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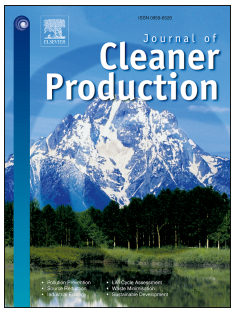

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Dumping, waste management and ecological security: Evidence from England

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Abstract: Illegal waste dumping has been widely regarded as one of the biggest source of environmental damage. Waste facilities management is an important way of combating illegal dumping for environmental protection and sustainability. This paper provides a comprehensive analysis on the determinants of illegal waste dumping based on panel data of England for a period of 7 years (2008 to 2014) using count data models, to access the effects of different drivers (economic, institution, policy). To be more specific the results show that (1) the increase of landfill cost (including landfill tax and landfill gate fee) have significant negative impact on the occurrence of illegal dumping (2) more waste landfill facilities, income level and intensity of penalty discourage illegal dumping. Such findings are robust using all models. The results indicate the main challenges in combating illegal waste dumping and the respective actions needed from the point of legal factors *(i.e.*, law enforcement), institution factors (*i.e.*, recycling rate, landfill dispersion) and economic factors (*i.e.*, income level).

Highlights: ► Increasing amounts of illegal dumping brought serious challenges to municipal waste managers. ► strengthening the capability of waste landfill facilities is one way to reduce illegal dumping. ►Other policies including increasing penalty on illegal waste dumping. ► Technical innovation is also important to increase waste recyclable rate and reduce tax on landfill.

Keywords: illegal waste dumping; fly tipping; waste management; England; count data models

1. Introduction

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Illegal dumping (also called fly dumping or fly tipping) refers to waste dumping on sites with no license instead of using an authorized rubbish dump and being disposed of properly at a landfill site. The underlying soil quality and watercourse are under high risk of being damaged if solid wastes are dumped inappropriately. Further, if the waste disposal is uncontrolled, it will damage the environment, particularly when it consists of used drugs, asbestos sheeting, and drums of toxic material or syringes (Ino, 2011).

Centralized collection and disposal is an important waste management strategy for waste taking the form of solids or liquids. It is used to manage waste of household, public sewage, hazardous waste of industries and business (Hamilton et al., 2013). England is declared as the "dustbin of Europe", it will run out of landfill sites in 2018. Every year, 57 million tons of rubbish, including industrial waste, are being disposed in landfill sites (Grice, 2010). The cost of collecting and dealing with commercial, industrial and municipal waste in UK reaches to 47 million pounds a year.

Based on the factor endowment theory (Sokoloff and Engerman, 2000), England is a small country with scarce land resources, the price of waste landfill can be costly. As a matter of fact, the cost of landfill gate fee has been increasing rapidly since 2005. The cost of landfill consists of two parts, landfill tax and landfill gate fee. Landfill tax is included in the council tax bill of the household trash. The business waste must enter the licensed landfill with a "gate fee" through a registered waste carrier. In England every waste carrier is obliged to pay for the fee of waste disposal.

The cost of waste landfill is increasing, from 2008 to 2015, the cost of landfill for non-hazardous, hazardous waste and landfill tax increased for 4 to 5 times. According to the data from The Waste and Resources Action Program (WRAP) gate fees annual report, the landfill

cost for nonhazardous waste increased from £45 in 2008 to £168 in 2015 in England (WRAP, 2015). Nevertheless, the average household recycling rate in England has been increasing. It might indicate that the landfill policy encouraging household recycling when illegal dumping does not exist. As a matter of fact, as the cost of waste landfill becomes more and more expensive, household may have more incentive to dump waste illegally or fly tipping.

The levying prices on waste disposal create incentive for agents to make illegal dumping (Hamilton et al., 2013). The increasing cost of disposing rubbish has been increasing the amount of individuals and business fly tipped waste in England. The main purpose of fly-tipping is to avoid paying the landfill tax. The cost of paying criminals for illegally dumping is half the cost of paying a legitimate waste disposal company (Morris and Read, 2001). It causes serious environmental problems. According to UK Environmental Agency, it costs over £100 million to investigate and clear up the dumped sites. According to The Department for Environment, Food and Rural Affairs (DEFRA), the penalty on waste illegal dumping has been increasing. Between 2008 and 2012, 40 companies were convicted for illegal waste dumping in Scotland (OCCRP, 2013). As a result, UK government works hard to combat fly-tipping including making it easy to report fly-tipping and illegal disposal online, increasing the penalty of fly- tipping, strengthening the cooperation between UK government and that of other countries for reducing international waste trafficking, increasing recycling rate as a mean to combat illegal dumping though effective collection schemes and segregation by source.

The primary aim of this paper is to provide preliminary robust empirical evidence for a vast district in England on the social economic, structural and legal drivers of illegal waste dumping dynamics, distinguishing between socio-economic and policy factors. Although waste policies have been in force for long time, the effectiveness of them has been greatly reduced by the illegal

dumping activities. To the best of our knowledge, the causes of illegal dumping activities have not been studied using quantitative methods. As such, the causes of illegal waste dumping are the focus of our study.

This paper is one of the first empirical works in testing what factors induce the illegal dumping in England. There are some studies on landfill management and illegal dumping on Korea, Japan, Thailand, South Africa and China. However, there is little research on illegal dumping and waste landfill management on England. Traditional understanding is that in order to achieve increased municipal waste recycling and recovery rates, it requires the development of the waste treatment infrastructure, and the support of high-intensity recycling and composting schemes. Moreover, it also needs the banning of alternative ways of collecting and disposal waste, such as fly-tipping and illegal dumping. England has good experiences in the waste management and combating illegal dumping.

This paper extends the work of Ichinose and Yamamoto (2011) in a number of dimensions. First, their work only considers the intermediate waste treatment facility, this paper examines all waste treatment facilities including landfill, recovery, incineration and recycling with the help of Waste Landfill Index, thus the estimation result is more accurate. Second, previous work did not consider the impact of income per capita on illegal dumping. This paper uses collected household waste per capita as the proxy of the income level in each district. Third, in their research, the impact of waste facility has negative impact on illegal dumping; however, it was not robust. We use regression models to address this issue and to draw important conclusions about the relationship between setting up waste facilities and illegal dumping.

2. Literature review

A comprehensive waste management policy requires the recognition of not only waste management at the generation stage but also the subsequent household behavior. Waste collection and disposal charge can discourage waste generation by households; nevertheless, it may also encourage the households to consider the options of illegal dumping to avoid paying for charge. Waste management research should include not only the waste reduction efforts by the household as well as the probability of illegal dumping (Choe and Fraser, 1999). Our research relates with two streams of literature: first, municipal solid waste management at the generation stage; second, waste management of illegal dumping.

Firstly, the majority of previous research on municipal solid waste management focuses on waste reduction of municipal waste generation. Table 1 shows several factors impacting the reduction of waste generation, waste recycling and reusing. Among them are the social and economic factors (such as education, access to allowance, income), and also the cost of landfill.

There are some studies about waste management in developing countries. Oyekale (2015) analyzes the factors influencing disposal and recycling of household waste in South Africa using bivariate Probit model, and identified that several factors influence the willingness of waste disposal and recycling, such as education, indigenous origin and access to social allowances. Challcharoenwattana and Pharino (2015) evaluate the landfill cost of municipal solid waste by controlling cities with and without community-based management programs (CBM) in Thailand, and found that cities with CMB program generated 9.68% less waste, and 16.80% less greenhouse gas (GHG) emission. Chen et al. (2014) study the municipal and industrial waste management in China by implementing Logarithmic Mean Divisia Index. They found that China had achieved absolute decoupling of industrial solid waste discharge from economic growth, but it has a long way to go for sustainability of municipal waste management.

The relation between waste generation and income is the most studied field in waste management. On the one hand, some researches did not find evidence for WKC (World Bank, 1992), no evidence was found by Cole et al. (1997) for delinking between municipal waste generation and income for OECD countries, similar studies have been done by Sppala et al. (2001). Mazzanti and Zoboli (2005) find no evidence for delinking between rates of municipal household waste generation and consumption expenditure. Similarly, using panel data of EU25, Mazzanti and Zoboli (2009) analyze the policy, structural and economic impacts on waste generation, however, they find no evidence to support the trend of Waste Kuznets Curve- the higher environmental and landfill policies prevent waste generation. On the other hand, other authors find delinking of waste generation to income (DEFRA, 2003), and delinking between waste generation to household expenditure (Johnstone and Labonne, 2004) The evidence from other researchers in favor of delinking between waste generation to household expenditure based on very specific waste indicators such as hazardous waste generation and (Berrens et al., 1997; Wang et al., 1998), and waste/consumption indicator (Raymond, 2004).

Table 1. Literature review - factors affecting waste generation

Number	Factors influence waste generation	Cases	author
1	Education, indigenous origin, access to social allowance	South Africa	Oyekale, 2015
2	Landfill cost of municipal solid waste	Thailand	Challcharoenwattana and Pharino, 2015
3	Economic growth	China	Chen et al., 2014
4	Income, but no evidence of WKC	OECD, developed nations, EU25	Cole et al., 1997; Sppala et al., 2001; Mazzanti and Zoboli 2005; Mazzanti and Zoboli, 2009;

5	Income, evidence for WKC	OECD, developed nations and the world	Johnstone and Labonne, 2004; Berrens et al., 1997; Wang et al., 1998; Raymond, 2004; Karousakis, 2009; Fischer-Kowalski and Amann 2001

The above studies focus on the waste management at the consumption, production and disposal stages, however, they ignores subsequent household behavior on illegal dumping. Another strand of literature studies the potential factors that cause illegal dumping. These factors include, but are not limited to, shortage of proper waste treatment facilities, landfill regulations, tax rate, enforcement power when waste regulation is violated, asymmetries of regulations between nations, price of legitimate dumping, global market of waste trading, and organized waste crime, among others.

Theoretically, the shortage of proper waste treatment facilities can increase the likelihood of illegal dumping (Munton, 1996). There is evidence that several factors may impact incidences of illegal dumping, such as rises in disposal cost, shortage of proper waste treatment facilities, penalties, tax, etc. Kim et al. (2008) demonstrate the starter of unit waste pricing of municipal solid waste encourages illegal dumping in Korea (Kim, 2008). Ichinose and Yamamoto (2011) is the first to empirically validate this theory with the evidence of Japan. Their findings show that the possibility of illegal dumping decreases as the waste treatment facilities and the penalties increase in Japan. However, they did not find robust evidence that waste treatment facility has impact on illegal dumping.

Some studies emphasized the organized waste crime is an important cause of the increasing illegal dumping. New legislation leverages waste treatment standards. Baird et al., (2014) systematically review the vulnerability of EU legislation and regulatory enforcement when facing organized waste crime. Massari and Monzini (2004) argue the weak regulatory enforcement of new legislation creates organized waste crime. Legitimate waste treatment services are undermined by increasing cost, making illegal waste operations more attractive (Dorn et al. 2007). The prohibitively expensive cost of ensuring fully with waste regulations creates opportunity for illegal business by the organized waste criminal (Van Erp and Huisman, 2010).

Another causes of illegal dumping is waste trading. A profitable global market for waste opens up opportunities for waste trafficking to restore, retreat and redispose waste anywhere else in the world (Tompson and Chainey, 2011). Dorn et al. (2007) argue waste trafficking is caused by asymmetries in regulation and enforcement abilities between nations. Bisschop (2012) believes the demand of waste in the end market is a major cause of waste trafficking. That is, the large scale of demand of waste as the raw materials contributes to GDP in the developing countries. Smith et al. (2004) find the reduction in the market price of scrap metal increase cost of legitimate vehicle scrapping and illegal dumping of cars, as a result, illegal dumping increased.

Literature shows theoretically that tax rate on waste disposal is also an important determinant on waste generation (Levinson, 1999a), and waste legal dumping (Levinson, 1999a; Levinson, 1999b; Sigman, 1998). Higher tax on waste will discourage the waste disposal and generation, further, when the waste tax went too high, households and companies will look for alternative wastes disposal-illegal dumping. Moreover, the number of illegal dumping incidences is also related to the restrictions on dumping, such as used oil disposal (Sigman, 1998).

172 Theoretically the best optimal policy is a combination of strictly charge on the household and
173 explicit monitoring of illegal waste disposal (Choe and Fraser, 1999). A summary of literature
174 review in the field of illegal dumping is summarized in table 2.

175 **Table 2. Literature on the causes of illegal dumping**

Number	Factors affecting illegal waste dumping	Cases	author	Journal
1	Shortage of proper waste treatment facilities	US	Munton, 1996	Georgetown University Press
2	Restrictions on dumping from EU Landfill Directives, such as the ban of tires	US	Sigman, 1998	RAND Journal of Economics
3	Tax rate	US	Levinson, 1999; Sigman, 1998	American Economic Review, Journal of Public Economics
4	Weak enforcement	Italy	Massari and Monzini, 2004	Global Crime
5	Asymmetries in regulations and enforcement abilities between nations	EU	Dorn et al., 2007	European Journal of Crime, Criminal Law and Criminal Justice
6	Unit waste pricing of municipal solid waste	Korea	Kim et al., 2008	Environmental Economics and Policy Studies
7	Enforcement power of waste regulations	EU	Van Erp and Huisman, 2010	Criminology and Public Policy
8	Global market for waste trading	EU	Tompson and Chainey, 2011	European Journal of Crime, Criminal Law and Criminal Justice
9	Waste treatment facilities, penalties on illegal dumping	Japan	Ichinose and Yamamoto, 2011	Resource and Energy Economics
10	Demand of waste from the developing countries; profitability of waste	EU	Bisschop 2012	Crime, Law and Social Change

11	Vulnerability of new legislation and regulatory enforcement facing organized waste crime	EU	Baird 2014	Waste Management and Research

There are three main contributions of this research to the literature. Firstly, there are a few empirical studies on landfill management and illegal dumping on Korea (Kim et al., 2008), Japan (Ichinose and Yamamoto, 2011), etc. However, there is little empirical research on the determinants of illegal dumping and waste landfill management on European countries. As the biggest waste producer and the initiator of Basel Convention, it is important to research the experience of England, since England has much experience in the waste management and successfully combating illegal dumping. Second, previous literatures show theoretically that tax rate on waste disposal is also an important determinant on waste generation (Levinson, 1999; Sigman, 1998). Nevertheless, little empirical evidence is provided for the impacts of tax. Third, this is the first study on the causes of illegal dumping using count data model. All models show robustness no matter which model is used, such as negative binomial model, Poisson model and zero-inflated models. Such methodology may be applied to other research on this subject. This is an improvement of the research of Ichinose and Yamamoto (2011), since their finding that the impact of facility on illegal dumping is not robust.

3. Illegal dumping and waste management in England

In UK, illegal dumping is also called fly tipping. "*Tip*" means throwing out of a vehicle, "*Fly*" means to through things casually. Fly-tipped wastes consist of large items of rubbish. Fly-tipping is illegal according to Environmental Protection Act of 1990 (EPA, 1990). UK waste comes under controls. A duty is imposed to ensure that waste is disposed of properly. Only the

196 licensed waste management companies can transport, recover, deposit, dispose of waste.
197 Moreover, waste can be deposited only at officially authorized deposit sites.

198 *3.1 UK waste discharge*

199 In 2012, 1,279 illegal waste dumping sites were shut down, compared with 759 shut down
200 sites in the previous year. Hazardous waste was found in the illegal sites. 1/20 of them
201 encompassed asbestos in waste, 1/5 contains chemicals, fuel and oil. Each year, illegal waste
202 dumping costs UK tax payers £1 billion (DEFRA, 2015).

203 As table 3 shows, according the nature of the waste, illegal waste dumping is categorized
204 into four types by DEFRA (2015), including electronics, construction and demolition wastes,
205 packaging waste, recyclables and healthcare. According to the impacts of waste on environment,
206 it can be categorized as non-hazardous waste and hazardous waste. The former includes organic,
207 residuals. The latter includes asbestos, chemicals, none edible oils, equipment and hazardous
208 containers.

209 **Table 3. Main contents of illegal waste dumping**

Waste type	Waste categories		Examples
According to the nature of wastes	electronic and electrical equipment		TV, Radio, computer
	construction and demolition wastes		cement scrap, wood scrap
	packaging waste		Black bag
	recyclables and healthcare		cans in metal and plastic
According to the environmental impact	non-hazardous waste	Organic, residuals, etc.	food oil
	hazardous waste and	asbestos, chemicals	brake fluid or print toner, batteries, solvents, pesticides
		none edible oils	car oil
		equipment containing ozone depleting	fridges

		substances	
		hazardous waste containers	machine oil barrel

(DEFRA, 2015)

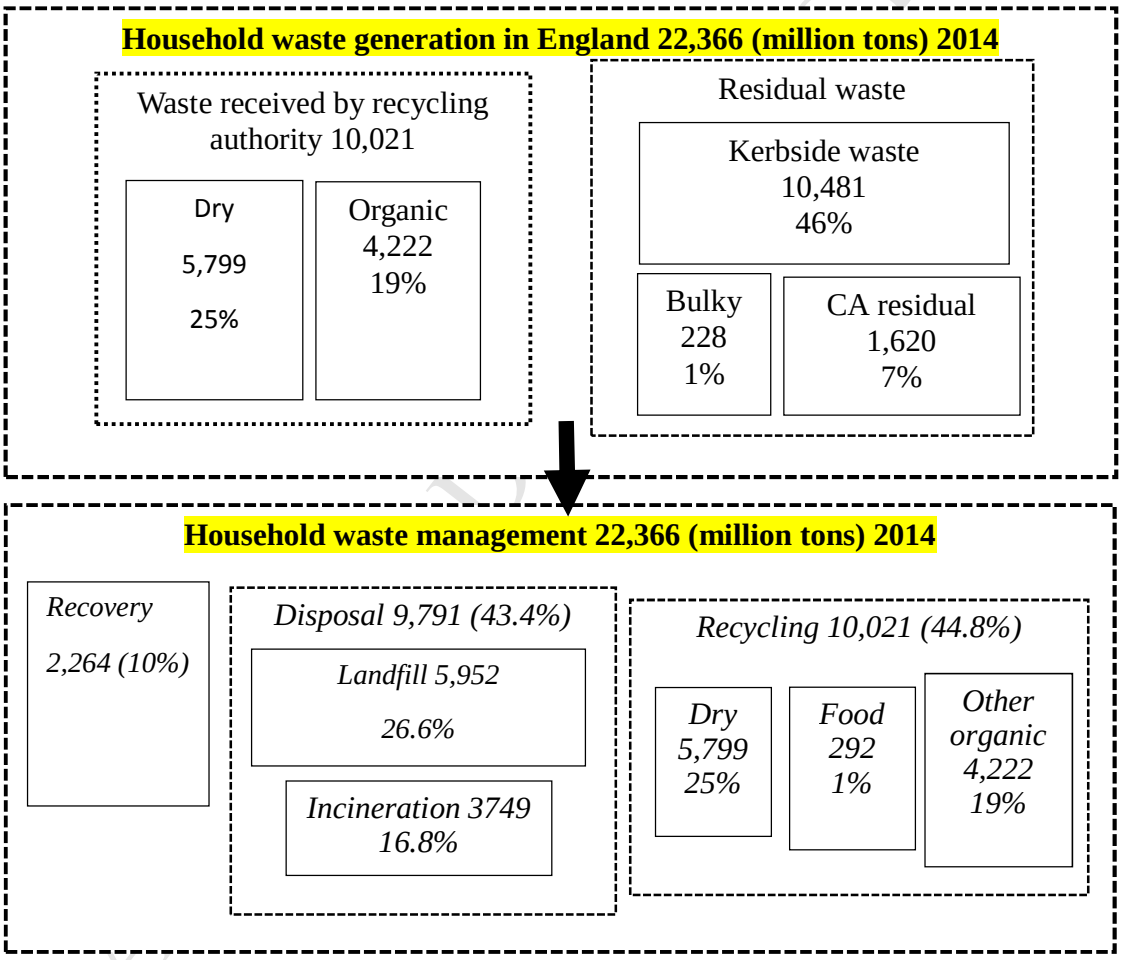
We summarize the status of households' waste release and management in England in figure 1. It shows the variety of households waste collected by local authority, including hazardous and biodegradable waste generated by household, and how they are treated. In 2014, 22,366 million tons of waste was discharged by households in England. This weight has increased only 1% comparing with that of 5 years ago. Among the wastes, 16.8% was incinerated, 26.6% was disposed directly in landfills, 10% is recovered and 44% of waste has been recycled.

Households waste responsible for 14% of total waste generation. Another 50% and 24% of waste were generated by construction, and commercial and industrial activities respectively. However, of a total of 900 thousands fly-tipping incidences in England in 2014, nearly two third of them involve household waste (DEFRA, 2015). Further, it is estimated by DEFRA (2016) that households waste takes the highest share of hazardous (4.7%) among all kinds of wastes.

Landfill disposal plays an important role in England waste treatment of hazardous compared to other treatment. Landfill received those waste that cannot be recovered or recycled, including those hazardous wastes. Moreover, hazardous waste should be send to waste landfills that are designed for treating hazardous waste. EU Landfill Directive has significant impact on the development of waste treatment facilities in UK. The purpose of the directive is to prevent, or reduce as far as possible, any negative impacts on human health or the environment due to the landfilling of waste, to prevent pollution of surface and ground waters soils and air. It also requires the improvement of the design, operation and management of landfills with restriction the types of waste that are allowed to be landfilled. Burnley (2001) studied the impact of EU

landfill directive on waste management in UK. He estimated, in order to meet the requirement of directive, the number of new incineration plants would increase to 130, if the growth of municipal solid waste generation was at 3% annually.

Figure 1. England local authority collected households waste (including hazardous waste)



Source: Calculate base on UK Statistics on Waste Data, (DEFRA, 2016)

239 *3.2 Illegal dumping in UK*

240 According to the Department for Environment, Food and Rural Affairs (DEFRA), the most
241 common items of fly tipped municipal waste are household waste, white goods, demolition and
242 construction waste, garden waste and business wastes. Figure 2 shows the composition of total
243 fly-tipping in England since 2007. Although the total incidents decreased since 2007, it has been
244 increasing dramatically after 2012, a potential cause of such increase is due to that council
245 started charging for the collection of household items. The collection fee is reflected by the
246 jumping of landfill tax and landfill entrance fee. The number of household black bags in 2012
247 was about half of that in 2007. It increased slightly since then. Other types of waste such as white
248 goods and commercial waste have been increasing dramatically after 2012, equivalent to its level
249 in 2008.

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254 **Figure 2.** Fly tipping incidence in England by type (2007-2014)

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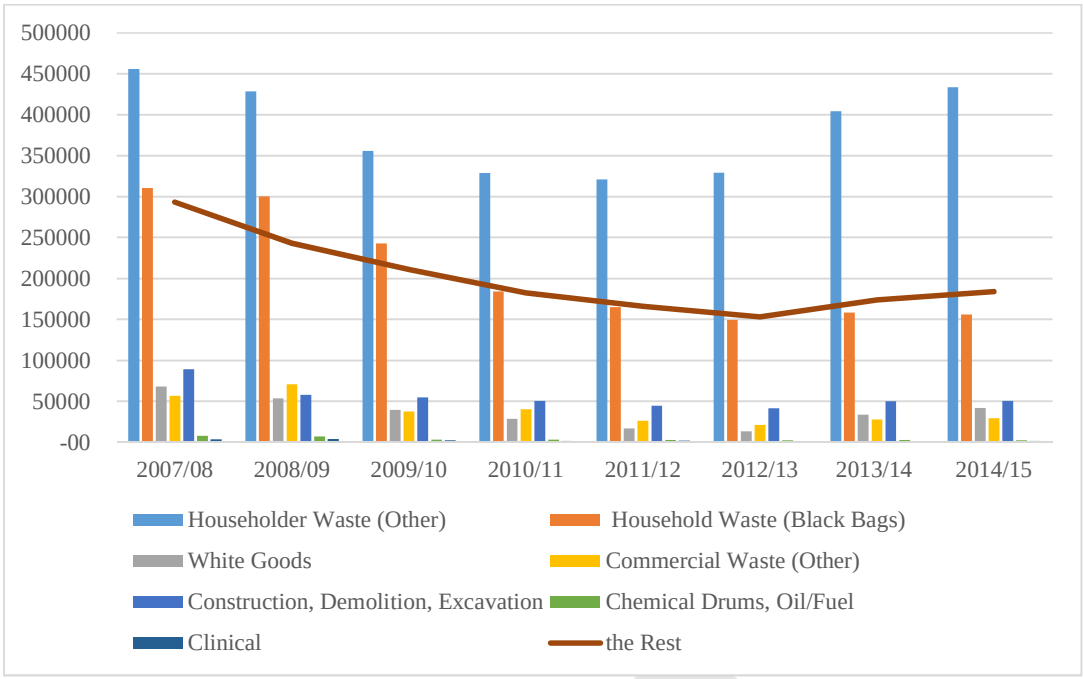

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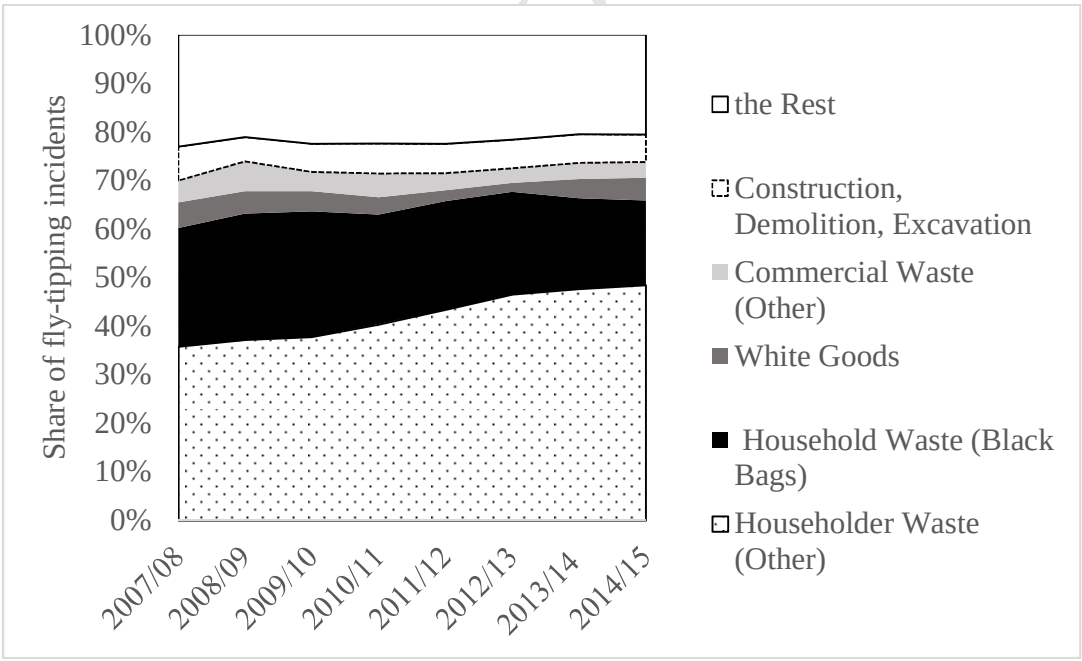
257 Source: Calculated based on fly-tipping statistics for England, (DEFRA, 2015)

258 **Figure 3. Share of** fly tipping incidents in England, 2007 to 2014



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260 Source: Calculated based on Fly-tipping Statistics for England, (DEFRA, 2015)

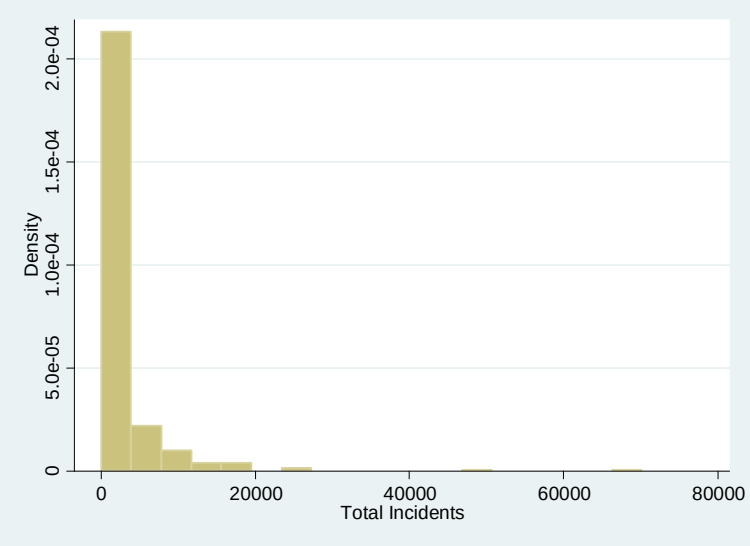
261 According to the data of DEFRA, as figure 3 shows, the major component of illegal dumping
262 waste is created by households, incidence of households waste takes over 60% of all the
263 dumping in 2007. White goods and commercial waste take up 10% of the total discharged illegal
264 dumping. The share of construction and demolition has been constant since 2007.

265 **4. Methodology**

266 The number of fly-tipping incidents is a non-negative integer. This dependent variable, fly-
267 tipping incidents of a district per year in England, is a count variable. Count data model is a
268 subset of discrete response regression models. It discovers the response to the number of
269 occurrences.

270

271 **Figure 4.** Frequency distribution of illegal dumping incidents



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273 Source: Calculated based on Fly-tipping Statistics for England, (DEFRA, 2015)

Figure 4 shows the frequency distribution of illegal dumping incidents in all districts of England in 2014. The distribution of dependent variable is heteroskedastic and right skewed. Each integer (fly-tipping) is identical to and independent of each other. The number of counts for England fly-tipping are discrete. It does not follow the property of Ordinary Least Square (OLS) model. Variables and residuals in OLS follow a bell-shape distribution. The distribution of fly-tipping is highly skewed, violating OLS assumption. The most used count data model is Poisson distribution regression (Liu and Zhang, 2015; Liu and Deng 2016). It estimates the possibility of the occurrence of a given count of fly-tipping (y_t) in a district of England.

$$\mathrm{P}\ (\mathrm{AD_t}=\mathrm{y_t}) = \exp(-\lambda_t)\frac{\lambda_t{}^{\mathrm{y_t}}}{\mathrm{y_t}\ !}, \mathrm{y_t} = 0,1,2,3 \ldots \text{(Poisson Distribution)} \quad (1)$$

A property of Poisson Distribution is that the mean of Y equals the variances of Y. Both of them equal λ_t. It interprets the average fly-tipping of a district in England during a year.

$$\mathrm{E(Y|X)} = \mathrm{Var(Y)} = \lambda_t \quad (2)$$

Dependent variable y is conditional on a set of x values. We need to know the influence of explanatory variable $X_{t\ (=x_1,x_2,x_3\cdots),}$ on fly-tipping λ_t:

$$(\mathrm{Y|X}) = \lambda_t \sim \mathrm{P}\{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \cdots)\} = \mathrm{P}\{\exp(\beta X_t)\} \quad (3)$$

That is to say the distribution of y is conditional on a set of variable X_t. $\mathrm{P}\{\exp(\beta X_t)\}$ may replace λ_t in (1):

$$\mathrm{P}\ (\mathrm{AD_t}=\mathrm{y_t}) = \exp(-\exp(\beta X_t)\frac{\exp(\mathrm{y_t}\beta X_t)}{\mathrm{y_t}\ !}\ \mathrm{y_t} = 0,1,2,3 \ldots \quad (4)$$

Poisson model implies the relation between log of dependent variable and independent variables:

$$log^{y_t} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \cdots \quad (5)$$

290 If the variance of Y does not equals to its mean, it violates the property of Poisson regression.
291 It also implies an over-dispersion exists as an error term. In this case, the mean and variance are
292 2,438 and 7,375, it follows negative binomial model.

293 Negative Binomial model (NB) is introduced to observe the over-dispersion of Y (the error
294 term) in Poisson regression (Hible, 2011).

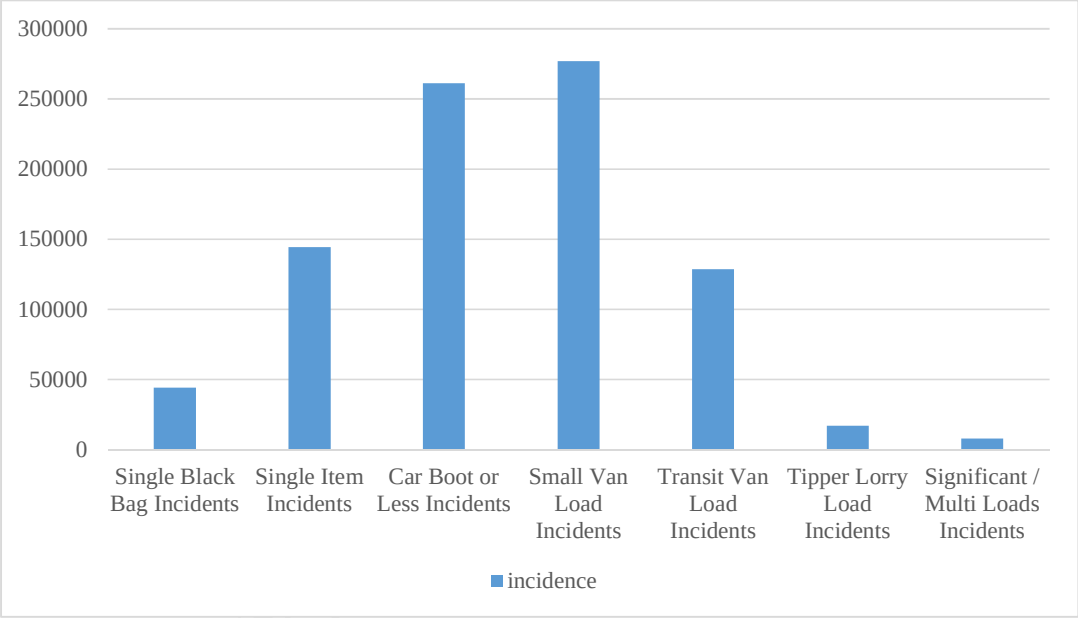
$$\mathrm{E(Y|X)} = \mathrm{var(Y|X)} + \mu = \lambda_t + \mu = \exp(\mathrm{a} + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \cdots) + \mu \quad (6)$$

295

296 The dependent variable Y (Illegal dumping) reports the occurrence of illegal dumping
297 incidents. The illegal dumping is investigated by every local borough or district council. Incident
298 of illegal dumping is reported by the Department for Environment, Food & Rural Affairs
299 (DEFRA). Using incidents regardless of the size of each waste pile, may ignoring weight and
300 causing bias on the real situation of illegal dumping. However, we will not use the volume of
301 waste illegally dumped as the indicator because of several reasons. First, volume of illegal
302 dumping weight data is not reported by the DEFRA, the volume of illegal disposal gauging is
303 extremely hard, the predicted data is not at all times trustworthy (Ino, 2011). Second, previous
304 researchers generally use the number of occurrences as the dependent variable to measure the
305 rigorousness of illegal dumping (Ino, 2011; Sigman, 1998; Kim, 2008). Three, empirical
306 evidence shows only a few illegal waste is reported as very large disposal. DEFRA reports illegal
307 dumping incidents by the number of containers that carries the waste. As figure 5 and table 4
308 show, most of the illegal dumping are small size piles. 97% of all the incidences involve

containers smaller or equal to transit van load (500-1500kg)[4]. Only 3% of incidences take place by very large size containers such as tipper lorry (24t-44t). The cost of clearance for the large size illegal dumping takes only 15% of all clearance cost in England. As a result, we will follow the method of the previous researchers, using the incidents to indicate the degree of illegal dumping.

Figure 5. Number of incidents by size of disposal 2007 to 2008



Source: Calculated based on Fly-tipping Statistics for England, (DEFRA, 2015)

Table 4. Incidents by size and the cost of clearance 2014-2015

[4] The payloads of van from variety of brands can be found at http://www.vanrental.co.uk/vansize.php

	Single Black Bag	Single Item	Car Boot or Less	Small Van Load	Transit Van Load	Tipper Lorry Load	Significant / Multi Loads	Total
incidence	44233	144491	261304	276997	128562	17052	7733	899087
share of incidence by size	5%	16%	29%	31%	14%	2%	1%	100%
clearance cost by size	309666	4190250	7577811	15511824	14784599	4794628	2355580	49524359
share of incidence by size (value)	1%	8%	15%	31%	30%	10%	5%	100%
average incidence clearance cost by size	7	29	29	56	115	281	305	55

Source: Calculated based on Fly-tipping Statistics for England, (DEFRA, 2015)

Table 5. Correlation matrix of variables

	Total incidents	Landfills dispersion	wlc	chwp	total actions	Prosecution actions	Law enforcement	Density perkm	RecyclingRate
total incidents	1								
landfills dispersion	0.133	1							
wlc	-0.101	0.040	1						
chwp	-0.021	0.241	0.020	1					
totalactions	0.238	0.129	-0.033	-0.032	1				
prosecution actions	0.153	0.161	0.009	0.028	0.434	1			
law enforcement	-0.015	0.060	-0.001	-0.009	-0.046	0.217	1		
density per km	0.363	0.131	-0.074	-0.199	0.271	0.065	-0.051	1	
recyclingrat	0.066	0.3913	0.160	0.514	0.066	0.045	0.005	0.070	1

e

323

324 **4.2 Independent variables**

325 Table 5 shows the correlation matrix of dependent variable and independent variables.
326 Income per capita decides the environmental regulation and comparative advantage of a district
327 in recycling. Higher incomes may induce changes in individual consumption bundles and the
328 creation of new need (Bagliani et al., 2008). According to Environmental Kuznets Curve (EKC),
329 as the income level of a district reaches high level, they are able to reduce environmental
330 degradation (Grossman and Krueger, 1995). However, the turning point of EKC for waste
331 generation is at high income per capita (post tax) from €23,000 to €*26,000* in Italy (Mazzanti et al.,
332 2009), Thus, attainable income of the majority of UK citizens should be on the left side of the
333 EKC for waste generation.[5] As such, the more household waste per person is collected, the
334 higher is his income.

335 The higher per capita income of a district, the less likely its citizens tend to engage in fly-
336 tipping and illegal dumping. The reasons are as follow: 1) Households with higher income are
337 more likely to be highly educated and less likely to break the law. 2) They may also have
338 stronger environmental protection consciousness and purchasing power to pay for waste service.
339 3) Further, poverty breeds crime, including waste organized crime. As a result, we assume the
340 districts with higher income level are less likely to fly-tip, vice versa. However, the per capita
341 income of each district is not available. As such, a proxy, collected household waste per person

[5] *The turning point of waste generation in Italy is equivalent to 22,200 GBP. Following the logic of heterogeneous turning points for EKC, the turning point of EKC for waste generation should be much higher in UK, as it is higher income country (Stern, 2015). The average disposable income of UK is 21,859 GBP or some 21% higher than that of Italy according to data from OECD statistics. Following the logic, the turning point for UK is also 21% higher. As a result, the estimated turning point for UK should be 27,000 GBP. As such, over 70% of UK citizens have attainable income less than 27,000 GBP.*

342 (chwp) by the local district council, is used to indicate the income per capita. As a result, we
343 assume the increasing chwp in a district have a negative impact on illegal dumping.

344 Waste recycling rate is the ratio between waste recoverable (such as waste recovered,
345 recycled, and composted), and total municipal waste collection. According to the data of DEFRA,
346 the recoverability of waste in England has been increasing from 30% in 2005 to about 60% in
347 2015. The rate of recoverability implies the strength of a district in handling and managing
348 recoverable waste. We assume as the rate of recoverability is getting higher, the incidence of
349 illegal dumping will reduce.[6]

350 $$\text{Recyclingrate} = \frac{wasterecoverable}{totalmunicipalwaste}$$

351 (7)

352 Waste landfill capability (WLC) is an independent variable in this research. In England, 27 %
353 of the municipal waste is send to landfills. In England, waste is collected by local district and
354 disposed by local authority. The landfill capability for every local authority is a scare resource.
355 Each authority should prioritize satisfying the demand of local waste landfilling. If the local
356 landfill is off-capacity, unrecoverable waste will be send to other landfills. An authority short of
357 landfill capability has to pay for permits to other authorities. In fact, there are around 362 district
358 councils in England in 2014, however only about 124 district councils has landfill. In order to
359 measure the landfill capability of each district, a new variable is introduced.

360 Wastes can be recycled, recovered, composted or incinerated; the rest of the waste should be
361 transported to the landfills. Unrecoverable waste equals total waste minus the waste that can be

[6] Effective collection schemes and segregation by source should have great impact on waste recycling rate. Since collection schemes and segregation are national wide activities. They may impact the nation as a whole. The heterogeneous impacts of collection schemes and waste segregation may decide the recycling rate of every authority, in the statistical model, we have an independent variable recycling rate to reflect such issue.

recycled, composted and incinerated (eq. 8). Wastes landfill capability is indicated as the share of landfilled wastes from other districts as percent of total waste it received. If a landfill, with high waste capability, has vacancy to take waste from other districts, its wastes landfill capability is indicated by a positive number; while if it is short of waste landfill capability, a district must send waste to the landfills in other districts. As such, its wastes landfill capability is indicated by a negative number. We indicate such waste landfill capability as WLC. It stands for the ability of a district in handling unrecoverable waste produced by other districts. It would closely reflect the additional cost/ profit of the waste treatment operations.

$$\text{wlc} = \frac{(\text{landfill} - (\text{totalmunicipalwaste} - \text{incineration} - \text{recycled} - \text{composted} - \text{recovered}))}{\text{landfill}} \quad (8)$$

Due to the limitation of financial and land resources in regional governments, landfills are becoming scarce resources. The cost of gate fee increases from 70 GBP in 2008 to 240 GBP (including landfill tax) for every ton of non-hazardous wastes entering into landfills. The local council that doesn't have landfills has a lot more pressure in handling wastes. A landfill serves for the local people easily; the cost of landfill for districts with no landfill is higher if the transportation cost is added. Waste management cost is going to be higher in the regions that have no landfill capability. This gives incentives for illegal dumping.

Some regional government has more landfills than other regional authority. In order to control the number of landfills, we use the number of district with landfills divide by the number of districts in the same regional authority, to indicate the dispersion of landfills distribution. We

383 call it landfills dispersion. We assume if the value is higher, it is less likely to happen illegal
384 dumping.

385 The Population Density (number of population per square kilometers) indicates the easiness
386 of illegal dumping (Ichinose and Yamamoto, 2011). Ichinose and Yamamoto use the cultivated
387 acreage area per capita to indicate population density and find a negative relation. However,
388 waste not only dumped illegally in cultivated acreage, but also in metropolitan districts. If there
389 is a lot of people around, it will be hard to dumping waste illegally without being spotted.
390 According to data provided by DEFRA, the density distribution of illegal dumping in
391 metropolitan districts (marked as "1") of England is much higher than that of none metropolitan
392 districts (marked as "0"). As a matter of fact, over 7,500 incidences were investigated in
393 Metropolitan areas, while around 2,000 incidences were investigated in nonmetropolitan districts.
394 Therefore, we assume incident of illegal dumping is more likely to be spotted and reported in the
395 districts with higher population density controlling the physical and geographical environment.

396 All of the illegal dumping involves crimes, therefore, the UK government does not suggest
397 the reporter to check the size and contents of the waste pile until he or she is sure it is safe to do
398 so. Many of the black bags contains hazardous waste, reporters are not suggested to open them.
399 All the above reasons may delay the time between spotting and reporting. However, three
400 reasons convince us to believe that the incidence reported is not biased. First, illegal dumping
401 data is reported annually, it is enough for reporting and investigation each case. Second, the
402 waste need to be replaced and cleaned before it disturbs and causes damage to the local
403 environment; it requires the local council to act as soon as possible. Third, in UK, the
404 government made it easy to report illegal dumping to the council through the internet. The local
405 council rewards those who provide the information that is able to successfully prosecute the

406 guilty party. For example, a £500 reward will be offered by Bromley Council for information
407 about a pile of abandoned waste (Barrie, 2014).

408 Increasing stringent regulations in EU induce firms to reduce product reusability, causing
409 increasing non-recyclable goods exports to the developing countries (the South). In the work of
410 Bernard (2015), he found the waste regulations such as the EU's Directive on Waste Electrical
411 and Electronic Equipment may induce firms from developed countries (the North) to reduce
412 product reusability. Under imperfect monitoring, second-hand products, with a mixture of
413 useable and non-usable waste, may be illegally export to the South. Bernard (2015) claims
414 increasing regulation is magnifying the pollution haven effects. This model uses the rate between
415 the number of prosecution incidents and total government actions against illegal dumping to
416 indicate the harshness of regulations. The strengthness of regulations is indicated by two groups
417 of indicators: a) the ratio between total actions responded by local district council and total
418 illegal dumping incidents (actions), and, b) the ratio between count of fines and total
419 prosecutions (law enforcement). They stand for different aspects of the deterrence effects of
420 regulation. First, actions stands for how much percent of illegal dumping is being responded by
421 investigators of local district council out of total incidents reported. Second, law enforcement
422 stands for the incentives provided by local council to illegal dumping and fly-tipping reporters. It
423 also indicates significant and richness of information provided by the reporters for successful
424 prosecutions. All dependent and independent variables and their explanations are reported in
425 table 6.

426 **Table 6. Description of all dependent and independent variables**

Variable	label	Obs.	Mean	Std. Dev.	Min	Max
TotalIncidence	Number of illegal	2520	2438.731	7375.103	0	176450

	dumping incidents					
LandfillsDispersion	landfills dispersion of each district under the same authority	2519	0.332	0.192428	0	2
wlc	waste landfill capability of each district	2520	-4971.091	17976.8	-208522	24475.800
chwp	collected household waste per person	2518	400.821	60.9063	255.726	981.635
actions	The ratio between total actions responded by local district council and total illegal dumping incidents	2405	1716.204	4701.229	0	115914
LawEnforcement	strengthen of law enforcement	2121	0.008	0.042	0	1
PopulationDensity	Number of population per square KM	2223	1708.201	2485.508	25	14735
RecyclingRate	percent of municipal waste not landfilled	2518	0.125	0.192	0	0.634

Source: Data is from DEFRA

5. Empirical results

The main findings of table 7 and table 8 are as follow. First, the coefficient of WLC is negatively and statistically significant in all models. It confirms our hypothesis. As the waste landfill capability decrease for 1 percent in a district, the illegal dumping incidence in that district is going to increase for 1 percent. [exp(0)=1, vice versa. Previous works only consider the

number of landfills in a certain area or the number of landfill sites in the neighboring prefectures to measure the capability of local waste management and treatment (Ino, 2011). However, the size and capability of each landfill varies, the Waste Landfill Capability index can measure the exact disposal capacities of a district. Thus better estimate the impact of waste treatment facilities on illegal dumping.

Second, the dispersion of landfill is positively and statistically significant on illegal dumping. The dispersion of landfills in a city indicates how difficult it is to find landfills for unrecoverable waste. If the landfill dispersion is 1 percent higher, illegal dumping is about 2.5% more likely to occur. That is to say the easier to landfill the waste, the less likely to fly-tip. This finding is similar with the results found by Ichinose and Yamamoto (2011). They use the number of waste treatment facilities in an area to indicate sufficiency of waste treatment facilities.

Third, the regression result shows income level is statistical significant at 1% confidence level. As the collected household waste increase for 1 point, illegal dumping is 2.7% less likely to happen. This confirms our hypothesis, areas with higher income level has preference for using environmental friendly products, since these products are usually more expensive. They are more likely to be able to afford more expensive service of the government licensed waste treatment companies. It is consistent with the consciousness that high income people are better educated and less likely to violate the low and engage in organized waste crime.[7] Illegal dumping is less likely to happen in a richer district than a less developed district.

Fourth, the two regulatory factors have negative impacts on illegal dumping. Nevertheless, the impact of law enforcement is not robust in all models. The probability of illegal dumping

[7] This is due to that households with higher income are better educated. Data from Employment project in the US shows people with higher educational attainment are more likely to be employed. While people with less than a high school diploma are 7% more likely to be jobless (available at http://www.bls.gov/emp/ep_chart_001.htm).. As a result, higher educated people may have stronger environmental protection consciousness and purchasing power to pay for waste service.

455 occurrence depends on how the local district council responds to illegal dumping actions.
456 Intensive responding actions against illegal dumping deter crime. Respond in actions by local
457 district include investigation, warning letter, and penalty actions (such as, statutory notice actions,
458 fixed penalty notice actions, duty of care inspection actions and, stop and search actions). If the
459 intensity of actions responding to illegal dumping reports is 1 percent higher in a district, illegal
460 dumping incidence is likely to decrease for 1 to 6 percent. It empirically confirms the literature
461 that the deterrence effect of regulation depends on how the law and regulation is enforced by the
462 government (Massari and Monzini, 2004). If the council sends investigators to cheek every case
463 reported, it would give a strong signal to the criminals that the government has determinants to
464 combat the crimes. This finding is similar with the economic model of Ichinose and Yamamoto
465 (2011) that penalty decreases illegal dumping.

466 Fifth, a new variable, the rate of prosecution counts out of all investigations (prosecution), is
467 added to indicate the sufficiency of the information on illegal dumping reports. A region with 1%
468 prosecution rate higher is likely to have 1.23 to 1.95 percent less illegal dumping. A successful
469 prosecution action indicates an illegal dumping crime is timely spotted, it also means the proof of
470 this crime is sufficient to send the suspects to trail. It has similar deterrence effects; however, it is
471 not robust if the government region is not controlled. This is because different regions of
472 England have different geographical and physical environment, the environmental characteristics
473 influence whether an illegal dumping can be successfully prosecuted. For example, illegal
474 dumping in cultivation acreage is less likely to be timely spotted and reported than that of
475 metropolitan area (Ino, 2011). Similarly, density per km has positive impacts on illegal dumping,
476 it is because more people will produce more waste, the illegal waste dumping indicates is likely
477 to be higher in a more popularized area.

Sixth, recyclable rate has positive relation with illegal dumping. This result suggests if the recyclable rate of a district is 1 point higher than other districts, it is 5.7% more likely to found an illegal dumping action. This finding is different from our assumption, probably because high recyclable rate is caused by capital investment in new technology and new facilities. The "Green Design" campaign in UK requires companies to be responsible for all product life. Manufacturers are not only responsible to produce but also to recycle waste after consumption. Increasingly stringent regulations will increase the cost of designing and producing. As the recyclable rate reaches to a high level, recyclable rate is becoming little elastic towards new investment. Companies from the "North" are encouraged not to make products unrecyclable but to export them to the "South" thus to reduce the cost of production (Ino, 2011).

Table 7. Empirical results of Negative Binomial (NB) Regression

Variables						
	Random effects			Fixed effects		
Models	(1)	(2)	(3)	(4)	(5)	(6)
landfillsdispersion	0.901***	0.901***	0.861***	0.861***	0.480**	1.189***
	(6.87)	(6.87)	(4.03)	(3.76)	(2.50)	(23.36)
wlc	-0.000**	-0.000**	-0.000*	-0.000**	-0.000***	-0.000***
	(-2.41)	(-2.41)	(-1.40)	(-2.41)	(-2.67)	(-6.87)
RecyclingRate	1.216***	1.216***	1.135***	1.216***	1.891***	1.711***
	(8.57)	(8.57)	(6.11)	(8.57)	(24.87)	(27.28)
PopulationDensity	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(26.41)	(26.41)	(15.23)	(15.84)	(31.47)	(61.69)
actions	-0.040***	-0.040***		-0.040***		-0.031***
	(-7.59)	(-7.59)		(-7.59)		(-15.07)
LawEnforcement	-1.748	-0.406		-0.677***	-0.262***	0.218***
	(-4.29)	(-0.72)		(-4.97)	(-3.27)	(-10.84)

hzwgf	0					
	(-0.60)					
chwp				-0.980***	-0.999*	-0.998*
				(-7.92)	(-1.72)	(-8.65)
FE Gor					Yes	Yes
FE Year				Yes	Yes	Yes
_cons	6.734***	6.734***	6.649***	6.734***	8.179***	7.209***
	(139.00)	(139.00)	(66.20)	(139.00)	(39.18)	(88.26)
lnalpha_cons	-0.033	-0.033	——	——	——	——
	(-1.21)	(-1.21)				
N	2059	2059	2059	2059	2059	2059

Note: Robust standard errors are in parentheses and ***, **, and * denote statistical significance of a coefficient at the 1%, 5% and 10% levels, respectively.

Table 8. Incidence rate ratio of NB regression

Variables						
	Pooled data			Fixed effects		
Models	(1)	(2)	(3)	(4)	(5)	(6)
landfillsdispersion	2.462	2.462	2.366	2.366	1.616	3.284
	(6.87)	(6.87)	(4.03)	(3.76)	(2.50)	(23.36)
wlc	1.000	1.000	1.000	1.000	1.000	1.000
	(-2.41)	(-2.41)	(-1.40)	(-2.41)	(-2.67)	(-6.87)
RecyclingRate	3.374	3.374	3.111	3.374	6.626	5.534
	(8.57)	(8.57)	(6.11)	(8.57)	(24.87)	(27.28)
PopulationDensity	1.000	1.000	1.000	1.000	1.000	1.000
	(26.41)	(26.41)	(15.23)	(15.84)	(31.47)	(61.69)

actions	0.961	0.961	0.961		0.969
	(-7.59)	(-7.59)	(-7.59)		(-15.07)
LawEnforcement	0.174	0.666	0.508	0.770	1.244
	(-4.29)	(-0.72)	(-4.97)	(-3.27)	(-10.84)
hzwgf	0				
	(-0.60)				
chwp			0.375	0.368	0.369
			(-7.92)	(-1.72)	(-8.65)

494

495 **Robustness check**

496 Table 9 shows the results of the Poisson regression, the direction of all variables are the
497 same with previous test. The statistical significance of most variables is the same, besides Law
498 Enforcement and hazardous waste landfill gate fee (hzwgf). The robustness of both variables
499 improved greatly.

500 **Table 9. Empirical results of Poisson regression model**

	(1) TotalIncidents	(2) TotalIncidents	(3) TotalIncidents	(4) TotalIncidents	(5) TotalIncidents	(6) TotalIncidents
TotalIncidents						
landfillsdispersion	1.181***	1.181***	0.999***	1.206***	0.323**	1.437***
	(535.80)	(537.43)	(5.04)	(5.39)	(1.96)	(1615.17)
wlc	-0.000***	-0.000***	-0.000**	-0.000***	-0.000***	-0.000***
	(-465.69)	(-480.78)	(-2.17)	(-2.64)	(-3.51)	(-858.15)
RecyclingRate	0.832***	0.831***	0.867***	0.856***	1.519***	1.281***
	(323.30)	(325.25)	(3.73)	(3.17)	(16.02)	(1085.13)
PopulationDensity	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(2086.35)	(2087.27)	(14.88)	(15.42)	(16.53)	(4243.28)
actions	-0.378***	-0.378***		-0.367***		-0.325***
	(-682.78)	(-682.83)		(-4.30)		(-1478.20)

LawEnforcement	-1.513***	-1.514***		-1.526	-0.910***	-1.910***
	(-103.03)	(-103.06)		(-1.45)	(-2.73)	(-309.57)
hzwgf	0.000***					
	(5.53)					
chwp				0.000	-0.002***	-0.001***
				(0.51)	(-4.59)	(-182.82)
FE Year	No	No	No	Yes	Yes	Yes
FE Gor	No	No	No	No	Yes	No
_cons	1268.19	7.152***	6.871***	7.232***	8.816***	7.539***
	(4646.16)	(6976.83)	(82.79)	(16.29)	(33.23)	(4368.80)
N	2059	2059	2223	2059	13669	13669
Pseudo R2	0.3835	0.3835	0.3835	0.039	0.037	0.039
Log likelihood	-3971550	-3971565	-4665917	-4665917	-4665917	3094881
AIC	7943115	7943144	4197.86	3785.68	3785.68	3785.68
BIC	7943160	7943183	9295855	7760797	7760797	7760797

Note: Robust standard errors are in parentheses and ***, **, and * denote statistical significance of a coefficient at the 1%, 5% and 10% levels, respectively.

According to table 10, as the rule of law is getting stricter, or the rate of illegal dumping fines increase for 1%, illegal dumping will decrease for 22%, holding other variables constant. Hazardous waste gate fee will positively impact illegal dumping. As the hazardous waste gate fee increase for 1%, illegal dumping will increase for 1 point, holding other variables constant.

Table 10. Incidence ratio of Poisson regression

	(1)	(2)	(3)	(4)	(5)	(6)
	TotalIncidents	TotalIncidents	TotalIncidents	TotalIncidents	TotalIncidents	TotalIncidents
TotalIncidents						
landfillsdispersion	3.256	3.259	2.716	3.34	1.3805	4.208
	(535.80)	(537.43)	(5.04)	(5.39)	(1.96)	(1615.17)
wlc	0.999	0.9999	0.999	0.9999	0.9999	0.9999
	(-465.69)	(-480.78)	(-2.17)	(-2.64)	(-3.51)	(-858.15)
RecyclingRate	2.298	2.294	2.38	2.354	4.5692	3.6
	(323.30)	(325.25)	(3.73)	(3.17)	(16.02)	(1085.13)
PopulationDensity	1	1	1	1	1	1

	(2086.35)	(2087.27)	(14.88)	(15.42)	(16.53)	(4243.28)
actions	0.6855	0.6855		0.6929		0.72224
	(-682.78)	(-682.83)		(-4.30)		(-1478.20)
LawEnforcement	0.22	0.22		0.2175	0.40234	0.148
	(-103.03)	(-103.06)		(-1.45)	(-2.73)	(-309.57)
hzwgf	1					
	(5.53)					
chwp				1	0.99804	0.9992
				(0.51)	(-4.59)	(-182.82)
FE Year	No	No	No	Yes	Yes	Yes
FE Gor	No	No	No	No	Yes	No
_cons	1268.19	1276.25	964.35	7.232***	8.816***	7.539***
	(4646.16)	(6976.83)	(82.79)	(16.29)	(33.23)	(4368.80)
N	2059	2059	2223	2059	13669	13669
Pseudo R2	0.3835	0.3835	0.3835	0.039	0.037	0.039
Log likelihood	-3971550	-3971565	-4665917	-4665911	-4665914	-4665920
AIC	7943115	7943144	4197.86	3785.68	3783	3780
BIC	7943160	7943183	9295855	7760797	7760793	7760780

Note: Robust standard errors are in parentheses and ***, **, and * denote statistical significance of a coefficient at the 1%, 5% and 10% levels, respectively.

In our case, we want to model how much illegal dumping incidence is occurred per district in England. The dependent variable is measured by illegal dumping incidence in every district. In some districts, zero illegal dumping was identified, however, there are two types of zeros. In the first group of "zero" districts, not a single illegal dumping or fly-tipping incident have occurred. In another group of "zero" districts, illegal dumping may be occurred, but such incidents were happened in private land and farm. In this case, such "zero" observations are called excess zeros. Since it was the responsibility of the landowner to remove it, thus they did not report. However, there is no data to distinguish these two types of "zero" incidents.

In order to control the counts of excess zeros in the dependent variable we use two types of zero-inflated model, Zero Inflated Poisson (ZIP) model and Zero Inflated Negative binomial (ZINB) model, to test the robustness of the results. ZIP/ZINB model works when the sample is

mixed by two types of "zero" districts. The count of the first group is generated by the standard Poisson regression model. Another group, absolute zero, has zero probability of a count greater than zero. As a result, the latter group mentioned above is considered as cause of the zero-inflated model. In the first step of regression, we use the dummy variable has landfill to estimate if the observation is eligible for non-zero response by a logistic regression model. It is "1" when a district has waste treatment capability, it is "0" when a district has no landfill capability at all. The other step determines the count for eligible individuals by a Poisson or Negative binomial regression. In particular, we use robust standard errors or cluster standard errors. The variables of key interest are waste landfill capability and waste recyclable rate.

Table 11. Incidence Rate Ratio for Zero Inflated Poisson Regression and Zero-inflated Negative Binomial Regression

	(1)	(2)	(3)	(4)	(5)	(6)
		ZINB			**ZIP**	
	TotalIncidents	TotalIncidents	TotalIncidents	TotalIncidents	TotalIncidents	TotalIncidents
TotalIncidents						
landfillsdispersion	2.4802	2.4612	2.454	3.25633	3.259	3.1583
	(4.26)	(4.23)	(4.17)	(5.72)	(5.86)	(5.55)
wlc	0.999	0.999	0.9999	0.99999	0.99999	0.999
	(-1.48)	(-1.63)	(-1.51)	(-2.35)	(-2.43)	(-2.24)
RecyclingRate	3.332	3.372	3.018	2.29	2.29453	1.9247
	(6.39)	(6.56)	(4.38)	(3.35)	(3.51)	(2.28)
PopulationDensity	1	1	1	1	1	1
	(14.66)	(14.53)	(14.97)	(14.95)	(14.84)	(14.40)
actions	0.9604	0.9604	0.961	0.6855	0.68555	0.6872
	(-4.95)	(-4.95)	(-4.90)	(-4.32)	(-4.31)	(-4.29)
LawEnforcement	0.57868	0.57501	0.58342	0.2201	0.22	0.2319
	(-1.05)	(-1.06)	(-1.06)	(-1.48)	(-1.49)	(-1.41)
hzwgf	0.9997			1		
	(-0.40)			(0.04)		

chwp			1			1.0012
			(0.83)			(1.48)
_cons	869.36	840.8	638.822	1268.19	1276.25	780.985
	(46.18)	(65.91)	(22.40)	(38.73)	(79.24)	(20.91)
inflate						
haslandfill	-1.11E-15	-1.11E-15	-1.11E-15	-1.11E-15	-1.11E-15	-1.11E-15
	(-0.00)	(-0.00)	(-0.00)	(-0.00)	(-0.00)	(-0.00)
	-	-	-	-	-	-
_cons	26.042***	26.042***	26.042***	41.000***	41.000***	41.000***
	(-1011.06)	(-1011.06)	(-1011.06)	(-1591.77)	(-1591.77)	(-1591.77)
lnalpha						
_cons	-0.033	-0.033	-0.034	-	-	-
	(-0.62)	(-0.62)	(-0.64)	-	-	-
N	2059	2059	2059	2059	2059	2059

In cases of over-dispersion, the fitness of ZIP model is the same with a standard Poisson model in C1-C3 in table 11. It indicates, when the over-dispersion or is considered, ZIP has equal capability in explaining the impact of WLC and RecyclingRate on illegal dumping with the standard Poisson model. We also tested them in ZINB and standard Negative Binomial model in C4-C6, it shows the same result.

6. Implications and policy suggestions

The empirical results of illegal dumping can provide some useful information not only for England but also for the world to establish a sustainable environment with low carbon and cleaner production. The EU Landfill Directive set schedule for the reduction of landfill waste for its member countries. The reduction of landfilled waste is helpful to achieve low carbon society, since landfill is a major source of GHG. However, the EU Landfill Directive did not include initiatives such carbon emission of the waste illegal dumped, fly tipped and smuggled to other developing countries. If those initiatives are included in the EU Landfill Directive then member countries should be encouraged to combat illegal dumping and to reduce water and air pollution

and minimize the negative effects of illegal dumped waste on human health and the environment. Some advices from the empirical results are as follow.

First, districts with higher income level, indicating by high amount of waste collected from household per person, are less likely to dump illegally. As such, it is suggested for the council with higher incidence of illegal dumping to develop the monitoring equipment (CCTV) for deterrent purpose.

Second, the waste landfill facilities and the hazardous waste gate fee also play important role in illegal dumping. Due to the landfill capability, dozens of landfills has been shut down every year. As a result, the waste management policy makers should not only focus on the increasing of recycling rate, but also increase subsidizing investment in the development of new technology for excavating and recycling wastes in shut down landfills (Song et al., 2015). Further, the possibility to upgrade landfill with energy recovery units should also be highlighted. It may be achieved through investment from the private and public sectors. As such, the increase in supplying landfill services will reduce the cost of waste gate fee, thus to reduce illegal dumping.

Third, the "green production" policy in England requires companies to increase recycling rate. The empirical results show the recycling rate has obvious positive impact on the waste illegal dumping, that is because of the challenge of reducing marginal cost as recyclable rate reaches high level. Requiring further higher recycling rate may encourage organized international waste trafficking thus increase illegal dumping (Baird et al., 2014; Tompson and Chainey, 2011). Waste policy makers should not only focus on increasing recycling rate but also to reduce illegal dumping. An optimal environmental policy is to subsidize technological investment so that to increase the capability of landfills so that to reduce landfill cost. Public-

572 private collaboration (take-back residuals policy, deposit-refund and other schemes) is another
573 way to improve rate recyclable waste and to decrease landfill cost (Qu et al., 2013).

574 Fourth, another way to combat illegal dumping is to strengthen penalty. It will help to
575 compensate for the high cost of law enforcement. The results indicate that illegal dumping also
576 depends on how the local district council responds to illegal dumping actions. Local district
577 councils that actively promote timely investigations increase the successful rates of illegal
578 dumping prosecution and punishment. In addition, intensive punishments against illegal dumping
579 deter crime and the prosecution also has deterrence effects to reduce the probability of illegal
580 dumping.

581 Lastly, education, training (Botelho 2012), campaigns and awareness (Desa et al. 2012)
582 related activities are important for achieving the goal of proper waste segregation and
583 management, particularly for hazardous waste. Public-private collaboration is needed in
584 promoting recycling. A trend towards more privatizing is found in the collection of municipal
585 household wastes. Pressure in cost efficiency on public services pushes governments to transfer
586 part of their services to the private sector. Empirical evidence shows the cost of private service is
587 much lower than public service in collection of household waste in all cases in Belgium
588 (Jacobsen et al. 2013).

589

590 **7. Conclusion**

591 This paper provides one of the first empirical analyses of the determinants of waste
592 illegal dumping in England. In this paper, we incorporate the capabilities of all types of waste
593 treatment facilities, including incineration, recovery, recycling and landfill simultaneously into

illegal dumping analysis. Further, we also conduct an empirical study of illegal dumping incorporating collected household waste per person for English illegal dumping during 2008-2014. The results show the main challenges in combating illegal waste dumping and the respective actions needed from the point of legal factors (law enforcement and prosecution actions of local council), institutional factors (Landfill dispersion, recycling rate, waste landfill capability and population density) and economic factor (income level). Such finding is robust using all models. The results support the literatures that the good waste treatment facilities help to decrease the probability of illegal dumping[8]. This finding is robust when we control the number of districts in the same governmental region that has landfills. It is a new contribution comparing to the previous works.

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[8] A good waste treatment facility may indicate that an authority can quickly provide waste collection, recycling, disposal and other related services needed for its citizens at a reasonable price avoiding illegal dumping. An authority that has to ask for permission of landfill from neighboring authorities will increase the cost of waste treatment services, thus increase the probability of illegal dumping. According to the "Broken Windows" Theory (Wilson and Kelling, 1982) and Single Crime Theory (Innes, 2004), an independent illegal dumped trash without being removed timely will attract more trash and single other more serious crimes, thus discourage financial investment in the area (EnCams, 2003) and the increasing of residential property values (EPA, 1998). As such, in the data and methodology section, we use landfill capabilities to imply the quality of waste treatment facilities.

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