inštitút environmentálnej politiky

Ministry of Environment of the Slovak Republic www.minzp.sk/iep

Fair Waste

An Analysis of the Effects of the Introduction of Unit-Based Pricing in Slovakia

October 2019

Economic Analysis 5

Author

Stella Slučiaková stella.sluciakova@enviro.gov.sk

Acknowledgments

I would like to thank Matej Šiskovič (MIM), Corine Hoeben, M.A. Allers (both from the University of Groningen) and Christopher Wright (Montana State University) for their assistance and comments on the technical part of the study. Secondly, I would also like to thank Zuzana Huljakova (MIM), Tibor Molnár (JRK) and Mária Bonková (Naturpack) for their assistance in preparing the practical part of the study. Finally, I would like to express gratitude to Martin Haluš, Veronika Antalová and Nina Fabšíková (all from the IEP MoE SR) for their comments on the text and consultation.

Review procedure

The analysis has been approved as reviewed by the Expert-Methodological Commission based on the reviews of Petr Tóth (NBS), Soňa Slobodníková (IFP MF SR) and Katarína Bednáriková (INCIEN).

Note

The study presents the views of the authors and the Institute for Environmental Policy, which do not necessarily reflect the official views of the Ministry of Environment of the Slovak Republic. The purpose of publishing the analyses of the Institute for Environmental Policy (IEP) is to stimulate and improve professional and public discussion on current topics. Citations of the text should therefore refer to the IEP (and not the MoE SR) as the author of the views.

Table of Contents

List of Graphs, Maps, Boxes and Tables

Non-Technical Summary

Just under 13% of the Slovak population pay a fee depending on the amount of waste generated. Most municipalities charge residents an annual flat fee, which is the same for all inhabitants of the municipality regardless of the amount of waste produced. A fee of such form does not motivate citizens to reduce production or to increase sorting or waste composting. On the other hand, billing households according to the weight or volume of the waste generated, so-called unit-based pricing, is a direct financial incentive and a tool for applying the 'pay-as-you-throw' principle. In practice, mainly volume-frequency pricing system is used in which the amount of the fee is calculated according to the frequency of collection and the volume of the container. The second most common type is unit-pricing scheme using tags which citizens hang on the container if they wish to have it emptied.

Unit-based pricing scheme in Slovakia significantly reduces the production of mixed municipal waste and increases the sorting rate. An analysis of data for the period of 2010-2018 shows that unit-based pricing scheme in Slovakia reduces the production of mixed municipal waste per capita by 22% on average. The introduction of tag collection reduces the amount of mixed municipal waste by almost 31%, volume-frequency collection by 11%, respectively. For this type of fee, the sorting of plastics is higher by 15% and the sorting of glass by 9%. Although the analysis did not show a higher rate of sorting for biowaste and paper, in fact, an increase in the sorting of these materials can also be expected. The problem is probably missing data in the records due to household composting or delivery of paper to paper scrap yards or school collection.

Table 1: Effect of unit-based pricing on waste production (% change compared to a flat fee)

	Mixed municipal waste	Plastics	Glass
Unit-based pricing	-22.3%	15.4%	9.1%
Tag	*-31.0%*	-	-
Volume-frequency	*-11.3%*	*22.1%*	*12.4%*

Source: IEP

The potential risk of illegal dumping can be minimized by appropriate setting of the pricing system and preventive measures. The analysis of the available data did not confirm the effect of unit-based pricing on the number of illegal landfills reported. However, based on experience gained from certain municipalities in Slovakia and abroad, the introduction of unit-based pricing scheme may be accompanied by problems with illegal disposal of waste. In practice, only few municipalities have encountered this problem. However, such behaviour can be effectively prevented by reasonable system settings (a minimum fixed fee, a discount system) and several preventive measures. Unit-based pricing scheme should be accompanied with adequate infrastructure for separate collection.

We found no evidence of waste tourism caused by unit-based pricing scheme implementation. Some experience and foreign studies confirm that after the introduction of unit-based pricing scheme, they have noticed disposing of waste to other neighbouring regions without unit-based pricing. Appropriate measures eliminated the problem in most cases. An analysis of the impact of unit-based pricing on waste tourism shows that unit-based pricing in Slovakia does not increase, but on the contrary reduces the production of mixed municipal waste in neighbouring municipalities. This may be due to the dissemination of information and awareness-raising among municipalities.

The introduction of tag collection in family houses and volume-frequency collection in residential buildings throughout Slovakia may result in financial savings for municipalities of EUR 28.5 mil. per

year. By reducing the amount of mixed municipal waste that is transported to landfills, municipalities will save the cost of its collection as well as the cost of landfill charges. On average, EUR 6 will be saved per capita per year.

A one-off investment in unit-based pricing can amount to EUR 0 - 28.6 mil., operating costs can range from EUR 0 to 2.3 mil. per year, depending on the type and system informatization. The introduction of simple unit-based pricing without electronic evidence of waste would only entail the cost of the awareness-raising campaign. The cost for an average municipality with a more sophisticated system with an electronic evidence can reach EUR 0 to 10.5 thousand one-off and EUR 0 to 838 per year, depending largely on the size of the municipality, the number of containers for mixed municipal waste, the selected type of collection and system informatization.

In addition, an increased rate of sorting will require costs for collection and composting. Additional costs for separate collection of plastics and glass are estimated at EUR 1.7 mil. per year. Provided that the same part of the paper potential in mixed municipal waste is sorted as in the case of plastics and glass, the additional costs would be EUR 0.7 million per year. The cost of the purchase of composters for all family houses would amount to almost EUR 6 mil. per year.

Table 2: Financial costs and benefits of the municipality for the unit-based pricing (EUR mil./year)

	Combination*
Landfill costs saved	28.5
Cost of system introduction and operation	
Single investment	0-28.6
Operation	0-2.3

*Tag collection in family houses, volume-frequency collection in residential buildings *Source: IEP*

Landfill reduction as a result of unit-based pricing brings both environmental benefits and increased motivation for people to sort waste. The estimates of external landfill costs vary considerably; we assume that landfill reduction due to the introduction of unit-based pricing scheme can save EUR 2 to 21 mil. per year. If we use the results of a Norwegian survey, the cost of lowering comfort of inhabitants due to the sorting of plastics and glass can reach EUR 352 ths. In addition, the application of the 'pay-as-you-throw' principle creates a fair system in which diligent citizens are rewarded.

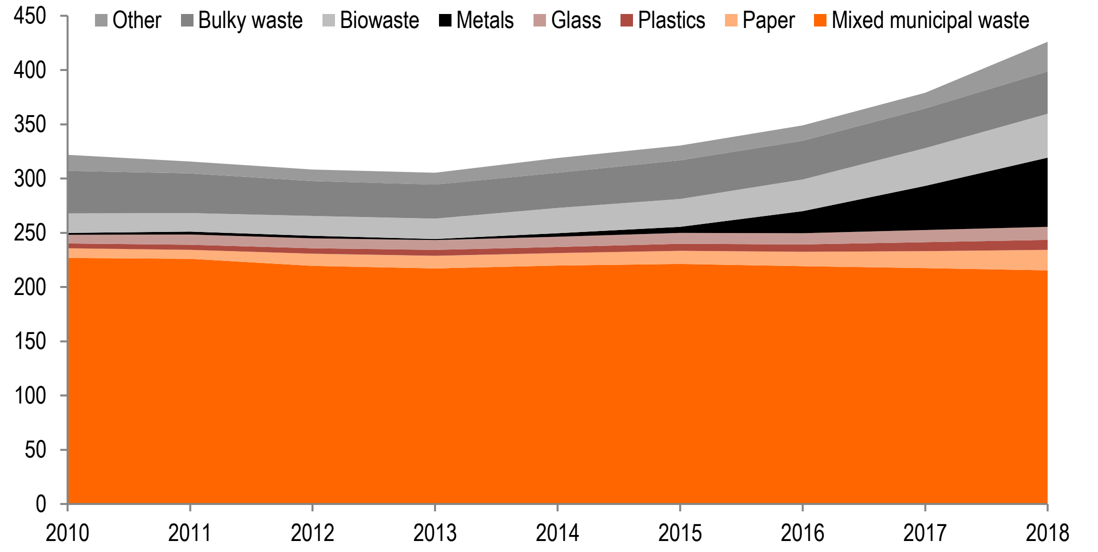
The current Act on Local Taxes and Fees creates a legislative barrier to the effective introduction of unit-based pricing scheme. The calculation of the fee according to the frequency of waste collection and the method of levying the fee itself do not allow the actual amount of waste collection to be taken into account. Possible solutions are the payment of a fee in the form of an advance with a subsequent settlement or setting a fee with the possibility of taking into account the actual amount of waste collection in the past year. The application of such solutions should be analysed by the MoE SR and the MoF SR in cooperation with the municipalities concerned.

Improving the collection of quality data are key in assessing the impact of measures and policies. In the analysis, we encountered data constraints such as insufficient data for separate collection, missing data on household composting or data on household waste that are not separated from other municipal waste. Possible solutions are a new waste management information system, the extension of the waste catalogue and the development of a methodology for recording household composting.

1 Production and Collection of Municipal Waste in Slovakia

In 2018, the average Slovak citizen generated approximately 426 kg of municipal waste. Municipal waste consists mainly of household waste, but also includes waste from companies, offices and public institutions. Up to 86% of municipal waste is mixed municipal waste and sorted paper, glass, plastic and metal waste and biowaste. The rest is mainly bulky waste, waste from markets and street-cleaning residues.

Graph 1: Development of municipal waste components (kg/person)



Source: IEP

On average, mixed municipal waste accounts for up to 67% of the total municipal waste produced. The average annual production of 220 kg per capita has been constant since 2010. On the other hand, the amount of all sorted components is growing year on year. Since 2010, metals have increased by almost 90%, paper, plastics and biowaste by 10%. The significant increase in metal waste is mainly due to changes in reporting and improved reporting by collection sites and paper scrap yards. In previous years, collection sites reported metal waste as industrial waste, but since 2015, it has been reported as municipal waste. The amount of metal waste is therefore only starting to be counted in the municipal waste evidence, but its amount is not likely to grow dramatically. The actual increase in municipal waste production is on average 1% per year.

Collection and recovery of sorted waste components such as paper, plastics, glass, beverage cartons, metal packaging and others are covered by the producer responsibility organizations, which finance a separate collection system through fees from the producers of packaging and non-packaging products. The producer may take into account the cost of sorting in the price of the product for the consumer. The costs of collecting and disposing of mixed municipal waste and bulky waste and the separate collection of biowaste are borne by the municipalities, which collect the fees for waste from citizens for this purpose.

The waste fee may be flat-rate or differentiated according to the volume or weight of waste produced. According to literature, the second option ('unit-based pricing') is an effective tool for increasing the rate of sorting and recycling while reducing the volume of waste going to landfills or incineration plants. While countries with recycling rates above 45% have some unit-based pricing in place, countries with recycling rates below 20% do not use any form of unit-based pricing (EEA, 2016). Unit-based pricing scheme applies the 'pay-as-you-throw' (PAYT) principle and motivates citizens to environmental behaviour (Eunomia, 2003).

In Slovakia, municipalities have the possibility to set a local fee on a flat-rate basis or according to the volume of waste generated, or their combination. Most municipalities charge inhabitants an annual flat fee, which is the same for all inhabitants of the municipality regardless of the amount of waste produced. Thus, the cost of waste for households that produces more waste is partially subsidized by households with lower waste production. Such form of a fee does not motivate citizens to reduce production or to increase sorting or compost biowaste. On the other hand, the fee, which depends on the weight or volume of waste produced, constitutes a direct financial incentive and a tool for applying the 'polluter pays' principle.

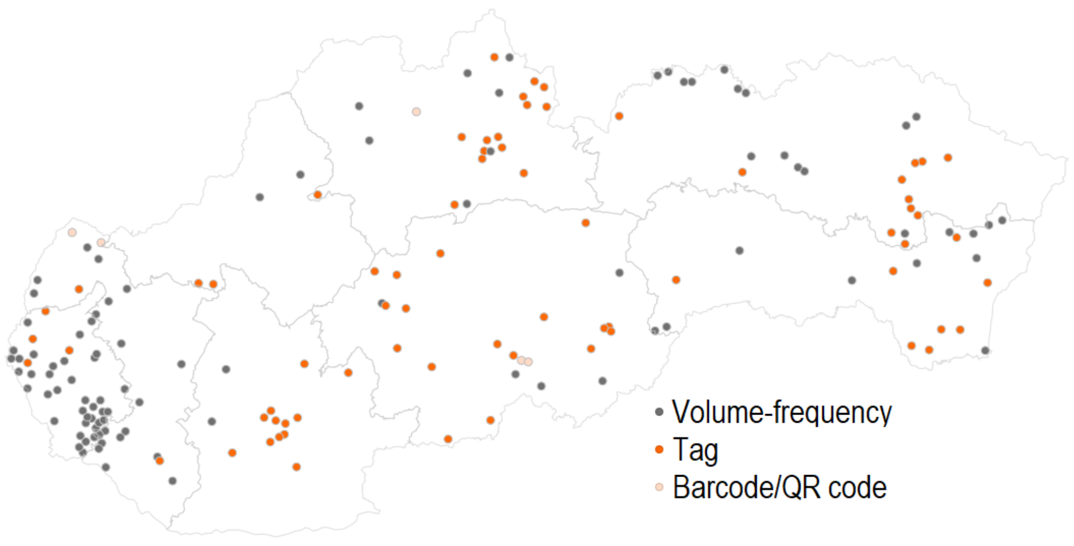
1.1 Unit-Based Pricing in Slovakia

In 2018, there were 167 municipalities in Slovakia with unit-based pricing of mixed municipal waste, of which 74 municipalities had tag collection[1] and 93 municipalities volume-frequency collection. Almost 13% of the Slovak population pay a fee depending on the amount of waste generated. The number of municipalities with unit-based pricing increased from 102 municipalities in 2010 to 167 in 2018.

Tag collection is widespread especially in the Tvrdošín, Malacky, Ružomberok and Nové Zámky districts. Most municipalities with a volume-frequency system are located in western Slovakia in the districts of Malacky, Senec, Senica and Pezinok. Another 283 municipalities have a combination of flat rate and variable fees. In 2018, unit-based pricing existed only in 4 cities[2] in Slovakia, namely Bratislava, Žiar nad Hronom, Dubnica nad Váhom and Spišská Stará Ves. Each of them has volume-frequency unit-based pricing, other types of unit-based pricing scheme are not in place in Slovak cities.

The weighted average flat fee amount in Slovakia is EUR 18 per capita per year. The unit-based fee amounts to an average of 2 eurocents per litre of mixed municipal waste.

Map 1: Municipalities with unit-based pricing in 2018 by pricing type



Source: IEP

Box 1: Types of mixed municipal waste pricing system in Slovakia

Flat fee

Most municipalities charge a flat annual per capita fee which is the same for all regardless of the amount

[1] Among the 74 municipalities with tag collection, we also included 5 municipalities with collection via QR or barcodes since the principle of the systems is the same.

[2] A city has the position of municipality in the legal system after meeting the conditions under Article 22 par. 1 of Act of the Slovak National Council No. 369/1990 Coll. on Municipal Establishment.

of waste generated.

Tag collection
For this type of fee, citizens buy a tag which they hang on their container if they wish to have it emptied. The waste transporter removes the tag and hands it over to the municipality. The price of the tag is determined by the size of the container and the cost of its disposal. Citizens thus regulate the fees according to the number of tags used.

Barcodes or QR codes and RFID chips
This type of collection works on the same principle as the tag system. In this case, citizens have a container identified by a specific barcode, QR code or RFID chip. If they want to have it emptied, they place the container in a designated place, where the carrier scans the code and empties the container.

Volume-frequency collection
Citizens' fees are calculated according to the frequency of waste collection and the size of container used. Citizens can choose the size of their container (usually 110, 120 or 240 l) as well as the frequency of waste collection (usually once, twice or four times a month) at the beginning of the year or during the year. Since the fee amount depends only on the predetermined size of the container and the frequency of collection, the impact is weaker compared to collection with tags or codes.

Combined collection
This is a combination of the flat rate and some of the unit-based types of collection in one municipality. Usually there is a distinction between people living in family houses, for which some form of unit-based pricing is introduced, and people in flats with flat-rate fees.

The correct setting for unit-based pricing leads not only to a reduction in waste production but also to cost savings for citizens and the municipality. One example is the municipality of Rakovnica, where a minimum fixed fee is set to cover the municipality's basic expenses for waste. Setting a minimum fee or a minimum frequency of waste disposal will provide the municipality with sufficient income to cover basic fixed costs and reduce the incentive for illegal landfilling. The municipality of Vrádište is one of the first municipalities with electronic evidence of waste using containers identified by barcodes. The reduction of waste generation as well as a balanced budget for waste inspired neighbouring municipalities to introduce unit-based pricing.

Box 2: Two examples of unit-based pricing success stories in Slovakia

Reduction of waste and costs in Rakovnica
The municipality of Rakovnica introduced a system of tags in 2017 with a mandatory purchase of at least 9 tags per household per year. In 2017 and 2018, the municipality produced on average 33% less mixed municipal waste per capita compared to the previous flat-rate collection period. Invoices published on the municipality's website also show that they have saved 37% on the costs of landfilling and collection of mixed municipal waste. The volume of sorted waste per capita has increased twice and the municipality has started to report the sorting of biowaste.

Inspiration from the municipality of Vrádište
The municipality of Vrádište is one of the first municipalities in Slovakia to register and charge fees for waste using barcodes, since 2013. After its introduction, they reported a reduction in municipal waste by an average of 7% and waste separation almost doubled. The municipality has also managed to cover the costs of collection and disposal from its income from fees. The positive experience also inspired the

neighbouring municipalities of Chropov and Dubovce, which introduced unit-based pricing in 2016 and 2019, respectively.

Experience shows that the electronic evidence of waste brings changes in waste production without introducing unit-based pricing. Waste evidence eliminates anonymity and provides an overview of waste production, creating a psychological effect on the population even without financial incentives. In the municipality of Košeca, they reduced the amount of landfilled waste without changing waste fees. In the case of electronic evidence, a waste collection company only transports identified containers, which in Senec led to the reporting of "stowaways" who used unregistered containers free of charge. Thus, the municipality will gain an overview of the actual number of collected waste containers and has the possibility to check the eligibility of financial costs for collection.

Box 3: Electronic register in Slovakia

Less waste without changing fees in Košeca
In April 2019, the municipality of Košeca introduced electronic waste evidence without any change in fees for citizens. Thanks to the register, the anonymity of household waste was removed, which led to a change in the behaviour of the population. The number of collected containers decreased by 24% year-on-year after the introduction of the register and the volume of waste at the landfill decreased by 17%, which reduced the municipality's costs (JRK, 2019).

Reporting of "stowaways" in Senec
In August 2018, the municipality of Senec introduced unit-based pricing with barcodes and electronic waste register. The volume of mixed municipal waste decreased and at the same time the sorting of all waste components increased. In addition, the introduction of the electronic register has resulted in the evidence of waste containers by "stowaways," whose waste had been collected for free from unregistered containers or who had been using more containers than permitted. The municipality signed an agreement with the waste collection company with an amendment on sanctions for the removal of an unidentified container. The waste collection company thus empties only identified containers, which motivates citizens to register while at the same time gives the municipality a picture of the actual number of containers emptied.

Discount system according to the sorting rate in the municipality of Rakovice
The municipality of Rakovice has registered both mixed and sorted waste electronically since the end of 2017. In addition, the municipality has adjusted local flat-rate fees for waste with the possibility of discounts for households if they demonstrate at least a 60% sorting rate based on electronic records (Rakovica, 2019). The municipality has thus increased the sorting rate year-on-year from 24 to 32%.

The current Act on Local Taxes and Fees creates a legislative barrier to the effective introduction of unit-based pricing. The calculation of fees depending on the frequency of collection and the method of charging fees as such do not allow for the actual number of waste collections to be taken into account. Possible solutions are the payment of fees in the form of advance payments with subsequent settlement, or the setting of fees with the possibility of taking into account the actual number of waste collections in the past year. The application of these solutions should be analysed by the Ministry of Environment and the Ministry of Finance of the Slovak Republic in cooperation with the municipalities concerned. A positive change in the draft amendment to the Act on Local Taxes and Fees would be to allow the municipality to reduce the fee for citizens who prove that they have sorted a specified percentage of municipal waste components.

Box 4: Legislation and unit-based pricing

Fee calculation

The law defines the method of calculating fees as the product of the frequency of waste collections, rate and volume of the waste container, while it is not clear what is meant by the frequency of waste collection. The frequency of waste collection can be understood as a fixed parameter when a citizen chooses the frequency of waste collection during the month. In this case, the fee amount does not take into account the actual number of waste collections per year.

It is possible to set a fixed frequency of waste collection per month at the beginning of the year and subsequently increase or reduce the fee based on the actual number of waste collections in the past year. However, the current law does not explicitly permit any increase or decrease in the fee introduced.

Charging fees

It is more advantageous to municipalities to charge fees due to the recovery of fees, but it does not allow for the actual number of waste collections to be taken into account as the fee is paid at the beginning of the year. Some municipalities that have a tag collection system charge a fee for a minimum frequency of collection to which a certain number of tags is assigned. If payers wish to get more frequent waste collection, they buy more tags. It is thus a combination of charging the fee through the assessment and another form, while the current legislation does not allow another form.

Discount system

A positive change in the Act on Local Taxes and Fees would be to allow a municipality to reduce the fee to citizens who prove that they have sorted a specified percentage of municipal waste components. The change thus creates a financial incentive to reduce the production of mixed municipal waste while increasing the sorting of waste. A higher sorting rate consequently reduces landfill charges, which has been calculated since 2019 based on the sorting rate at the municipal level in the previous year[3].

1.2 Best Practices Abroad

Unit-based pricing is widely distributed across Europe, the United States, Canada, Japan and South Korea. While in Slovakia there is only a container labelling system or a system based on container size and waste collection frequency, other forms of unit-based pricing are used abroad.

In Belgium and Switzerland, there is a widespread system of prepaid bin bags. The collection is organized by means of bags with a printed location on them, which citizens can buy in shops. The bags are usually color-coded depending on whether they are intended for mixed or sorted waste or biowaste. Waste is taken away only if it is in the correct printed bag. The bag's price includes the cost of waste collection, transport and recovery or disposal.

Unit-based pricing according to waste weight is used mainly in Germany, the Netherlands, France and Ireland. For unit-based pricing according to waste weight, the waste is collected in containers that are equipped with a chip and barcode assigned to each household. The inhabitants thus pay according to the weight of the waste weighed using a collection vehicle equipped with a reader and a weighing system. The weighing system requires more effort for maintenance and weighing-machine calibration, but it achieves better results than the bag collection system.

[3] Article 4 par. 4 of Act No.329/2018 Coll. on fees for waste landfilling

According to studies by Allers and Hoeben (2009) and Dijkgraaf and Gradus (2004) which evaluate several types of unit-based pricing in the Netherlands, the weight-based system and bag system achieve better results compared to the container volume system.

Unit-based pricing in cities may be less targeted and transparent compared to villages, as inhabitants live mostly in residential buildings with problematic waste evidence at the household level. Only 4 towns in Slovakia have unit-based pricing in place; it is more frequent abroad. The bag system also works in large cities (e.g., Brussels, Zurich, Geneva) where most of the population lives in residential buildings. As collection bags are purchased by citizens in shops, the system is able to fairly differentiate the fee in individual households and residential buildings. Another option is locking waste containers then opened with a chip which is assigned to each household or resident of a residential building. Lockable chip or card containers are used in several countries such as Italy, Portugal, France or Finland.

Box 5: Best practices abroad

The bag system, weight-based system or container locking are among the best practices abroad.

Bag system in Belgium and Switzerland

Belgium and Switzerland have a widespread system of prepaid bag collection that is easy to implement and does not require additional investments for its implementation (ADEME, 2018). The prices for collection bags are regulated by the government, which sets minimum and maximum prices. In Belgium, the rate for mixed municipal waste ranges from 1.3 cents to 4 eurocents/l in collection bags (OVAM, 2019). The average price per bag for the sorting of plastic, cans and beverage cartons is 0.26 eurocents/l (IVAGO, 2016). Collection of paper, glass and textiles is free for residents. In Switzerland, the price for a mixed municipal waste bag is on average 6.2 Swiss cents/l (HelloSwitzerland, 2019). If waste is placed incorrectly, a fine may be imposed and the waste will not be taken away. In both countries, the bag system has significantly increased the recycling rate of municipal waste to more than 50% and reduced the annual production of mixed municipal waste to 150 kg per capita. (European Commission, 2018).

Waste weighting system in Germany and Italy

In the German County of Aschaffenburg, an identification system with weighing at the door was introduced in 1997. The system led to an increase in recycling of up to 86% and a reduction in mixed municipal waste production to 50 kg per capita per annum (Morlok J., Schoenberger H., Styles D., Galvez-Martos J. L., 2017). The Italian regions of Treviso and Trento have reduced their mixed municipal waste to 55 and 100 kg/per capita per annum, respectively (European Commission, 2018).

Lockable containers in Parma

In the Italian city of Parma, in addition to unit-based pricing of household waste, they also have a flexible collection system through so-called 'eco-stations'. They are containers in a separate locked structure to which residents have access through their health insurance card. While separate collection is provided free of charge, the mixed municipal waste charge is 70 eurocents for a 40-litre bag (Zero Waste Europe, 2017).

2 Analysis of the Impact of Unit-Based Pricing on Waste Production

The amount of direct and indirect costs associated with waste disposal affects the demand for individual waste management methods. The resulting recycling rate therefore depends on the relative landfill charges and the prices of secondary waste treatment. The price charged for waste disposal in a landfill reflects the cost of collection, disposal of waste in the landfill, the legal landfill charge and should be included in the waste fee for residents. Similarly, the price of biowaste includes the cost of collecting and recovering biowaste and should also be included in fees for residents. The direct costs of sorting are paid only by producers and are zero for the population. The indirect cost of sorting for residents is the time they have to spend on additional sorting of waste. The time required depends on the availability of the infrastructure and its distance.

The price of other means of waste management such as illegal landfilling is affected, for instance, by the availability of a place where residents can illegally place waste or the number of fines they may receive.

In Slovakia, producer responsibility organizations have a legal obligation to ensure adequate infrastructure for separate collection in each municipality. This means that in municipalities where unit-based pricing and good availability of separate collection are in place, the direct cost of separate collection should be lower than the cost of disposing of mixed municipal waste. We have verified this assumption by analysing the effects of unit-based pricing on the production of mixed and sorted waste and the development of illegal landfills.

2.1 Foreign Literature

Foreign studies show the positive effect of unit-based pricing on reducing mixed municipal waste production in the short term (Dijkgraaf, 2004, Wright, 2011, Huang, 2011). According to estimates, the reduction of mixed municipal waste production due to the introduction of unit-based pricing ranges between 21 and 70%, depending on the type of collection. The weight-based system and the bag system, which is similar to tag collection, have the highest effect. The estimated collection effect by container volume and disposal frequency is lower but still significant. New research (Allers and Hoeben, 2009, Usui and Takeuchi, 2013) shows that the effect of unit-based pricing is significant, but lower compared to earlier studies. More recent studies use more extensive data and more sophisticated econometric methods and provide more credible, unbiased estimates.

Estimates of the effect of unit-based pricing on waste sorting differ according to foreign literature. According to some studies (Fullerton and Kinnaman, 1996, Jenkins et al., 2003, Kinnaman and Fullerton, 2000), the introduction of unit-based pricing did not lead to any sorting changes, but more recent analyses (Callan and Thomas, 2006, Kipperberg, 2007, Usui 2008, Allers and Hoeben, 2009) estimate a significant positive effect on increasing the volume of sorted waste.

The short- and long-term effects of unit-based pricing on waste production are often different. Immediately after the introduction of unit-based pricing, residents may react to the change in a different way in the short term in the first year than in the long term after several years. According to Allers and Hoeben (2009) and Usui and Takeuchi (2013), in the first year after the introduction, the effect is higher than in the long term, but not significantly. In contrast, Linderhof et al. (2001) and Dijkgraaf and Gradus (2009) estimate higher price elasticity in the long term. Although some studies estimate that the effect of unit-based pricing decreases over time, it does not disappear in the long term of 7 to 30 years (Dijkgraaf and Gradus, 2009, Usui and Takeuchi, 2013, Yamakawa and Ueta, 2002).

2.2 Data

When analysing the effect of unit-based pricing in Slovakia, we used data on the annual production of municipal waste, municipal waste fees and data on demographic and social characteristics. The data are at municipal level and come from the Statistical Office for the period 2010 to 2018.

The amount and type of fees for municipal waste are stated in the form within the annual report of municipalities proposed by the IEP in 2017 for the purpose of getting additional information on communal waste in Slovakia. We then verified the data on the type of fees over the phone directly with the 270 municipalities concerned and added the year in which the type of fee was introduced. The fee is only known for 2017 and 2018.

For the purpose of estimating the models, we omitted 7 municipalities out of a total of 2 887, which lack data on the type of fees or the year of introduction of unit-based pricing. In the case of sorted plastic, paper and glass waste, we replaced the missing values with the median of the type of waste in the relevant municipality. The number of missing values for sorted plastic and glass waste was less than 3%; for paper, a total of 15% data was missing for 9 years. The resulting data set thus consists of balanced data[4] for 2 880 municipalities for 9 years. Summary statistics of the data used are given in Table 3.

Due to gaps in the records, we have not analysed some types of waste separately, but only within other sorted waste. This includes kitchen biowaste, which started to be reported to a higher extent only in 2015, whereas in 2018 only one third of municipalities reported sorted kitchen biowaste. Similarly, here we include beverage cartons that started to be reported only in 2013 and metal packaging that was only reported for all metals in 2010 to 2017 and was not monitored separately. The rest of other sorted waste is waste that can be sorted and included in the numerator when calculating the sorting rate[5].

Table 3: Summary statistics at municipality level

	Weighted average	Min	Max
Mixed municipal waste (kg/inhabitant)	220	1	4 182
Paper (kg/inhabitant)	12	0	592
Plastics (kg/inhabitant)	6	1	524
Glass (kg/inhabitant)	10	1	503
Garden biowaste (kg/inhabitant)	23	0	711
Another sorted waste (kg/inhabitant)	6	0	1 605
Number of inhabitants	1 938	7	432 801
Population density (inhabitant/km^2)	111	1	1729
Proportion of the population under four years of age	5%	0%	22%
Proportion of the population aged 65+	14%	0%	63%
Median monthly income (in EUR)	487	5	1 125
Flat fee (EUR/ inhabitant)	18	1	50
Fee in the case of unit-based pricing (EUR/l)	1,7	0,1	4

Source: IEP

Data Limitations

Data on waste generation are provided by municipalities as part of municipal waste reports, with some limitations. The data on municipal waste include not only household waste but also waste from offices, schools and public institutions, whereas fees for waste from legal entities or entrepreneurs are often different. Thus, waste produced per capita may be overstated or understated in some municipalities. A possible solution is to extend the catalogue number for mixed municipal waste to mixed municipal waste from and outside households.

[4] For each municipality there is a figure in each year.
[5] Annex No.1 to Act No. 329/2018 Coll. on fees for waste landfilling

While data on mixed municipal waste have been correctly reported over the long term, data on separate waste collection are often understated or missing. This is also evidenced by an increasing number of municipalities reporting non-zero volumes of sorted waste from plastics, paper, glass and biowaste. On the one hand, separate collection increases every year, and on the other hand, there is increasing motivation to report separate collection of waste due to lower prices charged for waste disposal in a landfill. In 2014, the Act on fees for waste landfilling determined a rate based on sorted components. Since 2019, a fee for each municipality has been calculated based on the sorting rate in a municipality in the previous year. This is also associated with a significant increase in reported sorted metal waste since 2015. The new waste management information system should record the entire material waste stream, thus helping to improve and unify waste information.

Another limitation of data on separate waste collection is school collection, paper scrap yards and composting of biowaste by households. Despite the legal obligation,[6] paper scrap yards and mobile waste equipment often do not report all quantities collected, which results in evidence gaps. Data on composted biowaste on someone's own land are not recorded at all. Reporting of collected quantities within purchasing installations should be controlled, or sanctions should be imposed on them for the non-performance of obligations. The solution for the evidence of household composting is a methodology prepared by the Ministry of Environment of the Slovak Republic.

2.3 Spatial models with Fixed Effects

The majority of the studies that used panel data (Allers and Hoeben, 2009, Dijkgraff and Gradus, 2004, Usui and Takeuchi, 2013) estimate the effect of introducing unit-based pricing on waste production and separate collection using various variations of fixed effect models. However, these studies neglect the possible spatial dependence of waste generation. Czech studies (Rybová and Burcin, 2017, Rybová et al., 2018) confirmed a positive spatial dependence for mixed municipal waste, in the case of sorted plastic and glass waste spatial dependence was not found. The hypothesis of spatial dependence has also been confirmed by other studies (Keser et al., 2011, Ismaila et al., 2015), Ioannou et al. (2010) identified the spatial dependence of separate collection, too.

The resulting models for the production of mixed municipal waste and separate collection in the municipality *i* in the year *t* were estimated using the following equations:

1. Mixed municipal waste - Spatial Durbin Model with fixed effects of municipalities and years

$$Q_{it} = \rho \sum_{j=1}^{n} w_{ij}\, Q_{jt} + \alpha_{0i} + \alpha_{1t} + \beta_1 PAYT_{it} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \theta_1 \sum_{j=1}^{n} w_{ij}\, PAYT_{it} + \theta_2 \sum_{j=1}^{n} w_{ij}\, DEN_{it} + \theta_3 \sum_{j=1}^{n} w_{ij}\, Under4_{it} + \theta_4 \sum_{j=1}^{n} w_{ij}\, Over65_{it} + \theta_5 \sum_{j=1}^{n} w_{ij}\, Income_{it} + \varepsilon_{it} \quad (1)$$

2. Sorted plastic waste - Non-spatial model with fixed effects of municipalities and years

$$Q_{it} = \alpha_{0i} + \alpha_{1t} + \beta_1 PAYT_{it} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon_{it} \quad (2)$$

3. Sorted paper waste - Spatial Durbin Model with fixed effects of municipalities and years
4. Sorted glass waste - Model with spatial errors with fixed effects of municipalities and years

[6] Article 16 par. 2b) and par. 3 of Act No. 79/2015 Coll. on waste

$$Q_{it} = \alpha_{0i} + \alpha_{1t} + \beta_1 PAYT_{it} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon_{it}$$

$$\varepsilon_{it} = \varphi \sum_{j=1}^{n} w_{ij}\, \varepsilon_{jt} + \mu_{it} \qquad (3)$$

5. Biowaste - Non-spatial model with fixed effects of municipalities and years

$$Q_{it} = \alpha_{0i} + \alpha_{1t} + \beta_1 PAYT_{it} + \beta_2 DEN_{it} + \beta_3 Garden_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon_{it} \qquad (4)$$

Q_{it} means the amount of mixed municipal or sorted waste in the municipality *i* in the year *t* (in kilograms per capita).

$PAYT_{it}$ takes the value 1 if in the given year, the municipality has unit-based pricing in place, and the value 0 if the municipality has a flat fee.

$DEN_{it}, Under4_{it}, Over65_{it}$ means demographic variables, population density, proportion of the population aged 65+ and proportion of the population under four years of age.

$Income_{it}$ means an economic variable indicating the median monthly income received for permanent employment or employment for an agreement[7]

$Garden_{it}$ means the area of gardens per capita (in m^2 per capita)

α_{0i} and α_{1t} means coefficients that represent fixed effects of municipalities and years.

w_{ij} means the elements of the spatial weight matrix, which were created based on the so-called 'queen contiguity' rule, based on which two municipalities are adjacent if they share a common border, regardless of its length[8]. We used a row-normalized matrix, which means that the amount of waste Q_{it} depends on the average values of the independent variables in neighbouring municipalities.

For the variables $Q_{it}, DEN_{it}, Garden_{it}$ we used logarithmic transformation to achieve the desired linearity of the parameters.

Demographic and socio-economic characteristics of municipalities or households that may influence waste production are partially included in the fixed effects, and partially in the variables DEN_{it}, $Under4_{it}$, $Over65_{it}$, $Income_{it}$, $Garden_{it}$. Population density is used as a proxy for the residential space, while it is more difficult to store sorted waste in a small house (Usui and Takeuchi, 2013). A higher proportion of children under the age of 4 may result in higher waste production due to the use of diapers (Allers and Hoeben, 2009, Usui and Takeuchi, 2013). Municipalities with a higher proportion of the population aged 65+ can theoretically achieve higher recycling rates of glass and paper, as the sorting of these components has a long history in Slovakia. In addition, lower total waste generation per capita can be expected in these municipalities due to lower total consumption of the older population. Income can be considered as a proxy for consumption (a positive relation to waste generation), the opportunity cost for the time devoted to sorting (a negative relation to waste generation), or as a proxy for education level. The size of gardens in municipalities should have a positive effect on the production of garden biowaste.

Other explanatory variables commonly used in foreign literature to estimate waste production are the average household size, the educational structure of the population, the proportion of ethnic minorities, tourism or environmental awareness (Usui and Takeuchi, 2013, Dijkgraaf and Gradus, 2004, Agovino et al., 2016).

7 As a rule, the square of income is also used, in our case the use of this variable did not change the resulting effect of unit-based collection, so we kept the original model setting.

8 We developed a spatial weight matrix also using the distance of centroids of municipalities and the distance between individual municipalities in kilometres. The results achieved were very similar, so we do not provide them in the analysis.

Literature and practice agree that the collection system has a significant impact on waste production. The door-to-door collection system for biowaste or separate collection has a significant impact on both the high rate and quality of sorting (European Commission, 2015, OECD, 2006). These data are only available for one year or not at all, so we have not included them in the model. If such unobserved variables correlate with the amount of waste and also with the introduction of unit-based pricing, the estimated effect is biased. We can avoid this problem by including fixed effects that partially control changes in unobserved variables.

For the selection of suitable models, we followed Elhorst (2010) in three steps. We started from a basic non-spatial pooled regression where panel data structure is neglected. Subsequently, we estimated the model with fixed effects of municipalities and the model with two-way fixed effects of municipalities and years. When deciding between the pooled regression and the fixed effect model, we used the F-test of significance for fixed effects. With the Breusch-Pagan test, we tested the significance of time fixed effects. Based on this systematic selection, we have chosen a model with fixed effects of municipalities and years for each type of waste. We tested the inclusion of spatiality in the model using robust Lagrange multiplier tests.

As the second step we compiled Spatial Durbin Models with selected fixed effects of municipalities and years. Using Wald tests, we verified whether individual models could be simplified to a model with spatial displacement or a model with spatial errors. Finally, we tested whether specific fixed effects could be considered random using the Hausman test.

The results of all models used and their tests are shown in Table 19 and Table 20. Since conventional standard deviations may be underestimated due to auto-correlation, the significance level of the coefficients in Table 19 results from the t-values, which are based on robust standard deviations groped by municipalities and years, which are usually higher than usual standard deviations.

We used balanced data when developing spatial models, as missing data would mean a missing "neighbour" in the spatial weight matrix. For comparison, in Table 19 we provide the results of non-spatial models estimated for unbalanced waste data.

Table 4: Estimated coefficients of the resulting models

	Mixed municipal waste	Plastics	Glass	Paper
PAYT	-0.25***	0.14*	0.09*	0.11
ln DEN	-0.39***	-0.43**	-0.49***	-0.15
Over65	-0.16	0.13	0.83***	1.45***
Under4	0.33`	-0.56	0.72*	0.48
Income	-0.11*	0.09	0.07	0.07
W PAYT*	-0.19***	-	-	-0.15
*W*ln DEN*	0.32***	-	-	0.47*
*W*Over65*	-0.33	-	-	1.27
*W*Under4*	-0.53	-	-	0.98
*W*Income*	0.13`	-	-	1.29***
ρ	0.15***			0.28***
φ			0.29***	

*** p<0.001,** p<0.01, * p<0.05, ` p<0.1 *Source: IEP*

The results show that unit-based pricing has a significant effect on the reduction of mixed municipal waste production. The effect on increasing the separate collection of plastics and glass is also significant; in the case of paper, unit-based pricing has no effect. This may be due to the alternative option of delivering paper through purchasing installations or school collection. Population density is significant in all models except paper with a negative sign. For separate collection, the effect is in line with expectations (Usui and Takeuchi, 2013). The proportion of the population aged 65+ has a significant positive effect on separate collection of glass and paper, probably due to the long history of its sorting. The proportion of the population under four years of age is expected to have a positive effect on the production of mixed municipal waste.

2.3.1 Effects by the Type of Unit-Based Pricing

Different types of unit-based pricing can have different effects on waste production (Allers and Hoeben, 2009, Dijkgraaf and Gradus, 2004). When estimating the effects of individual types of unit-based pricing, we use modified equations in which we replace the variable $PAYT_{it}$ with the variables TAG_{it} and VF_{it}. The variable TAG_{it}, or VF_{it} takes the value 1 if the municipality has tag or volume-frequency collection in the given year. We did the same in the selection of models; the results of the models and tests used are given in Table 21 and Table 22.

Table 5: Estimated coefficients of the resulting models for unit-based pricing types

	Mixed municipal waste	Plastics	Glass	Paper
Tag	-0.37***	0.09	0.06	0.19*
VolumeFrequency	-0.12**	0.19*	0.12\`	0.02
ln DEN	-0.39***	-0.43**	-0.49***	-0.14
Over65	-0.15	0.13	0.83***	1.45***
Under4	0.33\`	-0.57	0.72*	0.48
Income	-0.11*	0.09	0.07	0.07
W Tag*	-0.08	-	-	-0.04
W VolumeFrequency*	-0.13\`	-	-	-0.23
*W*ln DEN*	0.29***	-	-	0.48**
*W*Over65*	-0.31	-	-	1.26
*W*Under4*	-0.54	-	-	1.01
*W*Income*	0.12	-	-	1.31***
ρ	0.15***			0.28***
φ			0.29***	

*** p<0.001,** p<0.01, * p<0.05, \` p<0.1 *Source: IEP*

2.3.2 Interpretation of results

Since the dependent variable waste quantity Q_{it} is logarithmically transformed, the effect of the variable $PAYT_{it}$ is calculated as $e^{\beta_1} - 1$, where β_1 is the estimated coefficient of this variable. The effect of introducing unit-based pricing is thus expressed as a percentage change in the quantity of waste in the case of shift from flat-rate to unit-based pricing. In this way, the results of the non-spatial model for sorted plastics collection and the model with spatial errors for sorted glass collection can be interpreted.

The effect of unit-based pricing on mixed municipal waste was estimated using the Spatial Durbin Model, which also considers the interaction between neighbouring municipalities. The overall effect of changing the explanatory variable thus consists of a direct effect on the relevant municipality and an indirect effect on neighbouring municipalities. As a result of the feedback effect, direct or indirect effect do not correspond to the coefficients β, or θ. The calculation of direct and indirect effects is stated in Annex 1 (Equation (11) according to LeSage and Pace (2009).

Table 6 shows only effects of unit-based pricing on waste production. The results of models for sorted paper collection with balanced data are significant, but in the non-spatial model with missing data, the effect is not significant and is even substantially lower (Table 21 and Table 22). Since in the case of papier, there was a lack of even 15% of data for a period of 9 years, we consider the result of the model with missing data as relevant, which is not significant.

Table 6: Effect of unit-based pricing on waste production (% change compared to a flat fee)

	Mixed municipal waste	Plastics	Glass	Paper
Unit-based pricing combin.	-22.3% (-4.3%)	15.4%	9.1%	-
Tag	*-31.0% (-6.1%)*	-	-	-
Volume-frequency	*-11.3% (-2.0%)*	*22.1%*	*12.4%*	-

**Indirect effects on neighbouring municipalities are indicated in brackets* *Source: IEP*

Unit-based pricing reduces mixed municipal waste production in the municipality by 22% in comparison with a flat fee. This reduction is due to the introduction of unit-based pricing at an average fee of 1.7 eurocents per litre of waste. The results in Table 6 show that the effect of unit-based pricing varies according to the collection type. White tag collection reduces the production of mixed municipal waste by 31%, volume-frequency collection only by 11% compared to a flat fee. The results are in line with expectations and foreign literature, as in the case of tag collection, the residents pay for the relevant disposal and in the case of volume-frequency collection they pay according to the pre-set frequency and the size of the containers.

In addition to the direct effects on mixed municipal waste production in the municipality, the introduction of unit-based pricing also has an indirect impact on mixed municipal waste production in neighbouring municipalities. The introduction of unit-based pricing in the municipality reduces waste generation per capita in neighbouring municipalities by an average of 4%. In the case of tag collection, the indirect effect reaches 6%, in the case of volume-frequency collection it reaches 2%, respectively. This may be due to the dissemination of information and awareness-raising in municipalities.

Unit-based pricing has a significant and positive impact on sorted plastics and glass collection. In municipalities, 15% more sorted plastic waste and 9% more glass is collected thanks to the introduction of unit-based pricing. The analysis did not show a significant effect of unit-based pricing on paper sorting. This may be due to alternative paper management options through purchasing installations or school collection, which have a long tradition in Slovakia. Data on the amount of paper waste received in such facilities is generally not reported and is absent in the waste register.

However, the resulting effect for a particular municipality may be lower or much higher. A municipality with higher fees, higher environmental awareness, an active mayor in the field of the environmental or a better information campaign and evidence may achieve better results. For instance, in the municipality of Košeca, they reduced waste production only thanks to the introduction of automatic waste evidence and high-quality enlightenment, without unit-based pricing (JRK, 2019). In addition, if a municipality has door-to-door collection for bio-waste and sorted waste, the effect of unit-based pricing may be higher (European Commission, 2015, OECD, 2006).

2.3.3 Testing Endogeneity

The use of models and their interpretation in Chapter 2.3 assumes the exogeneity of the introduction of unit-based pricing, i.e. the introduction of unit-based pricing does not correlate with a model error. We tested possible endogeneity using instrumental variables. Due to the robustness of the results, we assume that the introduction of unit-based pricing is exogenous.

One of the prerequisites for using the above methods is the so-called exogeneity, where the explanatory variables and the model error are uncorrelated, and a violation of this assumption may lead to biased estimates. The cause of endogeneity may be the omission of an important explanatory variable, which affects the choice of the introduction of unit-based pricing and waste production.

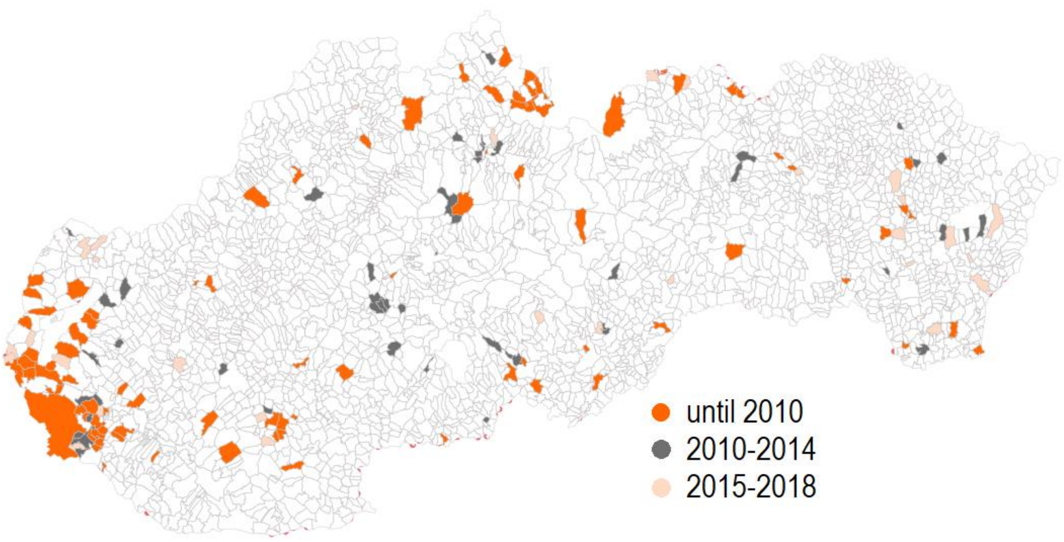
For instance, the inhabitants of some municipalities may have a higher environmental awareness as a result of campaigns, promotions or a mayor who promotes environmental policies and measures. In such municipalities, the introduction of unit-based pricing may be more likely than in those with a low-environmental awareness. At the same time, environmental awareness may affect the waste production regardless of the type of fees for collection, which could overestimate the effect of unit-based pricing (Dijkgraaf and Gradus, 2009). Another example could be municipalities with long-term high waste production, which would benefit more from the introduction of unit-based pricing.

The model with fixed effects used by us in the analysis of the effect of unit-based pricing on waste production, partially reduces possible endogeneity, which is based on the unobserved characteristics of municipalities such as environmental awareness, political ideology but it may not be sufficient in the case of specific characteristics of individual municipalities that change over time. Interaction of the municipalities can also be seen as a form of endogeneity that we eliminated by including spatial dependence in models.

For assessing possible endogeneity, we need relevant explanatory variables that influence the possibility of introducing unit-based pricing but do not directly affect waste production (Besley and Case, 2002). Allers and Hoeben (2009) estimate that the introduction of unit-based pricing depends on political ideology and on the introduction of unit-based pricing in neighbouring or surrounding municipalities. Political interaction for the introduction of unit-based pricing may result from the dissemination of information or the political competition of municipalities. Several studies have found that the introduction of any fee or tax is more likely if neighbouring municipalities have already introduced this type of fees (Ashworth et al., 2006, Brueckner, 2003, Heijnen, 2007).

The development of unit-based pricing in Slovakia suggests that the introduction of unit-based pricing is concentrated and may depend on the decision in the neighbouring or surrounding municipality. In Slovakia, municipalities have unit-based pricing in municipalities mainly in such districts as Tvrdošín, Ružomberok, Nové Zámky. Volume-frequency collection was introduced mainly in western Slovakia in the districts of Senec, Malacky and Dunajská Streda.

Map 2: Municipalities with unit-based pricing by year of introduction



Source: IEP

We estimated the possible endogeneity using the Two-Stage least squares method. In the first step we estimated the choice of introducing unit-based pricing using type of collection in surrounding municipalities in the previous year as the instrumental variable and other explanatory variables from the waste equation. The equation was estimated using a weighted regression model with fixed effects of municipalities and years. We used weights based on the ratio between municipalities with unit-based pricing and municipalities with a flat fee.

$$PAYT_{it} = \rho PAYTYN_{jt-1} + \alpha_{0i} + \alpha_{1t} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon_{it} \quad (5)$$

The variable $PAYTYN_{jt-1}$ takes the value 1 if in the vicinity of the municipality there is at least one municipality with unit-based pricing in the previous year, otherwise it is 0. We created the variable using a spatial weight matrix that we constructed based on the distance of the centroids of municipalities. We assume that the information on unit-based pricing in a municipality may also be disseminated to distant municipalities, with which they do not share a common border. The municipalities that introduced unit-based pricing before 2010 are omitted from the testing, as we do not have information whether in their vicinity there were any municipalities with unit-based pricing before the introduction. The results of the first degree of regression are shown in Table 23 in Annex 1.

In the next step we will use the predicted $\widehat{PAYT}_{it}$ and estimate the equation for mixed municipal waste using a non-spatial model with fixed effects. Due to the omission of municipalities in the first step, we cannot estimate the spatial model.

$$Q_{it} = \alpha_{0i} + \alpha_{1t} + \beta_1 \widehat{PAYT}_{it} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon_{it} \quad (6)$$

Table 7: Test for endogeneity

	Basic model	2SLS
PAYT	-0.265***	-0.255***
F-test of significance ρ (p-value)		*738 (0.00)*
Hausman test for endogeneity (p-value)		*1.22 (0.94)*

Source: IEP

The effect of introducing unit-based pricing according to the basic model without the treatment of endogeneity is similar to the result of the Two-Stage method. The Hausman test for endogeneity[9] of an explanatory variable does not reject the hypothesis that the explanatory variable is exogenous. The inclusion of fixed effects could eliminate potential endogeneity e.g. if municipalities introduce unit-based pricing as a result of high waste production. The F-test of significance of the collection type in surrounding municipalities in the previous year confirms the relevance of the instrumental variable used.

The number of municipalities with unit-based pricing corresponds to only almost 6% of all municipalities in Slovakia. We could only test the possible endogeneity with the chosen instrumental variable only for a half of the total number of municipalities with unit-based pricing, as up to 80 municipalities introduced unit-based pricing before 2010. For these municipalities we do not know their motivation to introduce unit-based pricing. We additionally verified the robustness of the results obtained using our own criteria for the selection of a data sample:

1) **Analysis of only those municipalities that have ever had unit-based pricing,** thus comparing only municipalities that are more similar, as they are the same municipalities at different periods of time.
2) **Analysis of only those municipalities that introduced unit-based pricing after 2010** for case that the municipalities that introduced unit-based pricing until 2010 were different.
3) **Analysis of only those municipalities that have ever had unit-based pricing and Monte Carlo simulation of municipalities with a flat fee,** in which we randomly selected 500 or 1000 municipalities from among flat-fee municipalities and this random selection was repeated 1000 times.

The results of the analyses 1), 2) and 3) performed for the selected sample show that the effect of unit-based pricing as well as types of unit-based pricing on mixed municipal waste is robust and significant. The effect of unit-based pricing on plastics is robust but in some cases it is no longer significant.

[9] We used robust standard deviations grouped by municipalities and year.

Table 8: Robustness test of results

	Mixed municipal waste	Plastics	Glass	Paper
Basic model	-0.26***	0.14*	0.12**	0.09
Tag	-0.39***	0.09	0.09	0.17`
Volume-frequency	-0.13**	0.19*	0.14*	0.02
(1)				
PAYT	-0.25***	0.13*	0.13**	0.08
Tag	-0.38***	0.09	0.12`	0.14
Volume-frequency	-0.12*	0.12`	0.14*	0.01
(2)				
PAYT	-0.27***	0.14*	0.12**	0.09
Tag	-0.39***	0.09	0.09	0.17`
Volume-frequency	-0.12**	0.19*	0.14*	0.02
(3)				
PAYT	-0.26***	0.14**	0.14	0.09
Tag	-0.39***	0.09	0.10	0.16
Volume-frequency	-0.12*	0.19*	0.13*	0.02

Significance level by t-values which are in (2) based on robust standard deviations grouped by municipalities, in (3) grouped by municipalities and years, *** p<0.001,** p<0.01, * p<0.05, ` p<0.01 *Source: IEP*

2.3.4 *Sensitivity Analysis*

In addition to testing for possible endogeneity, as part of the sensitivity analysis, we have verified other assumptions that may influence the magnitude of the unit-based pricing effect:

(1) **An analysis in which we omitted cities,** as only 2 cities have a unit-based pricing system in place.
(2) **An analysis of unbalanced data.**
(3) **An analysis without municipalities with combined collection.**

Since we omit some municipalities in the sensitivity analysis, we compare the results with a model with fixed effects of municipalities and years without spatial dependence. A comparison of the coefficients of spatial and non-spatial models stated in Annex 1 shows the robustness of the estimates.

The results of the sensitivity analysis in Table 9 show that the selected models are robust with respect to the data used.

Table 9: Sensitivity analysis

	Mixed municipal waste	Plastics	Glass	Paper
Basic model	-0.26***	0.14*	0.12**	0.09
Tag	-0.39***	0.09	0.09	0.17`
Volume-frequency	-0.13**	0.19*	0.14*	0.02
(1)				
PAYT	-0.25***	0.14*	0.12**	0.12
Tag	-0.36***	0.08	0.09	0.18`
Volume-frequency	-0.12**	0.21*	0.15**	0.06
(2)				
PAYT	-0.26***	0.13*	0.11*	0.06
Tag	-0.39***	0.07	0.09	0.11
Volume-frequency	-0.13**	0.20*	0.13*	0.00
(3)				
PAYT	-0.26***	0.14*	0.12**	0.11
Tag	-0.39***	0.09	0.09	0.18`
Volume-frequency	-0.13**	0.19*	0.14*	0.03

Significance level by t-values which are in (2) based on robust standard deviations grouped by municipalities, in (3) grouped by municipalities and years *** p<0.001,** p<0.01, * p<0.05	*Source: IEP*

2.4 Matching (Propensity score matching)

An alternative way of estimating the effect of a measure to a standard regression analysis approach is the matching technique. The purpose of matching is to find matches for units from a control group to all units from the treated group based on their characteristics and then compare the output values. Like regression models, matching techniques require explanatory variables that are responsible for the selection related to the control or treated group. The estimated effects are unbiased when all relevant explanatory variables have been included and there are no other unobserved variables. Unlike regression models, the matching technique does not require a linear functional form of parameters.

In the analysis we chose the propensity score matching, which is a conditional probability of the introduction of a measure, i.e. unit-based pricing, given the observed explanatory variables (Rosenbaum and Rubin, 1983).

We estimated the probability of introducing unit-based pricing for the given values of explanatory variables X using the logistic regression model

$$P(PAYT|X) = {e^{X\beta}}/{1+e^{X\beta}} \tag{7}$$

We used the same explanatory variables as in the equation (5) in Chapter 2.3.3. Thus, equation (7 can be written in a linear form

$$\ln\frac{p}{1-p} = \beta_0 + \beta_1 \sum_{j=1}^{n} d_{ij}\, PAYT_{jt-1} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon \tag{8}$$

Table 10: Logistic regression model results

	Estimated coefficient
Intercept	-3.93***
$\sum d_{ij}\, PAYT_{jt-1}$	7.21***
Den	-0.02
Under4	0.81
Over65	-3.97`
Income	1.46***

Source: IEP

The introduction of unit-based pricing in a neighbouring municipality in previous years as well as the median income have a significant positive effect on the introduction of unit-based pricing. Some authors (Austin et al., 2007, Caliendo and Kopeinig, 2008) suggest that the final model should include not only statistically significant variables, so we will leave all explanatory variables used in the model.

When matching municipalities, we applied the so-called nearest neighbour matching method, which found the nearest neighbour from among the municipalities without unit-based pricing (the control group) for each neighbour with unit-based pricing, based on calculated probabilities from logistic regression. When matching, we used the selection without regression, which makes it possible to use a municipality without unit-based pricing for matching with the municipalities with unit-based pricing only once.

The number of observations dropped after matching to 2,404 from the original 25,920, leaving out data outside the region of common support. Most omitted or unmatched municipalities is in the range of 0 to 0.2 due to the probability of introducing unit-based pricing (Graph 2 in Annex 2). The matching of municipalities significantly improved congruence between the distribution of probabilities of the introduction of unit-based pricing, which suggests a reduction in potential selection bias.

A key requirement of the matching technique is to achieve the covariate balance. This means that differences resulting from explanatory variables for municipalities with and without unit-based pricing are not statistically significant. The achieved balance was assessed by visual inspection, normalized mean differences and a chi-squared test.

After matching, the points in the quantile graph are on a diagonal, which means that the explanatory variables in both groups come from the same distribution (Graph 4 in Annex 2). The absolute value of the normalized mean differences for the explanatory variables dropped after matching to below 25% (Table 24 in Annex 2), which suggests an improvement in the balance of all variables (Stuart and Rubin, 2008). Hansen and Bowers (2008) proposed a test to check if there is at least one explanatory variable in the model for which the control and treated groups are different. A statistically significant result of the chi-squared test for unmatched data indicates that at least one variable in the model creates an imbalance between the control and the treated groups. For matched data, the result is not significant, indicating a balance between the groups (Table 25 in Annex 2).

Provided that conditional independence is met, on the basis of the explanatory variables used, the difference between the production of waste in municipalities with and without unit-based pricing is solely due to the effects of the introduction of unit-based pricing. We estimated the average effects of the introduction of unit-based pricing by using the method of least squares on the matched data in the common support region.

Table 11: Average estimated effect of introducing unit-based pricing on waste production

	Mixed municipal waste	Plastics	Glass	Paper
Matching technique	-0.26***	0.14***	0.21***	0.17***
Resulting models from Part 2.3	-0.25***	0.14*	0.09*	0.11

Source: IEP

The estimated effects of introducing unit-based pricing on mixed municipal waste production and plastic sorting are significant and coincide with the results of spatial or non-spatial models with fixed effects in Part 2.3. The effects of unit-based pricing on the sorting of glass and paper are significantly positive, but significantly higher compared to previous results. This may be due to the omission of unobserved variables affecting the sorting of paper and glass in municipalities, leading to biased estimates and a poor balance in matched municipalities. One example could be paper purchasing installations, which are found only in some municipalities and have a significant impact on the amount of paper in the sorted waste. The models in Part 2.3 check the effect of such unobserved variables through fixed effects of municipalities.

2.4.1 Sensitivity Analysis

When assessing the robustness of the matching results against possible bias due to an unobserved variable, we performed a sensitivity analysis. The Rosenbaum Sensitivity Test (2002) is based on the Wilcoxon sign rank test and the Hodges-Lehmann point estimate for the sign rank test.

The test statistic is calculated on the basis of the statistical significance of the resulting variable for different values of gamma, which is interpreted as the odds ratio of introducing unit-based pricing for two observations. Provided that the estimates are not biased due to an unobserved variable, the values of gamma close to 1 at which the corresponding p-value is 0.05 or higher indicate that the results are sensitive to a small change due to the implicit bias. High values of gamma are associated with robust results for which the effect of an unobserved variable must be considerable high for the estimates not to be statistically significant. Gamma values ranging from 1 to 2 are used in most studies (Rosenbaum, 2002).

The results of the Rosenbaum Sensitivity Tests are shown in Table 26 in Annex 2. For mixed municipal waste, the upper limit of the Wilcoxon sign rank test p-values changes to a statistically insignificant value when the gamma value is 1.9. This means that the odds ratio would have to change 1.9 times to make the estimates statistically insignificant. This potential effect of implicit bias is equivalent to an increase in the median income value by EUR 441, which is almost double. For sorted plastic, glass and paper waste, estimates are not significant even at lower gamma values.

The Hodges-Lehmann point estimate of an additive treatment effect is a robust estimate derived from the randomization of a rank test and can be interpreted as a difference of the median of the resulting variable in the control and treated group. The median difference in mixed municipal waste production is -0.21 if there is no implicit bias. For gamma values of 1.1, the median ranges from -0.32 to -0.12. Only when the gamma value is 2, the Rosenbaum interval includes a value of 0, which would mean the opposite effect of unit-based pricing on mixed municipal waste production. For sorted plastic and paper wastes, the interval covers a value of 0 at a gamma value of 1.3; for glass it is 1.5, respectively.

The results of Rosenbaum Sensitivity Tests thus indicate that the estimated results of the impact of unit-based pricing on mixed municipal waste production are relatively robust to possible bias due to an unobserved variable. Conversely, the positive effect of unit-based pricing on the sorting of plastics, paper and glass is sensitive to possible implicit bias.

3 Possible Negative Effects of Unit-Based Pricing

The introduction of unit-based pricing may be accompanied by problems with illegal disposal of waste in illegal landfills or the transport of waste to neighbouring municipalities without unit-based pricing. Another option is the incineration of waste by households or the disposal of mixed municipal waste through separate collection. In the municipalities of Hranovnica, Kajal and Nesluša there were cases when inhabitants did not set out any waste collection container at the curb for the whole year due to illegal landfilling of waste in nature. The inhabitants of Hranovnica even transported waste to the neighbouring town of Poprad without any sanctions. For these reasons, all the three municipalities were forced to cancel unit-based pricing.

Therefore, preventive measures, e.g. the installation of real or fake cameras with a possible penalty notice must be introduced together with unit-based pricing. Another option is to introduce a two-component fee with a minimum fixed fee and a variable fee depending on the amount of waste. The efficient operation of unit-based pricing requires available and sufficient infrastructure for separate collection. It is necessary to create a sufficient comfortable and incentive system for the inhabitants and to provide them with the necessary information before the system is introduced. The contents of sorted waste containers should be checked and should not be taken away in the event of unsorted waste.

3.1 Waste Tourism

The available data do not show that the reduction of waste production occurs after the introduction of unit-based pricing due to the transport of waste to neighbouring municipalities.

In the case of unit-based pricing, citizens pay according to how much waste they produce, which can lead to the disposal of waste to neighbouring municipalities without unit-based pricing. For example, after the introduction of the bag system in the municipality of Hranovnica, they noticed the transport of waste to waste containers in neighbouring Poprad (Hranovnica, 2007). Dutch studies Dijkgraaf and Gradus (2004) and Allers and Hoeben (2009) did not prove the occurrence of waste tourism. Conversely, the Japanese study Usui and Takeuchi (2013) showed that municipalities with unit-based pricing reduced waste production through illegal transport to neighbouring municipalities.

The impact of the introduction of unit-based pricing in a municipality on the production of waste in neighbouring municipalities can be determined using the estimated indirect effects of the Spatial Durbin Model for mixed municipal waste production from section 2.3. A positive indirect effect would indicate the possible disposal of waste by transporting it to neighbouring municipalities.

Table 12: Indirect effects of introducing unit-based pricing

	Indirect effect
Unit-based pricing	-4.2%
Tag	*-6.1%*
Volume-frequency	*-2.0%*

Source: IEP

The results of the model show that the introduction of unit-based pricing has little negative indirect effect on mixed municipal waste production in neighbouring municipalities. The introduction of unit-based pricing in a municipality thus reduces the production of mixed municipal waste in neighbouring municipalities by an average of 4.2%. This may be due to the dissemination of information and awareness-raising among municipalities.

3.2 Illegal Dumping

The results in chapter 2.3 show that the effect of unit-based pricing is more considerable for the reduction in mixed municipal waste than for higher sorting rate. While unit-based pricing reduces mixed municipal waste production by 33 kg per capita per year, separate collection increases by less than 2 kg of plastic and glass waste per capita per year. The impact of unit-based pricing on biowaste and other components of separate collection is not statistically significant (Table 19 and Table 21 in Annex 1).

In fact, mixed municipal waste can be reduced e.g. by home composting of biowaste or sorting paper for school collection or mobile purchasing installations. Data on these quantities are often missing and not entered in the record of municipal waste, so it may appear from the results of the analysis that unit-based pricing does not affect these components. Another option for reducing mixed municipal waste production may be lower total waste production or illegal landfilling.

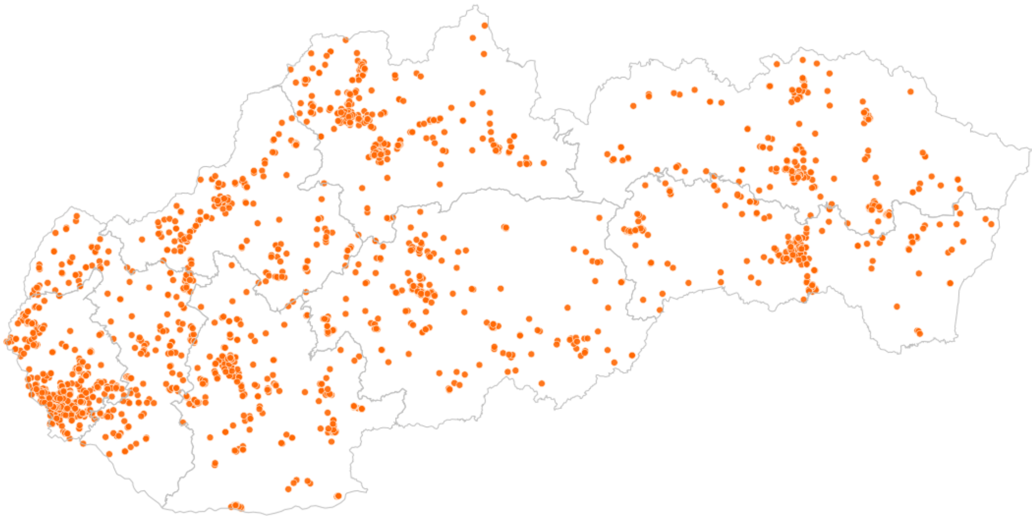
The increased incidence of illegal landfilling is indicated as another problem of introducing unit-based pricing (Eunomia, 2003, Kim and Kim, 2012, Fullerton and Kinnaman, 1996). Several analyses that relied on opinion polls or comparing changes in unsorted and sorted waste, confirmed an increased number of illegal landfills after the introduction of unit-based pricing (Kinnaman a Fullerton, 2000, Kim a Kim, 2012). In the Spanish city of Torrelles de Llobregat, where they introduced a bag system with fully variable charges, they estimated that 10 to 15% of the waste had been landfilled at road borders (Puig-Ventosa, 2008).

In the municipality of Hranovnica where they introduced the system in 2007, it happened that in some households they did not use any tags for waste collection and landfilled it illegally instead. This led to the total cancellation of unit-based pricing in 2015 (MŽP SR, 2014). Negative experience with illegal landfilling has led to the cancellation of unit-based pricing in the municipality of Kajal. Illegal waste disposal was also confirmed by the municipality of Budikovany, while the inhabitants do not face any sanctions for such activities.

In the absence of official data on illegal landfills, in the analysis of the effect on illegal landfilling we relied on data from the TrashOut mobile application. Among other things, the location of landfills, the size of the landfill (a bag, car and wheelbarrow) and the types of waste that are present on it are reported to the application.

In our case, we were only interested in illegal landfills where household waste was reported. We then linked the data with the data on municipal waste. Between 2013 and 2018, 2240 new illegal landfills with household waste were reported in the application, with about 40% of landfills of the size of a car, 40% of landfills of the size of a wheelbarrow and the remaining 20% of the size of a bag. As expected, most landfills were reported in regional capitals and western Slovakia. The number of reported landfills is lower than the actual number of illegal landfills in municipalities. The fact whether landfills are reported by inhabitants depends on several factors, e.g. on Internet literacy or information on the existence of an application.

Map 3: Illegal landfills reported in 2013-2018



Source: IEP based on TrashOut

When analysing the effect of unit-based pricing on the number of landfills reported, we used a Poisson regression model with fixed effects of municipalities and years in the form of

$$DUMP_{it} = \alpha_{0i} + \alpha_{1t} + \beta_1 PAYT_{it} + \beta_2 DEN_{it} + \beta_3 Under4_{it} + \beta_4 Over65_{it} + \beta_5 Income_{it} + \varepsilon_{it} \quad (9)$$

Where the dependent integer positive variable $DUMP_{it}$ from the Poisson distribution indicates the number of reported landfills of the size of a bag, car and wheelbarrow, or the number of reported landfills together. The explanatory variables used are the same as for the models in Chapter 2.3. Since we do not have data about Internet literacy of municipalities, this variable, which may affect the number of landfills reported, is included in the fixed effects of a municipality.

Since only 488 out of the 2 865 municipalities analysed had at least one landfill reported during the period under review, we estimated Equation (9) for all data and for a sample of data as follows:

1) All municipalities
2) Only the municipalities that have ever introduced unit-based pricing
3) Only the municipalities they introduced unit-based pricing after 2013
4) Only the municipalities in which at least one landfill was reported
5) Only the municipalities in which at least one landfill was reported and have ever introduced unit-based pricing

Table 13: Effect of unit-based pricing on the number of illegal landfills reported

	Bag size	Car size	Wheelbarrow size	Total
1)				
$PAYT_{it}$	-0.66	-1.84`	-0.28	-0.69
2)				
$PAYT_{it}$		-1.82`	-0.13	-0.71
3)				
$PAYT_{it}$		-1.86`	-0.14	-0.72
4)				
$PAYT_{it}$	-0.21	-0.96	-0.41	-0.62
5)				

$PAYT_{it}$	0.30	0.53	-0.07

Source: IEP

Based on the available data, we have not proved a significant effect of the introduction of unit-based pricing on the increased number of reported landfills. Since the actual number of illegal landfills is higher than the number of reported ones, we cannot conclude with certainty that unit-based pricing does not increase the number of illegal landfills.

A suitable measure against illegal landfilling is setting a minimum fixed fee for waste or installing cameras with a notice of a possible fine. The efficient operation of unit-based pricing requires available and sufficient infrastructure for separate collection (European Commission, 2018).

Box 6: Measures against illegal dumping

Discount system in Mikulov

In 2012, Czech Mikulov introduced an intelligent waste management system (obec Mikulov, 2012). Waste containers for sorted and mixed municipal waste are equipped with chips and barcodes for each household, which are scanned and stored in the database. In billing, households are credited with a bonus based on the total waste generation and the ratio of sorted and mixed municipal waste. Based on the bonus, households will receive a benefit in the form of a reduced fee for waste for the next year. The amount of the bonus, waste generation and success rate can be viewed on a website in the ranking of the best households, which motivates citizens to improve their waste collection.

Monitoring system in South Korea

In South Korea, illegal landfilling has increased sharply after the introduction of a countrywide bag system, but citizens' reports and the introduction of video surveillance systems have helped to solve the problem. Offenders were subject to a fine of up to 900 pounds. Since 2000, anyone who reported illicit activity has received a reward of 80% of the fine (Kim and Kim, 2012).

Minimum fixed fee for waste

The introduction of a minimum fixed fee may help to avoid illegal waste disposal (Bilitewski, 2008, Reichenbach, 2008). Such a fee has been introduced in Slovakia in the municipalities of Veľké Dvorníky and Nižná Sitnica. The municipalities of Slaská, Zbehňov, Halič and others have a minimum number of tags that a citizen must use in a given year or a minimum number of collection intervals per year.

Information campaign and sufficient infrastructure

The efficient operation of unit-based pricing requires available and sufficient infrastructure for separate collection. It is necessary to create a sufficient comfortable and incentive system for the inhabitants and to provide them with the necessary information before the system is introduced (European Commission, 2018).

4 Costs and Benefits of Unit-based pricing

The introduction of tag collection in family houses and volume-frequency collection in residential buildings throughout Slovakia may result in the financial savings for municipalities of EUR 28.5 mil. per year. A one-off investment in unit-based pricing can amount to EUR 0 - 28.6 mil. for municipalities, operating costs can range from EUR 0 to 2.3 mil. per year, depending on the type and system computerisation.

Additional costs for separate collection of plastics and glass are estimated at EUR 1.7 mil. per year. We have not been able to quantify the impact of unit-based pricing on the sorting of paper and bio-waste, but we can expect an increase. If the same part of the paper's potential in mixed municipal waste is sorted as in the case of plastics and glass, then additional costs would be EUR 0.7 mil. per year. If inhabitants sort paper through purchasing installations or mobile devices, the additional costs of a producer responsibility organization would be zero. Additional costs for the purchase of home composters would amount to almost EUR 6 mil. per year.

In addition to the financial costs and benefits, the introduction of unit-based pricing also brings non-financial costs and benefits in the form of environmental costs saved and increased discomfort associated with sorting.

4.1 Financial Benefits and Costs of Unit-Based Pricing

The introduction of unit-based pricing will save on average around EUR 6 per inhabitant per year on landfill charges, entry fees and mixed municipal waste collection costs for a municipality. Direct costs of a municipality associated with the introduction of unit-based pricing can reach EUR 0 to 18 ths. one-off and its operation on average EUR 838 per year, depending on the selected type of collection, the number of containers served and the system computerisation. A fully automated system brings about additional costs for a collection company, which must install an RFID chip reader on the vehicle in the amount of EUR 5.5 to 7 ths.

Increasing the sorting of plastics and glass will bring additional costs of almost EUR 1.7 mil. per year. We cannot quantify the cost of additional sorting of paper and biowaste, but we can expect its increase. In the case of plastics and glass, we estimate that approximately 4% of the potential of these components in mixed municipal waste will be sorted as a result of unit-based pricing. If the same part of the paper's potential is sorted, the additional costs would amount to EUR 0.7 million per year. If inhabitants sort paper through purchasing installations or mobile devices, the additional costs of a producer responsibility organisation would be zero. Additional costs for the purchase of home composters would amount to almost EUR 6 mil. per year.

Table 14: Financial costs and benefits of unit-based pricing (mil. EUR/year)

	Combination*
Landfill costs saved	28.5
Cost of system introduction and operation	
One-off investment	0 - 28.6
Operation	0 - 2.3
Cost of additional separate collection of plastics	1.5
Cost of additional separate collection of glass	0.2
Cost of additional separate collection of paper	N/A
Cost of home composters or composting	N/A

*Tag collection in family houses, volume-frequency collection in residential buildings *Source: IEP*

4.1.1 Saved Costs for Landfilling of Mixed Municipal Waste

Reducing mixed municipal waste production when introducing unit-based pricing will reduce the total cost of collection and landfilling. In addition, the cost of landfill charges, which will grow to EUR 11 - 33 per tonne in 2021, depending on the sorting rate,[10] would be reduced. Reducing mixed municipal waste production and increasing sorting will result in a higher sorting rate, allowing the municipality to fall into a category with lower landfill charges.

According to data from the 8 largest collection companies in Slovakia, the average price for the collection of mixed municipal waste in 2019 was EUR 68 per tonne. According to information from landfill site operators, the charge levied upon a given quantity of waste received at a waste processing facility (the so-called 'gate fee') in 2019 was, on average, EUR 33 per tonne of waste, i.e. it rose by nearly 7% year on year. We estimated waste generation as well as the sorting rate by 2021 using a simple linear regression for the time series during 2010-2018. In forecasting we considered a reduction in landfilled waste and an increased sorting rate due to the introduction of higher landfill charges (Haluš et al., 2018).

If tag collection in family houses and volume-frequency collection in residential buildings is introduced in 2020, the mixed municipal waste production could have decreased by 214 ths. tonnes. Thus in 2021, municipalities could save 28.5 mil. EUR, on average a cost saving of approximately EUR 6 per capita per year[11].

Table 15: Saved costs of a municipality for mixed municipal waste (mil. EUR/year)

	Combination*
Landfill charges	5,3
Gate fee	7,9
Collection	15,3
Total	**28,5**
Per capita (EUR/year)	**6,0**

*Tag collection in family houses, volume-frequency collection in residential buildings *Source: IEP*

4.1.2 Costs of Introducing and Operating Unit-Based Pricing

For the wide-scale introduction of unit-based pricing, one-off investment costs can range from 0 to 28.6 mil. EUR; operating costs can range from EUR 0 to 2.3 mil. per year. The costs of an average municipality thus reach EUR 0 to 10.5 ths. one-off and EUR 0 to 838 per year, depending largely on the size of the municipality, the number of waste containers, the selected type of collection and the system computerisation. A fully automated system brings about additional costs for a collection company, which must install a reader on the vehicle in the amount of 5.5 to 7 ths. EUR. We assume that only waste containers for mixed municipal waste for family houses would be identified where collection would be set according to the actual emptying intervals. Waste containers for residential buildings with volume-frequency collection would not be identified.

Simple systems such as tag and volume-frequency collection are the most widespread in Slovakia. The advantage of volume-frequency system is especially low costs, simplicity and low organizational and time-related demands for both the citizens and the collecting company. The experience of Nová Dedinka and Rohov, which introduced the system in 2016, shows that its implementation did not require any investment or operating costs. Similarly, the introduction of tag collection is only associated with one-off tag production

[10] Article 4 par. 4 of Act No.329/2018 Coll. on fees for waste landfilling
[11] We estimated the collection price in 2021 on the basis of the inflation forecast (IFP, 2019), for the landfill charges we expect a 7% year-on-year growth also due to the closure of landfills and a higher demand.

and the evidence of the number of collection based on the tags collected. The additional costs in this case are negligible.

The costs of more sophisticated electronic waste evidence systems are higher as they include software development for automatic collection evidence, operation and expert advice. In the simplest case, the additional operating costs include only the purchase of a reader, the costs of an employee for code scanning and container identification. For a fully automated system that includes access to the records for the collection company, the municipality as well as for each household, regular data evaluation, training and connection to the ECR system, the costs are much higher. We expect that the costs of an average municipality for the electronic evidence of mixed municipal waste from family houses are in the amount of EUR 697 per year in the simplest form; for a fully automated system, it is EUR 838 per year and EUR 10.5 ths. one-off (more in Box 7). If a municipality decides to make evidence also for separate waste collection, the operating costs would be higher. Collection companies also have additional costs, as they must install a chip reader in the amount of 5.5 to 7 ths. EUR.

Box 7: Cost of unit-based pricing with electronic waste evidence

Barcodes – operation within own capacity

Waste containers are identified by barcodes or QR codes that are assigned to each household. When waste is collected, the authorized employee of the municipality scans the code using a reader and the municipality evaluates the collected data on the number of waste collection at the end of the year.

This system is in place in the municipalities of Vrádište and Chropov, where the cost of buying the reader and identifying the containers with barcodes amounted to 1000 and 200 EUR, respectively. In both municipalities they have an employee who works under agreement who scans the codes on the containers being emptied. The time required to register the whole municipality for one collection is between 1 and 3 hours. Data transmission from the reader and data evidence, which is usually performed by a municipal employee, requires only 3 hours per year, which is a negligible cost.

The experience of municipalities shows that each family house has its own waste container in the volume of 110, 120 or 240 litres. According to the municipalities of Rakovice, Vrádište and Chropov, we have calculated that the worker will identify approximately 67 containers per hour when waste is collected. We estimate based on data on the frequency of waste collection from the municipal waste report and the super-gross minimum wage of EUR 4.04 per hour in 2019 that the average cost for the employee is EUR 697 per year.

According to JRK, the price of one code per container is 10 eurocents with a life cycle of 3 years. According to the 2011 census data on the number of family houses and flats, we estimated the waste container infrastructure for each municipality. Thus, the cost of container identification for family houses with a bar code with a life cycle of 3 years is thus EUR 10 per year in an average municipality.

Barcodes – operation in cooperation with a system supplier

Waste containers are again identified by barcodes or QR codes that are assigned to each household and the authorized employee scans the containers when being emptied. Data evidence is performed by the system supplier who provides regular evaluation and advice. This system was introduced by the municipalities of Rakovice and Košeca in cooperation with JRK for the evidence of mixed and sorted waste.

According to JRK, which operates the ELWIS waste evidence system, the one-off costs of identifying containers for mixed municipal waste can amount to EUR 150 per municipality and 50 cents per household. These costs include household data processing, communication campaign and initial training.

Thus, in an average municipality, the one-off costs amount to 306 EUR, with the identification of containers only for family houses.

Regular costs related to consulting and data processing by JRK in an average municipality amount to EUR 2400 per year. Operating costs, which include the purchase of a reader for 5-years, 3-year barcodes and a container identification worker, thus a total of EUR 3 097 per year.

The purchase of a code reader and the cost of the worker who identifies the containers by codes represent a significant part of the operating costs. If code readers are bought by collection companies, they would use the reader in several municipalities and the costs could be lower. Similarly, the municipality would save additional costs if containers were scanned by collection company employees.

RFID chips

In 2019, the municipality of Senec introduced the ESONA system with the identification of containers using a high-frequency identification chip (hereinafter referred to as RFID chip). The RFID chip is automatically scanned when the container draws close to a collection vehicle equipped with a reader. The advantage is therefore that there is no need for a worker to scan the codes.

According to MIM, which offers the system, the amount of investment and operating costs of a municipality depends on a number of parameters such as the number of waste containers served, whether it is made of plastic or metal, the matching requirement with the ECP system[12]. The system brings about additional costs also for the collection company, which must install a reading device on the vehicle in the amount of 5.5 to 7 ths. EUR. An alternative is a portable reader in the amount of EUR 799 and a EUR 20 monthly fee, which the worker of the collection company has attached to his wrist (Košeca, 2019). Operating costs for the user include the use of the application and are based on the number of containers.

One-off costs of a municipality for the implementation of the system amount to EUR 3 to 8 ths. without integration to ECR system; EUR 6 to 18 ths. with integration. The cost of purchasing a reader and mobile device is 500 EUR, with an expected life cycle of 5 years. The cost of the chips depends on the type of container. In case of metal containers, it is possible to use chips with unlimited useful life, for plastic containers, adhesive chips with a 5 years life cycle are used. Regular operating costs depend on the number of containers served.

Thus, the introduction of the system in an average municipality represents one-off investment costs of 10.5 ths. EUR. We assume that municipalities will replace all containers with plastic after a certain time and will use adhesive chips. The annual operating costs of a municipality, which include the purchase of chips and readers calculated for 5 years and the costs dependent on the number of containers, represent an average of 838 EUR.

For the purpose of unit-based pricing, we also assumed that a municipality will keep electronic records for mixed municipal waste only, the containers for sorted waste will not be identified. If a municipality decides also to register separate waste collection for the purpose of checking or rewarding citizens, the operating costs would be higher.

Table 16: Average investment and operating costs of a municipality with electronic evidence (EUR/year)

Collection type	One-off investment costs	Operating costs*
Barcode / QR code		
Operation within own capacity	0	697
External supplier	306	3 097

[12] ECR means an electronic cash register

RFID chips	10 500	838

*It includes purchase of reader and RFID chips calculated for 5 years, barcodes/QR codes calculated for 3 years — Source: *IEP*

4.1.3 Additional Costs for Separate Collection

The introduction of unit-based pricing increases the amount of sorted waste and thus the costs of the extended producer responsibility system. According to the results of the previous chapter, the introduction of unit-based pricing in 2020 across Slovakia would lead to an increase in separate collection of plastic and glass by roughly 7.2 ths. tonnes. Although the results of Chapter 2.3.2 indicate only increased sorting of plastics and glass, it is likely that the sorting of paper waste will also increase.

Analyses of the composition of mixed municipal waste performed by INCIEN show that about 12% of mixed municipal waste includes plastics, 9% paper and 6% glass. By introducing unit-based pricing, approximately 4% of the potential of plastics and 5% of the potential of glass in mixed municipal waste will be sorted. If the same part of the paper's potential is sorted, an additional 4.2 ths. tonnes per year would be sorted.

Based on these data, we have estimated the costs based on the amount of sorted waste separately for paper, plastic and glass (Annex 4). The additional net costs of financing separate collection of plastic and glass would thus amount to EUR 1.7 million per year. Assuming the same sorting of paper and glass, the cost would be EUR 2.4 mil. per year. If inhabitants sort paper through purchasing installations or mobile devices, the additional costs of a producer responsibility organisation would be zero.

Table 17: Additional costs for separate collection

	Quantity (ths. tonnes)	Costs (mil. EUR/year)
Plastics	4.6	1.5
Glass	2.6	0.2
Paper	4.2	0.7

Source: *IEP*

4.1.4 Additional Costs for the Collection of Biowaste

According to INCIEN's analyses of mixed municipal waste performed in 2016 and 2017, about 20% is garden waste and another 20% is biowaste. Nevertheless, the results of the analysis did not show a significant impact of unit-based pricing on the sorting of garden biowaste. This may be due to the fact that, when introducing unit-based pricing, residents begin to compost biowaste at home and these data are not included in waste statistics. We have also shown that unit-based pricing does not affect the production of other sorted municipal waste. We did not quantify the impact of unit-based pricing on kitchen waste due to insufficient records of these data. The sorting of kitchen waste depends heavily on the infrastructure and collection system provided, regardless of the type of fees. Thus, we can assume that reduced production of mixed municipal waste results mainly from reduced waste production and home composting. Another option is to dispose of waste through illegal landfilling, which we cannot exclude.

The recovery of biowaste would require additional costs for the purchase of home composters or the cost of collecting the waste in a composting plant. We calculated the number of home composters based on data about the number of family houses and residential buildings from the 2011 census and about the area of gardens in municipalities from the Statistical Office. According to market research, the average price of a garden composters in 2019 was approximately EUR 9 per year (Annex 4).

The cost of the purchase of an average composters for each family house would be EUR 5.9 million per year. The required number composters in each municipality was also calculated using the average size of the garden in a family house as a proportion of the garden area and the number of family houses in the municipality. The cost of purchasing composters depending on the average size of the garden in family houses in each municipality is EUR 5.9 mil. per year. The estimated cost of purchasing composters is an upper limit, as several households already have composters and some municipalities have obtained composters through an operational programme.

4.2 Model Example - Municipality of Budča

The municipality of Budča[13] reached a sorting rate of 25% in 2018 and produced approximately 233 kg of mixed municipal waste per capita (Budča, 2019). These figures are thus close to an average Slovak municipality. If they introduced a tag unit-based pricing for family houses and a volume-frequency collection for residential buildings in 2020, they could reduce the production of mixed municipal waste to 171 kg per capita and increase the sorting rate to 34%. By increasing the sorting rate above 30%, the municipality would move to a category with lower landfill charges. In comparison with the flat-rate collection, in 2021, the municipality could save landfill costs in the total amount of EUR 11.5 ths. per year or EUR 9 per capita per year.

According to the experience of municipalities, the introduction of simple tag collection and volume-frequency collection does not bring any additional investment or operating costs. For electronic evidence we assume the same effect on waste production as in the case of tags. If a municipality decides to introduce collection with electronic evidence for family houses using RFID chips with regular consultancy and data evaluation, the one-off costs could reach EUR 6 ths. and regular operating costs could be almost EUR 676 per year.

Table 18: Estimated financial costs and benefits of introducing unit-based pricing in Budča

	Total (ths. EUR/year)	Per capita (EUR/year)
Benefits	**11.4**	**9.2**
Collection costs saved	5.9	
Landfill costs saved	2.3	
Saved costs for landfill site operator	3.2	
Costs	**0-0.7**	**0-0.5**
Simple tag collection	0	
Collection with RFID chips and consultancy	0.7*	

**Plus, one-off investments of EUR 6,000 ths..* *Source: IEP*

4.3 Non-financial Benefits and Costs of Unit-Based Pricing

In addition to the financial costs and benefits, the introduction of unit-based pricing also brings non-financial costs and benefits in terms of environmental costs saved and increased costs of discomfort associated with sorting. Estimates of external landfill costs vary considerably, reducing landfilling thus can save EUR 2 to 21 mil. per year. Assuming the use of the results of a Norwegian survey, the cost of reduced comfort of inhabitants due to the sorting of plastics and glass can reach EUR 352 ths.

Environmental benefits

Reducing mixed municipal waste will not only save direct financial costs but also the costs of landfill externalities. Landfilling of waste produces greenhouse gases and pollutants escaping into the air or leakage into groundwater and soil. Landfilling can cause discomfort to people living near landfills in the form of an unpleasant smell, appearance, noise and increased health risks. Estimates of the external cost of landfilling differ considerably in foreign studies, so we considered the lower and upper limits of costs of 10 or 98 EUR/

[13] The municipality was selected at random on the basis of publicly available data on waste production on its website.

tonnes of waste (Nahman, 2011, Eunomia, 2011). Thus, the introduction of unit-based pricing can save external costs of EUR 2 to 21 million per year.

Additional consumer comfort costs

Increased sorting will bring discomfort to consumers in the form of additional time for washing, folding, sorting, or transporting waste to a collection centre. According to a Norwegian survey by Bruvoll et al. (2000) residents spend an additional 30 minutes a week on average for sorting, and they sort 221 kg per capita per year. Survey data show that sorting 1 tonne of waste takes 118 hours. Survey participants would be willing to pay an average of 49 EUR/tonne[14] per year for waste separation activities.

If we applied the same assumptions to Slovakia, the additional sorting of 7.1 ths. tonnes of plastic and glass waste with the country-wide introduction of unit-based pricing of waste, the cost of reduced inhabitant comfort would reach EUR 352 ths. per year. For additional sorting 4.2 ths. tonnes of paper, the cost of reduced comfort would increase by another EUR 204 ths. per year. In fact, the willingness to pay and also the time spent sorting can be significantly different in Slovakia. It is also possible that people would also sort additionally the other components, which would further increase the cost of discomfort.

Application of the 'pay-as-you-throw' approach

The introduction of unit-based pricing brings a fair fee system, in which each citizen pays based on how much waste they produce. This system applies the 'pay-as-you-throw' approach, introducing fairness and thus creating a direct financial incentive to reduce mixed municipal waste production and increase sorting.

[14] Converted according to PPP from Norwegian krones in 1998 to the Slovak euro 2018.

Bibliography

ADEME. (2018). *Benchmark of Pay as you throw practices for waste management.* Available on the Internet: https://www.rdcenvironment.be/wp-content/uploads/2018/08/benchmark-pay-throw-practices-2018-synthesis_en.pdf

Agovino M., Ferrara M., Garofalo A. (2016). *The driving factors of separate waste collection in Italy: a multidimensional analysis at provincial level.* Available on the Internet: https://link.springer.com/article/10.1007/s10668-016-9857-9

Allers A. M., Hoeben C. (2009). *Effects of Unit-Based Garbage Pricing: A Differences-in-differences approach.* Available on the Internet: https://link.springer.com/content/pdf/10.1007%2Fs10640-009-9320-6.pdf

Altonji J. G., Elder T. E., Taber Ch. R. (2005). *An Evaluation of Instrumental Variable Strategies for Estimating the Effects of Catholic Schooling.* Available on the Internet: https://msu.edu/~telder/2005-JHR.pdf

Ashworth J., Geys B., Heyndels B. (2006). *Determinants of tax innovation: The case of environmental taxes in Flemish municipalities.* Available on the Internet: https://www.sciencedirect.com/science/article/pii/S0176268005000431

Austin P.C., Grootendorst P., Anderson G.M. (2007). *A comparison of the ability of different propensity score models to balance measured variables between treated and untreated subjects: A Monte Carlo study.* Available on the Internet: https://www.ncbi.nlm.nih.gov/pubmed/16708349

Besley T., C. A. (2002). *Unnatural Experiments? Estimating the Incidence of Endogenous Policies.* Available on the Internet: https://onlinelibrary.wiley.com/doi/abs/10.1111/1468-0297.00578

Besley T., Case A. (2002). *Unnatural Experiments? Estimating the Incidence of Endogenous Policies.* Available on the Internet: https://onlinelibrary.wiley.com/doi/abs/10.1111/1468-0297.00578

Bilitewski, B. (2008). *From traditional to modern fee systems.* Available on the Internet: https://www.ncbi.nlm.nih.gov/pubmed/18829291

Brueckner, J. (2003). *Strategic interaction among governments: an overview of empirical studies.* Available on the Internet: https://pdfs.semanticscholar.org/81c8/b1fa0b609bfcc0ccc325e4453fac8e9287a5.pdf

Bruvoll A., Halvorsen B., Nyborg K. (2000). *Household sorting of waste at source.* Available on the Internet: https://www.researchgate.net/publication/228475080_Household_sorting_of_waste_at_source

Budča, O. (2019). Available on the Internet: http://www.budca.sk/download_file_f.php?id=1098773

Caliendo M., Kopeinig S. (2008). *Some practical guidance for the implementation of propensity score matching.* Available on the Internet: https://onlinelibrary.wiley.com/doi/10.1111/j.1467-6419.2007.00527.x

Callan S. J., Thomas J. M. (2006). *ANALYZING DEMAND FOR DISPOSAL AND RECYCLING SERVICES: A SYSTEMS APPROACH.* Available on the Internet: http://web.holycross.edu/RePEc/eej/Archive/Volume32/V32N2P221_240.pdf

Dijkgraaf E., Gradus R. (2009). *Environmental activism and dynamics of unit-based pricing systems.* Available on the Internet: https://econpapers.repec.org/article/eeeresene/v_3a31_3ay_3a2009_3ai_3a1_3ap_3a13-23.htm

Dijkgraaf E., Gradus R.H.J.M. (2004). *Cost savings in unit-based pricing of household waste: The case of The Netherlands.* Available on the Internet: https://www.sciencedirect.com/science/article/pii/S0928765504000168

EEA. (2016). *Municipal waste management across European countries.* Available on the Internet: eea: https://www.eea.europa.eu/downloads/9dbff3aa9f594a9683b6699ad9ab2d6b/1554806118/municipal-waste-management-across-european-countries.pdf

Elhorst, J. (2010). *Spatial panel data models.* Available on the Internet: https://www.researchgate.net/publication/226957388_Spatial_Panel_Data_Models

Eunomia. (2003). *Waste collection: To charge or not charge.* Available on the Internet: http://s3.amazonaws.com/zanran_storage/www.massbalance.org/ContentPages/1159112417.pdf

Eunomia. (2011). *Understanding the Policy Options for Implementing a Scottish specific landfill tax.* Available on the Internet: http://www.zerowastescotland.org.uk/sites/default/files/Scottish%20Landfill%20Tax%20Study%20Appendices.pdf

European Commission. (2015). *Assessment of separate collection schemes in the 28 capitals of the EU.* Available on the Internet: https://ec.europa.eu/environment/waste/studies/pdf/Separate%20collection_Final%20Report.pdf

European Commission. (2018). *Best Environmental Management Practice for the Waste Management Sector.* Available on the Internet: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/best-environmental-management-practice-waste-management-sector

Fullerton D., Kinnaman T.C. (1996). *Household Responses to Pricing Garbage by the bag.* Available on the Internet: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.727.8546&rep=rep1&type=pdf

Haluš M., Dráb J., Široký P., Výškrabka M. (2018). *Ako menej skládkovať.* Available on the Internet: https://www.minzp.sk/iep/publikacie/ekonomicke-analyzy/ako-menej-skladkovat.html

Hansen B. B., Bowers J. (2008). *Covariate balance in simple, stratified and clustered comparative studies.* Available on the Internet: https://arxiv.org/pdf/0808.3857.pdf

Heijnen, P. (2007). *Strategic Interactions in Environmental Economics.* Available on the Internet: https://www.researchgate.net/profile/Pim_Heijnen/publication/35149392_Strategic_interactions_in_environmental_economics/links/0deec519dc30ab1dbe000000/Strategic-interactions-in-environmental-economics.pdf

HelloSwitzerland. (2. 7 2019). Available on the Internet: https://www.helloswitzerland.ch/home

Hranovnica, o. (2007). *Skúsenosti po dvoch mesiacoch zavedenia vrecového množstvového zberu.* Available on the Internet: http://www.hranovnica.sk/odpady7.pdf

Huang J., Halstead J. M., Saunders S. B. (2011). *Managing Municipal Solid Waste with Unit-Based Pricing: Policy Effects and Responsiveness to Pricing.* Available on the Internet: http://sci-hub.tw/10.3368/le.87.4.645

IFP. (2019). *Makroekonomická prognóza.* Available on the Internet: https://www.finance.gov.sk/sk/financie/institut-financnej-politiky/ekonomicke-prognozy/makroekonomicke-prognozy/48-zasadnutie-vyboru-makroekonomicke-prognozy-jun-2019.html

Ioannou T., Lasaridi K., Kalogirou S. (2010). *SPATIAL ANALYSIS OF THE RECYCLABLE MUNICIPAL SOLID.* Available on the Internet: http://gisc.gr/docs/sk_papers/2_5_Ioannou_Lasaridi_Kalogirou_2010.pdf

Ismaila A.B., Muhammed I.,Bibi U.M., Husain M.A. (2015). *Modelling Municipal Solid Waste Generation Using Geographically Weighted Regression: A Case Study of Nigeria.* Available on the Internet: https://pdfs.semanticscholar.org/97ec/22965e5bac5b1e0aa0441a990f2726935d4d.pdf

IVAGO. (2016). *WHAT YOU NEED TO KNOW ABOUT HOUSEHOLD WASTE IN GHENT .* Available on the Internet: https://www.ivago.be/sites/default/files/u3/bestanden/brochures/Brochure%20Anderstaligen%20Engels.pdf

Jenkins R.R., Martinez S. A., Palmer K., Podolsky M. J. (2003). *The determinants of household recycling: a material-specific analysis of recycling program features and unit pricing.* Available on the Internet: https://www.sciencedirect.com/science/article/abs/pii/S0095069602000542

JRK. (2019). *Obec zaviedla evidovanie odpadu, znížila množstvo odpadu a šetrí na každom zbere ZKO.* Available on the Internet: https://www.odpady-portal.sk/Dokument/104816/obec-zaviedla-evidovanie-odpadu-znizila-mnozstvo-odpadu-a-setri-na-kazdom-zbere-zko.aspx

Keser S., Duzgun S., Aksoy A. (2011). *Application of spatial and non-spatial data analysis in determination.* Available on the Internet: https://www.ncbi.nlm.nih.gov/pubmed/22104614

Kim K., Kim Y. J. (2012). *Volume-based Waste Fee System in Korea.* Available on the Internet: http://webcache.googleusercontent.com/search?q=cache:I4uwcbf4lQcJ:www.eksp.kr/common/download.jsp%3Ffidval%3Ds%252B2DWAzJbUW9Fa%252FUa2bmrA%253D%253D+&cd=1&hl=sk&ct=clnk&gl=sk

Kinnaman T. C., Fullerton D. (2000). *Garbage and Recycling with Endogenous Local Policy.* Available on the Internet: https://www.sciencedirect.com/science/article/pii/S0094119000921740?via%3Dihub

Kipperberg, G. (2007). *A Comparison of Household Recycling Behaviors in Norway and the United States.* Available on the Internet: https://link.springer.com/article/10.1007/s10640-006-9019-x

Košeca. (2019). *Contract for the Right to Use the ELWIS Service.*

LeSage J., Pace R. K. (2009). *Introduction to Spatial Econometrics.* Available on the Internet: https://www.crcpress.com/Introduction-to-Spatial-Econometrics/LeSage-Pace/p/book/9781420064247

Linderhof V., Kooreman P., Allers M., Wiersma D. (2001). *Weight-based pricing in the collection of household waste: the Oostzaan case.* Available on the Internet: https://research.wur.nl/en/publications/weight-based-pricing-in-the-collection-of-household-waste-the-oos

Morlok J., Schoenberger H., Styles D., Galvez-Martos J. L. (2017). *The Impact of Pay-As-You-Throw Schemes on Municipal Solid Waste Management: The Exemplar Case of the County of*

Aschaffenburg, Germany. Available on the Internet: https://www.researchgate.net/publication/313590695_The_Impact_of_Pay-As-You-Throw_Schemes_on_Municipal_Solid_Waste_Management_The_Exemplar_Case_of_the_County_of_Aschaffenburg_Germany

MŽP SR. (2014). *Program predchádzania vzniku odpadu SR na roky 2014 – 2018 (Príloha 3).* Available on the Internet: http://www.minzp.sk/files/sekcia-enviromentalneho-hodnotenia-riadenia/odpady-a-obaly/registre-a-zoznamy/priloha3_priklady-pvo.pdf

Nahman, A. (2011). *Pricing landfill externalities: Emissions and disamenity costs in Cape Town, South Africa.* Available on the Internet: https://researchspace.csir.co.za/dspace/bitstream/handle/10204/5284/Nahman2_2011.pdf?sequence=3

Municipality of Mikulov. (2012). *Revoluce v nakládání s odpady - ISNO.* Available on the Internet: http://www.mikulov.cz/aktuality/detail/?contentId=132452

OECD. (2006). *Impacts of Unit-based Waste Collection Charges .* Available on the Internet: http://www1.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WGWPR(2005)10/FINAL&docLanguage=En

OVAM. (2. 7 2019). *OVAM.* Available on the Internet: https://www.ovam.be/

Puig-Ventosa, I. (2008). *Charging systems and PAYT experiences for waste management in Spain.* Available on the Internet: https://www.sciencedirect.com/science/article/pii/S0956053X08002249?via%3Dihub

Rakovica, O. (2019). *VZN č. 23/2018 o miestnom poplatku za komunálne odpady a drobné stavebné odpady.* Available on the Internet: https://www.rakovice.sk/samosprava/vzn/

Reichenbach, J. (2008). *Status and prospects of pay-as-you-throw in Europe – A review of pilot research.* Available on the Internet: https://www.ncbi.nlm.nih.gov/pubmed/18824346

Rosenbaum P. R. (2002). *Observational Studies.* Available on the Internet: https://www.springer.com/gp/book/9780387989679

Rosenbaum P. R. a Rubin D. B. (1983). *The central role of the propensity score in observational studies for causal effects.* https://watermark.silverchair.com/70-1-41.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAmAwggJcBgkqhkiG9w0BBwagggJNMIICSQIBADCCAkIGCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQMYH625VoQzUpcbaKwAgEQgIICE2MWXmMs9EoGV0KC32NrCcRCRQ82pO2OphJyW4kGop3NEtB.

Rybová K., Burcin B. (2017). *Does Spatial Dimension Matter in Waste Generation? Case Study of Czech Municipalities.* Available on the Internet: https://www.researchgate.net/publication/317686878_Does_spatial_dimension_matter_in_waste_generation_Case_study_of_Czech_municipalities

Rybová K., Burcin B., Slavík J. (2018). *Spatial and non-spatial analysis of socio-demographic aspects influencing municipal solid waste generation in the Czech Republic.* Available on the Internet: https://digital.detritusjournal.com/articles/spatial-and-non-spatial-analysis-of-socio-demographic-aspects-influencing-municipal-solid-waste-generation-in-the-czech-republic/15

Stuart E. A., Rubin D. B. (2008). *Best Practices in Quasi–Experimental Designs: Matching Methods for Causal Inference.* Available on the Internet: https://methods.sagepub.com/book/best-practices-in-quantitative-methods/d14.xml

Usui T., Takeuchi K. (2013). *Evaluating Unit-Based Pricing of Residential Solid Waste: A Panel Data Analysis.* Available on the Internet: https://link.springer.com/article/10.1007/s10640-013-9702-7

Usui, T. (2008). *Estimating the effect of unit-based pricing in the presence of sample selection bias under Japanese Recycling Law.* Available on the Internet: https://www.sciencedirect.com/science/article/pii/S0921800907004776

Wright Ch., Halstead J. M. (2011). *Using Matching Estimators to Evaluate the Effect of Unit-Based Pricing on Household Solid Waste Disposal.* Available on the Internet: https://core.ac.uk/download/pdf/6502907.pdf

Yamakawa H., Ueta K. (2002). *Waste reduction through variable charging programs: its sustainability and contributing factors.* Available on the Internet: https://link.springer.com/article/10.1007/s10163-002-0070-6

Zero Waste Europe. (2017). *The story of Parma - case study.* Available on the Internet: https://zerowasteeurope.eu/downloads/case-study-7-the-story-of-parma/

Annexes

Annex 1: An Analysis of the Effect of Unit-Based Pricing on Waste Production

Model selection

Table 19: Estimation of the effect of unit-based pricing on the amount of waste - non-spatial models

Fixed effects	(1) Without	(2) Municipalities	(3) Municipalities + years
Mixed municipal waste			
PAYT	-0.16***	-0.26***	-0.27***
ln DEN	0.13***	-0.28**	-0.31***
Over65	0.59***	0.05	-0.13
Under4	-4.1***	0.28	0.32
Income	0.98***	0.14***	-0.09
Within R^2	0.15	0.01	0.01
N	25 920	25 920	25 920
F statistics of the model (p-value)	893 (0.00)	37 (0.00)	33 (0.00)
F-test of significance of fixed effects (p-value)		22 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			13 317 (0.00)
Robust LM test lag			0.80 (0.37)
Robust LM test error			0.05 (0.82)
Plastics (balanced)			
PAYT	0.14***	0.22***	0.14*
ln DEN	-0.05***	-0.22*	-0.43**
Over65	0.41**	2.27***	0.13
Under4	-6.12***	-0.88`	-0.56
Income	2.67***	2.69***	0.09
Within R^2	0.21	0.22	0.002
N	25 920	25 920	25 920
F statistics of the model (p-value)	1 368 (0.00)	1 264 (0.00)	10 (0.00)
F-test of significance of fixed effects (p-value)		12 (0.00)	
Breusch Pagan LM test 2 fix. effects χ^2 (p-value)			275 (0.00)
Robust LM test lag			0,02 (0.89)
Robust LM test error			5,44 (0.02)
Paper (balanced)			
PAYT	0.37***	0.09	0.09
ln DEN	0.31***	0.12	0.10
Over65	1.42***	2.74***	1.98*
Under4	-7.94***	0.83	0.82
Income	3.16***	1.37***	0.49**
Within R^2	0.19	0.04	0.002
N	25 920	25 920	25 920
F statistics of the model (p-value)	1 189 (0.00)	191 (0.00)	9 (0.00)
F-test of significance of fixed effects (p-value)		17 (0.00)	
Breusch Pagan LM test 2 fix. effects χ^2 (p-value)			6 421 (0.00)
Robust LM test lag			69.20 (0.00)
Robust LM test error			49.69 (0.00)
Glass (balanced)			

PAYT	0.24***	0.14**	0.12**
ln DEN	-0.06***	-0.42***	-0.51**
Over65	0.45***	1.79***	0.80
Under4	-4.96***	0.56	0.59
Income	1.96***	1.47***	0.12
Within R^2	0.13	0.09	0.003
N	25 920	25 920	25 920
F statistics of the model (p-value)	805 (0.00)	487 (0.00)	17 (0.00)
F-test of significance of fixed effects (p-value)		16 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			624 (0.00)
Robust LM test lag			0.34 (0.56)
Robust LM test error			5.51 (0.02)
Plastics			
PAYT	0.13***	0.22***	0.13*
ln DEN	-0.05***	-0.23`	-0.43**
Over65	0.41**	2.33***	0.02
Under4	-6.19***	-1.05**	-0.62
Income	2.69***	2.81***	0.06
Within R^2	0.21	0.23	0.002
N	25 139	25 139	25 139
F statistics of the model (p-value)	1 325 (0.00)	1 295 (0.00)	9 (0.00)
F-test of significance of fixed effects (p-value)		11 (0.00)	
Breusch Pagan LM test 2 fix. effects χ^2 (p-value)			14 098 (0.00)
Paper			
PAYT	0.37***	0.07	0.06
ln DEN	0.33***	0.08	0.02
Over65	1.17***	3.17***	1.97
Under4	-9.22***	0.77	0.83
Income	3.50***	2.00***	0.78***
Within R^2	0.20	0.07	0.002
N	21 865	21 865	21 865
F statistics of the model (p-value)	1 125 (0.00)	266 (0.00)	8 (0.00)
F-test of significance of fixed effects (p-value)		13 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			2 896 (0.00)
Glass			
PAYT	0.24***	0.13**	0.11*
ln DEN	-0.06***	-0.47***	-0.55**
Over65	0.33*	1.93***	0.80
Under4	-5.39***	0.79	0.85
Income	1.97***	1.57***	0.05
Within R^2	0.13	0.10	0.004
N	24 974	24 974	24 974
F statistics of the model (p-value)	769 (0.00)	513 (0.00)	17 (0.00)
F-test of significance of fixed effects (p-value)		15 (0.00)	
Breusch Pagan LM test 2 fix. effects χ^2 (p-value)			592 (0.00)
Biowaste			
PAYT	0.07	-0.38*	-0.33**
ln DEN	0.06*	0.74`	0.63

Ln GARDEN	0.02	0.45	0.26
Over65	5.95***	0.81	-0.42
Under4	-1.36	1.44	-0.29
Income	1.50***	2.59***	0.89
Within R^2	0.06	0.07	0.003
N	6 042	6 042	6 042
F statistics of the model (p-value)	61 (0.00)	59 (0.00)	2 (0.05)
F-test of significance of fixed effects (p-value)		9 (0.00)	
Breusch Pagan LM test 2 fix. effects χ^2 (p-value)			272 (0.00)
Other sorted waste			
PAYT	0.07	-0.08	-0.13
ln DEN	0.04***	0.44`	0.34`
Over65	1.32***	5.51***	3.24**
Under4	-9.73***	0.25	0.43
Income	3.14***	2.75***	0.19
Within R^2	0.13	0.08	0.002
N	21 728	21 728	21 728
F statistics of the model (p-value)	658 (0.00)	342 (0.00)	6 (0.00)
F-test of significance of fixed effects (p-value)		6 (0.00)	
Breusch Pagan LM test 2 fix. effects χ^2 (p-value)			548 (0.00)

Significance level by t-values which are in (2) based on robust standard deviations grouped by municipalities, in (3) grouped by municipalities and years
*** p<0.001,** p<0.01, * p<0.05, `p<0.1

Source: IEP

Table 20: Spatial Durbin Model with two-way fixed effects of municipalities and years

	Estimated coefficients	Direct effect	Indirect effect	Total effect
Mixed municipal waste				
PAYT	-0.25***	-0.25***	-0.04***	-0.29***
ln DEN	-0.39***	-0.39***	-0.07***	-0.46***
Over65	-0.16	-0.15	-0.03	-0.18
Under4	0.33`	0.33*	0.06*	0.39*
Income	-0.11*	-0.11**	-0.02**	-0.13**
W PAYT*	-0.19***			
*W*ln DEN*	0.32***			
*W*Over65*	-0.33			
*W*Under4*	-0.53			
*W*Income*	0.13`			
R^2	0.78			
Wald lag	36.06 (0.00)			
Wald error	35.71 (0.00)			
Hausmann	1 377 (0.00)			
Plastics				
PAYT	0.13**	0.14**	0.10**	0.24**
ln DEN	-0.40***	-0.42***	-0.30***	-0.72***
Over65	0.33	0.34	0.25	0.59
Under4	-0.38	-0.40	-0.28	-0.68
Income	0.11	0.12	0.08	0.20
W PAYT*	-0.06			
*W*ln DEN*	0.16			
*W*Over65*	-0.84`			
*W*Under4*	-0.11			

*W*Income*	-0.03			
R^2	0.75			
Wald lag	5.83 (0.32)			
Wald error	1.94 (0.86)			
Hausmann	630 (0.00)			
Paper				
PAYT	0.11	0.11`	0.04`	0.15`
ln DEN	-0.15	-0.15	-0.05	-0.20
Over65	1.45***	1.47***	0.52***	1.99***
Under4	0.48	0.48	0.17	0.65
Income	0.07	0.07	0.03	0.10
W PAYT*	-0.15			
*W*ln DEN*	0.47*			
*W*Over65*	1.27			
*W*Under4*	0.98			
*W*Income*	1.29***			
R^2	0.76			
Wald lag	53.28 (0.00)			
Wald error	61.93 (0.00)			
Hausmann	289 (0.00)			
Glass				
PAYT	0.09*	0.09*	0.04*	0.13*
ln DEN	-0.56***	-0.57***	-0.22***	-0.79***
Over65	0.71**	0.72**	0.27**	0.99**
Under4	0.66*	0.67*	0.26*	0.93*
Income	0.13`	0.13`	0.05`	0.18`
W PAYT*	0.16`			
*W*ln DEN*	0.29*			
*W*Over65*	-0.16			
*W*Under4*	-0.79			
*W*Income*	-0.07			
R^2	0.74			
Wald lag	11.77 (0.04)			
Wald error	7.27 (0.20)			
Hausmann	1 340 (0.00)			

*** p<0.001,** p<0.01, * p<0.05, `p<0.1 *Source: IEP*

p-values for direct, indirect and total effects are simulated p-values according to LeSage and Pace (2009)

Table 21: Estimation of the effect of unit-based pricing types on waste production - non-spatial models

Fixed effects	(1) Without	(2) Municipalities	(3) Munic. +years
Mixed municipal waste			
Tag	-0.47***	-0.38***	-0.39***
VolumeFrequency	0.08***	-0.12*	-0.13**
ln DEN	0.13***	-0.29***	-0.31***
Over65	0.61***	0.06	-0.13
Under4	-4.16***	0.28	0.32
Income	0.96***	0.15***	-0.09
Within R^2	0.16	0.01	0.01
N	25 920	25 920	25 920
F statistics of the model (p-value)	807 (0.00)	34 (0.00)	32 (0.00)
F-test of significance of fixed effects (p-value)		22 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			16 (0.00)

Robust LM test lag			3.09 (0,08)
Robust LM test error			0.36 (0.55)
Plastics (balanced)			
Tag	0.31***	0.19*	0.09
VolumeFrequency	0.00	0.24*	0.19*
ln DEN	-0.05***	-0.22*	-0.43**
Over65	0.39**	2.28***	0.13
Under4	-6.07***	-0.88`	-0.57
Income	2.68***	2.69***	0.09
Within R^2	0.21	0.22	0.002
N	25 920	25 920	25 920
F statistics of the model (p-value)	1 149 (0.00)	1 053 (0.00)	8 (0.00)
F-test of significance of fixed effects (p-value)		10 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			12 312 (0.00)
Robust LM test lag			0.04 (0.84)
Robust LM test error			7.19 (0.00)
Paper (balanced)			
Tag	0.45***	0.17	0.17`
VolumeFrequency	0.31***	0.01	0.02
ln DEN	0.31***	0.13	0.10
Over65	1.42***	2.74***	1.98*
Under4	-7.91***	0.83	0.83
Income	3.16***	1.37***	0.49**
Within R^2	0.19	0.04	0.002
N	25 920	25 920	25 920
F statistics of the model (p-value)	992 (0.00)	160 (0.00)	8 (0.00)
F-test of significance of fixed effects (p-value)		17 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			6 491 (0.00)
Robust LM test lag			70.53 (0.00)
Robust LM test error			50.76 (0.00)
Glass (balanced)			
Tag	0.40***	0.13`	0.09
VolumeFrequency	0.12***	0.15**	0.14*
ln DEN	-0.06***	-0.42***	-0.51**
Over65	0.44***	1.79***	0.80
Under4	-4.91***	0.56	0.59
Income	1.97***	1.48***	0.12
Within R^2	0.14	0.09	0.003
N	25 920	25 920	25 920
F statistics of the model (p-value)	678 (0.00)	406 (0.00)	14 (0.00)
F-test of significance of fixed effects (p-value)		16 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			637 (0.00)
Robust LM test lag			0.35 (0.55)
Robust LM test error			5.55 (0.02)
Plastics			
Tag	0.29***	0.19*	0.07
VolumeFrequency	-0.004	0.25*	0.20*
ln DEN	-0.05***	-0.23`	-0.44**

Over65	0.39**	2.33***	0.02
Under4	-6.14***	-1.05`	-0.62
Income	2.71***	2.82***	0.06
Within R^2	0.21	0.23	0.002
N	25 139	25 139	25 139
F statistics of the model (p-value)	1 113 (0.00)	1 080 (0.00)	8 (0.00)
F-test of significance of fixed effects (p-value)		11 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			14 098 (0.00)
Paper			
Tag	0.45***	0.13	0.11
VolumeFrequency	0.31***	-0.006	0.00
ln DEN	0.34***	0.08	0.02
Over65	1.16***	3.17***	1.97
Under4	-9.19***	0.77	0.83
Income	3.51***	2.01***	0.78***
Within R^2	0.20	0.07	0.002
N	21 865	21 865	21 865
F statistics of the model (p-value)	938 (0.00)	221 (0.00)	7 (0.00)
F-test of significance of fixed effects (p-value)		12 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			2 941 (0.00)
Glass			
Tag	0.40***	0.12`	0.09
VolumeFrequency	0.12***	0.14*	0.13*
ln DEN	-0.06***	-0.47***	-0.55**
Over65	0.31*	1.94***	0.80
Under4	-5.35***	0.79	0.85
Income	1.98***	1.57***	0.05
Within R^2	0.13	0.10	0.004
N	24 974	24 974	24 974
F statistics of the model (p-value)	647 (0.00)	428 (0.00)	14 (0.00)
F-test of significance of fixed effects (p-value)		15 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			601 (0.00)
Biowaste			
Tag	-0.40**	-0.44	-0.47
VolumeFrequency	0.30**	-0.35	-0.27
ln DEN	0.05	0.74`	0.62`
Ln GARDEN	0.02	0.44	0.26
Over65	6.09***	0.81	-0.43
Under4	-1.63	1.41	-0.35
Income	1.47***	2.60***	0.88*
Within R^2	0.06	0.07	0.003
N	6 042	6 042	6 042
F statistics of the model (p-value)	56 (0.00)	50 (0.00)	2 (0.08)
F-test of significance of fixed effects (p-value)		9 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			289 (0.00)
Another sorted waste			
Tag	0.23***	0.04	-0.01
VolumeFrequency	-0.07	-0.23	-0.27

ln DEN	0.04***	0.44*	0.34
Over65	1.30***	5.51***	3.23**
Under4	-9.68***	0.25	0.43
Income	3.15***	2.76***	0.19
Within R^2	0.13	0.08	0.002
N	21 728	21 728	21 725
F statistics of the model (p-value)	551 (0.00)	285 (0.00)	5 (0.00)
F-test of significance of fixed effects (p-value)		6 (0.00)	
Breusch Pagan LM test of time fix. effects χ^2 (p-value)			545 (0.00)

Significance level by t-values which are in (2) based on robust standard deviations grouped by municipalities, in (3) grouped by municipalities and years
*** p<0.001,** p<0.01, * p<0.05, `p<0.1

Source: IEP

Table 22: Spatial Durbin Model with fixed effects of municipalities and years (unit-based pricing types)

	Estimated coefficients	Direct effect	Indirect effect	Total effect
Mixed municipal waste				
Tag	-0.37***	-0.37***	-0.06***	-0.43***
VolumeFrequency	-0.12**	-0.12***	-0.02***	-0.14***
ln DEN	-0.39***	-0.39***	-0.07***	-0.45***
Over65	-0.15	-0.15	-0.03	0.18
Under4	0.33`	0.33`	0.06`	0.39`
Income	-0.11*	-0.11***	-0.02***	-0.13***
W Tag*	-0.08			
*W*VolumeFrequency*	-0.13`			
*W*ln DEN*	0.29***			
*W*Over65*	-0.31			
*W*Under4*	-0.54			
*W*Income*	0.12			
R^2	0.78			
Wald lag	37.52 (0.00)			
Wald error	38.84 (0.00)			
Hausmann	1 246 (0.00)			
Plastics				
Tag	0.07	0.08	0.05	0.13
VolumeFrequency	0.21***	0.21***	0.16***	0.37***
ln DEN	-0.39***	-0.42***	-0.30***	-0.72***
Over65	0.33	0.34	0.25	0.59
Under4	-0.38	-0.39	-0.29	-0.68
Income	0.11	0.12	0.08	0.20
W Tag*	0.09			
*W*VolumeFrequency*	-0.22`			
*W*ln DEN*	0.17			
*W*Over65*	-0.84`			
*W*Under4*	-0.09			
*W*Income*	-0.02			
R^2	0.75			
Wald lag	8.90 (0.18)			
Wald error	4.00 (0.67)			
Hausmann	636 (0.00)			
Paper				
Tag	0.19*	0.10`	0.03`	0.13`
VolumeFrequency	0.02	0.10	0.03	0.13
ln DEN	-0.14	0.11	0.04	0.15

Over65	1.45***	0.38***	0.14***	0.52***
Under4	0.48	0.47	0.16	0.63
Income	0.07	0.13	0.04	0.17
W Tag*	-0.04			
*W*VolumeFrequency*	-0.23			
*W*ln DEN*	0.48**			
*W*Over65*	1.26			
*W*Under4*	1.01			
*W*Income*	1.31***			
R^2	0.76			
Wald lag	54.39 (0.00)			
Wald error	63.17 (0.00)			
Hausmann	289 (0.00)			
Glass				
Tag	0.07	0.07	0.03	0.10
VolumeFrequency	0.12`	0.12`	0.04`	0.16`
ln DEN	-0.56***	-0.57***	-0.22***	-0.78***
Over65	0.71**	0.72**	0.27**	0.99**
Under4	0.66*	0.68*	0.25*	0.93*
Income	0.13`	0.13`	0.05`	0.18`
W Tag*	0.21`			
*W*VolumeFrequency*	0.11`			
*W*ln DEN*	0.30*			
*W*Over65*	-0.16			
*W*Under4*	-0.78			
*W*Income*	-0.07			
R^2	0.74			
Wald lag	12.99 (0.04)			
Wald error	7.48 (0.28)			
Hausmann	1 397 (0.00)			

*** p<0.001,** p<0.01, * p<0.05, `p<0.1 *Source: IEP*

p-values for direct, indirect and total effects are simulated p-values according to LeSage and Pace (2009)

Calculation of Direct, Indirect and Overall Effects

While linear regression coefficients have a direct interpretation, in models containing a spatial dependency of an explanatory or dependent variable, the interpretation is more complicated. The spatial models include information from neighbouring observations or municipalities. The Spatial Durbin Model can be written in the form of

$$Y_{it} = \rho W Y_{it} + \alpha_{0i} + \alpha_{1t} + \beta X_{it} + \theta W X_{it} + \varepsilon_{it}$$
$$Y_{it} = (I - \rho W)^{-1}(\beta X_{it} + \theta W X_{it}) + (I - \rho W)^{-1}\alpha_{0i} + (I - \rho W)^{-1}\alpha_{1t} + (I - \rho W)^{-1}\varepsilon_{it} \quad (10)$$

With the partial derivation of both sides of the equation according to the k-th explanatory variable X (x_{ik} pre i=1,...,N) we get

$$\left[\frac{\partial Y}{\partial x_{1k}} \cdots \frac{\partial Y}{\partial x_{Nk}}\right] = \begin{bmatrix} \frac{\partial y_1}{\partial x_{1k}} & \cdots & \frac{\partial y_1}{\partial x_{Nk}} \\ \vdots & \ddots & \vdots \\ \frac{\partial y_N}{\partial x_{1k}} & \cdots & \frac{\partial y_N}{\partial x_{Nk}} \end{bmatrix}$$
$$= (I - \rho W)^{-1} \begin{bmatrix} \beta_k & w_{12}\theta_k & \cdots & w_{1N}\theta_k \\ w_{21}\theta_k & \beta_k & \cdots & \vdots \\ \vdots & \cdots & \ddots & \cdots \\ w_{N1}\theta_k & w_{N2}\theta_k & \cdots & \beta_k \end{bmatrix} \quad (11)$$

Where w_{ij} je (i, j) is a spatial matrix element W. The direct effect is defined as the sum of the elements on the diagonal of the matrix, the indirect effect is defined as the diameter of the elements outside the diagonal (Lesage and Pace,2009). The overall effect is the sum of both the direct and indirect effects.

The estimated indirect effects of the explanatory variables should be used to test the hypothesis that there is a spatial spill-over effect, i.e. the neighbouring regions interact with each other. Since indirect effects are composed of different coefficient estimates due to complex mathematical formulae, it is not possible to test the significance of the spatial spill-over effect from the relevant standard deviations and t-values. To assess the statistical significance of direct and indirect effects, Lesage and Pace (2009) propose a simulation of the distribution of direct and indirect effects using a covariance matrix estimated by the Maximum Likelihood method.

Test for Endogeneity

Table 23: First degree of regression

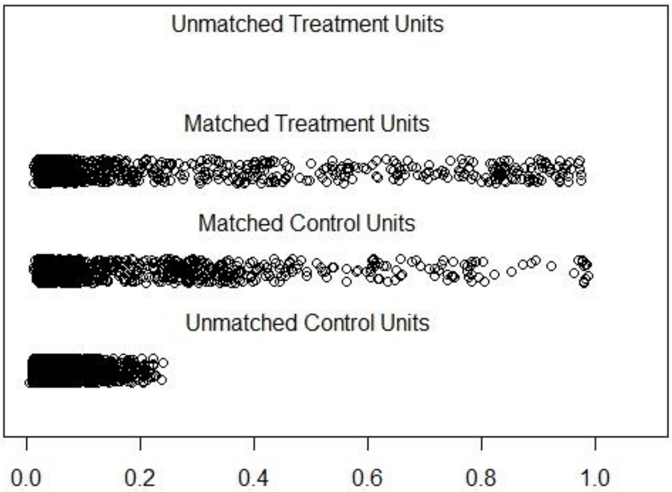
	Estimated coefficient
PAYTYN	0.19***
ln DEN	0.55***
Over65	0.90***
Under4	0.17
Income	0.26***
F-test of significance PAYTYN (p-value)	738 (0.00)
R^2	0.002
N	25 146

Source: IEP

Annex 2: Propensity Score Matching

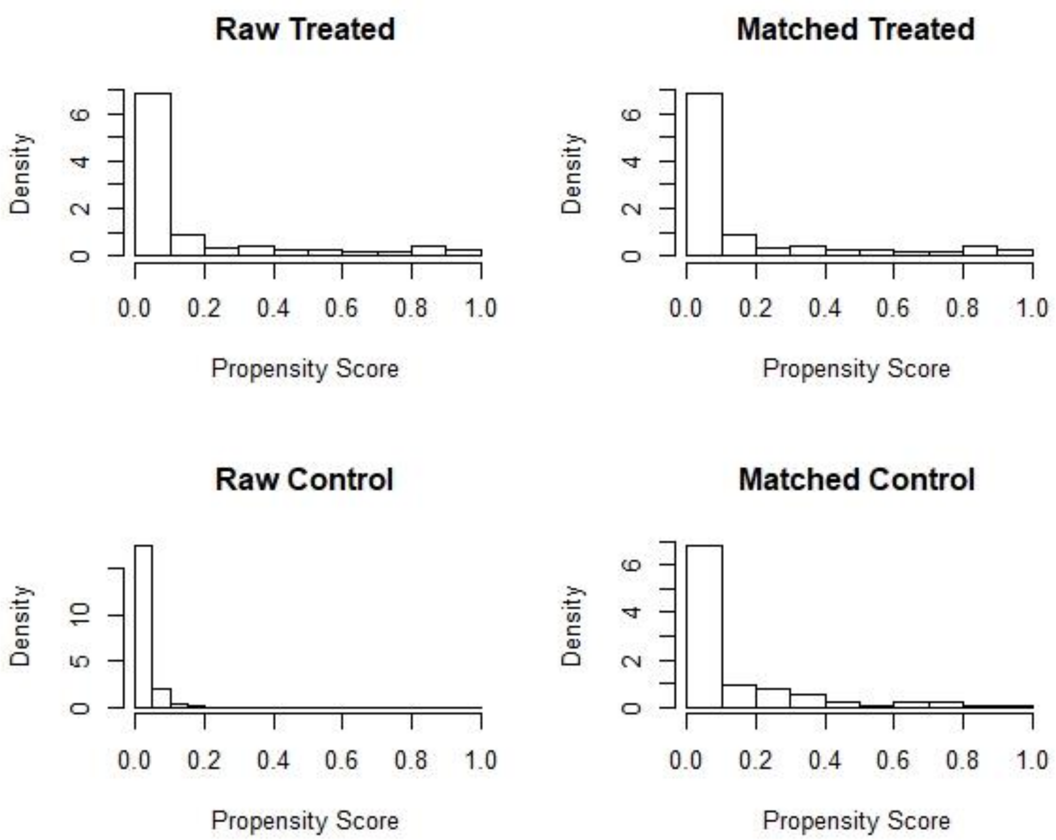
Common Support Region Analysis

Graph 2: Distribution of probabilities before and after matching of municipalities



Source: IEP

Graph 3: Histogram of probabilities before and after matching of municipalities



**Raw Treated – municipalities with unit-based pricing before matching, Matched Treated – municipalities with unit-based pricing after matching*

Source: IEP

Raw Control – municipalities with a flat fee before matching, Raw Treated – municipalities with a flat fee after matching

Evaluation of the Balance Achieved

Table 24: Verification of the balance by calculations

		Average		Normalized differences of avg. values
		Treated	Control	
$\sum d_{ij}\, PAYT_{jt-1}$	unmatched	0.176	0.036	86%
	matched	0.176	0.156	9%
DEN	unmatched	4.014	4.248	25%
	matched	4.193	4.248	6%
Under3	unmatched	0.051	0.053	8%
	matched	0.052	0.053	4%
Over65	unmatched	0.149	0.154	8%
	matched	0.149	0.149	1%
Income1000	unmatched	0.483	0.561	52%
	matched	0.546	0.561	10%

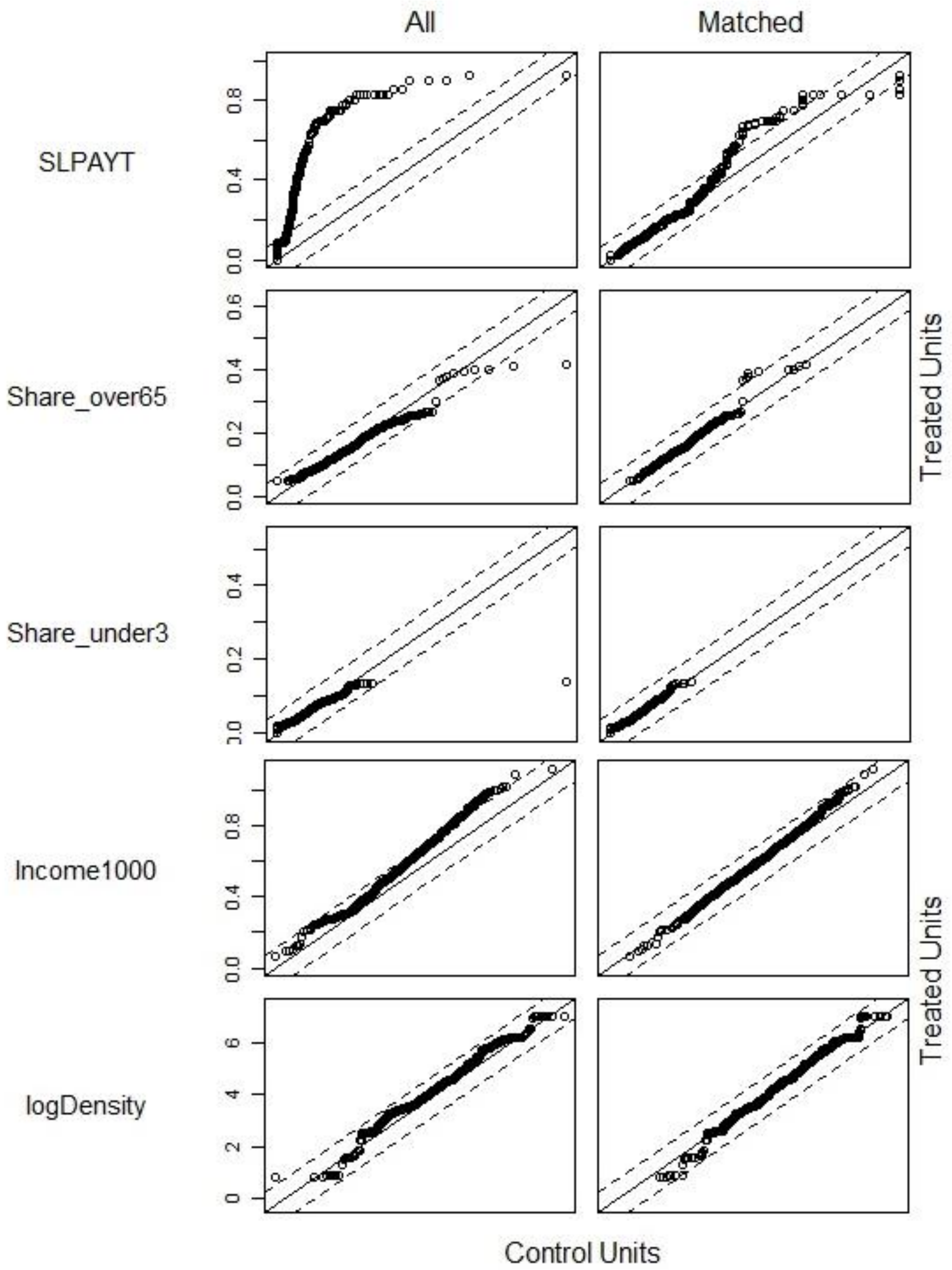
Source: IEP

Table 25: Chi-squared test

	Chi-squared	p-value
Unmatched data	3 130	0.00
Matched data	9.7	0.08

Source: IEP

Graph 4: Visual inspection of the balance achieved



Source: IEP

Sensitivity Analysis

Table 26: Rosenbaum Sensitivity Test

	p-value for Gamma		Point estimate		Equivalent of implicit bias
Gamma	Lower limit	Upper limit	Lower limit	Upper limit	Income1000
Mixed municipal waste					
1	0	0	-0.22	-0.22	0
1.1	0	0	-0.32	-0.12	0.06
1.2	0	0	-0.32	-0.12	0.12
1.3	0	0	-0.32	-0.12	0.18
1.4	0	0	-0.41	-0.02	0.23
1.5	0	0	-0.41	-0.02	0.28
1.6	0	0	-0.41	-0.02	0.32
1.7	0	0	-0.41	-0.02	0.36
1.8	0	0.03	-0.41	-0.02	0.40
1.9	**0**	**0.15**	**-0.52**	**-0.02**	**0.44**
2.0	0	0.38	-0.52	0.08	0.48
Plastics					
1	0	0	0.18	0.18	0
1.1	0	0	0.08	0.28	0.06
1.2	0	0	0.08	0.28	0.12
1.3	**0**	**0.05**	**-0.02**	**0.38**	**0.18**
1.4	0	0.30	-0.02	0.38	0.23
1.5	0	0.69	-0.02	0.38	0.28
1.6	0	0.93	-0.12	0.48	0.32
1.7	0	0.99	-0.12	0.48	0.36
1.8	0	0.99	-0.12	0.48	0.40
1.9	0	1	-0.22	0.58	0.44
2.0	0	1	-0.22	0.58	0.48
Glass					
1	0	0	0.18	0.18	0
1.1	0	0	0.07	0.27	0.06
1.2	0	0	0.07	0.27	0.12
1.3	0	0	-0.02	0.37	0.18
1.4	0	0.04	-0.02	0.37	0.23
1.5	**0**	**0.26**	**-0.02**	**0.37**	**0.28**
1.6	0	0.62	-0.02	0.37	0.32
1.7	0	0.88	-0.12	0.47	0.36
1.8	0	0.98	-0.12	0.47	0.40
1.9	0	0.99	-0.12	0.47	0.44
2.0	0	0.99	-0.12	0.47	0.48
Paper					
1	0	0	0.23	0.23	0
1.1	0	0	0.14	0.34	0.06
1.2	0	0.01	0.04	0.44	0.12
1.3	**0**	**0.15**	**0.04**	**0.44**	**0.18**
1.4	0	0.53	-0.06	0.54	0.23
1.5	0	0.86	-0.06	0.54	0.28
1.6	0	0.98	-0.16	0.64	0.32
1.7	0	0.99	-0.16	0.64	0.36
1.8	0	0.99	-0.25	0.74	0.40
1.9	0	1	-0.25	0.74	0.44
2.0	0	1	-0.26	0.74	0.48

Source: IEP

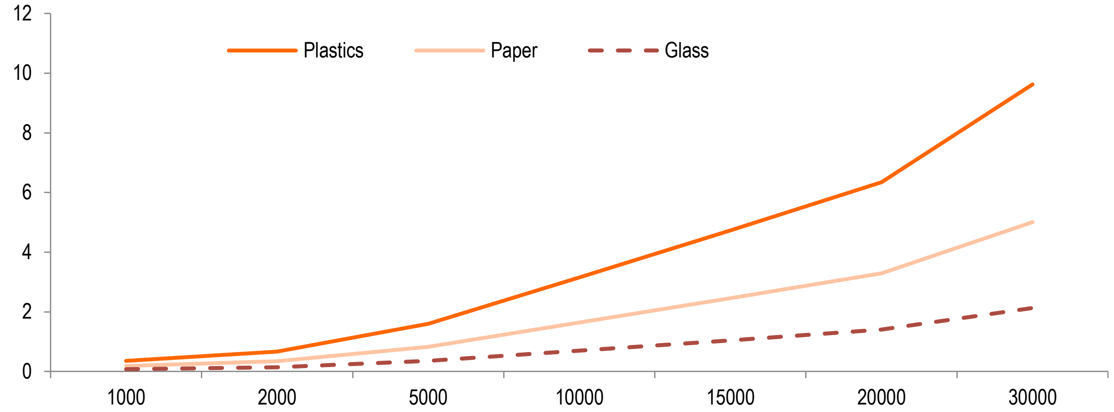
Annex 3: Costs of Separate Collection

The activity reports of producer responsibility organizations that finance separate collection provide data on the amount of waste collected and the amount of net collection and recovery costs between 2016 and 2018. We have estimated the cost curve for separate collection from these data based on the amount collected.

The Naturpack company has provided us with net cost data by material type that varies significantly. The cost of collecting one tonne of plastic is up to 4 times higher than glass collection costs and 2 times higher than paper collection costs. This is due to a lower purchase price for plastics as well as higher costs for plastic collection due to a large volume and low weight compared to other materials.

To calculate the cost by the type of material, we assumed that the slope of the curve is the same for each material and differs only by the value of the constant that we calculated from the Naturpack data.

Graph 5: Net costs of separate collection (mil. EUR)



Source: Estimation of IEP on the basis of reports from PROs

Annex 4: Cost of home composters

Table 27: Market research on garden composters

	Price	Capacity (in litres)	Life cycle (years)	Costs (EUR/year)
				4
Prosperplast 380	25	380	3	8
Prosperplast 400	32	400	3	11
Jelinek Trading K 290	44	300	10	4
Prosperplast 600	45	600	3	15
Jelinek Trading K 390	49	390	10	5
Prosperplast 800	55	800	3	18
Jelinek Trading K 400	57	400	10	6
JRK PREMIUM 335	85	335	20	4
Jelinek Trading K 700	90	720	10	9
JRK PREMIUM 445	95	445	20	5
JRK PREMIUM 650	149	650	20	7
JRK PREMIUM 800	159	800	20	8
JRK PREMIUM 1050	176	1050	20	9
JRK PREMIUM 2000	371	2000	20	19
Average	**100**	**632**	**13**	**9**

Source: IEP based on www.zemito.sk