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Post Separation of Plastic Waste: Better for the Environment and Lower Collection Costs

Elbert Dijkgraaf[1]
Raymond Gradus[2]

[1] *Erasmus School of Economics, Erasmus University Rotterdam, and Tinbergen Institute, The Netherlands;*
[2] *Faculty of Economics and Business Administration, VU University Amsterdam, The Netherlands.*

Tinbergen Institute Amsterdam
Gustav Mahlerplein 117
1082 MS Amsterdam
The Netherlands
Tel.: +31(0)20 525 1600

Tinbergen Institute Rotterdam
Burg. Oudlaan 50
3062 PA Rotterdam
The Netherlands
Tel.: +31(0)10 408 8900
Fax: +31(0)10 408 9031

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Elbert Dijkgraaf[1] and Raymond Gradus[2]

Abstract: the European Union (EU) advocates a plastic waste recycling rate of more than 55% through home separation by households. Even for the Netherlands, which has already invested heavily in plastic recycling policies, there is still a challenge to meet this target. We show that post separation is an advisable alternative with more separation of plastic waste and lower collection costs. Based on data for 2013-2014, Dutch municipalities with post-separation have 6.2 kilogram more plastic than municipalities with only bring locations. Moreover, the effectiveness of post separation increases significantly over time to 8.4 kilograms in 2014. Also curbside collection of plastic waste can be effective, if it is combined with an unit-based pricing system, but in such a case the collection costs are higher. Therefore, there are indications that the cost effectiveness of recycling plastic waste increases, if post separation is chosen.

Keywords: plastic waste, recycling, post separation, home separation, cost effectiveness.

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1. Introduction

In July 2014, the European Commission send a directive to European Parliament amending Directive 2008/98/EC on waste. It proposed that EU member states should meet a target that 70% of household waste should be recycled in 2030 and many member states has some objections against this legislation. In the final Directive, which passed parliament in April 2016, the Commission lowered the target to 65% and for six EU member-states that currently have a recycling rate lower than 20% the deadline of meeting this target was postponed to

[1] Erasmus School of Economics and Tinbergen Institute, Erasmus University Rotterdam, email: dijkgraaf@ese.eur.nl; corresponding author.
[2] Faculty of Economics and Business Administration, VU University Amsterdam, email: r.h.j.m.gradus@vu.nl

2035 (EU, 2015a). Also Directive 94/62/EC on packaging and packaging waste was amended and for plastic the target is 55% in 2025 (EU, 2015b).

In Dijkgraaf and Gradus (2016), we showed that on average, Dutch municipalities recycled 50% of their (household) waste in the period 1998–2012. Although the Netherlands has invested heavily in policies to stimulate recycling there is still a large challenge even for the Netherlands to meet this target. Despite Dutch policy efforts such as separate curbside collection of paper, glass, plastics and compostable waste, the introduction of unit-based pricing (UBP) in one third of Dutch municipalities and the provision of special containers in many municipalities, the recycling rate dropped from 50% in 1998 to 48% in 2012. However, The Dutch recycling rate is far above the EU average of 42% (Eurostat, 2014). For plastic the Netherlands recycled 50% in 2014, only 5% below the mentioned long term goal.

As even in the Netherlands it seems difficult to reach the target of 65% recycling, the question is which separation options are available to increase recycling. Almost all attention has been given to source separation by households to increase recycling. This is also a central point in the Directive 2008/98/EC. It was stated in point 20:

> "Compliance with the obligation to set up separate collection systems for paper, metal, plastic and glass is essential in order to increase preparing for re-use and recycling rates in Member States." (EU, 2015a)

Recently, some municipalities in the Netherlands invested in post separation of plastic. Instead of sorting the waste out at home, plastic waste is collected together with mixed waste streams and separated in a factory. Owners of these factories claim that they can sort out plastic better than people do at their homes. In this paper, we use recent data for Dutch municipalities to test this claim, which is not tested in the literature until now.

Dutch municipalities may choose how plastic waste is collected (Dijkgraaf and Gradus, 2016). In 2013-2014, of all municipalities 88% have home separation and 11% have only post separation.[3] In the home separation municipalities plastic is collected at the curbside or citizens can deliver them to collection points at central locations nearby, such as shopping centres and schools. Interestingly, the number of municipalities with curbside collection increased from 37 percent in 2007-2012 to 65 percent in 2013-2014. In 2013-2014,

[3] In this period, 1% of Dutch municipalities does not separate plastics at all. However, the number of Dutch municipalities with no separating of plastics is rapidly decreasing from 49 in 2012 to 8 in 2013 and 3 in 2014.

approximately a half of these municipalities (43%) collect them once a month and somewhat more (48%) twice a month.

Based on data over 2013 and 2014 for all Dutch municipalities, we investigate in this paper whether municipalities with post-separation produce more kilograms of separated household plastics. It seems that Dutch recycling companies did some innovations with infrared techniques to separate plastics out of mixed waste and that there are effective with separating plastics. As we have detailed data for frequency of curbside collection and the type of container, we are able to test also whether this influences the quantity of collected plastic. It could be the case that on average post separation performs better, but not if curbside collection is optimized by collection method and frequency. We discuss also the interaction with unit-based pricing systems as the combination with home separation might influence effectiveness.

The relative performance of post separation is not only interesting from an environmental point of view, but also from a financial perspective. Home separation is quite expensive as it demands a separate collection infrastructure (Gradus et al., 2016). For the Netherlands the infrastructure costs for the collection and separation of household plastic strongly outweigh the revenues that are generated from the sale of recycled plastic. Therefore, a municipality is compensated for this deficit by the packaging industry and in 2015 got a contribution of 677 Euro per tonne of collected household plastic. In Gradus et al. (2016) we calculate the implicit price of one tonne of CO2 reduction by means of plastic home separation and recycling (compared with incineration) and showed that it is equal to 178 Euro. This calculation is based on the mass balance of home separated plastic waste from households. The recycling rate for this collected mixed plastic is 75 percent, meaning that 25 percent of the collected household plastic is still used for energy recovery. There are some indications that this source is more polluted than separated plastics from post-separation. Therefore, in this paper we discuss not only the relative effectiveness of post separation in the quantity of plastic waste, but also in economic terms. Furthermore, we discuss in a sensitivity analysis if the recycling rate goes up and if the quality of secondary plastics is increasing due to post-separation.

The paper is organized as follows. In Section 2, data and method are discussed. Estimation results are given in Section 3. In Section 4 we discuss cost-effectiveness of post separation versus home separation. Finally, Section 5 contains some conclusions and some suggestions for future research.

2. Data and method

Data on the amount of separated plastic waste by type of separation for (nearly) all Dutch municipalities in 2013 and 2014 come from *Afvalfonds Verpakkingen.* Furthermore, data on different collection methods come from Statistics Netherlands. We have data for 407 municipalities with a total of 778 observations.[4] Total recycled plastics per individual is on average 11 kilogram per inhabitant (see Appendix A for the variable definitions). There are large differences in plastic separation between Dutch municipalities. The four largest cities in the Netherlands (i.e. Amsterdam, the Hague, Rotterdam and Utrecht) separate on average 1 á 2 kilogram, while some rural municipalities separately collect 30 kilogram yearly.[5] Interestingly, the amount of separated plastic increased from 9 kilogram in 2013 to 13 kilogram in 2014.

In the table 1 the different separation systems are summarized.

Table 1. Number of municipalities with different separation systems

	Post	Curb	Bring	2013	2014	Both years	
PS	1	0	0	43	43	86	11%
CS	0	1	0	127	105	232	30%
BS	0	0	1	90	67	157	20%
PCS	1	1	0	15	27	42	5%
PBS	1	0	1	5	16	21	3%
CBS	0	1	1	95	88	183	24%
PCB	1	1	1	18	28	46	6%
None	0	0	0	8	3	11	1%

In 2013-2014, 11% of the 788 Dutch municipalities have only post separation (total 86). In 30% of municipalities there is a system of only curbside collection of plastic waste and 20% of Dutch municipalities have a system of only bring locations. Some of these municipalities combine different systems. Most important combination is curbside collection and bring locations with 24% of the municipalities. A small number of municipalities combines post separation with curbside collection (5%) or bring collection (3%) or even both (6%). In the

[4]In 2014 we have 402 municipalities.
[5]This comes close to maximum of plastics packaging production of individuals (KIDV, 2016).

first model these different systems are defined as dummies as shown in this table (with *None* as a benchmark).

First, we model the amount of (separated) plastic per inhabitant as a function of the separation system and socio-economic variables as household size, population density, share of elderly people and ethnicity[6], as follows:

$$PL_{it} = \alpha_0 + \lambda_1 PS_{it} + \lambda_2 CS_{it} + \lambda_3 BS_{it} + \lambda_4 PCS_{it} + \lambda_5 BPS_{it} + \lambda_6 CBS_{it} + \lambda_7 PCBS_{it} + \beta_1 HS_{it} + \beta_2 PD_{it} + \beta_3 EL_{it} + \beta_4 ET_{it} + \pi_{14} + \varepsilon_{it}, \quad (1)$$

where PL_{it} is the plastic amount in kilogram per inhabitant of municipality i in year t, PS_{it} is a dummy with value 1 if municipalities collect plastic by only post separation, HS_{it} is a dummy with value 1 if municipalities collect plastic by only curbside collection, BS_{it} is a dummy with value 1 if municipalities collect plastic by only bring separation, HPS_{it} is a dummy with value 1 if municipalities collect plastic by curbside and post separation, BPS_{it} is a dummy with value 1 if municipalities collect plastic by bring and post separation, HBS_{it} is a dummy with value 1 if municipalities collect plastic by curbside and bring separation and PCB_{it} a dummy with value 1 if municipalities collect plastic by curbside, bring and post separation. HS is the household size, PD is the population density, EL is the share of elderly people (above 65 years) and ET is ethnicity, defined as the share of non-western people. Finally, π_{14} is the year dummy for 2014 and ε_{it} is the normally distributed error term. Table 2 contains all descriptive statistics. All estimations are based on pooled ordinary least squares (OLS) with VCE Robust estimator to correct for clustered standard errors.

We also estimate alternative models. Second, as post separation became fully active in the course of 2013, it is better to take 2014-effect to understand the current effectiveness. Therefore, in the second model, we multiply the separation variables with the year dummy for 2014. According to our prior, we would expect that the coefficient for this 2014-dummy is positive. The equation becomes now:

$$PL_{it} = \alpha_0 + \lambda_1 PS_{it} + \gamma_1 PS14_{it} + \lambda_2 CS_{it} + \gamma_2 CS14_{it} + \lambda_3 BS_{it} + \gamma_3 BS14_{it} + \lambda_4 PCS_{it} + \gamma_4 PCS14_{it} + \lambda_5 PBS_{it} + \gamma_5 PBS14_{it} + \lambda_6 CBS_{it} + \gamma_6 CBS14_{it} + \lambda_7 PCBS_{it} + \gamma_7 PCBS14_{it} + \beta_1 HS_{it} + \beta_2 PD_{it} + \beta_3 EL_{it} + \beta_4 ET_{it} + \pi_{14} + \varepsilon_{it}. \quad (2)$$

[6] The data on socio-economic variables and on collection methods come from Statistics Netherlands (CBS).

In the Netherlands municipalities charge households for waste collection. In addition, the way citizens pay for mixed waste collection differs by Dutch municipality (Dijkgraaf and Gradus, 2015). In most Dutch municipalities, 59% in 2013-2014, a flat-rate system is used. In other municipalities, an unit-based pricing system is used for mixed waste.[7] This introduces a price that provides an incentive to reduce the quantity of waste and to sort plastics better. Thus, with UBP, it is expected that municipalities collect less priced waste and more unpriced plastic waste. 60% of municipalities with only a home separation system have also UBP, while this is only 18% for municipalities with only post separation. For municipalities with only a bring separation system this is 20%. Therefore, we include interaction effects if a municipality chooses for both UBP and a specific separation system. Even for only post estimation an effect might occur. The possibilities for households to separate plastics are limited in this case, but there can be an effect on total quantity due to shopping behaviour (see also D'Amato et al. (2016)). The equation becomes now:

$$PL_{it} = \alpha_0 + \lambda_1 PS_{it} + \gamma_1 PS14_{it} + \delta_1 PSUB_{it} + \lambda_2 CS_{it} + \gamma_2 CS14_{it} + \delta_2 CSUB_{it} + \lambda_3 BS_{it} + \gamma_3 BS14_{it} + \delta_3 BSUB_{it} + \lambda_4 PCS_{it} + \gamma_4 PCS14_{it} + \delta_4 PCSUB_{it} + \lambda_5 PBS_{it} + \gamma_5 PBS14_{it} + \delta_5 PBSUB_{it} + \lambda_6 CBS_{it} + \gamma_6 CBS14_{it} + \delta_6 CBSUB_{it} + \lambda_7 PCBS_{it} + \gamma_7 PCBS14_{it} + \delta_2 PCBSUB_{it} + \beta_1 HS_{it} + \beta_2 PD_{it} + \beta_3 EL_{it} + \beta_4 ET_{it} + \varepsilon_{it}. \quad (3)$$

Fourth, we test whether differences in the frequency of home collection influences the results. Although the effectiveness of increasing frequency of curbside collection has been disputed, in recent years this frequency increased on average in Dutch municipalities (Dijkgraaf and Gradus, 2016). On average the number of times a year plastic waste is collected at the curbside is 22 for municipalities with a home separation system. If it is combined with post separation, waste is less frequently collected with 18 times a year on average. The equation becomes now:

$$PL_{it} = \alpha_0 + \lambda_1 PS_{it} + \gamma_1 PS14_{it} + \delta_1 PSUB_{it} + \lambda_2 CS_{it} + \gamma_2 CS14_{it} + \delta_2 CSUB_{it} + \theta_2 CSFR_{it} + \lambda_3 BS_{it} + \gamma_3 BS14_{it} + \delta_3 BSUB_{it} + \lambda_4 PCS_{it} + \gamma_4 PCS14_{it} + \delta_4 PCSUB_{it} + \lambda_5 PBS_{it} + \gamma_5 PBS14_{it} + \theta_2 CSFR_{it} + \delta_5 PBSUB_{it} +$$

[7] Hereby we can distinguish between four different systems: volume-, frequency-, bag- and weight-based with a different incentive structure (Dijkgraaf and Gradus, 2015). As we are interested in the interaction between different separation methods and unit-based pricing systems and due to data limitations we are not able to distinguish between these UBP-systems. .

$$\lambda_6 CBS_{it} + \gamma_6 CBS14_{it} + \delta_6 CBSUB_{it} + \theta_6 CBSFR_{it} + \lambda_7 PCBS_{it} + \gamma_7 PCBS14_{it} + \delta_7 PCBSUB_{it} + \theta_7 PCBSFR_{it} + \beta_1 HS_{it} + \beta_2 PD_{it} + \beta_3 EL_{it} + \beta_4 ET_{it} + \varepsilon_{it}, \quad (4)$$

where FR_j is a variable that denotes the number of times in a year curbside collection takes place.

Fifth, we have information on the type of container, which is used for curbside collection. In the Netherlands municipalities supply bags, crates, duo-bins or mini-bins. We include dummies for the last three types with the bag system as benchmark. A bag is the most popular (55%) to collect plastics. Other type of containers are duo-bin (with other recyclable material such as glass) (1%), mini-bins (6%) and crates (3%). So finally, we estimate:

$$PL_{it} = \alpha_0 + \lambda_1 PS_{it} + \gamma_1 PS14_{it} + \delta_1 PSUB_{it} + \lambda_2 CS_{it} + \gamma_2 CS14_{it} + \delta_2 CSUB_{it} + \theta_2 CSFR_{it} + \lambda_3 BS_{it} + \gamma_3 BS14_{it} + \delta_3 BSUB_{it} + \lambda_4 PCS_{it} + \gamma_4 PCS14_{it} + \delta_4 PCSUB_{it} + \lambda_5 PBS_{it} + \gamma_5 PBS14_{it} + \theta_2 CSFR_{it} + \delta_5 PBSUB_{it} + \lambda_6 CBS_{it} + \gamma_6 CBS14_{it} + \delta_6 CBSUB_{it} + \theta_6 CBSFR_{it} + \lambda_7 PCBS_{it} + \gamma_7 PCBS14_{it} + \delta_7 PCBSUB_{it} + \theta_7 PCBSFR_{it} + \sum_{j=1}^{o} \lambda_j CR_{jit} + \beta_1 HS_{it} + \beta_2 PD_{it} + \beta_3 EL_{it} + \beta_4 ET_{it} + \varepsilon_{it}, \quad (5)$$

CR_j is a vector of dummy's that indicates the use of container type j (mini-bin, duo-bin, bag or crate).

Table 2. Descriptive statistics

	Mean	Min	Max	Stdev
Plastic per inhabitant	11.11	0	29.80	5.45
Only post separation	0.11	0	1	0.31
- extra effect 2014	0.06	0	1	0.23
- with UBP	0.02	0	1	0.15
Only curbside collection	0.30	0	1	0.46
- extra effect 2014	0.13	0	1	0.34
- with UBP	0.18	0	1	0.39
- frequency	6.42	0	52	10.96
Only bring collection	0.20	0	1	0.40
- extra effect 2014	0.09	0	1	0.28
- with UBP	0.04	0	1	0.21
Curbside and post separation	0.05	0	1	0.23
- extra effect 2014	0.03	0	1	0.18

- with UBP	0.03	0	1	0.18
- frequency	0.95	0	64	4.70
Bring and post separation	0.03	0	1	0.16
- extra effect 2014	0.02	0	1	0.14
- with UBP	0.01	0	1	0.11
Curbside and bring separation	0.24	0	1	0.42
- extra effect 2014	0.11	0	1	0.32
- with UBP	0.09	0	1	0.29
- frequency	4.73	0	52	9.29
Curbside, bring and post separation	0.06	0	1	0.24
- extra effect 2014	0.04	0	1	0.19
- with UBP	0.02	0	1	0.15
- frequency	1.05	0	52	4.77
None separation system	0.01	0	1	0.12
Bag collection	0.55	0	1	0.50
Duo-bin collection	0.01	0	1	0.12
Mini-bin collection	0.06	0	1	0.24
Crate collection	0.03	0	1	0.16
Household size	2.36	1.67	3.41	0.18
Population density	0.72	0.00	5.21	0.88
Inhabitants 65+	19.65	8.72	31.44	3.11
Ethnicity	5.81	0.94	37.23	5.35
D2014	0.48	0	1	0.50

3. Results

Table 3 contains estimations results.

Table 3. Estimation results main models

	First	2014 effect	UBP effect	Frequency	Technique
Only post separation	6.212***	4.775***	5.848***	5.793***	5.765***
- extra effect 2014	-	3.605***	3.615***	3.596***	3.584***
- with UBP	-	-	0.012	-0.024	-0.060
Only curb separation	5.557***	4.960***	1.528	-1.487	-1.741
- extra effect 2014	-	1.916***	1.398***	1.304***	1.333***
- with UBP	-	-	7.569***	7.250***	7.270***
- frequency	-	-	-	0.148***	0.142***
Only bring separation	0.326	0.709	-0.221	-0.206	-0.225
- extra effect 2014	-	-0.392	0.007	-0.009	-0.028
- with UBP	-	-	4.839***	4.766***	4.699***
Curb and post separation	8.024***	6.394***	4.822***	4.846**	4.741**
- extra effect 2014	-	3.367***	2.128**	2.091**	1.892**
- with UBP	-	-	5.094***	5.065***	5.397***
- frequency	-	-	-	-0.003	-0.017
Bring and post separation	6.510***	4.157**	3.605**	3.568**	3.470**
- extra effect 2014	-	3.986***	3.230***	3.269***	3.342***
- with UBP	-	-	3.636***	3.543***	3.524***
Curb and bring separation	3.428**	3.647**	1.231	-0.779	-1.035
- extra effect 2014	-	0.171	0.724	0.660	0.558
- with UBP	-	-	7.142***	6.947***	7.007***
- frequency	-	-	-	0.103***	0.102***
Curb, bring and post separation	7.617***	6.740***	4.621***	4.122***	4.145***
- extra effect 2014	-	2.220*	2.930***	2.734***	2.659***
- with UBP	-	-	5.852***	5.578***	5.157***
- frequency	-	-	-	0.036	0.018
Duo-bin	-	-	-	-	3.040**
Mini-bin	-	-	-	-	1.647**
Crate	-	-	-	-	1.249**
Household size	-2.538**	-2.327*	-2.406***	-2.291***	-1.759**
Population density	-0.879***	-0.849***	-0.691***	-0.743***	-0.669***
Inhabitants 65+	-0.097	-0.089	-0.109**	-0.085*	-0.063
Ethnicity	-0.259***	-0.254***	-0.151***	-0.149***	-0.157***
2014	1.352***	-	-	-	-
Constant	16.204***	15.842***	14.978***	14.306***	12.699***

Note: ***/**/* indicates significance at 99%/95%/90% level. Models estimated with VCE Robust estimator.

In the first estimation, we compare the different separation systems. The estimation results show that municipalities with only post separation separate 6.2 kilogram more plastic waste.

Also curbside collection can be effective with 5.6 more kilograms. Only collection by bring stations is clearly no effective strategy to increase the amount of recycled plastic waste. For these municipalities, the estimation of the bring dummy (compared with municipalities with no system) is not significant at all. The combination of post separation and curbside collection gives 7.6-8.0 kilogram, but this is a rather expensive solution which gives a modest increase in separated plastic waste compared with the single systems. Also other combinations do not yield extra plastics than separated systems already do.

In the second estimations we include for different systems a 2014 dummy. As post separation became fully active in the course of 2013, the amount of separated plastic increases from 4.8 kilograms in 2013 to 8.4 kilograms in 2014. Therefore, the 2014-effectiveness of post separation including the 2014-dummy is more accurate. Also curbside collection becomes more effective in 2014, but the effect is less than for post-separation. For only curbside collection, this effect is 1.9 kilograms, but if we correct for an unit-based pricing system, an increase in frequency or another type of container of curbside collection, it becomes 1.3 kilogram more separated plastics.

For the curbside collection the effectiveness almost depends entirely on the introduction of an unit-based pricing systems. If there is only curbside collection from Table 3 it follows that the extra amount from having such a combination is 7.6 kilos. If a municipality does not have an unit-based pricing system, the effect of curbside collection is not significantly different from zero. If a municipality has post-separation the effect of an UBP system is also zero, which gives an indication that the effect of such system on reduction of plastic waste through shopping behaviour is insignificant or very small. Interestingly, also for the system with only bring locations the effect of having an UBP system is significant and more than 4.8 kilograms. Furthermore, if curbside collection is combined with post separation the effectiveness of UBP becomes smaller to 5.1 kilograms, so it seems in such a case households are less eager to separate waste.

So, in case of home separation an UBP system is needed. However, in Dijkgraaf and Gradus (2015) we discuss different UBP systems for the Netherlands and their drawbacks. For example, the disadvantages of the bag-based system are that Dutch legislation limits the number of bags carried per waste-collection employee and that there is an incentive for households to put as much waste as possible in each bag, which might make them difficult to handle. In addition, for some Dutch (coastal) municipalities, there are indications that bags have another disadvantage, as birds such as gulls will cause extra nuisance by picking over bags. For the weight-based and frequency-based pricing systems, the disadvantages of the bag

system are not present. The introduction of these unit-based pricing systems may, however, have adverse effects as well. In particular, the weight system has large administrative costs and illegal dumping may occur. However, Allers and Hoeben (2010) show that illegal dumping is not a serious problem in the Netherlands, as one would expect that many municipalities would have abolished user fees if this were the case and this has not happened (substantially). For other countries illegal dumping is an issue (Fullerton and Kinnaman, 1996)

Furthermore, for curbside collection we add the frequency of collection in the fourth equation. As we would expect, there is a positive relationship between the frequency of collection (expect the combination of curbside collection with post-separation) and the quantity of collected plastics. If instead of once a week at the curbside plastics are collected every two weeks, the amount of plastics increases by 3.6 kilograms.[8] If we have also bring locations, the effectiveness of increasing the frequency becomes smaller. If instead of once a week at the curbside plastics are collected every two weeks, the amount of plastics increases by 2.6 kilograms.

Also we do get some significant effects for the type of container. For a crate (compared with a bag) the effect is 1.2 kilogram more plastics. Especially, for duo-bin the effect is large with 3.0 kilograms.[9] However, there are some anecdotic indications that this can also be partly due to awareness effects (of which we do not have detailed information).[10]

In terms of the socio-economic variables, we find that three variables are significant (in all equations). First, municipalities with a large household size density have less separated plastic waste per inhabitant. This is reasonable as these municipalities have families with more children. Second, municipalities with a high density of population have less separated plastics. In these municipalities, the number of flats seems high and it is more difficult to store plastics. Third, municipalities with a larger share of non-western ethnic groups recycle substantially less plastics. This is in line with Abbott et al. (2013), who found that western ethnic groups have a stronger social norm to recycle. For the share of inhabitants above 65 years there is only a significant effect if we correct for the unit-based pricing systems.

[8] We also test for the non-linearity of this frequency variables and we have no indication for that. Those results are available upon request.
[9] It should be noted that the number of municipalities with a duo-bin (i.e. 9) is rather small, this might bias the estimate.
[10] Based on an experience in Flanders in Belgium in 2014 in some (small) Dutch municipalities an awareness campaign started to limit the amount of (mixed) waste per household to 100 kilograms yearly and separate several recyclables by duo-bins.

4. Cost-effectiveness of post separation versus home separation

Ideally, the effects on the quantity of separated plastic should be compared with the costs of home versus post separation. Let us assume that in case of home separation a municipality choose for curbside collection. The costs for curb separation are known. Gradus et al. (2016) show that in 2015 the collection cost of home separated plastic are on average 408 euro per tonne plastic. A municipality gets also a compensation fee of 269 euro per tonne plastic waste for the net treatment costs of transporting and making plastic granulate of it. This seems rather high also according to an international comparison (see Marquez and da Cruz, 2015), but it should be noticed that the Dutch recycling rate for this collected mixed household plastic is only 75 percent, meaning that 25 percent of the collected household plastic is still used for energy recovery (Gradus et al., 2016). Also the quality of this mixed plastics is rather low and there is some indication that the quality of plastic by post separation is higher. However, we start with the assumption of similar quality in curb and post separation and later on we relax this assumption. Moreover, we only focus on the monetarized costs and thereby neglect the extra cost of household investment in terms of time spend on separating the waste.[11]

The economic gain when municipalities choose for post separation is 348 euro per tonne plastic in terms of collection costs.[12] These collection costs can be saved if post separation is applied as the plastic is collected together with unsorted waste. Unfortunately, we do not have a good estimation of the cost of the production process of post separation. However, we can calculate what post separation might cost for a break even between curb and post separation. Table 4 gives this calculation based on the results of Table 3. Hereby, we take the 2014-case as this gives a more accurate description of the effectiveness of post-separation.

[11] Kinnaman et al. (2014) shows that these costs are rather small compared with collection costs.
[12] Gradus et al. (2016, table 2) show that the cost of plastic waste collection are 408 euro per tonne and for mixed waste 60 euro per tonne.

Table 4. Calculation available resources for post separation

	Post	Curb	Difference-2014	Difference 100%-recycling	Difference Higher Price
Kilo separated plastic per inhabitant[1]	14.89	13.39	1.50	1.50	1.50
Collection costs euro per kg[2]	0.06	0.41	-0.35	-0.35	-0.35
Collection costs euro per inhabitant	0.89	5.46	-4.57	-4.57	-4.57
Savings on virgin material and energy euro per kg[3]	0.19	0.19	0.00	0.00	0.00
Savings on virgin material and energy euro per inhabitant	2.86	2.57	0.29	0.34	0.41
Net costs euro per inhabitant	-1.97	2.89	-4.86	-4.91	-4.98
Available for post separation euro per inhabitant			4.86	4.91	4.98
Available for post separation euro per tonne			326	330	335

Notes:

1. For post and curb separation we take the mean if there is only curb collection or only post separation.

2. See Gradus et al. (2016).

3. Value of virgin plastic minus treatment costs and opportunity costs of separated plastic, see Gradus et al. (2016).

In Table 4 kilograms separated plastic waste is given per inhabitant in the first row. At the mean, in 2014, post separation results in 1.50 kilogram more separated plastic. The collection costs of both options are included in row 2 giving total collection costs per inhabitant in row 3 of Table 4. Per kilogram separated plastic waste, money is saved as the production costs of virgin material (495 euro per tonne) is higher than the treatment costs for recycled plastic (269 euro per tonne separated plastic). Combining the first row with these net savings (226 euro per tonne) gives total savings per inhabitant. Adding the third row to the fifth row gives net costs in euro per inhabitant. This means that per inhabitant 4.86 euro is saved if post separation is chosen. This 4.86 euro can be spend to collect the quantity of 14.89 kilo, resulting in available savings of 326 per tonne plastic.[13] Thus, if separation costs are below 326 euro per tonne post separation should be chosen from an economic perspective.

[13] For the technique model this threshold becomes 338 euro per tonne.

We also calculate two different scenario's based on a better quality of post separated plastic. [14]In the first scenario all separated plastic waste is recycled instead off 75%. In that case the savings on virgin material goes up and becomes 0.34 euro per inhabitant and the threshold becomes 330 euro. If we assume that the price of secondary plastic will rise by 10 percent, from 495 to 544 Euro per tonne due to a better quality, this threshold becomes 335 euro. In both cases the threshold price is even higher. Summarizing, if the separation costs are lower than 325 euro per tonne plastic, from cost effectiveness point of view the post separation model should be chosen.

5. Conclusions

By using Dutch municipal data for 2013–2014, we estimate the effect of different separation methods on plastic waste recycling. Municipalities with only post separation separate 6.2 kilogram more plastic waste than those without separation. As in the course of 2013 post separation became active in most municipalities also the 2014-effect was estimated and the amount of separated plastic increases to 8.4 kilograms in 2014. To give the best estimate for the effectiveness of this system the last figure should be chosen. Also curbside collection can be effective with 5.6-5.9 more kilograms and only collection by bring stations is not an effective strategy to increase the amount of recycled plastic waste. The combination of post separation and curbside collection gives 7.6-8.0 kilogram.

For curbside collection, we test also the interaction effects with an unit-based pricing system, frequency of collection and type of container. The combination of curbside collection with UBP gives an extra amount of 7.6 kilograms. Also increasing the frequency can be effective. If instead of once in a fortnight plastics are collected every week, the amount of plastics increases by 3.6 kilograms. If curbside collection is combined with post separation the effectiveness of UBP becomes smaller or in case of frequency even zero.

Furthermore, we test the interaction effect of post-separation with UBP as well. As this effect is almost zero, this gives an indication that the effect of such a system on reduction of plastic waste through other (shopping) behaviour is insignificant or very small. D'Amato et al. (2016) give an indication that especially higher educated are motivated to change their shopping behaviour if waste is priced, which is not in accordance with our results, although it was not tested directly.

[14] There is some anecdotal evidence for this.

Although we do not have information about the total costs of post separation, there are indications that the cost effectiveness will increase if it is chosen. The collection costs are much lower in case of plastic waste as a part of mixed waste. We calculate that if the separation costs are lower than 325 euro per tonne plastic post separation is the cost effective solution. This threshold increases if one takes into account that the quality of secondary plastic and the price of plastic increases if post separation is chosen.

Based on European policy, in the Netherlands home separation of plastic waste mostly by curbside collection is the most implemented policy. In case of home separation, it seems advisable to combine it with UBP. However, unit-based pricing systems can have some drawbacks as well. In Dijkgraaf and Gradus (2015), we compare different UBP systems in the Netherlands and show that bag-based and weight-based has some drawbacks and the frequency-based systems is preferred. Nevertheless, unit-based pricing systems can be used in small municipalities, for large cities with many flats it will be harder to implement. In such a case, post separation could be an alternative as shown by this article also due to the fact that it has the potential of increasing effectiveness over time. For home separation this will be more difficult. Therefore, we advise that the European Directive should be amended in such a way that also post-separation could be an alternative for home separation.

There are many avenues to explore in future research. First, it is important to test whether the effectiveness of post-separation also increases in 2015 and 2016. Unfortunately, for 2015 and 2016 information about separation methods is not available yet. Second, cost information about post separation is important to understand to overall cost effectiveness of this process. Hereby, as pointed out in the sensitivity analysis in section 4 the increase in quality of recycled plastics as a consequence of post separation should be taken into account. There is some anecdotal evidence for this, but empirical evidence is lacking. Third, as home separation is only advisable if it is combined with UBP the drawbacks of pricing systems should be investigated. As far as we know the last Dutch investigation of illegal dumping related to UBP was from Allers and Hoeben (2010) and based on data until 2006. Therefore, we encourage a more detailed enquiry of this and also how different municipalities are dealing with this. Fourth, one municipality's decisions can be influenced by a neighbouring municipality's, and this can be tested using spatial models (see Brueckner 2003).

Appendix A. Definition of variables

Plastic waste	Separately collected plastic waste in kg per inhabitant
Household size	Number of inhabitants per household
Population density	Municipal area in square kilometres per household
Inhabitants 65+	Share of inhabitants older than 65
Ethnicity	Share of non-western people (born in or parents from non-Western country) in total number of inhabitants
UBP: Volume	Dummy is 1 if volume-based pricing system is present and 0 otherwise
UBP: Frequency	Dummy is 1 if frequency-based pricing system is present and 0 otherwise
UBP: Bag	Dummy is 1 if bag-based pricing system is present and 0 otherwise
UBP: Weight	Dummy is 1 if weight-based pricing system is present and 0 otherwise
Only post separation	Dummy is 1 if municipality has no source, but only post separation
- extra effect 2014	- idem times dummy with value 1 for observations in 2014
- with UBP	- idem times dummy with value 1 for municipalities with an UBP system
Source and post separation	Dummy is 1 if municipality has source and post separation
- extra effect 2014	- idem times dummy with value 1 for observations in 2014
- with UBP	- idem times dummy with value 1 for municipalities with an UBP system
Source separation	Dummy is 1 if municipality has source separation (plastic is collected at the frontdoor)
Bring	Dummy is 1 if municipality has a bring system for plastics
Frequency kerbside	Number of times a year plastic waste is collected at the curbside
Duo-bin	Dummy is 1 if plastic waste is collected at the curbside from a duo-bin
Mini-bin	Dummy is 1 if plastic waste is collected at the curbside from a mini-bin
Bag	Dummy is 1 if plastic waste is collected at the curbside from a bag
Crate	Dummy is 1 if plastic waste is collected at the curbside from a crate
2014	Dummy is 1 for observations in 2014

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