Weight-based charge	Local authority charge per Kg (mixed waste); zero if not offered	Local authorities	0.00605	0.0501	0	0.470

Table 4: Variables and descriptive statistics for black and green bin panel data models; 132 observations for 2003-2006; variables are average values by year and county						
Variable	**Description**	**Source**	**Mean**	**Std. Dev.**	**Min**	**Max**
Mixed waste (black bin) per household	Mixed (black bin) waste per household (tonnes per annum)	Analysis of NWR data and linearly interpolated CSO census data on number of households	0.659	0.195	0.348	1.32
Dry recyclable (green bin) waste per household	Segregated recyclable (green bin) waste per household (tonnes per annum)	*Ibid.*	0.116	0.0784	0	0.468
Real disposable income	Real disposable income per capita in area (€ per annum at December 2006 prices)	Analysis of CSO data; County Incomes and Regional GDP reports and CPI	20,200	1,840	16,400	24,500
Persons per household	Average persons per household	Analysis of linearly interpolated CSO census data	2.87	0.139	2.50	3.17
Volume-based charge	Local authority charge per lift for collecting 240 litre bin (mixed waste); zero if not offered	Local authorities	1.20	2.49	0	8.00
Weight-based charge	Local authority charge per Kg (mixed waste); zero if not offered	Local authorities	0.0106	0.0630	0	0.470

The panel data models are estimated in first-differences to eliminate any spurious association between the non-stationary variables (waste arisings and income). They also allow for unobserved heterogeneity between local authority areas, although the relevant fixed effects cannot be recovered due to the differencing process.

One important shortcoming of the data available in Ireland is that we do not have enough degrees of freedom to take account of endogeneity in local waste management arrangements. As per Kinnaman and Fullerton (2000b), it is likely that the scale and characteristics of local waste arisings both affect, and are affected by, the collection arrangements put in place by local authorities and commercial service providers. Moreover, decisions taken over collection arrangements could be affected by unobserved factors (e.g. the level of local support for environmental policies generally) that also affect arisings but are omitted from our dataset.

3.1.2 Model results

In this section, we report results for three sets of cross-sectional and panel data regression models explaining household waste arisings. The three dependent variables used measure total waste, mixed waste and segregated dry recyclables

Total waste

Our first set of models examines total waste per household. As expected, real disposable income has a positive relationship with total waste, and we find an elasticity a bit higher than one in both the cross-sectional models (Table 5 below) and the panel data models (Table 6 below). A coefficient of greater than one on real income implies that waste volumes grow slightly faster over time than real income, absent any policy effects. This value is considerably higher than those reported in most international studies. For example Table 1 in Choe and Fraser (1998) reports income elasticities from several US studies, and none is higher than 0.6.[2] Further research is needed to determine whether our estimate for Ireland is robust, and if it is, to assess the stability and trend in this parameter over time. Other research suggests that Irish consumption patterns are still adjusting to the country's recent macroeconomic convergence with better-off OECD countries (Lyons *et al*., 2009), so it is possible that the high income elasticity of waste generation may gradually converge (downwards) towards a "rich country" level over time.

The constant term in the panel data model is not significantly different from zero, which means we have no evidence of a time trend in total waste quantities, so the time pattern of waste arisings appears to be driven by incomes rather than changing tastes in our sample period.

[2] See also Kinnaman and Fullerton (2000a).

Table 5: Total waste per household, OLS cross-section regression results				
Variables and statistics	**All variables**		**Preferred model**	
Dependent variable	*ln(total waste/household)*		*ln(total waste/household)*	
	Coef.	Standard error	Coef.	Standard error
Ln(real disposable income)	1.73	0.454***	1.37	0.400***
Persons per household	-0.0576	0.261		
Kerbside recycling	-0.0273	0.0736		
Pay by weight offered	-0.0952	0.127		
Pay by weight price	-0.871	0.441*	-0.958	0.320***
Tag-based offered	-0.166	0.123		
Tag price	0.0206	0.0123		
Constant	-17.2	4.58***	-13.9	3.97***
Observations	31		31	
Adjusted R^2	0.307		0.336	
Heteroscedasticity	$\chi^2(1)=1.80$ [0.180]		$\chi^2(1)=0.610$ [0.435]	
*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Numbers in brackets are p-values. Data sources: see Table 2 above.*				

Table 6: Total waste per household, panel regression results (all variables in first-differences, balanced panel)				
Variables and statistics	**All variables**		**Preferred model**	
Dependent variable	*ln(totalwaste/household)*		*ln(total waste/household)*	
	Coef.	Standard error	Coef.	Standard error
Ln(real disposable income)	0.991	0.202***	1.08	0.194***
Persons per household	-0.140	0.126		
Volume-based charge	0.0134	0.00818		
Weight-based charge	-0.904	0.336***	-0.943	0.336***
Constant	0.00114	0.0241	0.000627	0.0242
Sample	34 local authorities		34 local authorities	
Time periods	2003-2006		2003-2006	
Observations	195		195	
Adjusted R^2	0.158		0.149	
Heteroscedasticity	$\chi^2(1)=0.54$ [0.464]		$\chi^2(1)=0.32$ [0.571]	
*Note: All variables are in first differences apart from the constant; *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Numbers in brackets are p-values. Data sources: see Table 3 above.*				

The income elasticity of 1.08 from the parsimonious version of the panel data model is used in the current version of ESRI's ISus model to predict the relationship between income and total household waste quantities in Ireland.

We also find a statistically significant negative association between pay-by-weight charges and total waste in both cross-sectional and panel data models, with qualitatively similar coefficients. To illustrate the magnitude of this effect, suppose that pay-by-weight charging was introduced in an area that did not previously have it, with the price set equal to the charge applied by Cork County Council in 2006

(€0.46 per Kg in our panel dataset).[3] The coefficient for the parsimonious model in Table 6 above indicates that this change would be associated with a 43% reduction in total waste arisings. This is a reassuring result, because the actual reduction in waste quantities when pay-by-weight charging was introduced in West Cork was 45%, as per Scott and Watson (2006). This figure is also consistent with case study evidence in O'Callaghan-Platt and Davies (2008), which identified an average reduction of 47% due to pay-by-weight charging in three local authorities.

Surprisingly, we find no significant role for the average size of households in these models. There may insufficient variation in average household sizes across our dataset for the former effect to be detected. Because there is strong evidence from theory and other empirical research that this coefficient should be greater than zero, we use estimates based on household level modelling in Scott and Watson (2006) to set the parameter linking household size to household waste quantity in ISus.

Mixed waste

The presence of tag-based pricing in a local authority area has a negative, but not significant, coefficient in the full cross-sectional model of total waste quantities. The proxy for volume-based charges used in our panel data models is never statistically significant. Given that volume-based pricing applies to collection of mixed waste, we might expect that they would have more significant effects in the separate models estimated for mixed waste quantities (Table 7 and Table 8 below). However, the tag price takes a perverse (positive) value in the cross-sectional models. We doubt that this result indicates a true positive relationship between the use of volume-based pricing and waste quantities. Instead, it is possible that that our regressions suffer from endogeneity problems: perhaps areas with high waste arisings per household are more prone to adopt volume-based charging. We do not have sufficient data to check the direction of causality.

[3] Since the explanatory variable is in levels (€/Kg) and the dependent variable in logs, the predicted percentage change in waste quantities is -0.943*0.46.

Table 7: Mixed waste per household, OLS cross-section regression results				
Variables and statistics	**All variables**		**Preferred model**	
Dependent variable	*ln(mixed waste/household)*		*ln(mixed waste/household)*	
	Coef.	Standard error	Coef.	Standard error
Ln(real disposable income)	2.02	0.468***	1.97	0.434***
Persons per household	0.0824	0.2699		
Kerbside recycling	-0.153	0.07602*	-0.156	0.071**
Pay by weight offered	0.0635	0.131		
Pay by weight price	-1.31	0.456***	-1.06	0.324***
Tag-based offered	-0.0549	0.127		
Tag price	0.0268	0.0127**	0.0228	0.0109**
Constant	-20.8	4.7321***	-20.1	4.33***
Observations	31		31	
Adjusted R^2	0.434		0.479	
Heteroscedasticity	$\chi^2(1)=0$ [0.960]		$\chi^2(1)=0$ [0.988]	

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Numbers in brackets are p-values. Data sources: see Table 2 above.*

Table 8: Mixed waste per household, panel regression results (all variables in first-differences, balanced panel)				
Variables and statistics	**All variables**		**Preferred model**	
Dependent variable	*ln(mixed waste/household)*		*ln(mixed waste/household)*	
	Coef.	Standard error	Coef.	Standard error
Ln(real disposable income)	1.42	0.261***	1.54	0.244***
Persons per household	0.0589	0.151		
Volume-based charge	0.0121	0.00860		
Weight-based charge	-0.940	0.336***	-0.931	0.333***
Constant	0.00876	0.0290	0.00891	0.0290
Sample	34 local authorities		34 local authorities	
Time periods	2003-2006		2003-2006	
Observations	132		132	
Adjusted R^2	0.240		0.240	
Heteroscedasticity	$\chi^2(1)=0.19$ [0.660]		$\chi^2(1)=0.28$ [0.597]	

*Note: All variables are in first differences apart from the constant; *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Numbers in brackets are p-values. Data sources: see Table 4 above.*

Another more explicable difference between the mixed waste and total waste models is that mixed waste quantities have a negative association with the availability of kerbside recycling in an area. The cross-sectional models indicate that areas with kerbside recycling present about 15% less mixed waste than those that do not.

Coefficients on weight-based charges and real disposable income are broadly similar to those in the total waste models, although the income effect appears to be somewhat stronger – with an elasticity around 1.5 – when we look at mixed waste in isolation. Here too we find no significant time trend in waste volumes (via the constant term in the first-differenced panel models) after taking account of other variables.

Segregated dry recyclable waste

For completeness, we also report modelling results for the quantity of segregated dry recyclables ("green bin" waste) in each area. The results are shown in Table 11 and Table 12 in the appendix. However, the fit, diagnostic statistics and level of significance of key variables in these models was not as high as those for total and mixed waste.[4] There is evidence of strong income elasticity for dry recyclable collection and the availability of kerbside recycling has a positive effect on quantities as expected, but none of the other service availability or price terms has a statistically significant impact. This result is qualitatively similar to the findings of Jenkins *et al*. (2003), who analysed survey data from the United States and found that the availability of kerbside recycling significantly increased the intensity of recycling activity. They too were unable to find a significant effect on recycling from prices for mixed waste collection. It is possible that the characteristics of kerbside collection services for dry recyclables vary more across areas than those of mixed waste services and that our data are simply not detailed enough to control for such variations. This might help explain the lack of explanatory power in these models.

3.1.3 Summary of results in this sub-section

All the waste categories we examined have a positive income elasticity greater than one. As real incomes rise over time, household waste quantities are likely to continue rising at least as quickly unless policy measures prevent this from happening. This stands in contrast to most estimates for other countries, which tend to show an income elasticity of demand significantly below one. Ireland's unusually high income elasticity of demand for waste services may reflect the relatively recent convergence of its economy to a high average income level. Lyons *et al. (*2009) provides evidence for lags in the adjustment of Ireland's consumption patterns to its new-found wealth. If this is so, the country might experience a fall in the sensitivity of waste demand to income over the coming years.

Unsurprisingly, the availability of kerbside recycling in an area has a significant effect in diverting waste from mixed waste bins, and thus ultimately may help reduce

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[4] We found evidence of heteroscedasticity in some of the models, so robust standard errors are reported.

the quantities going to landfill. In line with previous research, we found evidence that weight-based pricing has a significant effect in reducing mixed waste volumes, although it is not clear how much of this was actual reduction in waste generated vs. waste diverted to recycling. Our results are in line with extensive past research showing that weight-based pricing can substantially reduce the amount of household mixed waste sent to landfill.

We were unable to measure the effects of volume-based charging or changes in household size, and our models of segregated collection of dry recyclables leave much to be desired. Until data availability improves, many parameters required to forecast household waste quantities in Ireland will have to be drawn from the international literature or from small-area studies such as Scott and Watson (2006).

3.2 Brown bin collection

We have shown that data gaps in Ireland present considerable challenges for those examining the effects of policy options such as pay-by-use charging that are already relatively widespread. The difficulties are still more formidable when one wishes to look at options that have not been employed historically in Ireland or have only been used recently or in a small number of areas. In such cases, regression analysis is not possible.

One such example is the use of three-bin collection systems as a way to encourage segregation of compostable waste at source. Organic biodegradable waste accounts for approximately 30 per cent of household waste (Table 9, National Waste Report 2006) and if collected separately from other waste would facilitate more sustainable management options. In this sub-section, we examine the effects that three-bin systems seem to have had on the average disposition of household waste in the few areas where they have been employed. Of course, it is not possible to control for other variables or unobserved area characteristics using such an approach, so the results must be treated with caution.

A three-bin system includes a “brown bin” for compostable organic waste as well as the more common bins for mixed waste and dry recyclables. As discussed earlier, we do not have sufficient data in Ireland to estimate household-level demand models for waste services, so the best indication of households’ likely responses to a third bin comes from aggregate outcomes in areas that already provide such a service. The

National Waste Report 2006 (Le Bolloch *et al.*, 2007) reports waste streams collected by one, two and three bin schemes within each local authority area (both private and public collectors). Table 9 shows the average proportion of waste collected as mixed residual waste, dry recyclables, food and garden waste, or other disposal options within urban and rural areas during 2006.

Table 9: Household Waste Collection - Black, Green and Brown Bin Collection

	Mixed residual (Black Bins) %	**Mixed dry recyclables (Green Bins) %**	**Food and garden waste (Brown Bins) %**	**Other disposal options %**	**Total %**
Mostly Urban Areas					
2-bin collection	66	13	0	20	100
3-bin collection	43	17	22	18	100
Mostly Rural Areas					
2-bin collection	48	10	0	41	100
3-bin collection	42	12	10	36	100

Source: analysis of data from Le Bolloch et al., 2007

In urban areas where a third bin is available, approximately 22 per cent of waste is collected in the ‘brown’ bin. When one compares urban areas without a third bin collection to those that have one, there is almost a one-for-one correspondence between higher black bin waste volumes in the former and brown bin volumes in the latter. Assuming similar waste generation in urban and rural households the collection of 22 per cent of waste in brown bins represents approximately 75 per cent of available organic biodegradable waste. Therefore, within urban areas brown bin collection is a very effective method of segregating the organic fraction of household waste for subsequent treatment. Brown bins are less effective collecting the organic waste stream in rural areas. Rural households tend to be offered a different mix of services and pricing options than urban ones due to the different economics of waste collection in less densely populated areas. Rural households thus avail of a greater number of options to manage waste generated. For instance, a greater proportion of rural households do not have (or avail of) a kerbside waste collection service and consequently the potential of a brown bin service to collect organic biodegradable waste is lower. Where brown bin collection service was provided in rural areas it accounted for only 10 per cent of collected waste (roughly 33 per cent of the household organic waste stream), which is less than half that collected in urban areas.

In rural areas brown bin collection appears to substitute for other waste management options, for example home composting. Across both urban and rural areas with 3-bin collection, mixed residual waste constitutes roughly 42 per cent of household waste set out for kerbside collection.

4 Putting behavioural evidence to use: estimating the effects of policy interventions on waste disposition

In this section we focus on the potential effects of two sets of policies for diverting biodegradable waste away from landfills. The first involves increasing the landfill levy while extending the rollout of pay-by-weight tariffs. These two policies prove to have mutually-reinforcing effects. The second policy is to extend the rollout of three-bin recycling systems to the nation as a whole.

Note that these examples fall short of full cost-benefit analyses, because we do not consider the costs associated with the measures.

4.1 Effects of increased rollout of pay-by-weight tariffs and higher landfill levy

In this sub-section we simulate the effect of regulatory action to increasing the use of pay-by-weight tariffs by waste collection companies, together with varying the rate of the landfill levy.[5] These two policies may interact in ways that influence their effects on waste presentation, so it is useful to model them together.

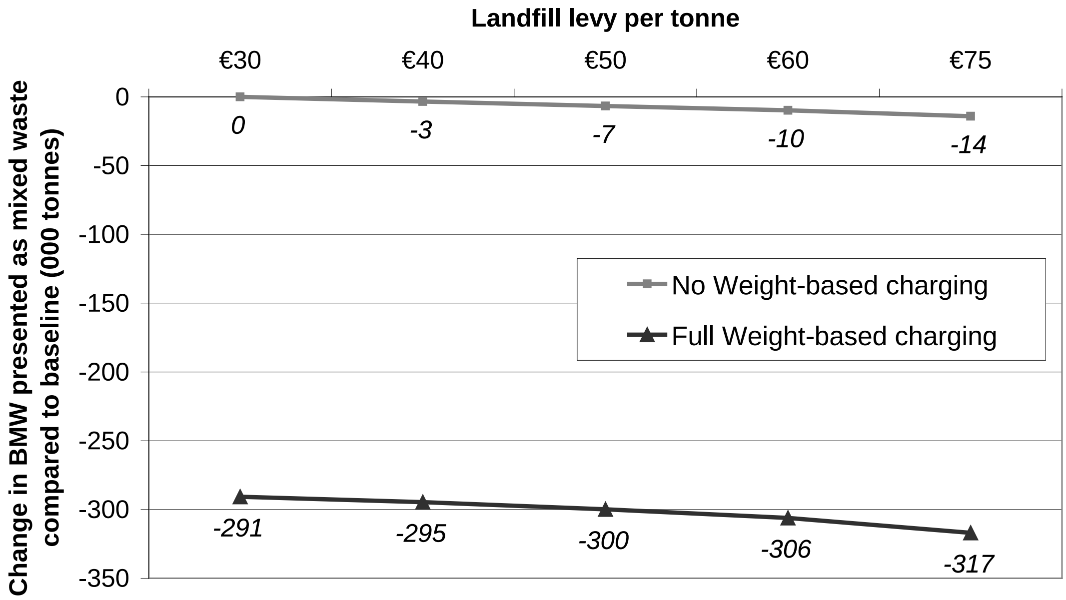
We focus on the amount of BMW presented as mixed waste, and thus liable to be placed in landfill (unless additional incineration or other post-collection waste processing is put in place). Two possible measures are modelled here, separately and together. Extending weight-based charging would reduce the amount of mixed waste presented, to the extent that households respond to paying a non-zero price for collection. Increasing the landfill levy should also decrease presentation of mixed waste, but only to the extent that it is passed through to households in the form of a per-unit charge. Households not paying on a per unit basis will have no incentive to

[5] EPA (2008) compares the extension of volume-based charging and the landfill levy using a similar approach.

reduce the quantity presented as the levy rises.[6] Thus we expect to see two interacting effects: higher penetration of weight-based charging will have a direct effect, and a higher landfill levy will have an effect that is stronger at higher levels of weight-based charging.

Figure 3 below illustrates the change in BMW quantities presented as mixed waste for a range of scenarios, each of which is compared to a case with no weight-based charging, 50% of households on volume-based charging and a €30 per year landfill levy. These results are drawn from the ISus model, using the income and price elasticities reported in this paper along with others drawn from the international literature.[7] Across the x-axis, we increase the landfill levy, and the line with triangle markers shows the effect of switching all flat rate and volume-based charging to weight-based.

Figure 2: Projected BMW presented as mixed waste in 2015 with varying landfill levy and penetration of weight-based charging



Source: analysis using the ISus model

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[6] Strictly speaking, some households might stop purchasing collection services altogether to avoid paying higher fixed charges, but it seems likely that the access price elasticity for this service is low (and for this analysis we assume it is zero).

[7] See http://www.esri.ie/research/research_areas/environment/isus/ for full details and parameter values.

By far the more substantial reduction comes from the switch in charging method, reducing arisings by about 290,000 tonnes per annum. This would amount to approximately 25% of the total BMW landfilled in 2015 in our base case. Simply changing the landfill levy has a very small effect on quantities presented as mixed waste in the base case, and only slightly more in the full weight-based charging case (the annual reduction rises from 14,000 tonnes to 26,000).

The landfill levy may well have a significant role to play in changing the economics of post-collection processing of waste. Ideally, it should be set at a level that offsets the externalities of landfill relative to incineration and other processing options such as mechanical-biological treatment. However, it will not make a significant difference to the quantity of mixed waste material presented for collection, particularly if pay-by-use tariffs are less than fully implemented.

4.2 Extending use of three-bin collection systems

In this sub-section, we estimate the likely effects of rolling out three-bin collection schemes in areas of Ireland that do not presently have such a system. Table 9 above compared the proportion of waste collected by different methods across urban and rural households and across 2-bin and 3-bin collection schemes in 2006. That information was used to estimate the change in waste that would have been collected by black, green and brown bins if brown bin collection were to be rolled out nationwide in 2006. The estimates are contained in Table 10, which implicitly assume that households face similar pricing structures and collection procedures to the brown bin collection schemes operating in 2006. In reality this is unlikely to occur but nonetheless gives a reasonable indication of the potential household response to nationwide expansion of brown bin collection.

Table 10: Predicted impact of extending 3-bin collection nationally on household waste collection, based on waste quantities in 2006 (thousand tonnes)

	Mixed residual (Black Bins)	Mixed dry recyclables (Green Bins)	Food and garden waste (Brown Bins)	Other disposal options	Total
Urban Areas	-127	22	118	-12	0
Rural Areas	-67	18	102	-54	0
Total	-194	40	220	-66	0

Source: analysis of data from Le Bolloch et al., 2007

The analysis suggests that the rollout of brown bin collection would (using 2006 quantities) have led to the separate collection of an additional 220,000 tonnes of food and garden waste and an almost commensurate decline in mixed residual waste collection of 194,000 tonnes. In addition, collection of dry recyclables would have increased by 40,000 tonnes. The increased collection of mixed dry recyclables associated with provision of brown bin is most likely a household response to the pricing structure associated with a three bin collection, and to a lesser extent an 'announcement' type effect encouraging more sustainable disposal of waste. At present mixed residual waste is predominantly disposed in landfill, therefore, the further rollout of brown bin collection would result in a significant diversion of BMW from landfill.

However, the analysis does raise a question about the merits of brown bin collection, particularly in rural areas. We are not aware of any published information on the potential cost of rolling out brown bin collection across Ireland, but it is likely that the provision of the service in rural areas would be significantly more expensive than urban areas. Given the lower rates of segregated food and garden waste collected in rural areas (either in aggregate or as a proportion of all waste), as shown in Table 9, the return on investment on roll out of 3-bin collection is likely to be considerably lower in rural than urban areas. The relative merits of other waste collection systems should also be considered, either as alternatives or in combination with the use of a three bin system. For example, the previous section demonstrated that the roll out of pay-by-weight charging for households (which does not necessarily include 3-bin collection), would be at least as effective as brown bins at diverting BMW from landfill. From an environmental perspective, segregated BMW improves the options for treatment and subsequent use of collected BMW; however, further cost benefit analysis is merited prior to the mandatory roll out of brown bin collection.

5 Conclusions

To arrive at more sustainable and efficient solid waste disposal practices in Ireland, and to meet international obligations, more information is needed on how much waste is being generated, what collection arrangements are applied, how much influence specific behavioural factors have on the growth in arisings, and what effects particular policy measures would have if they were widely adopted. In this paper we have used county-level data on waste quantities to model household waste disposal and recycling behaviour.

Demand for household waste collection services in Ireland exhibits roughly a unit income elasticity, which is unusually high by international standards. This suggests that waste quantities will be relatively sensitive to macroeconomic fluctuations. However, we have noted that this parameter may not be stable over time.

In common with other studies, we find that weight-based charges and availability of curbside recycling have significant (negative) effects on mixed waste quantities. Introducing kerbside recycling reduces mixed waste quantities by about 15%.

The policy examples considered in this paper indicate that hundreds of thousands of tonnes of waste materials could be diverted from landfill by changing collection arrangements, in particular by rolling out pay by weight collection or introducing a three-bin system. However, simply increasing the landfill levy is unlikely to have a significant effect on the quantity of mixed waste collected from households (although it may affect post-collection processing of waste, which we did not include in the analysis). Of course, these results represent only half the picture: to do a full cost-benefit analysis one would need much more information on the likely costs of these policies than is available in the public domain.

While we have been able to estimate some key parameters using existing data, further research is required to check that these estimates are robust and assess how some parameters are likely to change over time. Additional studies using household- or firm-level data such as Scott and Watson (2006) would be particularly valuable. Moreover, significant data gaps concerning waste management in Ireland remain. There is little regionally disaggregated information on the details or trends in services provided by waste collectors to the public, e.g. the structure and take-up of pricing options, price levels or service characteristics. Very little is published on the costs of existing services in Ireland or of arrangements that might be mandated by policy, such as different collection systems or post-collection processing. While much work has been done internationally on the external costs of landfill and incineration, it is not clear how applicable such results are to Ireland. Less information is available on the external costs of other treatment options such as recycling, composting and MBT. There are reasons to think that settlement patterns and specific site characteristics would have material effects on such costs, and these tend to be country- or region-specific.

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Appendix: Additional quantitative results

Table 11: "Green bin" dry recyclable waste per household, OLS cross-section regression results

Variables and statistics	All variables		Preferred model	
Dependent variable	*ln(green bin waste/household)*		*ln(green bin waste/household)*	
	Coef.	Robust Standard error	Coef.	Robust Standard error
Ln(real disposable income)	2.47	0.800***	2.46	0.622***
Persons per household	0.141	0.320		
Kerbside recycling	0.305	0.150*	0.277	0.136**
Pay by weight offered	-0.0818	0.197		
Pay by weight price	-0.0122	0.234		
Tag-based offered	-0.226	0.212		
Tag price	-0.00389	0.0238		
Constant	-27.1	8.12***	-26.7	6.22***
Observations	31		31	
R^2	0.433		0.395	
Heteroscedasticity	$\chi^2(1)$=5.49 [0.0191]		$\chi^2(1)$=3.84 [0.0501]	

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Numbers in brackets are p-values. Data sources: see Table 2 above.*

Table 12: "Green bin" dry recyclable waste per household, panel regression results (all variables in first-differences, unbalanced panel)

Variables and statistics	All variables		Preferred model	
Dependent variable	*ln(green bin waste/household)*		*ln(green bin waste/household)*	
	Coef.	Robust Standard error	Coef.	Robust Standard error
Ln(real disposable income)	3.77	1.01***	3.94	0.915***
Persons per household	-0.376	0.449		
Volume-based charge	0.0209	0.0244		
Weight-based charge	-0.709	0.470		
Constant	0.0560	0.107	0.0530	0.105
Sample	34 local authorities		34 local authorities	
Time periods	2003-2006 (with some omissions)		2003-2006 (with some omissions)	
Observations	121		121	
R^2	0.151		0.140	
Heteroscedasticity	$\chi^2(1)$=4.45 [0.0349]		$\chi^2(1)$=3.28 [0.0702]	

*Note: All variables are in first differences apart from the constant; *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Numbers in brackets are p-values. Data sources: see Table 4 above.*

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