Examining the Price Incentive Effect on Waste Generation: the Volume Based Waste Fee system in Korea

By

KANG, Aerim

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Committee in charge:

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ABSTRACT

EXAMINING THE PRICE INCENTIVE EFFECT ON WASTE GENERATION: THE VOLUME BASED WASTE FEE SYSTEM IN KOREA

By

KANG, Aerim

The Volume Based Waste Fee (VBWF) system aims to reduce household solid waste and encourage voluntary recycling by giving a price incentive to households. In this paper, I conduct a fixed-effect analysis to estimate the price incentive effect of the VBWF system on household waste generation. By analysing a 12-year panel data set, the results show that for a 1% increase in the average price of standard waste bags, household solid waste decreases by 0.162%. However, the estimates on recycling and illegal waste disposal do not present statistically significant results. Moreover, after dividing the samples into sub-groups, the results indicate that the price elasticity of collecting household solid waste is higher in less urbanised and rural areas than urban areas. It suggests that local governments should exploit different policy strategies depending on regional characteristics.

Keywords: Volume Based Waste Fee system, VBWF, price incentive, household solid waste, recycling, waste management, fixed-effect, Korea

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1. Introduction

It has been 25 years since South Korea (hereinafter Korea) implemented the Volume Based Waste Fee (VBWF) system in 1995 on a national scale. The VBWF system aims to reduce the amount of waste generated, encourage voluntary recycling, and improve fiscal soundness in the waste management sector. There are numerous factors in the generation of household waste and separate discharge of recyclables. In a broad context, waste generation and recycling are affected by industries, population, urbanisation (Ministry of Strategy and Finance & Korea Research Institute for Human Settlements, 2016; van Beukering et al., 2009), government policies (Hong, 2015; Korea Economic Institute, 2011), economic development and global environmental responses (Kaza et al., 2018). At an individual level, various surrounding factors, such as level of income (Chu et al., 2019; Jaligot & Chenal, 2018), housing style, changes in consumption pattern (Hong, 2015; Oh, 2006; Lee, 1996), and the number of family members (Ministry of Environment, 2014), affect household waste generation and recycling.

Waste management is one of the most serious global environmental issues, and it requires the efforts of both government and society (OECD 2019; Kaza et al., 2018). There is commonly a positive correlation between waste generation and economic growth. Kaza et al. (2018) predict that the amount of global waste could reach 3.40 billion tonnes by 2050 as the global income level increases. In particular, daily waste generation per capita in low- and middle-income countries is expected to rise by about 40 per cent or more, which is more than two times higher than that of high-income countries. According to Kaza et al. (2018), lower-income countries send 93 per cent of waste to open dumps, while high-income countries send only 2 per cent. Such a gap comes from the absence of adequate waste management systems and facilities in low- and middle-income countries. This indeed calls for special measures to be taken - for example, reducing waste generation and establishing well-managed recycling systems, incineration facilities, and landfill areas. However, taking such measures usually requires a massive budget, which is one of the most significant obstacles that lower-income countries face. In this respect, the polluter-pays waste fee system is considered an appropriate tool for not only generating government revenue for waste management, but also for encouraging individuals to reduce waste generation and recycle more (Ministry of Strategy and Finance & Korea Research Institute for Human Settlements, 2016; Korea Environment Institute, 2011).

In 1995, the year of enforcement of the VBWF system, Korea was experiencing rapid economic and social changes. As income levels get higher and cities become more urbanised, waste management becomes more critical (Chu et al., 2019; Jaligot & Chenal, 2018; Usui & Takeuchi, 2014; van Beukering et al., 2009). The VBWF system has seen some steady success in waste reduction over the years. Evidence shows that total household waste per capita per day decreased from 1.07 kg in 1995 -the year the new system was enforced- to 0.87 kg[1] in 2017. During the same period, the landfill ratio also decreased from 72.3% to 13.8%[2], while the recycling ratio increased from 23.7% to 59.5%[3] (Korea Environment Institute, 2011). Early studies evaluated the VBWF system positively as it had reduced waste generation, increased recycling (Kim et al., 1997; Lee, 1996), and increased the financial autonomy of local governments' waste management (Korea Environment Institute, 2011). However, later studies have shown that the effect of waste reduction was overestimated because early studies did not take into account trends of waste reduction in the 90s, as well

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[1] Total household waste per population: 45,008.9 (tonnes) / 51,778,544. Environmental Statistics (2017). In this study, total household waste is the sum of household solid waste and recyclable resources.

[2] Landfill waste out of household waste generation: 6,229.1 / 45,008.9 (tonnes). Environmental Statistics (2017).

[3] Recyclables out of total household waste: 26,763.1 / 45,008.9 (tonnes). Environmental Statistics (2017).

as other side effects, such as illegal dumping and incineration (Park, 2009; Oh, 2006; Hong, 2001; Park, 2000).

The aim of this paper is to estimate the continuing price incentive effect of the VBWF system in recent years on household waste reduction and recycling increases, by using up to date 12-year panel data of all administrative districts in Korea at the municipal level. To eliminate the influence of other factors on the results, related demographic and economic factors are controlled for. Also, to determine the negative balloon effect driven by the VBWF system, such as illegal waste disposal, the sum of illegal dumping and burning cases is used as an additional dependent variable. Throughout the analysis, this study is expected to contribute to effective waste management by offering policymakers rigorous statistics on the effect of the VBWF on households' recycling and waste reduction behaviour.

Overall, the results show that the amount of household solid waste reduces by 0.162% when the price of standard waste bags increases by 1%. This pattern appears to be constant in the robustness check using different levels of controls and dependent variables. In contrast, recyclables and illegal waste disposal show no statistical significance in both the main regression and robustness check. It recommends that local governments should exploit different policy strategies to stimulate recycling among households. In addition, the price elasticity of collecting household solid waste is varying among sub-groups. It implies the need of specialised policy strategies depending on regional characteristics.

This paper begins by providing a background of the VBWF system and the current waste management status in Korea. Section 3 reviews previous studies of the price incentive effect on waste generation. Section 4 and 5 define data, illustrate summary statistics, and present the analysis model and related empirical strategies. Section 6 demonstrates the results of the fixed effect analysis, both in total and by sub-groups, and robustness checks. The final section discusses the results in relation to previous studies and provides conclusions.

2. Background

2.1. *The Volume Based Waste Fee (VBWF) System in Korea*

The VBWF system went into effect nationwide at the beginning of 1995, in replacement of the previous fixed-fee system. Formerly, the fixed-fee was imposed based on building areas or property taxes rather than the actual amount of waste discharged. As the fixed-fee was determined irrespective of the actual amount of waste, households did not have an incentive to reduce the quantity of waste generated and separately discharge recyclable resources (Ministry of Strategy and Finance & Korea Research Institute for Human Settlements, 2016). On the other hand, the current VBWF system applies the polluter-pays principle by imposing some portion of the waste management cost to individual waste dischargers through purchasing standard waste bags. This is in line with the Pigouvian tax, which is a tax to reduce negative externalities resulting from any market activity by internalising negative externalities into the private cost (Krugman et al., 2005). In the Korean case, through the internalisation of the social cost for waste management[4] into the private waste disposal cost, the VBWF system is intended to induce voluntary waste reduction and promote separate discharge of recyclable resources (Wastes Control Act, 2020). To further stimulate this behaviour, local governments collect recyclable resources for free; it provides more incentive to households to separately discharge recyclables and reduce the amount of waste discharged using standard waste bags as far as possible in order to save private waste disposal cost (Ministry of Strategy and Finance &

[4] Waste management refers to the whole process of waste collection, transportation, cleaning, and disposal.

Korea Research Institute for Human Settlements, 2016).

Currently, the VBWF system applies to all administrative areas in Korea. The country is divided into three levels of administrative districts. The highest is the metropolitan level, which is composed of two special cities (*si*), six metropolitan cities (*si*), and nine provinces (*do*). At the municipal level, general cities (*si*) and counties (*gun/gu*) make the second levels of administrative districts. Communities and villages (*eup/myeon/dong*) are the third levels of administrative districts.

Each municipality manufactures standard waste bags in various sizes. The selling price of standard waste bags[5] is based on (1) the production cost, (2) the waste management cost, and (3) the target ratio of revenue-to-expenditure in local governments' waste management (Resident burden[6]) (Ministry of Environment, 2019). Waste management cost may differ depending on the characteristics of each municipality, such as dwelling density, waste management facilities[7], geographical characteristics, and the proportion of urban areas (Ministry of Environment, 2014; Lee, 1996). In cities with high-density dwellings or where the distance between houses is short, waste collection and transportation costs are relatively lower than in areas that are otherwise (Korea Environment Institute, 2018).

In addition to reducing waste and increasing recycling, the VBWF system is intended to improve the financial autonomy of local governments[8] in the waste management sector by

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[5] The selling price of each size of standard waste bags = (Waste management cost per litre × Volume of the bag ＋ Production cost) × Target ratio of residents burden ＋ Sales fee

[6] Resident burden (%) = (Tax revenue from sales of garbage bags / Expenses incurred in waste collection, transportation, and disposal) × 100. Tax revenue from sales of garbage bags shall be calculated excluding expenses incurred in selling garbage bags.

[7] Such as incineration facilities and landfill areas

[8] Financial autonomy = (Total waste-fee revenue + Incidental income of recyclables sales and etc.) / Total waste management cost. (Ministry of Environment, 2019)

generating revenues through the sales of standard waste bags. To improve financial autonomy, local governments need to reduce waste management costs or increase waste-fee revenue and sales revenue of recyclables. According to the Ministry of Environment (2014), the accumulated reduction in waste generation compared to Business As Usual (BAU) reached about 103 billion tonnes between 1995 and 2012. During the same period, the total accumulated economic benefits of reducing waste management costs and selling recyclables amounted to at least[9] KRW 19,560 billion, composed of KRW 14,830 billion from waste reduction and KRW 4,730 billion from selling recyclables. Yang et al. (2014) also calculated the present value of waste disposal reduction costs, setting 2009 as the base year. The authors stated that the total accumulated savings reached KRW 19,419 billion. As of 2017, the financial autonomy rate in the waste management sector was 32.53%[10]. It means that 32.53% of the waste management process is covered by the revenue from the waste-fee system.

2.2. *Classification of Waste and Waste Collection System*

The Korean government classifies waste into six main categories and applies different waste-fee systems: household waste, food waste, large-size waste, industrial waste, construction waste, and recyclable resources (Wastes Control Act, 2020, article 14). The VBWF system applies to household waste, some industrial waste[11], and food waste. Individuals

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[9] It is because only 5 items were included in the calculation: paper, glass bottles, cans, plastics, and scrap metal. If all other recycled materials were included in the calculation, the accumulated economic value derived from recycling would be increased (Ministry of Environment, 2014).

[10] Korean Statistical Information Service (KOSIS). (2020, June 12). *Financial autonomy rate in the waste management* (2017) [Data set]. http://kosis.kr/statHtml/statHtml.do?orgId=106&tblId=DT_106N_26_0200006&conn_path=I3

[11] Industrial wastes are divided into two parts: general wastes that have similar features to household waste and others. The VBWF system applies to industrial general wastes only. Other wastes are managed by stricter waste management standards.

are obliged to discharge each type of waste using specialised standard waste bags. In the case of large waste items, such as furniture, domestic electronic equipment and construction waste, additional costs are charged because of the relatively large size of the waste items. On the contrary, recyclables are collected for free by local governments to encourage voluntary waste separation (Wastes Control Act, 2020, article 14).

Among the abovementioned types of waste generation, this paper focuses on the price incentive effect of the VBWF system on household waste generation. There are three components constituting household waste: household solid waste, recyclable resources, and wet food waste. Household solid waste refers to materials that are not suitable for recycling. For example, fruit and vegetable rinds, animal bones, and hard fruit seeds are included in household solid waste, rather than as food waste. Contaminated papers and plastics are also classified as household solid waste since they are not recyclable either. When it comes to the discharge of recyclables[12], it is necessary to wash, dry, and separately discharge these items by the appropriate types of waste (Act on the Promotion of Saving and Recycling of Resources, 2020). By definition, recyclable resources refer to products or by-products which are reusable with or without reconditioning. Reconditioning means repairing the products as well as the recoverable energy and waste heat (Act on the Promotion of Saving and Recycling of Resources, 2020). After implementing the Ban on Direct Landfilling of Food Waste (2005), wet food waste is separately aggregated and managed using standard food waste bags or food waste RFID boxes.

[12] In principle, recyclables shall be separately discharged and collected by types: paper, plastic, cans, bottles, scrap metal, etc. In addition, batteries, fluorescent lights, electronic devices, and styrofoam are also collected separately in communal residential areas. The main method of discharge is to put recyclables in transparent plastic bags and discharge them at designated place or front door. After removing foreign substances, recyclables are discharged into the form of lumps by each type through compression, and these products can be reused as recycled raw materials. Products such as PET bottles and glass bottles can be collected and recycled by the producers (Korea Environment Institute, 2011).

Households are obliged to discharge household waste at a designated time and place, such as household front doors or selected collection points. The Ministry of Environment (2018) reported that approximately 80% of municipal waste, including recyclables and non-recyclables, were from door-to-door collection and 20% from dedicated collection points, as of 2017. In communal residential areas, such as apartment and studio flat complexes, wastes are generally discarded at certain waste collection points, while for detached-housing it is at each resident's front door. On the other hand, in remote areas of agricultural and fishing villages, where door-to-door waste collection is hard due to the low housing density, a village-based VBWF system is applied to facilitate collection. In such cases, vacant lots in villages are often designated as a collection point. Therefore, under the village-based VBWF system, household wastes are jointly collected by village unit and the system also distributes the disposal costs according to the amount of collection (Ministry of Environment, 2018). Local governments designate different days of the week to collect recyclables and solid waste, respectively, to prevent them from being mixed (Korea Environment Institute, 2011).

After collecting household waste, local governments transport it to appropriate waste management facilities, and household waste is managed through landfill, incineration, and recycling. In general, resource recovery facilities manage recyclable resources, incineration facilities manage flammable solid waste, and landfill areas handle non-flammable waste and incineration residues (Guidelines for Implementing the VBWF System, 2019). Between 1996 and 2017, the landfill ratio has decreased from 68.9% to 13.8%, while the recycling ratio has increased from 26% to 59.5%. The incineration rate also has increased from 5.1% to 26.7%[13].

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[13] Environmental Statistics. (2017). *Status of Waste Generation and Treatment* and *Status of the VBWF system* [Data set].
http://stat.me.go.kr/nesis/mesp/stat/branch/branchStat.do?task=I&leftMenu=stat&menu_id=106H_01_006

3. Literature Review

In the early stage of the VBWF system, several studies (e.g., Kim et al., 1997; Lee, 1996) found that the implementation of the VBWF system in 1995 remarkably reduced waste generation and increased the amount of separately discharged recyclables at the same time. However, there are also critiques arguing that the early studies overestimated the effect of the VBWF system and that there were omitted variables, such as lifestyle changes and illegal waste disposal (Park, 2009; Oh, 2006; Hong, 2001). Also, other studies have employed a fixed-effects model to analyse the price incentive effect (Hong, 2015; Kim et al., 2011; Seo & Jung, 2007). Although the fixed-effects analyses found some positive incentive effects on recycling increases and waste reduction, the results are either at a lower significance level or found a relatively small effect compared to the earlier studies.

The typical strategy used by the earlier studies was to compare the amount of waste before and after the enforcement of the VBWF system in 1995. According to the Korea Environment Institute (2011), total daily waste generation decreased from 58,118 tonnes to 47,774 tonnes between 1994 and 1995, approximately a 20% decrease after the implementation of the VBWF system. During the same period, Lee (1996) found that daily solid waste reduced by 26.7% from 49,191 tonnes to 36,052 tonnes and recyclables increased by 34.8% from 8,927 tonnes to 12,039 tonnes. Additionally, he conducted a sub-group analysis by dividing areas into two groups: metropolitan cities and metropolitan provinces. The results showed that metropolitan provinces, composed of small- and -medium-sized cities and counties, had a higher reduction ratio of 31.7% than that of metropolitan cities, 21.4%. He claimed that illegal waste dumping and burning in the areas with weak monitoring systems might have caused the differences between the sub-groups. In a later study, Kim (2008) also argued that regional characteristics need to be considered to implement waste management policy.

Kim et al. (1997) conducted a before-and-after study to analyse the effect of the VBWF system. They found that average bulk density[14] increased from 158.4kg/m^3 in 1994 to 161.9kg/m^3 in 1995. Moreover, dwelling areas showed a higher average bulk density than the average in total. They assumed that households started to separately discharge recyclables more carefully after the enforcement of the VBWF system. Also, they pointed out that the characteristics of recyclables, i.e., relatively light bulk density, could be another contributing factor to increasing bulk density in dwelling areas.

However, Hong (2001) argues that the overall trend of waste generation is not entirely due to the VBWF system, but rather multiple other economic and social factors. Thus, this requires the price incentive effect to be distinguished from other factors. For example, it is argued that the most significant contribution to waste reduction in the 90s was the reduction of briquette ash ('yeontan'[15]) and food waste due to economic growth and lifestyle changes (Oh, 2006; Hong, 2001; Lee, 1996). According to Andrei Lankov (2007), in 1988, 77.8% of all Korean households used yeontan, however, it had rapidly dropped to 32.8% by 1993. In 2001, only about 1.5% of households were still using yeontan. The proportion of briquettes ash among household waste was 1.2% in 2006[16]. After that time, the briquettes ash category was removed because the portion was too low to report separately. In addition, since 2006, food waste has been separately and independently disposed from general waste (Wastes Control Act, 2019). Another possible factor affecting waste generation is illegal waste disposal. According to Kim and Kelleher (2004), a 1% increase in the price of the standard waste bag yields a 0.5% increase in reports of illegal waste dumping.

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[14] The average bulk density = weight of sample waste (kg) / volume of the container (m^3)

[15] Yeontan is coal briquettes used for cooking and home heating.

[16] 502 out of 40,899.6 tonnes (1.22%). Status of waste generation and treatment (MOE).

Hong (2001) analysed the effect of price incentives using panel data of 62 cities with control variables[17]. He stated that the estimate on household solid waste reduction was not statistically significant, while the estimate on the increase of recyclables was statistically significant at the level of 5%. Oh (2006) also claimed that waste reduction is not the fruit of the introduction of the VBWF system alone. She found trends of already declining waste disposal before 1995 and argued that the phenomenon began to ease after the system was introduced. Park (2009) measured the effect of the VBWF system on reducing waste amounts through a simple time-series intervention model analysis. The analysis showed that the introduction of the VBWF system caused about a 2.8% household waste reduction at a 90% confidence level. However, Park's (2009) study appears to have left out important aspects like regional characteristics, e.g., a wide gap in the level of income and lifestyle between different regions.

Having discussed the early stage studies and potential bias issues, this paper will turn to recent studies which have adopted the fixed-effects analyses. Seo and Jung (2007) conducted a fixed-effects analysis using 650 observations from 1995 to 2004. They controlled for variables such as district areas (m^2), household consumption, the ratio of the elderly (over 65-years-old), education level (university or beyond), waste management budget, and year. The results indicated that recyclables increased while landfill disposal decreased when the unit price rose. However, their study covered only some parts of Korea, and it used the price of a 20-litre standard waste bag as a proxy for the price. On the other hand, Hong (2015) makes meaningful contributions as he conducts a study on the price incentive effect of the VBWF system on a national scale, covering all second-level administrative districts. He finds that an increase in

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[17] Hong (2001) controlled population density, level of education, Gross Regional Domestic Products (GRDP), waste management budget per capita, and regional dummies.

unit price reduces the amount of household solid waste, whereas it increases the amount of food waste and recyclables. Nevertheless, as the unit price increase contributes to a rise in the total quantity of household waste, he suggests the possibility of feedback effects from the increase in recycling, separate discharge of food waste, and illegal waste disposal.

In the previous studies, the price of the most popular 20-litre standard waste bags was used as a proxy for an independent variable to analyse the price incentive effect of the VBWF system. However, this would not reflect the fact that the price becomes cheaper when the size gets larger. This would in fact provide ‘additional’ price incentives to customers. Therefore, in this study, the average price per litre is calculated by arithmetically averaging the price of each size of standard waste bags. For an additional dependent variable, illegal waste disposal is used as a proxy for illegally disposed household waste to complement the limitations observed in the previous studies. Illegal waste disposal is one of the adverse balloon effects caused by the VBWF system (Oh, 2006; Kim & Kelleher, 2004; Hong, 2001; Park, 2000). Illegal waste disposal is the sum of illegal dumping and illegal incineration cases inspected by government officials and residents.

In this study, observations cover all local governments of city and county level. As each municipality generates a different amount of household waste per capita, it is necessary to consider regional characteristics (Kim, 2009; Gardiner & Hajek, 2020). In addition to the main regression analyses of price incentive effects on household waste generation, in this paper, I conduct two sub-group analyses: (1) special/metropolitan cities (*si*) and metropolitan provinces (*do*) and (2) urban (*si*) and rural areas (*gun*). The sub-group analyses are expected to identify which areas are more elastic to price incentives. Based on the analyses, this paper recommends that all regional governments exploit different policy strategies depending on regional characteristics.

4. Data and Descriptive Statistics

4.1. *Data*

In this paper, I analysed a panel dataset over 12 years between 2006 and 2017. The unit observations are the second-level administrative districts (*si/gun/gu*). The base year of the research period was set to 2006 to reflect the enforcement of the Ban on Direct Landfilling of Food Waste (2005). As of 2017, the number of administrative districts at the second level totalled to 229[18]. The VBWF system covers all 229 second-level municipalities, 3,496 out of 3,500 *eup/myeon/dongs* at the third-level. It accounts for 99.9%[19] of the total households, including 19,000 households using the village-based VBWF system (Ministry of Environment, 2018). The non-covered households are in tiny villages with fewer than 50 households or located in remote areas that are difficult to reach, such as mountains and islands (OECD, 2017).

There are four dependent variables: *total household waste per capita*[20] (tonnes per day), *household solid waste per capita* (tonnes per day), *discharge of recyclables per capita* (tonnes per day), and *the number of illegal waste disposal cases* (per 1,000 residents). The data for the dependent variables was from the 'Status of Waste Generation and Treatment'[21] and 'Status of the VBWF system'[22], which are annually published by the Ministry of Environment. The waste related dependent variables were calculated by dividing the amount of waste

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[18] During the research period, one special city was added and a total of four administrative districts were merged with other districts. In addition, there was a reorganization of administrative districts such as Dangjin-gun's promotion to Dangjin-si in 2012 and Yeoju-gun's promotion to Yeoju-si in 2013.

[19] 21,616,000 out of 21,633,000 households were covered.

[20] In this study, total household waste is the sum of household solid waste and recyclable resources. The amount of food waste is excluded.

[21] Environmental Statistics. (2017). *Status of Waste Generation and Treatment* (2006-2017) [Data set]. http://stat.me.go.kr/nesis/mesp/knowledge/MorgueStatistical.do?task=I

[22] Environmental Statistics. (2017). *Status of the VBWF system* (2006-2017) [Data set]. http://stat.me.go.kr/nesis/mesp/knowledge/MorgueStatistical.do?task=I

generation (tonnes per day) by the regional population and multiplying 1,000 to change the unit from tonne to kilogram. The annual population data[23] was collected by the Ministry of the Interior and Safety and reported to the Korean Statistical Information Service (KOSIS).

The amount of household waste is reported in three sections: mixed discharge by standard waste bags, separated discharge of recyclable resources, and food waste[24]. In this study, household waste and recyclable resources were limited to 'mixed discharge by standard waste bag' and 'separated discharge of recyclable resources', respectively. The remaining food waste were excluded from the analysis as there is a different waste-fee system for food waste. The amount of food waste has been separately aggregated and reported since 2006 after the enforcement of the Ban on Direct Landfilling of Food Waste (2005). For this reason, the base year of this study is 2006, and the total household waste refers to the sum of household solid waste and recyclables, excluding food waste. The last dependent variable is *the number of illegal waste disposal cases*, which was added as a proxy variable for the amount of illegal disposal of household waste driven by the VBWF system. Illegal waste disposal[25] was limited to illegal waste dumping using non-official plastic bags and illegal waste incineration. The number of illegal waste disposal cases is the sum of the cases inspected by government officials and reported by residents.

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[23] Korean Statistical Information Service (KOSIS). (2020, November 12). *Statistics of Residence Registration Population* (2006-2017) [Data set]. https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1B040A3&conn_path=I3

[24] Before the implementation of the Ban on Direct Landfilling of Food Waste (2005), there were only two categories, mixed discharge by plastic garbage bags and recyclable resources. The amount of food waste was integrated and reported in 'mixed discharge by plastic garbage bag' before 2006.

[25] In the Status of the VBWF system, illegal waste disposals are classified into six means: dumping small amounts of garbage, cigarette, etc.; dumping using non-official plastic bags; illegal incineration; littering in a resort; dumping garbage using driving equipment; and dumping of industrial waste. Among the six, only two of them were used in this study: dumping using non-official plastic bags and illegal incineration because it is difficult to assume that other means are committed to avoid waste-fee payment for household waste disposal. Since (impulsive) littering in a resort or small amount of waste, such as cigarettes, and industrial waste or large-size waste have different features from household waste, they were excluded.

The primary independent variable is the *average price (AP)* of standard waste bags per litre. Because the price of standard waste bags varies by size, the primary explanatory variable was calculated as the arithmetic mean of the price per litre of each size.

(1) $AP_{it} = \frac{1}{n(K_{it})} \sum_{k \in K_{it}} Price\ per\ litre_{it}^{k}$

AP_{it} is the average price of waste bags in municipality *i* in year *t*; K_{it} is a set of different size of standard waste bags in municipality *i* in year *t*; n(K_{it}) is the number of elements in the set. The price per litre was calculated by dividing the price of a waste bag by the size of the bag (litre).

Furthermore, two additional price variables, a *weighted average price (WAP)* per litre relative to the sales volume of each year and a *weighted average fixed price (WAFP)* per litre relative to sales volume as of 2006, were calculated to reflect the demand of each size of the bags.

(2) $WAP_{it} = \frac{1}{n(K_{it})} \sum_{k \in K_{it}} (Weight_{it}^{k} \times Price\ per\ litre_{it}^{k})$

(3) $WAFP_{it} = \frac{1}{n(K_{it})} \sum_{k \in K_{it}} (Weight_{i2006}^{k} \times Price\ per\ litre_{it}^{k})$

The weight was calculated as the ratio for each size of the bags: the sales volume of the bag out of the total sales volume in each year. For the *WAFP*, the sales volume of standard waste bags and the total sales volume were fixed at the 2006 level to reflect the price change only. These additional price variables were further used in the robustness check to confirm the price incentive effect. The price and sales volume data of each size was from the 'Status of the VBWF system,' which is annually reported by the Ministry of Environment.

For control variables, *Gross Regional Domestic Product (GRDP)* per capita, *Agriculture, Forestry, and Fishery (AFF) ratio*, *single-household ratio*, *apartment ratio*, and *population density* were included.

GRDP data[26] is annually collected from each municipality and reported to KOSIS. The base year changes every five years, and each municipality recalculates GRDP using a new GDP deflator accordingly. This study used base years of 2005, 2010, and 2015 for economic variables. For data consistency, GRDP data from 2006 to 2009 was used for the base year of 2005; from 2010 to 2016 for the base year of 2010; and 2017 for the base year of 2015. The base year of 2015 was only applied to the 2017 GRDP since only half of the municipalities reported a new GRDP with the base year of 2015 when this research was being conducted. GRDP per capita was GRDP divided by the registered population of each municipality. The *AFF ratio* refers to the proportion of the agricultural, fishery, and forestry industries out of GRDP.

Single-household ratio and *apartment ratio* were used from the Population Census[27] by Statistics Korea. Single household ratio is the percentage of single-person households out of the total households, regardless of the size. The apartment ratio covers modernised communal residential facilities such as apartments, row houses, and studio flats. As of 2017, modernised communal residential facilities account for approximately 56% of the total residence. Because the census data was collected every five years before 2015, it is assumed that the 2005 and 2010 data remained the same for the following five years. The yearly census data was used from 2015 to 2017.

Population density is the population number per floor area (km^2) of each

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[26] Korean Statistical Information Service (KOSIS). (2019). *Gross Regional Domestic Product* (2006-2017) [Data set] https://kosis.kr/index/index.do

[27] Korean Statistical Information Service (KOSIS). (2020, August 31). *Population Census* (2000-2017) [Data set]. http://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1YL21161&conn_path=I3

administrative district. Floor area data were used from Cadastral Statistics[28] by the Ministry of Land, Infrastructure and Transport.

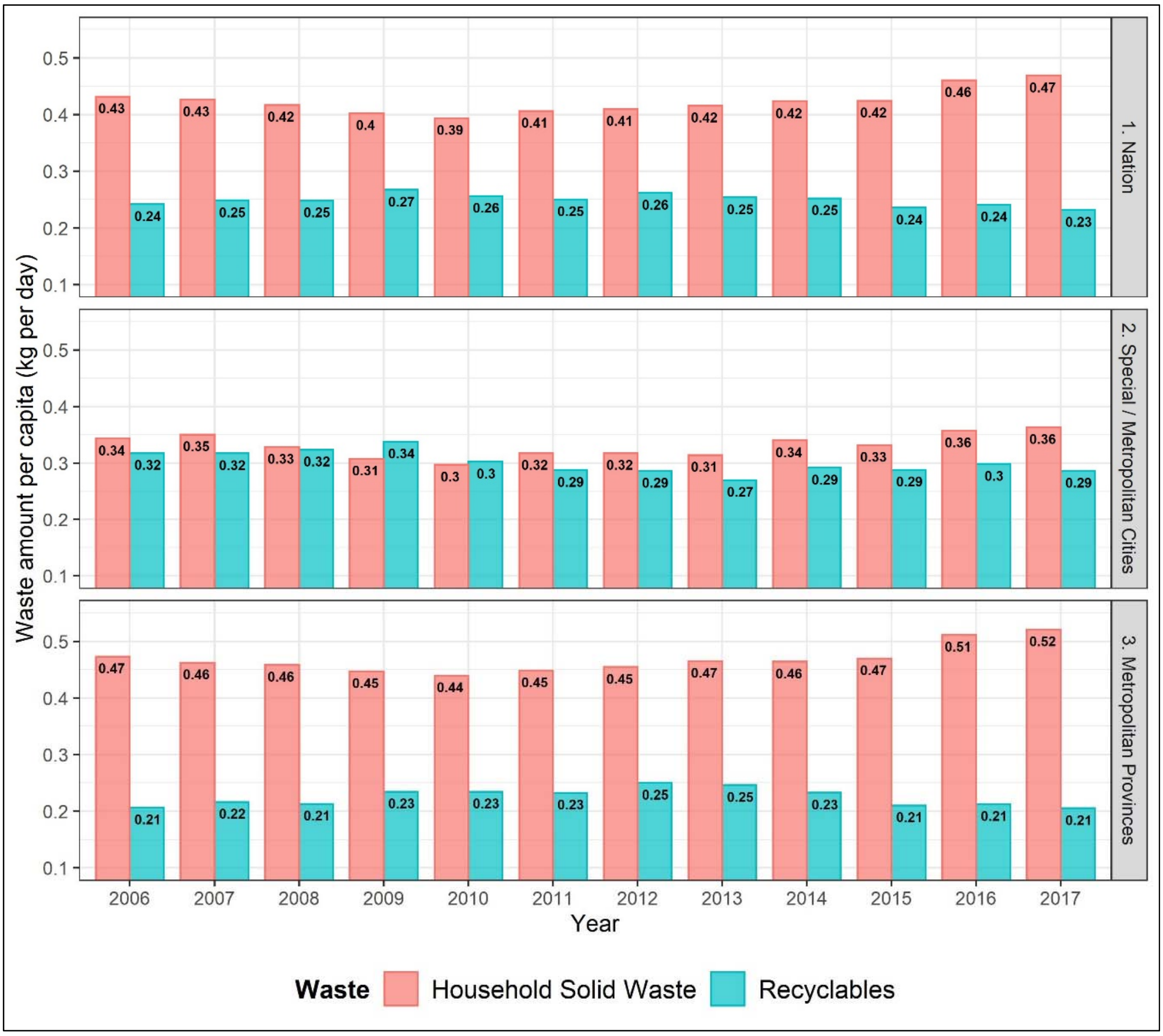
Additionally, *municipality* variable controlled for unobserved time-invariant region-specific features and *year* variable controlled for change in waste generation due to time trends, global social changes, and other socio-economic changes.

4.2 *Descriptive Statistics*

Figure 1 shows the time trend of two dependent variables, household solid waste and recyclables, depending on regional groups: a national scale, special/metropolitan cities, and metropolitan provinces. On a national basis, household solid waste per capita had decreased from 0.43 kg per day to 0.39 kg per day between 2006 and 2010, but from 2010, it started to increase. This trend is also noticeable in the sub-group: special/metropolitan cities and metropolitan provinces. However, the composition of household solid waste and recyclables in the sub-group is significantly different between them. While special/metropolitan cities show relatively even ratio between household solid waste and recyclables, a clear gap was observed between them in metropolitan provinces. On average, household solid waste in metropolitan provinces accounts for more than twice of recyclables.

[28] Korean Statistical Information Service (KOSIS). (2020, July 22). *Cadastral Statistics* (2007-2017) [Data set]. http://kosis.kr/statHtml/statHtml.do?orgId=116&tblId=DT_MLTM_2300&conn_path=I3

FIGURE 1 - Trend of Household Solid Waste and Recyclables by Regional Groups



Sources: The data is from 'the Status of the VBWF system (2006-2017),' which is annually reported by the Ministry of Environment (MOE). The figure was made by the author using R-Studio.

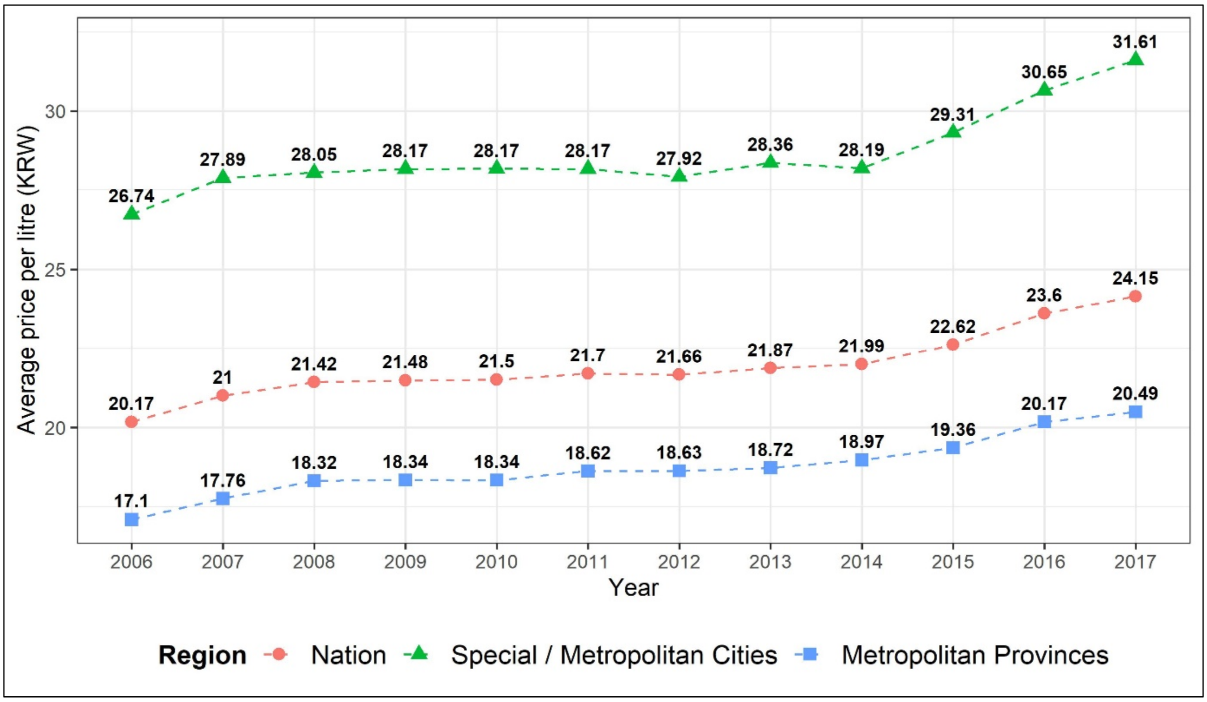
Notes. The figure shows the trends of household solid waste and recyclables per capita from 2006 to 2017 depending on regional groups: national level, special/metropolitan cities, and metropolitan provinces. The vertical axis refers to the waste amount per capita (kg per day), and the horizontal axis is year. In this paper, total household waste refers to the sum of household solid waste and recyclables. The labels on the bars are the exact amount of waste, and they are rounded at 2 decimal points.

Figure 2 represents the trend of average price depending on the regional groups. The nationwide average price per litre rose by about 19.73% from KRW 20.17 per litre in 2006 to KRW 24.15 per litre in 2017, with the average annual increase rate[29] of 1.65%. The average

[29] Compound Annual Growth Rate (CAGR) = (End value/Beginning value)$^{1/\text{number of period}}$-1

price per litre by sub-group[30] shows that special/metropolitan cities have a higher average price than metropolitan provinces throughout the research period between 2006 and 2017. Although the increase rates in both sub-groups are quite similar (Table 1), the gap between the two groups has been widened from KRW 9.64 per litre in 2006 to KRW 11.12 per litre in 2017. Hong (2001) suggested that people in large cities might be more interested in waste management due to the relatively high population density and lack of landfill areas. In addition, he assumed that because of the relatively high-income level in urban areas, the tolerance to higher price of waste bags might be higher than in less-urbanised areas.

FIGURE 2 - Trend of Average Price by Regional Groups



Sources: The data is from 'the Status of the VBWF system (2006-2017),' which is annually reported by the Ministry of Environment (MOE). The figure was made by the author using R-Studio.

Notes. The figure shows the trends of average price per litre from 2006 to 2017 depending on regional groups: national-level, special/metropolitan cities, and metropolitan provinces. The vertical axis refers to the average price per litre, and the horizontal axis is year. The labels refer to the exact average price, and they are rounded at 2 decimal points.

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[30] In this paper, there are two kinds of sub-groups: metropolitan areas and municipality. At the metropolitan level, the observations were categorised into 'special/metropolitan cities (*si*)' or 'metropolitan provinces (*do*)' groups. At the municipality level, the observations were categorised into 'urban areas (*si/gu*)' or rural areas (*gun*). A *gun* is an area with less than 150,000 population, and *guns* are generally located in agricultural and fishing areas. There are no sub-groups at the third level of administrative districts.

Table 1 shows the simple time trend of dependent variables and the primary independent variable in the beginning and end year of the research period, 2006 and 2017, followed by the total increase rate and annual increase rate. The primary explanatory variable, *average price*, is also presented by sub-groups and metropolitan areas. Panel A shows that the total household waste per capita, household solid waste per capita and illegal waste disposal cases per 1,000 residents have increased from 2006 to 2017 by 4.48%, 8.64% and 49.21%, respectively. During the same period, recyclables per capita have decreased by 4.16%.

In metropolitan areas, Busan-si shows a decrease of 0.37% in the average price per litre compared to 2006. Busan-si, however, has the highest price per litre in both 2006 and 2017. Korea Environment Institute (2018) stated that the geographical features of Busan-si, where a large portion of dwellings are located in high-altitude areas, require significantly above-average human resources to collect household waste from door-to-door. The unit price per ton for collecting household waste in Busan-si is 2.5 times higher than that of other special/metropolitan cities, and the unit price per person for collecting household waste is 2.8 times higher.

Figure 3 illustrates the maps of average price per litre in 2017 and the total increase rate between 2006 and 2017 of each municipality. The map of average price per litre on the left shows that on average, the price of municipalities in special/metropolitan cities is relatively high compared to municipalities in metropolitan provinces. This is consistent with the trend of average price by regional groups shown in Figure 2. As to the map of the total price increase rate on the right, it indicates that the municipalities of which the average price has increased by more than 60 per cent are evenly distributed throughout the country. Most municipalities have increased the price of standard waste bags; however, 29 municipalities show negative growth rates, which means that the average price for 2017 has decreased compared to 2006.

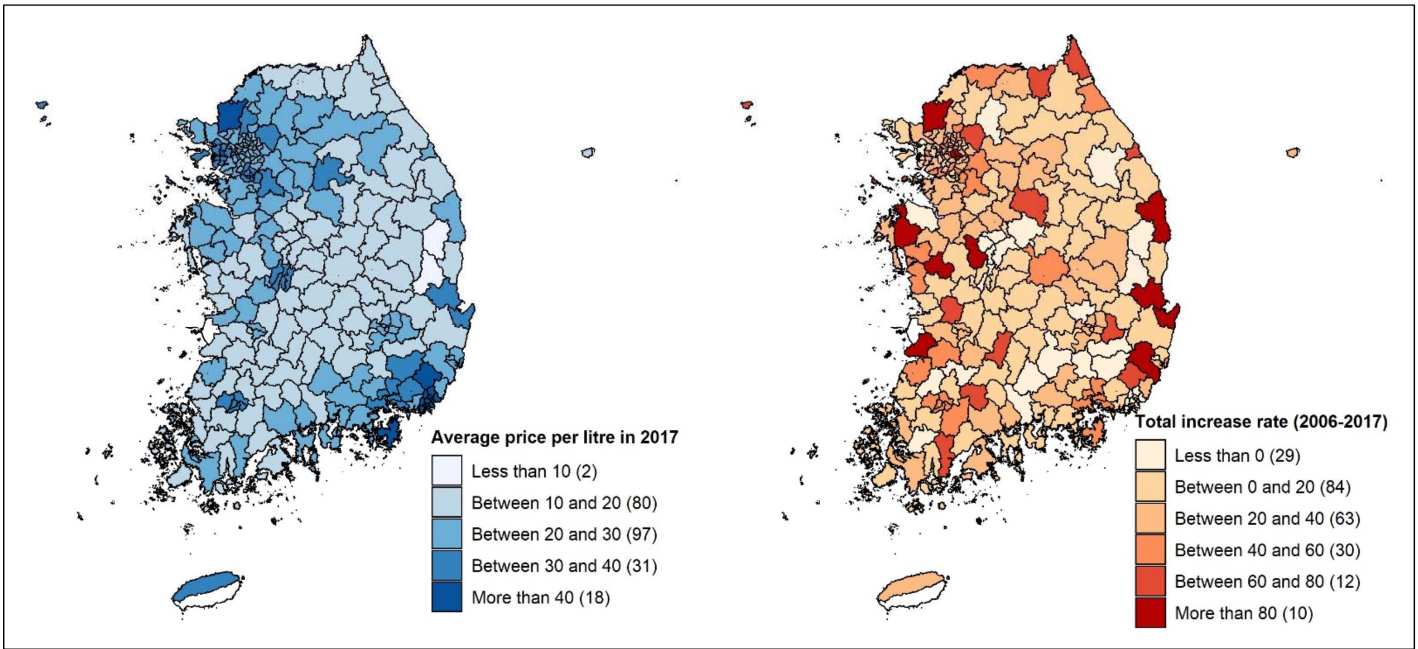
TABLE 1 – TREND OF DEPENDENT VARIABLES AND MAIN REGRESSOR

	Year		Increase rate	
VARIABLES/REGIONS	2006	2017	Total	Annual
Dependent variables			(Unit: kg per day, %)	
Total household waste per capita	0.67	0.70	4.48	0.40
Household solid waste per capita	0.43	0.47	8.64	0.76
Recyclables per capita	0.24	0.23	-4.16	-0.39
Illegal waste disposal (cases per 1,000)*	1.89	2.82	49.21	3.70
Average price by Sub-groups			(Unit: KRW per litre, %)	
Nationwide	20.17	24.15	19.73	1.65
Special/Metropolitan cities (*si*)	26.74	31.61	18.21	1.53
Metropolitan provinces (*do*)	17.10	20.49	19.82	1.66
Average price by Metropolitan areas				
Seoul-si	18.09	25.25	39.61	3.08
Busan-si	40.75	40.59	-0.37	-0.03
Daegu-si	21.75	29.15	34.01	2.70
Incheon-si	30.30	32.71	7.95	0.70
Gwangju-si	23.77	37.34	57.09	4.19
Daejeon-si	33.20	33.20	0.00	0.00
Ulsan-si	22.54	29.85	32.45	2.59
Sejong-si**	-	27.37	-	-
Gyeonggi-do	21.38	27.23	27.35	2.22
Gangwon-do	15.89	19.53	22.85	1.89
Chungcheongbuk-do	14.65	15.68	7.06	0.62
Chungcheongnam-do	16.17	19.47	20.36	1.70
Jeollabuk-do	13.96	17.64	26.42	2.15
Jeollanam-do	14.29	16.48	15.33	1.31
Gyeongsangbuk-do	13.65	16.01	17.29	1.46
Gyeongsangnam-do	22.32	25.69	15.10	1.29
Jeju-do	24.14	35.00	44.97	3.43

Sources: Author's calculation using 12-year panel data from '*Status of the VBWF system* (2006-2017)' by the Ministry of Environment (MOE). Waste-related data, including all dependent variables and the primary regressor, are annually reported by MOE.

Note. Waste per capita is the amount of national waste generation divided by population. Total increase rate is the price increase rate in 2017 compared to 2006. Annual increase rate refers to Compound Annual Growth Rate (CAGR). The unit of illegal waste disposal* is the total number of inspected or reported cases divided by population and multiplied 1,000. The average price is the arithmetic mean of price per litre. Sejong** special city was established in 2012; therefore, there is no comparable price data in 2006.

FIGURE 3 - Map of Average Price in 2017 and Total Increase Rate by Municipalities



Sources: The data is from 'the Status of the VBWF system (2006-2017),' which is annually reported by the Ministry of Environment (MOE). The figure was made by the author using R-Studio.

Notes. The figure shows the maps of average price per litre in 2017 on the left side and the total price increase rate between 2006 and 2017 on the right side of each municipality. As of 2017, there are a total of 228 municipalities except for the missing data of Seogwipo-si in Jeju-do, which is coloured white. The number of municipalities in each indicator is in parentheses.

Table 2 gives the summary statistics of dependent and independent variables. The mean of household waste per capita is 0.67 kg per day; household solid waste per capita, 0.42kg per day; recyclables per capita, 0.25 kg per day; and the number of illegal waste disposal cases per 1,000 residents, 2.09. The mean average price per litre is KRW 21.93, and the mean of GRDP per capita is KRW 26.76 in million. The average AFF ratio is 7.77%; single-household ratio, 25.95%; and apartment ratio is 38.69%. Population density shows the most widely distributed values, which has a mean of 3,974 residents per km^2 with a minimum density of 19 per km^2 to the maximum density of 28,938 per km^2.

TABLE 2 - DESCRIPTIVE STATISTICS

VARIABLES	Obs.	Mean	S.D.	Min.	Max.
Total household waste per capita (kg/day)	2,764	0.67	0.30	0.14	2.71
Household solid waste per capita (kg/day)	2,764	0.42	0.23	0.04	2.34
Recyclables per capita (kg/day)	2,764	0.25	0.17	0	1.47
Illegal waste disposal (case/1,000 people)	2,764	2.09	4.82	0	94.30
Average price (KRW per litre)	2,762	21.93	8.52	7.48	47.07
GRDP per capita (KRW in million)	2,523	26.76	24.18	6.01	354.07
AFF ratio (%)	2,522	7.77	9.49	0	44.6
Single-household ratio (%)	2,753	25.95	6.18	12.1	46.3
Apartment ratio (%)	2,761	38.69	20.47	0.09	87.08
Population density (resident/km^2)	2,764	3,973.66	6,323.21	19.40	28,938.46

Sources: Author's calculation using 12-year data from KOSIS and MOE. All dependent variables and primary regressor are from MOE. Remainders are available on the KOSIS website.

Note. In this paper, I use 12-year panel data between 2006 and 2017. The first four variables are dependent variables, and others are independent variables. The average price is the primary regressor of this paper. GRDP refers to Gross Regional Domestic Products and AFF refers to agriculture, forestry, and fishery industries.

For empirical analysis, all dependent variables, average price, GRDP per capita, and population density were used in logarithmic transformations.

5. Methodology

The aim of this paper is to estimate the price incentive effect of the VBWF system on household waste generation. The base dataset is 12-year panel data for the period 2006-2017, and the unit of analysis is administrative districts at the municipal level. A total of 2,764 observations was subject to a fixed-effect analysis with municipality and year fixed effects, as well as economic and demographic controls. The measurement was modified from Hong's (2015) method, which was also applied by Kim et al. (2011), Seo and Jung (2007), and Hong (2001).

5.1 *Model Specification*

In this paper, the following waste collection demand function was estimated:

$$(4)\ \ln WG_{it} = \beta_0 + \beta_1 \ln AP_{it} + \gamma^E X_{it}^E + \gamma^D X_{it}^D + \alpha_i + \tau_t + \varepsilon_{it}$$

where, WG_{it} is the waste generation of municipality i in year t; AP_{it} is the average price in municipality i in year t; X_{it}^E is a vector of economic control variables including (ln)GRDP per capita and AFF ratio; X_{it}^D is a vector of demographic control variables composed of single household ratio, apartment ratio, and (ln)population density; α_i is municipality fixed effect; τ_t is year fixed effect; and the unobservable error term, ε_{it}. α_i and τ_t control for the unobserved but time-invariant region-specific and region-invariant time-specific factors, respectively.

β_1 is the coefficient of interest which evaluates the price incentive effect of the VBWF system on household waste generation. Based on the theory of the relationship between price and demand, β_1 is expected to be negative on household solid waste generation while it is expected to be positive on the discharge of recyclables due to the substitution effect. Based on the theory, it is possible that households sort more recyclables from household solid waste to reduce the purchasing cost for standard waste bags. If the effects on the two dependent variables were to offset one another, β_1 of total household waste generation will not be significantly different from 0.

5.2. *Empirical Strategy*

In this study, the fixed-effect model was used to eliminate omitted variable bias arising from the factors that are unobservable but time-constant and region-constant. In addition, two economic variables and three demographic variables were used as control variables to eliminate the potential differences in waste generation among observations.

Waste Generation (WG_{it}) is composed of four kinds of dependent variables: total household waste[31] per capita (tonnes per day), household solid waste per capita (tonnes per day), recyclables per capita (tonnes per day), and illegal waste disposal (number of cases per 1,000 residents). Previous studies have also conducted analyses of the price incentive effect on waste reduction and recycling increase; however, due to the lack of data, the negative balloon effect of the VBWF system on illegal waste disposal was not estimated. In this study, the number of illegal waste disposal cases, composed of illegal dumping and incineration, was used as a proxy for the amount of illegal waste disposal.

This study takes independent variables of average price, municipality, year, and other control variables. *Average price* (AP_{it}) is the primary explanatory variable in this study. It is an arithmetic average price of standard waste bags to incorporate additional price incentive effects when the size gets larger. In each local government, the selling price of standard waste bags may vary depending on the waste management costs and the target rate of revenue-to-expenditure in waste management. As the waste collection and transportation cost vary by size, the price per litre of each size may also differ within the same local government. Therefore, the price of the most popular 20-litre waste bags is not sufficient to be a price variable. In the main regression, this average price was used as the primary independent variable as households make a purchasing decision based on the market price information. In addition, *weighted average price* (WAP_{it}) considering the sales volume of each waste bag size in each year and *weighted average fixed price* ($WAFP_{it}$) considering the sales volume in the year of 2006 were added as

[31] Total household waste refers to the sum of household solid waste and recyclables.

explanatory variables for the robustness check in section 5.

There are two groups of control variables: economic and demographic controls. For economic controls, X_{it}^{E}, the gross regional domestic product (GRDP) per capita of each municipality, and the proportion of Agricultural·Forestry·Fishery industries (AFF ratio) accounted for in the GRDP were used. GRDP per capita is a proxy for income level. Generally, an income increase results in a consumption increase, which yields more waste generation (Seo & Jung, 2007). According to previous studies, higher-income groups generate more waste than lower-income groups in both household solid waste and recyclables (Chu et al., 2019; Jaligot & Chenal, 2018; Usui & Takeuchi, 2014). Oh (2006) also stated that after controlling for populations, the amount of waste increased when the consumption increased. That is, without appropriate income control, the estimate of the analysis can be biased. The AFF ratio refers to the proportion of agricultural, forestry, and fishery industries out of total GRDP. The AFF ratio was used as an economic control variable as it has an industrial specific feature, in that residential and workplace wastes are not clearly distinguished. Moreover, the possibility of illegal waste disposal is relatively higher in rural areas than urban areas due to the lack of monitoring and differences in consumption and living patterns (Hong, 2015; Choi et al., 2004; Kim & Kelleher, 2004)

Demographic controls, X_{it}^{D}, include the single household ratio, apartment ratio, and population density. The single household ratio is the number of single-person households out of the total number of households regardless of the family size. It was used to reflect the recent trends in family structure and consumption patterns. The Ministry of Environment (2014) reported that due to the upward trend of single-housing and elderly-housing, small size households with one or two members have tended to increase in recent years. Between 2003 and 2012, single households increased by 61.1% from 2,818,000 to 4,539,000 while households with four members decreased by 39.9% from 4,432,000 to 3,760,000. The base assumption about single households is that they generate more household waste per capita than households with multiple members as they have more convenience-oriented consumption patterns such as food delivery and the use of single-use products. Besides, even if only one person lives in a house, daily necessities such as cleaning, bath, and cooking equipment, would be still needed in the same way as multiple-member households. Therefore, if the proportion of single households increases, total waste emissions, including recyclables, are also expected to increase.

Apartment ratio measures the number of households living in modernised communal residential facilities out of total households. This variable was added based on the assumption that waste management practice in multi-housing areas may differ from households living in detached housing areas. More recycling is expected as communal residential facilities generally operate a dedicated waste collection point that is monitored by a facility management team. Additionally, there is a government-led incentive system for waste reduction targeting large-scale buildings such as apartment complexes and studio flats (Guidelines for Implementing the VBWF System, 2019). This could encourage households living in communal facilities to recycle more than those in detached housing areas. In contrast, Hong (2015) argued that, where the apartment ratio is high, households discharge a smaller amount of recyclables because they do not have enough space to keep recyclables separately.

The indicators of municipality (α_i) and year (τ_t) variables were included to represent the region fixed effect and time fixed effect. ε_{it} is an error term, which contains all other uncontrolled factors in this study that may influence the amount of waste generation.

This study contains four main regressions: (1) the price incentive effect of the VBWF system on total household waste, (2) the price incentive effect of the VBWF system on household solid waste, (3) the price incentive effect of the VBWF system on recycling, and (4) the price incentive effect of the VBWF system on illegal waste disposal. Total household waste was included to estimate the integrated effect of waste reduction and recycling increase. Based on the theory of the relationship between price and demand, when the price of standard waste bags increases, the demand for collecting household solid waste is expected to decrease. On the other hand, the demand for collecting recyclables is supposed to increase by the substitution effect. That is, even though there is a solid waste reduction effect, it can be offset by the increase in recyclables. Therefore, by adding total household waste as a dependent variable, the estimate is expected to find the price incentive effect on the net waste reduction.

6. Results

6.1 *Main Results*

The goal of this study is to estimate the price incentive effect of the VBWF system on household waste generation. Waste generation is composed of four types: total household waste, household solid waste, recyclables, and illegal waste disposal cases. The number of illegal waste disposal cases is proxy data for the amount of illegal waste disposal, which was not available.

Table 3 presents the results of the model from equation (4) to estimate the price incentive effect on household waste generation. All estimations were based on the fixed-effect analysis with municipality fixed effect, year fixed effect and the standard deviation for clustered errors. All economic and demographic controls were also included. Column (1) estimates the price incentive effect of the VBWF system on the amount of total household waste generation, which is the sum of household solid waste and recyclables. Columns (2) and

(3) respectively examine the price incentive effect on household solid waste and recyclables. Column (4) concerns the side effect of the VBWF system, represented as illegal waste disposal. In all four regressions, coefficients had the expected sign directions, and it is in line with the hypothesis: by imposing a waste fee to households based on the amount of waste generation, it may reduce household solid waste generation and encourage voluntary recycling. The expected sign of the coefficient on illegal waste disposal was positive due to the increase in average price as a side effect. Even though all signs point to the expected directions, only column (2) was statistically significant at the 5% significance level. The price elasticity of collecting household solid waste was 0.162%.

TABLE 3 – PRICE INCENTIVE EFFECT ON HOUSEHOLD WASTE

VARIABLES	(1) Total	(2) Solid	(3) Recycle	(4) Illegal
ln (average price)	-0.075	-0.162**	0.102	0.428
	(0.064)	(0.067)	(0.165)	(0.329)
Economic controls	YES	YES	YES	YES
Demographic controls	YES	YES	YES	YES
Municipality FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	2,510	2,510	2,510	2,387
R-squared	0.027	0.057	0.038	0.031
No. of municipality	233	233	233	233

Note. The table indicates the regression coefficients of the four dependent variables using the base dataset of 12-year panel data (2006-2017) with total 2,510 observations. Columns 1-4 respectively refer to total household waste, household solid waste, recyclables, and illegal waste disposal. All regressions include economic and demographic controls as well as municipality and year fixed effects. Economic controls include GRDP and AFF ratio, and demographic controls are single household ratio, apartment ratio, and population density. All dependent variables are transformed in logarithm. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4 shows the summary statistics by sub-groups. Depending on the level of administrative districts, there are two kinds of sub-groups: (1) special/metropolitan cities (*si*) and metropolitan provinces (*do*) at the metropolitan level, and (2) urban areas (*si/gu*) and rural areas (*gun*) at the municipal level in metropolitan provinces. As to the sub-group analysis, the hypothesis of this paper is that each group has different price elasticity to waste collecting demand due to the difference in economic and demographic features among the sub-groups.

TABLE 4 - DESCRIPTIVE STATISTICS: SUB-GROUPS

		Special/Metropolitan cities (*si*)			Metropolitan province (*do*)		
VARIABLE	Unit	Obs.	Mean	Std.	Obs.	Mean	Std.
Panel A. Metropolitan level							
Total household waste per capita	(kg/day)	894	0.63	0.31	1,870	0.69	0.30
Household solid waste per capita	(kg/day)	894	0.33	0.18	1,870	0.47	0.23
Recyclables per capita	(kg/day)	894	0.30	0.18	1,870	0.22	0.16
Illegal waste disposal	(case/1,000 people)	894	2.78	5.43	1,870	1.76	4.46
Average price	(KRW per litre)	894	28.61	9.11	1,868	18.73	6.00
GRDP per capita	(KRW in million)	763	30.44	40.09	1,760	25.16	11.55
AFF ratio	(%)	762	0.80	2.20	1,760	10.79	9.84
Single-household ratio	(%)	891	23.98	6.18	1,862	26.89	5.95
Apartment ratio	(%)	891	47.93	16.15	1,870	34.30	20.84
Population density	(resident/km^2)	894	10,435.18	7,226.20	1,870	884.57	2,154.09
Panel B. Municipality Level in Metropolitan Provinces		Urban (*si*)			Rural (*gun*)		
		Obs.	Mean	Std.	Obs.	Mean	Std.
Total household waste per capita	(kg/day)	938	0.66	0.29	938	0.72	0.31
Household solid waste per capita	(kg/day)	938	0.44	0.20	938	0.50	0.25
Recyclables per capita	(kg/day)	938	0.23	0.16	938	0.22	0.16
Illegal waste disposal	(case/1,000 people)	938	2.10	4.41	938	1.41	4.47
Average price	(KRW per litre)	937	22.11	5.91	937	15.34	3.74
GRDP per capita	(KRW in million)	893	25.45	13.38	872	24.96	9.40
AFF ratio	(%)	893	4.95	6.60	872	16.73	9.00
Single-household ratio	(%)	927	23.73	5.35	938	30.02	4.73
Apartment ratio	(%)	935	50.86	14.26	938	17.89	11.15
Population density	(resident/km^2)	938	1,678.01	2,826.30	938	88.07	61.18

Note. This table contains summary statistics of the base dataset by sub-groups. There are two types of sub-groups: at the metropolitan level, there are two groups of special/metropolitan cities (*si*) and metropolitan provinces (*do*). At the municipal level in metropolitan provinces, there are two groups of urban areas (*si*) and rural areas (*gun*).

Panel A in Table 4 shows that the mean of the average price in special/metropolitan cities was about 1.5 times higher than metropolitan provinces. Moreover, the result shows that the mean of population density in special/metropolitan cities was more than 11 times bigger than that of metropolitan provinces. At the municipal level in metropolitan provinces, regional groups were divided into urban and rural areas to estimate the differences between the two areas since each metropolitan province is composed of some urban and rural areas. Therefore, even though districts are in the same metropolitan province, they may have different features of urban or rural areas. In that regard, in order to distinguish the rural areas at the municipal level, this paper used *Gun* district as a base area, the smallest administrative unit among the three categories (*si/gun/gu*), with the population size of fewer than 150,000 (OECD, 2017), generally.

Table 5A represents the price incentive effect on waste generation by sub-groups at the metropolitan level. Columns (1) to (4) refer to total household waste, household solid waste, recyclables, and illegal waste disposal, respectively. Panel A shows that no estimates were statistically significant in the areas of special/metropolitan cities. The AFF ratio was statistically significant at 5% and 1% levels for column (1) and column (2), but not in others. Panel B is the regression results of metropolitan provinces. In contrast with special/metropolitan cities, estimates on total household waste and household solid waste were statistically significant at least at the 10% level of significance. The estimates of column (1) and column (2) imply that, for a 1% increase in average price, they decrease by 0.149% and 0.185%, respectively. Column (3) indicates that recyclables decrease when the average price increases; however, it was not statistically significant.

TABLE 5A – PRICE INCENTIVE EFFECT ON HOUSEHOLD WASTE BY SUB-GROUPS: METROPOLITAN LEVEL

	Total (1)	Solid (2)	Recycle (3)	Illegal (4)
Panel A .Special/Metropolitan Cities				
ln(average price)	0.061	-0.050	0.132	0.393
	(0.107)	(0.096)	(0.300)	(0.732)
Observations	760	760	760	713
R-squared	0.085	0.126	0.078	0.078
No. of municipality	75	75	75	75
Panel B. Metropolitan Provinces				
ln(average price)	-0.149*	-0.185**	-0.047	0.437
	(0.076)	(0.084)	(0.191)	(0.372)
Observations	1,750	1,750	1,750	1,674
R-squared	0.029	0.049	0.058	0.029
No. of municipality	158	158	158	158
Economic controls	YES	YES	YES	YES
Demographic controls	YES	YES	YES	YES
Municipality FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note. The table shows the regression results of sub-groups at the metropolitan level, using the base dataset. Columns 1-4 respectively refer to total household waste, household solid waste, recyclables, and illegal waste disposal. All regressions include economic and demographic controls as well as municipality and year fixed effects. Economic controls include GRDP and AFF ratio, and demographic controls are single household ratio, apartment ratio, and population density. Panel A is a group of special/metropolitan cities (*si*), and Panel B is a group of metropolitan provinces (*do*). All dependent variables are transformed in logarithm. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5B represents the price incentive effect on waste generation by sub-group at the municipal level in metropolitan provinces. Columns (1) to (4) refer to total household waste, household solid waste, recyclables, and illegal waste disposal, respectively. Panel A is a group of urban areas (*si*), and panel B represents a group of rural areas (*gun*). The overall results of Table 5B are in line with the results of Table 5A; urban areas did not show statistically significant estimates while the estimates of columns (1) and (2) in panel B indicate statistically significant coefficients. In rural areas, the price elasticity of collecting total household waste and household solid waste was 0.244% and 0.3%, respectively.

TABLE 5B – PRICE INCENTIVE EFFECT ON HOUSEHOLD WASTE BY SUB-GROUPS: MUNICIPALITY LEVEL IN METROPOLITAN PROVINCES

	Total (1)	Solid (2)	Recycle (3)	Illegal (4)
Panel A .Urban areas (si)				
ln(average price)	-0.061	-0.093	-0.034	0.671
	(0.105)	(0.112)	(0.283)	(0.563)
Observations	882	882	882	865
R-squared	0.046	0.076	0.106	0.027
No. of municipality	80	80	80	80
Panel B. Rural areas (gun)				
ln(average price)	-0.244**	-0.300***	-0.036	0.256
	(0.100)	(0.110)	(0.271)	(0.495)
Observations	871	871	871	812
R-squared	0.044	0.047	0.051	0.054
No. of municipality	79	79	79	79
Economic controls	YES	YES	YES	YES
Demographic controls	YES	YES	YES	YES
Municipality FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note. The table shows the regression results of sub-groups at the municipality level in metropolitan provinces, using the base dataset. Columns 1-4 respectively refer to total household waste, household solid waste, recyclables, and illegal waste disposal. All regressions include economic and demographic controls as well as municipality and year fixed effects. Economic controls include GRDP and AFF ratio, and demographic controls are single household ratio, apartment ratio, and population density. Panel A is a group of urban areas (*si*), and Panel B is a group of rural areas (*gun*). All dependent variables are transformed in logarithm. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6.2 *Robustness Checks*

In this section, two kinds of robustness checks are conducted: (1) changing the level of control variables and (2) replacing average price with weighted average price and weighted average fixed price. One caveat in the dataset is the lack of GRDP information for the capital city, Seoul. The Seoul Special City has reported GRDP data since 2010; therefore, the data for the years before 2010 are not available. Since Seoul is the capital city of Korea, and also the most densely populated area with the highest income level, the lack of economic controls can generate biased estimates.

Table 6A presents the result of regressions with different control variables. All columns hold municipality and year fixed effects. Columns (1)-(4) have different types of controls: no control, economic control, demographic control, and full control. Panels A-D represent each dependent variable in order of total household waste, household solid waste, recyclables, and illegal waste disposal. Overall, household solid waste and recyclables are consistent across columns, while total household waste and illegal waste show changeable results depending on the type of control variables.

Total household waste in panel A presents negative signs in all four columns, but only two estimates in columns (1) and (2) are statistically significant at least at the 10% level of significance. When demographic controls were included, the results became statistically insignificant. The signs of panel B coefficients are in the expected direction, and it shows statistical significance with a range of -0.162 to -0.177 at least at the 5% significance level. Besides, coefficients of GRDP on household solid waste are also statistically significant at the 10% level, with and without demographic control variables. This result indicates that, when the price of a standard waste bag increases by 1% per litre, the amount of household solid waste decreases by 0.162-0.177%, whereas a 1% increase in income yields 0.116-0.117% increase in household solid waste. That is, the price elasticity works more sensitively than the income elasticity. With full controls, panel C shows the most significant increase by the price increase; however, none of the estimates is significant with or without control variables. Panel D presents positive signs in all four columns, but only two estimates in columns (1) and (3) are statistically significant at the 10% level of significance. In contrast to the results of panel A, illegal waste disposal became statistically insignificant when economic controls were included.

TABLE 6A. ROBUSTNESS CHECK: CONTROL CHANGE

DEPENDENT VARIABLE	No (1)	Economic (2)	Demographic (3)	Full (4)
Panel A. *Total Household Waste*				
ln(Average price)	-0.134**	-0.109*	-0.095	-0.075
	(0.060)	(0.062)	(0.061)	(0.067)
Panel B. *Household Solid Waste*				
ln(Average price)	-0.177***	-0.173***	-0.163**	-0.162**
	(0.066)	(0.066)	(0.067)	(0.067)
Panel C. *Recyclables*				
ln(Average price)	-0.068	0.023	0.024	0.102
	(0.150)	(0.167)	(0.147)	(0.165)
Panel D. *Illegal waste disposal*				
ln(Average price)	0.058*	0.421	0.539*	0.428
	(0.308)	(0.308)	(0.310)	(0.329)
Economic controls	NO	YES	NO	YES
Demographic controls	NO	NO	YES	YES
Municipality FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note. The table checks robustness of the main result using different types of control variables. It uses the 12-year panel data (2006-2017). Panels A-D are dependent variables: total household waste, household solid waste, recyclables, and illegal waste disposal. Columns 1-4 hold different types of control variables: no control, economic controls only, demographic controls only, and full controls. Municipality and year fixed effects are included in all columns. All dependent variables are transformed in logarithm. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6B presents robustness checks with different price calculations. Here, in addition to the average price per litre, the sales volume of each size is considered. Columns (1)–(4) are total household waste, household solid waste, recyclables, and illegal waste disposal, respectively. Panels A-C shows the coefficient of different independent variables, in order of average price, weighted average price, and weighted average fixed price. Panel A shows the same results as the main result of Table 3. Although the sign of all estimates in panel B and panel C is in line with the expected directions, only household solid waste is statistically significant at the 5% level of significance. This is confirmed by the result from Table 3, showing that the price incentive only affects household solid waste reduction. The coefficients of column (2) indicate that an increase in price per litre by 1% affects solid waste reduction in a range from -0.134 to -0.162%.

TABLE 6B. ROBUSTNESS CHECK: MAIN REGRESSOR CHANGE

MAIN REGRESSOR	Total (1)	Solid (2)	Recycle (3)	Illegal (4)
Panel A. *Average Price*	-0.075	-0.162**	0.102	0.428
	(0.064)	(0.067)	(0.165)	(0.329)
Panel B. *Weighted Average Price*	-0.024	-0.134**	0.195	0.181
	(0.059)	(0.066)	(0.151)	(0.305)
Panel C. *Weighted Average Fixed Price*	-0.032	-0.144**	0.213	0.257
	(0.063)	(0.072)	(0.155)	(0.324)
Economic controls	YES	YES	YES	YES
Demographic controls	YES	YES	YES	YES
Municipality FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note. The table checks robustness of the main results using different types of control variables. It uses the 12-year panel data (2006-2017). Panels A-C are for main regressors: average price, weighted average price, and weighted average fixed price. Columns 1-4 refer to total household waste, household solid waste, recyclables, and illegal waste disposal. All regressions include economic and demographic controls as well as municipality and year fixed effects. Economic controls include GRDP and AFF ratio, and demographic controls are single household ratio, apartment ratio, and population density. All dependent variables are transformed in logarithm. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

7. Discussion and Conclusion

In this study, I analysed the price incentive effect of the VBWF system on household waste generation using the fixed-effect analysis to control unobserved time-invariant region-specific and region-invariant time-specific features. The results of regression analysis demonstrate that an increase in the price of the standard waste bag leads to household solid waste reduction. The estimates on household solid waste have a negative sign in all regressions and are mostly statistically significant in a range of -0.134 to -0.300 at least at the 5% significance level. This result is in line with Hong (2015) and the hypothesis on the reduction of household solid waste depending on a price increase. The only exceptions are from sub-group analysis, which shows that the groups of special/metropolitan cities and urban areas do not have significant results on household solid waste. The result from the sub-group analysis demonstrates that the price elasticity of collecting household solid waste varies across sub-groups; less urbanised or rural areas show higher price elasticity of collecting household waste than the more urbanised or urban areas. It implies that less urbanised areas or rural areas are more sensitive to the price increase, thus they are more likely to reduce household solid waste when the price increases; the results are statistically significant at the 5% significance level at the least.

In contrast, the estimates on recyclables are not statistically significant throughout the study. For recyclables, none of the estimated coefficients throughout all regression analyses in this study differ significantly from zero, and the direction of sign is not consistent. The sub-groups analysis suggests the need to employ different waste management strategies in different groups to reduce household waste and encourage recycling.

The results of illegal waste disposal show that the price increase has no statistically significant impact on illegal waste disposal throughout the study, including the sub-group analysis and robustness check. It seems inconsistent with the assumption that the VBWF system may induce illegal waste disposal as a side effect (Hong, 2015; Oh, 2006; Lee, 1996). The result of illegal waste disposal analysis gives two possibilities: (1) the price increase does not affect illegal waste disposal and (2) the data used in this study is not adequate as a proxy for the amount of illegal waste disposal. The first possibility is that the price imposing does not affect illegal waste disposal, but other unobserved factors do. According to Choi et al., (2004), households in agriculture and fishery villages customarily incinerate small amounts of household waste. In this case, people hardly think it is illegal to burn some household waste in the fireplace. Another possibility is that the number of illegal waste disposal cases could not be a proxy for the amount of illegal waste disposal. Because there are no available data on the amount of illegal waste disposal, the number of illegal waste disposal cases does not guarantee a strong correlation with the amount of illegally disposed waste. In addition, if monitoring performance varies across municipalities, the number of illegal waste disposal cases would not be appropriate as a proxy for the amount of illegal waste disposal. Due to this limitation, it is difficult to draw a sound conclusion regarding the side effect of the VBWF system from these analyses.

During the research period, demand for reusable waste bags has increased from 64,077 to 321,859, and its market share reached 36.5% in 2017. In contrast, the market share of the standard waste bag has decreased from 91% to 73.5% during the same period (Ministry of Environment, 2006; Ministry of Environment, 2018)[32]. Due to the limited data available, this study could not incorporate the price of the reusable waste bag. However, considering the fact that the price of the reusable waste bag is different[33] from the standard waste bag, this study recommends integrating the two types of waste bags to estimate the price incentive effect on household waste generation in future research.

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[32] The biggest difference of the reusable waste bag from the standard waste bag is that households can use the reusable waste bag in neighbouring administrative districts, while they should buy and consume the standard waste bag in the same administrative district. This is because the purpose of the reusable waste bag is to discourage households using single-use plastic shopping bags. The government recommends people buy and use the reusable waste bag after shopping, instead of using single-use plastic bags (MOE, 2006; MOE, 2018).

[33] The t-test result shows that the mean difference of the price of the standard waste bag and the reusable waste bag is statistically different from 0 (t = 4.3158, p. value = 1.000).

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