VU Research Portal

Effectiveness of deposit-refund systems for household waste in the Netherlands

Linderhof, Vincent; Oosterhuis, Frans H.; van Beukering, Pieter J.H.; Bartelings, Heleen

published in

Journal of Environmental Management
2019

DOI (link to publisher)

[10.1016/j.jenvman.2018.11.102](https://doi.org/10.1016/j.jenvman.2018.11.102)

document version

Publisher's PDF, also known as Version of record

document license

Article 25fa Dutch Copyright Act

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Linderhof, V., Oosterhuis, F. H., van Beukering, P. J. H., & Bartelings, H. (2019). Effectiveness of deposit-refund systems for household waste in the Netherlands: Applying a partial equilibrium model. *Journal of Environmental Management*, 232, 842-850. <https://doi.org/10.1016/j.jenvman.2018.11.102>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Research article

Effectiveness of deposit-refund systems for household waste in the Netherlands: Applying a partial equilibrium model

Vincent Linderhof^{a,*}, Frans H. Oosterhuis^b, Pieter J.H. van Beukering^b, Heleen Bartelings^a^a Wageningen University and Research, the Netherlands^b Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, the Netherlands

ARTICLE INFO

Keywords:

Deposit-refund schemes
Effectiveness
Partial equilibrium model
Batteries
Small electric appliances
The Netherlands

ABSTRACT

Deposit-refund schemes (DRS) are basically a combination of two instruments: a tax on the purchase of a certain product, and a subsidy on the separate collection of the same product in its after-use stage. They can be efficient policy instruments to encourage reuse and recycling. However, empirical studies on impact of DRS systems on recycling rates are hardly done. In this paper, we applied the Fullerton-Wu model, a partial equilibrium model, to simulate the impact of introducing mandatory DRS for small electric appliances and batteries in the Netherlands. For small electric appliances, a deposit-refund rate of €5 to €15 per appliance would lead to an increase in the recycling rate (recycled appliances as a percentage of total amount of appliances disposed of) from 60.7% to 64.7% and 76.4% respectively. For batteries, a DRS would increase the recycling rate from 86.9% to between 87.2 and 89.2% depending on the deposit tax level ranging from €5 to €20 per kg and the price elasticities assumed (low and high). Obviously, the performance of DRS in terms of additional recycling is stronger in cases where current recycling rates are relatively low. Moreover, the pre-existence of an infrastructure for separate collection would make small white goods an interesting candidate for this instrument.

1. Introduction

The European Union has ambitious targets for the reuse and recycling of various waste streams (see e.g. [Ferreira da Cruz et al., 2014](#)) and has developed an action plan for a ‘circular economy’ ([European Commission, 2015](#)). EU Member States will need to apply a variety of policy instruments to achieve these objectives.

Deposit-refund schemes (DRS) are basically a combination of two instruments: a tax on the purchase of a certain product, and a subsidy on the separate collection of the same product in its after-use stage. They can be efficient policy instruments to encourage reuse and recycling ([Walls, 2011](#)). In particular, DRS are desirable instruments for environmental regulation where monitoring of emissions (or environmental impacts) is difficult ([Mrozek, 2000](#)). In practice, DRS are widely applied with applications ranging from beverage container recycling to automobile carcass disposal ([Walls, 2011](#)). DRS can be applied on a voluntary or a mandatory basis. Generally, DRS lead to high return rates and a reduction of littering. However, the handling and administration costs can be substantial ([Hogg et al., 2011](#)). For the Netherlands, there are only cost estimates for DRS of the recyclable plastic 1.5 L bottles which range from 2.5 to 5 cents per bottle (Thoden [van Velzen](#)

and Bos-Brouwers, 2012; Warringa et al., 2014).

Most studies on DRS in the economic literature are based on a sound theoretical analysis, but there are hardly any empirical studies on the impact of DRS on recycling rates. However, to measure the effectiveness, the impacts of DRS should be assessed with quantifiable indicators ([Guimarães et al., 2010](#)). This study contributes to the literature by applying a partial equilibrium model for real life examples in the Netherlands. With such a model, the impacts of economic incentives (taxes and subsidies for instance) on behavior of actors can be evaluated including possible feedback mechanisms of behavioral changes. The theoretical model was developed by ([Fullerton and Wu, 1998](#)). With the Fullerton-Wu model, a number of different environmental taxes and subsidies, such as a deposit-refund system, can be evaluated. In DRS, products are taxed when consumers purchase the product, and the products are subsidized when they are separately disposed of.

The Fullerton-Wu model distinguishes a representative household that consumes commodities and either recycles products or disposes of them as waste. The production of garbage depends on the total amount of consumption goods, the packaging rate and the degree of recyclability of the commodities. Utility of households depends on the amount of consumer commodities, and the level of recycling.

* Corresponding author. PO Box 29703, 2502 LS The Hague, the Netherlands.
E-mail address: vincent.linderhof@wur.nl (V. Linderhof).

Households maximize utility subjected to a budget constraint.

Firms produce commodities and have the option to use recycled products. They also decide on the packaging rate of the commodities. Firms maximize profits. By imposing a tax on packaging of consumer products or on the products themselves and a subsidy on recycling, we can evaluate DRS.

The Fullerton-Wu model is applied to small electric appliances – the so called white and brown goods – and batteries in the Netherlands. Both types of goods contain polluting substances, which may contaminate the environment whenever the goods are inappropriately disposed. For this reason, both types of goods are already monitored regularly in the Netherlands, so that data for empirical analyses is available.

The structure of the paper is as follows. Section 2 discusses the background of applying DRS and presents examples of DRS in the Netherlands and abroad. Section 3 discusses the methodology of the Fullerton-Wu model for the empirical analysis. The calibration of the model and the results of the model for small electric appliances and batteries are presented in section 4. Finally, section 5 concludes and presents policy recommendations.

2. Literature review

The earliest economic analyses of DRS date back to more than 35 years ago (Bohm, 1981). Stavins (2000) mentions three reasons why DRS may be attractive: i) DRS reduce monitoring costs, as they reduce the incentive to illegal dumping; ii) DRS can provide firms with incentives to prevent losses of the material in the industrial process in which it is used; and iii) due to the inevitable net losses in the production and consumption processes, incentives exist for firms to look for substances that cause less damage to the environment – substances to which the DRS does not apply. Mrozek (2000) argues that DRS are particularly desirable instruments for environmental regulation where monitoring of emissions (or environmental impacts) is difficult.

More recently, several authors have studied the conditions under which DRS can be considered a useful policy instrument to attain maximum welfare, and how they should be designed. For example, (Aalbers and Vollebergh, 2008), using a general equilibrium model, found that DRS can provide the optimal incentives to recycling, land-filling and dumping, taking into account the possibility of waste mixing and the efforts needed to keep waste streams separated. (Hong and Jhih-Sian, 2011) confirm the results of Aalbers and Vollebergh based on a Stackelberg model. (Hong and Jhih-Sian, 2011) argue that a deposit-refund should be applied to all products, combined with a disposal fee (waste tax). Ino (2011) introduced monitoring costs explicitly in the model and showed that the refund of recyclables depends on the monitoring costs and the price level in the recycling markets. In addition (Numata, 2010, 2016), claimed that the provision of correct information about the impacts of the DRS system are crucial factors for a successful DRS program. Finally (Lavee, 2010), explored a full cost-benefit analysis for DRS system for beverage bottles in Israel and found that the benefits outweigh the costs of the DRS system.

2.1. The Netherlands

Although the Environmental Protection Act (article 15.32) in the Netherlands offers the opportunity to impose mandatory deposit-refund or 'return premium' schemes, this instrument is not (yet) used in Dutch waste policy. Voluntary DRS, however, do exist, for example for beer bottles, beer bottle crates, and large PET – plastic – bottles. These schemes can contribute to reuse and recycling and to a reduction of the amount of packaging waste, as they tend to lead to high return rates (95% for large bottles) (Bergsma et al., 2001).

The possible introduction of mandatory deposit-refund schemes has been used as a 'big stick' to stimulate firms to co-operate in realising the objectives in the area of packaging waste and littering. In this respect,

Section 6 of the Dutch Decree on packaging and packaging waste¹ provides for a deposit-refund scheme for drinks packaging, which will only enter into force if the envisaged targets for collection, reuse or litter reduction will not be realised.

2.2. Foreign experiences

Traditionally, deposit-refund schemes for beverage packaging are in place on a voluntary basis. In some countries the use of such schemes has been stimulated by the fact that high return rates allow companies to enjoy privileges, e.g. a reduced rate or exemption from packaging taxes. Particularly Germany, countries in Scandinavia and Central and Eastern Europe, as well as a number of states in the USA and provinces in Canada, have been applying mandatory deposit-refund systems for several years (Oosterhuis et al., 2009). The types of beverage containers covered differ (e.g. they may or may not include non-refillable containers such as cans), as do the deposit rates. Generally, these systems lead to high return rates and a reduction of littering. On the other hand, the handling and administration costs can be substantial.

3. Methodology

To determine the effectiveness of DRS we apply the partial equilibrium model developed by (Fullerton and Wu, 1998). In DRS, products are taxed when consumers purchase the product, and the products are subsidized when they are separately disposed of. By imposing a tax on consumer products (e.g. batteries and small electric appliances) and a subsidy on recycling, we can evaluate DRS.

The Fullerton-Wu model consists of a representative household that has the incentive to separate waste for recycling due to the DRM system, firms that can use recycled products in their production processes, and a waste collection firm.

The model distinguishes a representative household that consumes commodities q . After consumption, the household can either recycle the product (r) or dispose of the product (g). The production of garbage depends on the total amount of consumption commodities q , the packaging rate θ and the degree of recyclability of the commodities ρ . In addition to the Fullerton-Wu model, we assume that the generation of disposed products also depends on the price level of the consumption commodity p_q and the price level of recycled products p_r .

The technology of waste disposal is:

$$g = \delta_0 \rho^{\delta_p} \theta^{\delta_\theta} (p_q + t_q)^{\delta_{pq}} (p_r + t_r)^{\delta_{pr}}, \quad (1)$$

where the δ 's are the parameters of the variables and δ_0 is the positive scaling parameter. The parameter δ_θ is positive, which means that more commodities and a higher share of packaging of the commodities will lead to more generation of waste disposal. We assume that the total amount of consumption commodities remains constant. Waste disposal is restricted to the products considered. Higher price levels for commodities or recycling (including taxes t) will lead to lower levels of waste disposal, because the demand for new commodities will decline (and waste disposal as well) and recycling becomes more attractive. The technology of recycling by households is:

$$r = \gamma_0 \rho^{\gamma_p} (p_q + t_q)^{\gamma_{pq}} (p_r + t_r)^{\gamma_{pr}}, \quad (2)$$

where the γ 's are the parameters of the variables and γ_0 is the positive scaling parameter. The parameter for ρ and the parameters for the commodity price (γ_{pq}) and recycling price (γ_{pr}) are positive. Higher price levels will lead to more recycling.

Utility of households depends on the amount of consumer commodities q , and the amount of recycling (r) and other commodities GN . Households maximize utility subjected to a budget constraint. The utility function is:

¹ Besluit beheer verpakkingen 2014, Staatsblad (Law Gazette) 2014, 409.

$$U = q^{\alpha_q} h^{\alpha_h} r^{\alpha_r} G N^{\alpha_{GN}}, \quad (3)$$

where α 's are the utility parameters which are all positive. The variable h is the amount of resources produced and consumed at home, such as time spent on recycling for instance. According to Equation (3), more recycling efforts at home (higher level of h) will result in higher level of utility. Intuitively, more recycling efforts lead to more utility which reflects the willingness to recycle. For households that do not spend any time on recycling, utility is unaffected, because $h = 0$. The budget constraint is:

$$(k - k_h) + (p_r + t_r)r = (p_q + t_q)q + (p_g + t_g)g, \quad (4)$$

where k is the labour resources supplied by households to firms to produce commodities, k_h is the time used at home ($k_h = h$), t_r is the subsidy on recycling, t_q is the tax on commodities, p_g is the price of waste collection and t_g is the tax of waste collection. The left-hand side the budget constraint in Eq. (4) reflects the revenues from labour inputs and recycling, while the right-hand side reflects the expenditures on consumption and waste collection.

Firms produce commodities and have the option to use recycled products. They also decide on the packaging rate of the commodities. The production function is a Cobb-Douglas function:

$$q = \beta_0 k_q^{\beta_k} r^{\beta_r} \rho^{\beta_\rho} \theta^{\beta_\theta}, \quad (5)$$

where k_q is the resource used for production (labour), and β 's are the production function parameters. The parameter β_0 is the scaling parameter. The production function exhibits constant returns to scale, so that $\beta_k + \beta_r + \beta_\rho + \beta_\theta = 1$. Firms maximize profits (π), and the profit function is:

$$\pi = p_q q - p_r r - k_q. \quad (6)$$

In addition, there is a waste collection industry with the linear production technology:

$$g = \varepsilon k_g. \quad (7)$$

where k_g is the resource input for the waste collection industry provided by households. The parameter ε reflects the amount of resource input per unit of waste collected. To close the model, the sum of resource inputs is limited to k , so that $k = k_q + k_h + k_g$.

4. Model application and results

Taking into account the 'priority waste streams' in Dutch waste policy of the early 2000s, a number of products was selected for an analysis of DRS impacts, focusing on waste streams for which a high degree of separate collection was considered to be important. This has resulted in the following selection:

- Electric and electronic equipment (conversion of the current system of producer responsibility to DRS);
- Batteries (idem).

For batteries as well as electric and electronic equipment, the Netherlands introduced producer responsibility in 1995 and 1999, respectively. Producer responsibility implies that producers are responsible for the disposal of batteries and electric and electronic equipment. In the case of electric and electronic equipment, producers stimulate take back activities and separate collection of appliances. In the case of batteries, the separate collection is widely stimulated. In 2007, the amount of batteries separately collected was 38% of the amount sold, while 86% of the batteries disposed was separately collected according to Stibat i.e. the Dutch Battery Foundation (Stibat, 2008). For electric and electronic equipment, the share of appliances reused or recycled was 43% of the number of appliances sold in 2006. About two-third of all electric and electronic equipment disposed were separately collected according to the NVMP Association, which is the

Table 1

Development of the number of disposable and rechargeable batteries sold in the period 2000–2007 (in millions per year).

	Disposable batteries	Rechargeable batteries	Total	Share of rechargeable batteries
2000	189.2	19.8	208.9	9.5
2001	204.4	18.8	223.2	8.4
2002	203.6	20.1	223.8	9.0
2003	244.5	27.9	272.4	10.3
2004	280.5	36.4	316.9	11.5
2005	309.2	38.9	348.1	11.2
2006	315.2	38.7	353.9	10.9
2007	317.6	42.4	360.0	11.8

Source: (Stibat, 2008).

collective advocate of six foundations of manufacturers and importers (electrical and electronic equipment) that are directly involved in the regulation and legislation in the field of EU Waste Electrical and Electronic Equipment (NVMP, 2007).

4.1. Results for batteries

As shown in Table 1, the total number of batteries sold grew with 72% in the period 2000–2007. The number of rechargeable batteries sold more than doubled in the same period. The share of rechargeable batteries increased from 9 to 12%.

The total amount of batteries sold increased with 34% in the period 2002–2007 and exceeded the amount of 8000 tonnes in 2007. The number of appliances using batteries is still increasing (toys, cell phones, etcetera). The total amount of batteries separately collected increased with almost 50% and amounted to 3018 tonnes in 2007. From household rest waste, another 456 tonnes of batteries were separated. The amount of batteries in household rest waste declined gradually between 2002 and 2007 with 40%.

Since 2004, 80% of the batteries collected were collected separately, which was the target (Stibat, 2008). In 2002, this was only 71%, while in 2007 it was 86%. However, from 2009 onwards, the recovery rate is no longer calculated based on the total amount of batteries collected but on the total amount of batteries sold according to the new EU Directive for batteries (2006/66/EC). The recovery targets from the EU Directive were 25% in 2012 and 45% in 2016. In 2007, the recovery target rate in the Netherlands was 36.7%.

In total 3474 (3018 + 456) tonnes of batteries were separately collected or separated from rest waste, while the total weight of batteries sold was 8215 tonnes. There are a number of reasons for the discrepancy between sales and collection. First, new batteries are stored before usage. Second, batteries are stored after usage. Third, the lifetime of batteries increases due to the fact that the share of rechargeable batteries increased. In 2007, about 12% of the batteries sold were rechargeable.

For the model, we assume that a maximum of half of the batteries sold will return after one year. The reasons to assume that the average lifespan of batteries is longer than one year are the same three as those just mentioned for the discrepancy between sales and collection.

With the adjusted Fullerton-Wu model, we simulate the impacts of the DRS for batteries in the Netherlands, taking 2007 as the base year. The base situation is that 3018 tonnes of batteries are collected separately, and 456 tonnes of batteries are separated from rest waste. From the Fullerton-Wu model, we derive the demand for the collection of rest waste and the demand for recycling. Both types of demand depend on the prices of rest waste collection and recycling including taxes, respectively, instead of the total amount of batteries sold. Imposing a deposit on the purchase of a commodity will reduce the demand for the commodity if the price elasticity is negative. The model further assumes that batteries can be recycled for the production of new batteries. Also, firms pay a price for recycled batteries to households including the

refund.

In the literature, estimations of the price elasticity of the demand for batteries are not available. ECOTEC (2001) argues that the price elasticity of batteries is very low. Dimarso (1995) concluded in a conjoint analysis that consumers are hardly aware of the price of batteries. Moreover, batteries are used for durable appliances and when consumers would not buy batteries they will not be able to use the appliances. This indicates that the price elasticities of batteries will be low (i.e. close to zero). Therefore, we assume a -0.1 price elasticity of the price of new batteries on the generation of rest waste batteries and recycled batteries. If the price of batteries increases, the demand for batteries will decline, and consequently, the generation of rest waste batteries and recycled batteries as well. In addition, we assume a -0.1 price elasticity of the price of recycled batteries (the refund rate) on the generation of rest waste batteries. The own-price elasticity of recycled batteries is positive (0.15). In practice, the price of recycled batteries is zero. In equilibrium models, however, we cannot assess prices which are initially zero. For convenience, we assume a positive price for recycled batteries which is equal to the costs of manufacturers for using recycled products. The higher the price of recycled batteries, the more households are willing to recycle batteries. The actual values of the price elasticities are unknown, so we use conventional assumptions for the estimations.

We have no information on the recyclability rate of batteries. For convenience, we assume that it is equal to the recycling rate, so that the recyclability rate is calculated based upon recycled and sold batteries. For a fixed rate of recyclability ($0.367 = 3018/8219$), we simulated the results for DRS with deposits of €5, €10, €15 and €20 per kg. Given an average weight of 23.4 g per battery (Stibat, 2008), the ‘€5 per kg’ deposit is equivalent to a deposit of €0.12 per battery, while a ‘€20 per kg’ deposit is equivalent to €0.52 per battery. The average price per battery without deposits ranges from €1 to €2, so that the highest deposit considered is in the range of 25–50% of the retail price of batteries. The labour input of the batteries production is constant. Due to higher amounts of recycling, manufacturers of batteries will be able to produce more batteries. Table A.1 in the Appendix summarizes the model parameters.

Fig. 2 shows the development of the recycling rate for batteries for deposits in the range of €5 to €20 per kg of batteries. Initially, the amount of batteries separately collected is 36.7% compared to the newly sold batteries. Due to a deposit of €5 per kg, the rate of separate collection would increase to 37.1% in the case that we assume that the price elasticities of recycling are low (inelastic). If the deposit rate is gradually increased to €20 per kg, the recycling rate would increase to 38.3%. This is equivalent to an 88.2% separate collection rate of all batteries disposed of. Note that it is assumed that the existing widespread network of batteries collection is maintained.

Table 2 presents the results of the Baseline, DRS5, DRS10, DRS15 and DRS20 scenarios. The total amount of batteries in rest waste decreases with the implementation of DRS, while the amount of recycled batteries increases. In the case of a deposit of €20 per kilogramme (i.e. €0.511 per battery), the total amount of recycled batteries increases from 86.9 to 88.2% of the amount of batteries disposed.

The total amount of batteries separately collected increases with 1.8% in the DRS5 scenario, while the total amount of batteries recycled increases to the same extent. The price for batteries including the tax of €5 per kg increases with 9.0%, while the price for recycling including the subsidy increases with 0.5%. The total amount of batteries sold increases with 0.8%. The profits of firms decline because the increase of sold batteries is offset by a decrease of the retail prices excluding taxes. The firms lower the retail prices (excluding tax) in order to compensate a part of the tax imposed. Households face the price including tax, and firms receive the price without tax. Firms thus compensate part of the tax in order to reduce the decline in batteries sold.

According to a number of studies, the price elasticity of new batteries is low. However, there is no quantitative information on the

Table 2

Results on DRS for batteries with an inelastic demand*.

Parameter values	Base	DRS	DRS	DRS	DRS
Deposit tax and refund (€ per appliance)	€0	€5	€10	€15	€20
<i>Changes in physical flows</i>					
Batteries sold (tonnes)	8219	8278	8337	8393	8447
Batteries in rest waste collected (tonnes)	456	450	443	437	432
Recycled (tonnes)	3018	3073	3128	3181	3232
Total amount of batteries disposed (tonnes)	3474	3523	3571	3618	3664
<i>Recycling rate</i>					
Recycled batteries/Sold batteries (in %)	36.7	37.1	37.5	37.9	38.3
Recycled batteries/Disposed batteries (in %)	86.9	87.2	87.6	87.9	88.2
<i>Changes in retail values</i>					
Purchase price of batteries excl. deposit (€1000 per tonne)	51.0	50.6	50.2	49.9	49.6
Total price of batteries (€1000 per tonne)	51.0	55.6	60.2	64.9	69.6
<i>Changes in recycling values</i>					
Price of recycled batteries paid by firms (€1000 per tonne)	55.5	54.5	53.5	52.7	51.8
Total price of recycled batteries received by households (€1000 per tonnes)	55.5	59.5	63.5	67.7	71.8

* In the model, the price of recycled batteries is equivalent to the costs of recycled batteries for the production of new batteries. Manufacturers pay the suppliers of recycled batteries (households). By supplying more recycled batteries, households can increase their budget and consequently purchase more new batteries. Simultaneously, the production and consumption of new batteries increases with the growing amount of recycled batteries given a fixed amount of labour input.

actual value of this price elasticity. In the inelastic demand scenarios, we assumed that the price elasticity was -0.1 . To verify the impact of the price elasticity, we now rerun the series of scenarios with a doubled price elasticity of the demand for new batteries, and for recycled batteries, see Table A.1. The impact of a more elastic demand on the recycling rate is shown in Fig. 2. Clearly, the amount of recycled batteries increases with a more elastic demand for batteries. In the case of a deposit of €20 per kg, the recycling rate would increase to 39.5% compared to 38.3% in the inelastic scenario. This means that 89.2% of the disposed batteries are separately collected (see Table 3).

In conclusion, the impacts of the implementation of DRS for batteries are modest even if the deposit is set at €20 per kg. The share of separately collected batteries compared to the newly sold batteries

Table 3

Results on DRS for batteries with a more elastic demand.

Parameter values	Base	DRS	DRS	DRS	DRS
Deposit tax and refund (€ per appliance)	€0	€5	€10	€15	€20
<i>Changes in physical flows</i>					
Batteries sold (tonnes)	8215	8324	8431	8534	8634
Batteries in rest waste collected (tonnes)	456	445	433	422	412
Recycled (tonnes)	3018	3116	3217	3316	3414
Total amount of batteries disposed (tonnes)	3474	3561	3650	3738	3826
<i>Recycling rate</i>					
Recycled batteries/Sold batteries (in %)	36.7	37.4	38.2	38.9	39.5
Recycled batteries/Disposed batteries (in %)	86.9	87.5	88.1	88.7	89.2
<i>Changes in retail values</i>					
Purchase price of batteries excl. deposit (€1000 per tonne)	51.0	50.3	49.7	49.1	48.5
Total price of batteries (€1000 per tonne)	51.0	55.3	59.7	64.1	73.5
<i>Changes in recycling values</i>					
Price of recycled batteries paid by firms (€1000 per tonne)	55.5	53.7	52.1	50.5	49.1
Total price of recycled batteries received by households (€1000 per tonnes)	55.5	58.7	62.1	65.5	74.1

Fig. 1. Development of batteries sold, collected and separated from rest waste, 2002–2007. Source: Stibat (2008).

increases from 36.7% to 38.3% (or to 39.5% if the demand for batteries is more elastic). The reason for this modest increase is probably the high share of batteries separately collected compared to the amount of batteries disposed of. Almost 90% of the batteries disposed of is separately collected with a more elastic demand.

The discrepancy between the amount of batteries sold in 2007 (8.2 million kg) and the amount of batteries disposed of (3.5 million kg) is quite large. As shown in Fig. 1, this discrepancy seems to be of a structural nature. On the one hand, the use of batteries increased due to the number of electr(on)ic appliances using batteries. On the other hand, the storage of unused and/or used batteries in households increased. Unfortunately, there is no information on storage of used or unused batteries at households.

The implementation of DRS for batteries would also induce higher transaction costs, which were not accounted for in the model. Especially in the case of batteries, where there is already a wide network of free batteries collection, the transaction costs of implementation could be limited if the current network would be maintained. However, because collectors have to return the refund for batteries, DRS will inevitably lead to higher transaction costs for collectors. This might lead to a partial breakdown of the collection network, unless the recycling of batteries is economically attractive for both recyclers and collectors.

4.2. Results for small electric appliances

In 2007, there has been an extensive survey on the possession, purchase and disposal of electric household appliances (GFK Panel Services Benelux, 2007). This section concentrates on small electric appliances (so-called white and brown goods) that often end up in the households' rest waste. The appliances under consideration include

Fig. 2. Changes in recycling rate of batteries when demand for batteries is inelastic and more elastic.

Table 4

Possession, purchase and disposal of white and brown good appliances (in millions pieces in 2006).

	Possession	Purchased – new	Purchased – Second hand	Disposed	Share of reuse
Large white goods	45.4	3.7	0.9	3.1	34
Small white goods	167.0	19.6	1.3	10.7	27
Kitchen	83.7	9.7	0.8	5.5	31
Personal care	37.9	5.2	0.1	2.5	19
Others	45.5	4.7	0.4	2.7	27
Brown goods	102.9	10.1	1.4	4.4	36
Visual	38.5	3.5	0.6	1.4	35
Home audio	22.0	1.0	0.3	0.8	46
Portable	30.4	3.6	0.2	1.6	31
Other brown goods	12.0	2.0	0.3	0.6	41

Source: GFK Panel Services Benelux (2007).

appliances used in the kitchen, used for personal care or for entertainment. Examples are coffee machines, blenders, shaving equipment, electric toothbrushes, audio-visual and portable appliances. Large electric appliances such as refrigerators, freezers, washing machines and dishwashers are not considered.

Table 4 presents data on the disposal of the different white and brown good appliances in the Netherlands. The disposed appliances are either reused directly (through second-hand shops or virtual second hand markets on the Internet like E-bay), or recycled. For recycling, we assume that the disposal of appliances through separate collection or large household waste collection makes recycling feasible. The discarded appliances are disposed of in the rest waste. More than half of all brown and white goods are either reused or recycled. For the small white goods, 70% of the collected appliances is recycled or reused. More than 20% of the small white goods is disposed of as rest waste.

The number of discarded brown goods is smaller (4.4 million pieces) than the number of discarded white goods (13.8 million pieces) (see Table 5). The recovery rates of 57% for portable brown goods and 61% for other brown goods are the lowest for brown goods categories. In the case of the portable brown goods, 30% of the appliances are disposed of as households' rest waste. For small appliances, such as small white goods and portable brown goods, it is relatively easy to dispose of appliances as household rest waste. DRS can be effective in reducing these disposed appliances in households' rest waste. The main reason for discarding white and brown goods is a deficiency of the appliance (49% for brown goods and 56% for white goods), under-utilisation (21% and 17%) and the purchase of a newer, better quality version of the appliance (16% and 14%).

For the scenario of DRS on small electric appliances, we concentrate on DRS for small 'white good' appliances.

For the model, we assume that a maximum of half of the appliances sold will return after one year. The life span of small white appliances is more than 10 years (GFK Panel Services Benelux, 2007). With the adjusted Fullerton-Wu model, we simulate the impacts of DRS for small white appliances. The base situation is that 2.9 million appliances are recycled separately, and 7.8 million appliances can still be recycled.

We use the same assumptions for the Fullerton-Wu model as the previous subsection on batteries. Both the demand for the collection of rest waste and the demand for recycling depend on the prices of rest waste collection, the prices of recycling, and the prices of new appliances including taxes and deposits. Imposing a deposit on the purchase of an appliance will reduce the demand for the appliance if the price elasticity is negative. The model further assumes that recycled appliances can be reused or recycled for the production of new appliances. Also, firms pay a price for recycled appliances to households including a refund.

Table 5

Disposal, reuse and recycling of white and brown good appliances
(in million pieces in 2006).

	Disposed	Reused	Recycled ^a	Disposed of as rest waste	Other	Recovery rate ^b
Large white goods	3.1	1.0	1.6	0.3	0.2	85
Small white goods	10.7	2.9	3.6	3.2	1.0	61
Kitchen	5.5	1.7	1.8	1.5	0.5	63
Personal care	2.5	0.5	0.8	1.0	0.2	51
Others	2.7	0.7	1.0	0.7	0.3	64
Brown goods	4.4	1.6	1.3	0.8	0.6	67
Visual	1.4	0.5	0.6	0.2	0.1	77
Home audio	0.8	0.4	0.2	0.1	0.1	75
Portable	1.6	0.5	0.4	0.5	0.2	57
Other brown goods	0.6	0.2	0.1	0.1	0.2	61

Source: GFK Panel Services Benelux (2007) recalculated by authors.

^a The recycled appliances are separately collected, see GFK Panel Services Benelux (2007).

^b Based on the calculation (The sum of the numbers of reused and recycled appliances divided by total number of disposed appliances).

Fig. 3. Changes in recycling rate of small white appliances when demand for small white appliances is inelastic and more elastic.

Similar to batteries, there is no specific information on the price elasticity of demand for small white appliances available in the literature. Since the lifespan of appliances is more than 10 years, the income elasticity will play a larger role in the demand for appliances than price elasticities. Therefore, we assume a -0.1 price elasticity of the price of new appliances on the generation of rest waste appliances and recycled appliances. If the price of a new appliance increases, the demand for new appliances will decline, and as a consequence, the generation of rest waste and recycling declines as well. In addition, we assume that a -0.1 price elasticity of recycled appliances on the generation of rest waste appliances. The own-price elasticity of recycled appliances is positive (0.15). In practice, the price of recycled small white appliances is zero. In equilibrium models, however, we cannot assess prices which are initially zero. For convenience, we assume a positive price for recycled small white appliances. This price corresponds to the costs of manufacturers for using recycled products. The higher the price of recycled appliances, the more households are willing to recycle appliances. The actual values of the price elasticities are unknown, so we use conventional estimates for the estimations, i.e. the 'inelastic demand scenario' as shown in Fig. 3.

We simulate the impact of DRS with different levels of deposit rates. A similar subsidy is provided for recycled appliances. The average price per appliance varies with the type of appliance. For convenience, we set an average price at €25, and simulate the impact of three tax scenarios: €5, €10 and €15 per appliance.

For the production of small white appliances, the labour input supplied by households is kept constant. In order to 'close' the partial equilibrium model, we assume that the labour input is fixed. As a consequence, an increase in recycled products by households will stimulate the production of small white appliances.

Fig. 3 shows the development of the recycling rate for small white appliances for taxes in the range of €5 to €15 per appliance. Initially, the recycling rate (amount of small white appliances separately collected and reused or recycled as a percentage of the total amount sold) is already 41.6%. Due to a deposit rate of €5, the rate of separate collection would increase to 45.5% in the case we assume that the price elasticities of recycling are low (inelastic). If the deposit rate is gradually increased to €15, the recycling rate would increase to 50.8%. Almost 70% of all small white appliances disposed of would be separately collected. The model assumes that the increased recycling of appliances implies that more recycled products can be used in the production of small white appliances. The prices of appliances without deposit would slightly decrease.

Table 6 presents the results of the Baseline, DRS5, DRS10 and DRS15 scenarios. The total amount of appliances in rest waste decreases with the implementation of DRS, while the amount of recycled appliances increases. In the case of a deposit rate of €15 per appliance, the total amount of recycled appliances is more than 50% of the amount of new appliances sold. In addition, almost 70% of the disposed appliances

Table 6

Results on DRS for small white appliances with an inelastic demand.

Parameter values	Base	DRS	DRS	DRS
Deposit tax and refund (€ per appliance)	€0	€5	€10	€15
<i>Changes in physical flows</i>				
Appliances sold (millions)	15.60	15.74	15.86	15.95
Appliances in rest waste collected (millions)	4.21	3.92	3.72	3.58
Recycled (millions)	6.49	7.16	7.68	8.10
Total amount of appliances disposed (millions)	10.70	11.08	11.40	11.68
<i>Recycling rate</i>				
Recycled appliances/Sold appliances (in %)	41.6	45.5	48.4	50.8
Recycled appliances/Disposed appliances (in %)	60.7	64.7	67.3	69.4
<i>Changes in retail values</i>				
Purchase price of appliances excl. deposit (€ per appliance)	25.64	25.39	25.22	25.08
Total price of appliances (€ per appliance)	25.64	30.39	35.22	40.08
<i>Changes in recycling values</i>				
Price of recycled appliances paid by firms (€ per appliance) ^a	6.16	5.58	5.21	4.94
Total price of recycled appliances received by households (€ per appliance)	6.16	10.58	15.21	19.94

^a In the model, the price of recycled appliances is equivalent to the costs of recycled appliances for the production of new appliances. Manufacturers pay the suppliers of recycled appliances (households). By supplying more recycled appliances, households can increase their budget and consequently purchase more new appliances. Simultaneously, the production of new appliances increases with the increased amount of recycled appliances given a fixed amount of labour input.

Table 7
Results on DRS for small white appliances with a more elastic demand.

Parameter values	Base	DRS	DRS	DRS
Deposit tax and refund (€ per appliance)	€0	€5	€10	€15
<i>Changes in physical flows</i>				
Appliances sold (millions)	15.60	15.89	16.10	16.28
Appliances in rest waste collected (millions)	4.21	3.69	3.34	3.08
Recycled (millions)	6.49	7.79	8.92	9.94
Total amount of appliances disposed (millions)	10.70	11.48	12.26	13.01
<i>Recycling rate</i>				
Recycled appliances/Sold appliances (in %)	41.6	49.0	55.4	61.0
Recycled appliances/Disposed appliances (in %)	60.7	67.9	72.8	76.4
<i>Changes in retail values</i>				
Purchase price of appliances excl. deposit (€ per appliance)	25.64	25.18	24.84	24.57
Total price of appliances (€ per appliance)	25.64	30.18	34.84	39.57
<i>Changes in recycling values</i>				
Price of recycled appliances paid by firms (€ per appliance)	6.16	5.13	4.48	4.03
Total price of recycled appliances received by households (€ per appliance)	6.16	10.13	14.48	19.03

is then recycled.

As mentioned above, we have no information from the literature on the price elasticity of small white appliances. For the results of the original series of scenarios in Table 6, we assumed an inelastic demand for small white appliances. However, we rerun the series of simulations with double price elasticities for the demand for small white appliances and for recycled appliances, see Table A.2 in the Appendix.

The impact on the recycling rate of a more elastic demand for small white appliances for the various tax levels is shown in Fig. 3. As shown in Table 7, the recycling rates increase substantially stronger if the price elasticity of demand is doubled. Under those conditions, the total amount of appliances in rest waste decreases with the implementation of DRS, while the amount of recycled appliances increases more. In the case of a tax of €15 per appliance, the total amount of recycled appliances is more than 60% of the amount of new appliances sold. In addition, more than three quarter of the disposed appliances is then recycled.

The scenarios with the adjusted Fullerton-Wu model show that the implementation of DRS has a significant positive impact on the recycling rates. In the case of small white appliances, the income effect of the demand for small white appliances is ignored, although income effects play a significant role in the purchase of durable goods. The underlying assumption of the Fullerton-Wu model for small white appliances is that the present system of collection due to the producer responsibility will be maintained. Especially in the case of appliances, where there is already a wide network of free appliances collection (as part of the producer responsibility), the transaction costs of a collection system are probably limited. This will also have a positive impact on the environment as emissions from disposing electric appliances are avoided. However, DRS might lead to higher transaction costs for collectors, because they have to return the refund for all individual appliances.

Appendix. Parameter values in the models

Table A.1
Initial values for variables and parameter values for the batteries example of the adjusted Fullerton-Wu model

Variable/parameter	Definition	Low price elasticities	Moderate price elasticities
<i>Overall model assumptions</i>			
q	Composite commodity	8125	8125
ρ	Degree of recyclability (= 3.015/8.215)	0.367	0.367
θ	Packaging rate	0.05	0.05

(continued on next page)

5. Conclusions and policy recommendations

Deposit-refund schemes (DRS) can be effective in redirecting waste streams from final disposal to reuse and recycling. The advantage of a DRS is that it reduces the incentive for illegal dumping while it simultaneously stimulates reuse and recycling of products. In addition, it reduces the amount of waste. For large bottles, with a recycling rate of 95%, the voluntary DRS in the Netherlands is very successful. Foreign experiences with mandatory DRS show that these systems also tend to lead to high return rates and a reduction of littering. On the other hand, the handling and administration costs can be substantial.

The success of DRS depends largely on the existing design of the system from which it has to emerge. For example, as a result of the principle of producer responsibility, a comprehensive collection system is present in the Netherlands for batteries and small white appliances. A DRS helps to create consumer responsibility, which is particularly relevant for products that entail risk of pollution of the environment due to landfilling or incineration of (non-separated) household waste. Since more than 50 percent of batteries sold are not separately collected, a DRS is still to be considered. According to our results, the added value of DRS for batteries in terms of increased separate collection will be modest, as the present rate of separate collection is already high. For small white appliances more added value can be expected from the introduction of DRS.

For batteries, more research would be necessary to determine the waste flows of batteries more carefully. Also, more research on consumer behavior with respect to the purchases of batteries and on waste is needed. Furthermore, the incentives of purchasing batteries might be related to small electric appliances which use batteries.

Small electric appliances are characterized by lifetimes of ten years or more. This implies that the time period between deposit and refund is relatively long. The introduction of full DRS will take ten years or so. Moreover, for small electric appliances (so-called brown and white goods), there is an active (physical and virtual) second-hand market with which the lifetime of the products can be extended. DRS will probably have a negative effect on these second-hand markets, and thus on the lifetimes of the products. The environmental impacts of the effects of DRS remain ambiguous and therefore require further research.

DRS have a strong potential to achieve high collection and recycling rates. Their application therefore deserves consideration of policy makers, especially with respect to (discarded) products for which separate collection rates are currently low, while an adequate infrastructure is already in place or can be created without excessive cost. Small electric appliances may be a case in point to introduce a DRS. However, policy makers should be aware that there should be sufficient capacity to recycle small electric appliances and their material accordingly. Also, consumers will be more willing to cooperate when it is clear that separation of waste streams is contributing to a sustainable society. Before introducing (mandatory) DRS, their impact on international trade and interactions with other (EU) policies should be further investigated. The administrative costs and overall environmental impact would also require more detailed analysis.

Table A.1 (continued)

Variable/parameter	Definition	Low price elasticities	Moderate price elasticities
r	Recycling	3015	3015
g	Garbage collection	1093	1093
k_q	Inputs of resources for production of f	167.5	167.5
k_g	Inputs of resources for production of g	10	10
h or k_h	Commodity produced and consumed at home	10	10
<i>Waste and recycling sector prices</i>			
p_r	Price of recycled goods	55	55
p_q	Price of commodity goods	50	50
p_g	Price of garbage	9	9
<i>Rest waste generation (households)</i>			
δ_0	Scaling parameter	1.51	3.34
δ_p	Parameter for recyclability	−0.2	−0.2
δ_θ	Parameter for packaging	0.2	0.2
δ_{pq}	Parameter for commodity price	−0.1	−0.2
δ_{pr}	Parameter for recycling price	−0.1	−0.2
<i>Recycling production (households)</i>			
γ_0	Scaling parameter	1.36	0.50
γ_p	Parameter for recyclability	0.2	0.2
γ_{pq}	Parameter for commodity price	0.1	0.2
γ_{pr}	Parameter for recycling price	0.15	0.3
<i>Production function (firms)</i>			
β_0	Scaling parameter	1.51	1.51
β_k	Parameter for resource inputs	0.4	0.4
β_r	Parameter for recycling inputs	0.4	0.4
β_p	Parameter for recyclability	−0.1	−0.1
β_θ	Parameter for packaging	0.3	0.3
ε	Garbage production parameter	0.04573	0.0457

Table A.2

Initial values for variables and parameter values for the appliances example of the adjusted Fullerton-Wu model

Variable/parameter	Definition	Low price elasticities	Moderate price elasticities
<i>Overall model assumptions</i>			
q	Composite commodity	15.6	15.6
ρ	Degree of recyclability (= 6.494/15.6)	0.416	0.416
θ	Packaging rate	0.1	0.1
r	Recycling	6.5	6.5
g	Garbage collection	4.2	4.2
k_q	Inputs of resources for production of f	140	140
k_g	Inputs of resources for production of g	10	10
h or k_h	Commodity produced and consumed at home	20	20
<i>Waste and recycling sector prices</i>			
p_r	Price of recycled goods	6.2	6.2
p_q	Price of commodity goods	25.6	25.6
p_g	Price of garbage	2.4	2.4
<i>Rest waste generation (households)</i>			
δ_0	Scaling parameter	9.3	15.4
δ_p	Parameter for recyclability	−0.2	−0.2
δ_θ	Parameter for packaging	0.2	0.2
δ_{pq}	Parameter for commodity price	−0.1	−0.2
δ_{pr}	Parameter for recycling price	−0.1	−0.2
<i>Recycling production (households)</i>			
γ_0	Scaling parameter	4.3	2.3
γ_p	Parameter for recyclability	0.2	0.2
γ_{pq}	Parameter for commodity price	0.1	0.2
γ_{pr}	Parameter for recycling price	0.15	0.3
<i>Production function (firms)</i>			
β_0	Scaling parameter	8.7	8.7
β_k	Parameter for resource inputs	0.25	0.25
β_r	Parameter for recycling inputs	0.2	0.2
β_p	Parameter for recyclability	−0.05	−0.05
β_θ	Parameter for packaging	0.6	0.6
ε	Garbage production parameter	0.421	0.421

References

- Aalbers, Rob F.T., Vollebergh, Herman R.J., 2008. An economic analysis of mixing wastes. *Environ. Resour. Econ.* 39 (3), 311–330. <https://doi.org/10.1007/s10640-007-9128-1>.
- Bergsma, Geert, Paul van Soest, Jan, Potjer, Berend, Jan, Vroonhof, Haitjema, Aart,

- Verdonkschot, Sabine, Guido, Willems, et al., 2001. “Inzamel- en beloningsystemen ter vermindering van zwerfafval. Drie concepten voor een aanpak.” CE rapport 01.5090.21. CE Delft, PWC, De Straat Milieu-adviseurs, Delft. http://www.ce.nl/publicatie/inzamel-en-beloningsystemen_ter_vermindering_van_zwerfafval_drie_concepten_voor_een_aanpak/166.
- Bohm, Peter, 1981. Deposit-refund Systems: Theory and Applications to Environmental,

- Conservation, and Consumer Policy. Resources for the Future, Washington, DC.
- Dimarso, 1995. Ecotaks Op Batterijen; Prijsverhoging En Omruilgedrag. Conjoint-Analyse Bij de Belgische Bevolking. Dimarso-Report. Brussel).
- Ecotec, 2011. Study on the Economic and Environmental Implications of the Use of Environmental Taxes and Charges in the European Union and its Member States. Final Report. Brussels/Birmingham April 2001.
- European Commission, 2015. Closing the Loop - an EU Action Plan for the Circular Economy, vol. 2015. COM, pp. 614 final. Brussels, 2.12.2015.
- Ferreira da Cruz, Nuno, Ferreira, Sandra, Cabral, Marta, Pedro, Simões, Marques, Rui Cunha, 2014. Packaging waste recycling in Europe: is the industry paying for it? *Waste Manag.* 34 (2), 298–308. <https://doi.org/10.1016/j.wasman.2013.10.035>.
- Fullerton, Don, Wu, Wenbo, 1998. Policies for green design. *J. Environ. Econ. Manag.* 36 (2), 131–148. <https://doi.org/10.1006/jeem.1998.1044>.
- GfK Panel Services Benelux, 2007. Bezit, afdanking en verkrijging van Witgoed, bruingoed en grijsgoed. Rapport. Dongen.
- Guimarães, B., Simões, P., Marques, R., 2010. Does performance evaluation help public managers? A Balanced Scorecard approach in urban waste services. *J. Environ. Manag.* 91 (12), 2632–2638.
- Hogg, Dominic, Sherrington, Chris, Vergunst, Thomas, 2011. A Comparative Study on Economic Instruments Promoting Waste Prevention. Eunomia Research & Consulting, Bristol December 2011.
- Hong, I-Hsuan, Jhih-Sian, Ke, 2011. “Determining advanced recycling fees and subsidies in ‘E-Scrap’ reverse supply chains. *J. Environ. Manag.* 92 (6), 1495–1502. <https://doi.org/10.1016/j.jenvman.2010.12.004>.
- Ino, Hiroaki, 2011. Optimal environmental policy for waste disposal and recycling when firms are not compliant. *J. Environ. Econ. Manag.* 62 (2), 290–308. <https://doi.org/10.1016/j.jeeem.2011.03.007>.
- Lavee, Doron, 2010. “A cost-benefit analysis of a deposit–refund program for beverage containers in Israel. *Waste Manag.* 30 (2), 338–345. <https://doi.org/10.1016/j.wasman.2009.09.026>.
- Mrozek, J.R., 2000. Revenue neutral deposit/refund systems. *Environ. Resour. Econ.* 17, 183–193.
- Numata, D., 2016. “Policy mix in deposit-refund systems – from schemes in Finland and Norway. *Waste Manag.* 52 (June), 1–2. <https://doi.org/10.1016/j.wasman.2016.05.003>.
- Numata, Daisuke, 2010. On illegal activities in the California state beverage container deposit system. *J. Mater. Cycles Waste Manag.* 12 (4), 314–320. <https://doi.org/10.1007/s10163-010-0303-z>.
- NVMP, 2007. “Annual Report 2007.” Annual Report. Zoetermeer (the Netherlands): Dutch Association for the Disposal of Metal and Electrical Products. the NVMP foundation.
- Oosterhuis, F., Bartelings, H., Linderhof, V.G.M., van Beukering, P.J.M., 2009. Economic Instruments and Waste Policies in the Netherlands: Inventory and Options for Extended Use. IVM Instituut voor Milieuvraagstukken, ” Amsterdam.
- Stavins, 2000. Market-based environmental policies. In: Portney, P.R., Stavins, R.N. (Eds.), *In Public Policies for Environmental Protection*, second ed. Resources for the Future Press, Washington, DC.
- Stibat, 2008. “Annual Report 2008.” Annual Report. Zoetermeer (the Netherlands). Dutch Battery Foundation (Stibat).
- Thoden van Velzen, E.U., Bos-Brouwers, H.E.J., 2012. FBR report. Analyse Nederlands statiegeldsysteem voor PET-flessen: Studie naar kosten, materiaalgebruik en energiegebruik van het Nederlandse statiegeldsysteem voor frisdrank- en waterflessen, vol. 2012 Wageningen Food & Biobased Research, Wageningen.
- Walls, Margaret, 2011. Deposit-refund Systems in Practice and Theory. RFF Discussion paper DP 11-47. Resource for the future, Washington, DC.
- Warringa, Geert, Aarnink, Sanne, Bergsma, Geert, 2014. Kosten Statiegeldsystemen Voor Grote PET-flessen. CE Report. (Delft, CE Delft).