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Evaluating the Effectiveness of Landfill Taxation on Waste Streams

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Abstract: Waste generation is steadily increasing, and is prospected to continue to do so in the decades to come. With greater amounts of waste generated, the importance of efficient waste treatment intensifies. Following this, the present paper empirically examines the effect of waste policies on waste stream allocation in Europe. Specifically, fixed effects estimation is employed on a cross-country setting to investigate the diverting power of landfill taxation on (i) the amount of waste landfilled, (ii) the amount of waste incinerated, and (iii) the amount of waste recycled. The data utilized is a panel data set of 23 European Union member states over the period 1998- 2017. The results from the regression analyses indicate that landfill taxation positively impact the amount of waste treated in incineration plants. No significant relationship between landfill taxes and landfilling or recycling is found.

Keywords: waste management, landfill taxation, landfilling, waste incineration, recycling

JEL: C33, H23, Q53, Q58

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1. Introduction

The treatment and disposal of waste is becoming an increasingly important topic as waste generation is continually on the rise. Around the world, more waste than ever is being generated today, and more waste than today is likely to be generated tomorrow (World bank 2018). At the same time, the supply of natural resources is beginning to run low: a progression partly sustained by the linear characteristics of present day's economy. To keep up with the increasing amounts of waste and limit the extraction of virgin materials, it is important to treat and dispose of the waste as efficiently as possible (OECD 2019). In an attempt to transition into more sustainable practices, the European Union (EU) launched the so called 'Circular Economy Action Plan' in the beginning of 2015. Within this framework, the importance of reuse and repurposing of waste was highlighted in order to subvert from the 'take-make-dispose' mentality presently employed (European Commission 2015). As of this year, the world has entered into a new decade, after leaving the last with environmental concerns at the top of the international agenda (Brown 2020), and the end of the first Circular Economy Action Plan. It is thus a time with increased attention and prioritization in regard to waste management, where new and extended practices are being (re-)written in order to account for the future. To help design these new policies, a clear understanding regarding the success (or failure) of previously employed instruments is crucial.

The European Union has launched numerous waste management directives during the last couple of decades. Within these frameworks, waste disposal by landfill has been deemed the least desirable waste treatment option, most evidently in the EU's 1999 Landfill Directive (1999/31/EC) and Waste Hierarchy (2008/98/EC). The Waste Hierarchy is a ranking of waste treatment options, from the least- to most desirable alternative (see Figure 1.1).

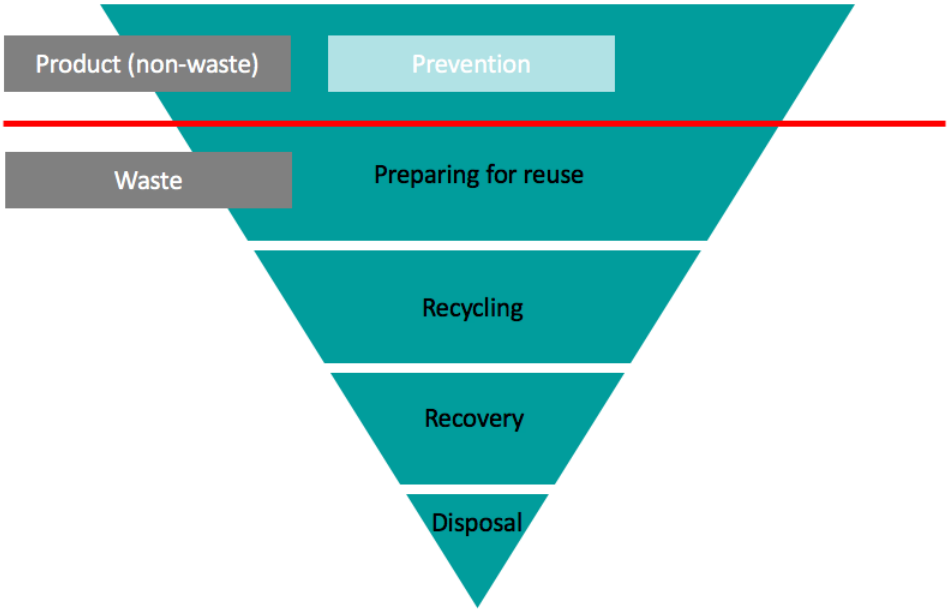


Figure 1.1 Waste Hierarchy of the European Union. Source: 2008/08/EC. Figure is author's own rendition.

The Hierarchy is primarily based on environmental concerns, and thus does not take economic aspects into account to any higher degree. Following this established inferiority of landfilling of waste, various policies aimed at diverting waste from landfill sites have been implemented

in the European Union (and other places). The economic instrument most widely used within the EU to try and achieve this diversion from landfill sites is the implementation of landfill taxes. Today, all EU member states except three make use of landfill taxation. However, despite the broad implementation, it is unclear whether taxes on landfilled waste actually successfully divert waste streams from landfill sites, or if the effect is strictly a diversion of finances. On this, existing research is divided. Furthermore, the studies that have investigated the impact of landfill taxation on the allocation of waste streams in a European context have done so almost exclusively using single country cases. The generalizability of existing evidence is thus limited, as the recognized success (or non-success) of taxation within one nation might depend on some characteristics unique for the country in question. A lack of empirical research on an aggregated EU level might inhibit the design of effective waste practices within the European Union going forward.

Accordingly, the aim of this paper is to provide additional information for policy makers to consider when deciding upon the most optimal waste management practices for the future. This will be achieved by investigating the impact of landfill taxes on the treatment of waste on a cross-country scale, on a sample of 23 EU member states[1]. The study will be conducted using a panel data set on the countries in question, spanning from 1998 to 2017; two decades that has seen an increased activity regarding waste management. Thus, the research question that the present paper sets out to answer is the following:

How has the implementation of a landfill tax affected the allocation of waste between different waste treatment options, if at all?

2. Conceptual Framework

In order to be able to design a model that effectively answers the research question, additional knowledge about waste management is needed. Hence, the paper will begin with a section describing waste management practices. Specifically, the available waste types, waste treatment options and waste policies (with a particular focus on landfill taxes). Since the geographical scope of this paper is limited to the European Union, the waste types, -options and -policies described also pertain to this area.

2.1. Waste Types

This paper focuses on the policies and treatments surrounding so called municipal waste. The reason for this is that this type of waste has been readily discussed and researched in the past, with a lot of policies targeted at its particular treatment, making municipal waste statistics an important source to follow up on such directives. Furthermore, data on this type of waste is relatively extensive and more similar across countries than other types of waste, such as industrial waste. Thus, municipal waste is better suited for cross-country analysis. As per the joint definition of municipal waste by Eurostat and OECD, it includes household waste and similar waste (originating from e.g. small businesses and schools), waste from certain municipal services (for example street sweeping), and – if treated as waste – bulky waste and yard waste. The definition explicitly excludes waste from sewage networks and construction and demolition sites (European Commission 2016).

[1] The countries included in the analysis are Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Sweden and the United Kingdom. The United Kingdom is included in the analysis despite no longer being part of the European Union as of 02-01-2020, since it was a member state for the entirety of the sample period.

Moreover, the European Union has established a 'List of Waste' (henceforth LoW), wherein they list all waste types according to either the origin of the waste or the type of the waste. Since this is a cross-country study covering EU member states, this classification will be utilized in favor over national variations. The classification is applicable regardless of whether public or private actors are the one's collecting and treating the waste, and can thus be used for all countries presently relevant (2018/C 124/01).

The LoW contains 20 chapters further divided into sub-chapters. The chapters relevant for municipal waste are chapter 20 'Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions' and sub-chapter 01 of chapter 15 'packaging (including separately collected municipal packaging waste)' (2018/C 124/01. Consequently, the waste types relevant to the present paper are the following:

- Paper and cardboard
- Textiles
- Plastics
- Glass
- Metals
- Organic materials from households
- Hazardous household waste
- Bulky waste
- Mixed waste from households and similar institutions (residual- /combustible waste)
- Garden and park waste
- Waste from public bins and street sweepings
- Market cleansing waste
- Cemetery waste

For clarification, these waste types can be grouped into six groups based on their waste streams, namely: (1) separately collected waste (paper and cardboard, textiles, plastics, glass and metals), (2) biodegradable waste (organic materials from households and garden and park waste), (3) hazardous household waste, (4) bulky waste, (5) mixed waste, and (6) other municipal waste (waste from public bins and street sweepings) (European Commission, 2016).

2.2. Waste Management and Disposal Options

Today, there are four main options for waste disposal, namely landfilling of waste, waste incineration (with and without energy recovery), recycling and composting of waste. In addition to the final treatment alternatives, there are also two types of so-called 'pre-treatment' options; mechanical-biological treatment (MBT) and separate collection of waste through sorting. Mechanical-biological treatment primarily pertains to biodegradable and organic waste, while sorting of waste is done for waste types such as paper, metal and glass (separately collected waste) (European Commission 2016). Figure 2.1 Illustrates the basic different waste streams generated by municipal solid waste (MSW).

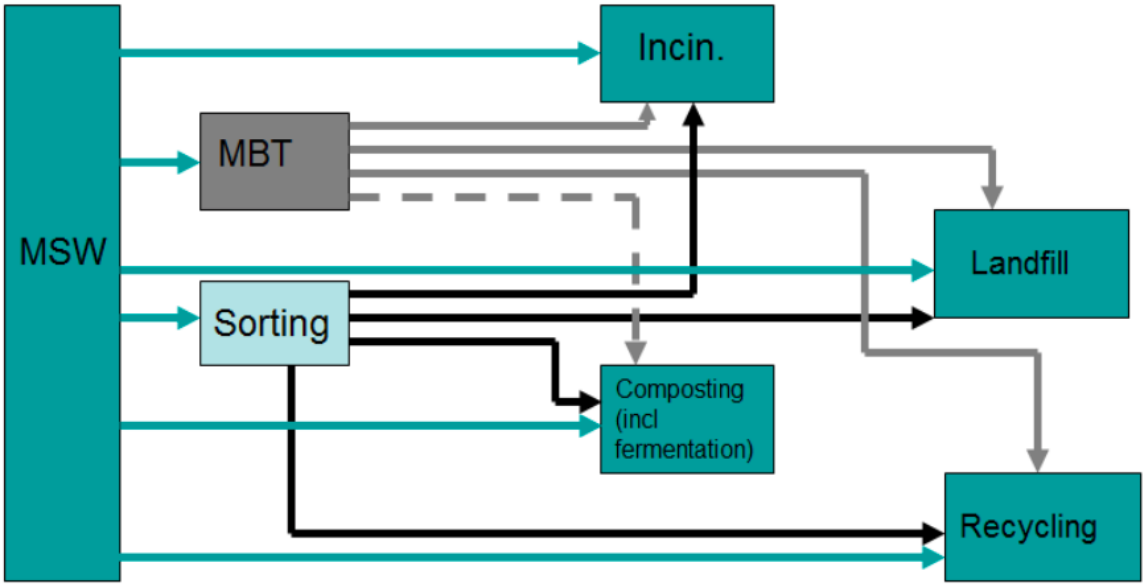


Figure 2.1 Municipal Solid Waste Flows. Source: European Commission, 2016, Guidance on Municipal Waste Data Collection. Figure from source.

The reason there are several different waste treatment options is to accommodate for both the heterogeneity of types of waste and the varying ability for responsible authorities to dispose of the waste. The municipal offices bear the main responsibility for the collection and treatment of municipal waste across all countries in the sample. However, in the majority of the countries, parts of the waste management process are outsourced to private companies via contracts, or alternatively taken care of by 'hybrid companies', i.e. collaborative associations consisting of both public and private entities. For example, separately collected waste aimed for recycling are often taken care of by the companies producing the original commodities via various 'extended producer responsibility' (EPR) schemes. The municipal authorities themselves own and operate the majority of landfill sites across the sample, while private ownership is more common for waste incineration plants (Eunomia Research and Consulting Ltd 2000). Following these responsibility schemes, it can be deduced that the local authorities are the main actors within each country's waste management framework. Thus, to enable reallocation between the amount of waste disposed via the alternative treatments, the reallocation must first and foremost be feasible with consideration to the characteristics of the waste in question (for example, it is not possible to compost waste that is not biodegradable), and the municipal offices, primarily, has to be incentivized to do so. However, while this is also true for recycling, the process determining how much municipal waste is actually recycled is a bit more complicated. The amount of waste ultimately recycled largely depends on the households, due to the fact that a substantial part of household waste aimed for recycling stations are separately sorted by the households themselves, and the majority of municipal waste is household waste (Barterlings et al. 2005). For this reason, the households' incentives to recycle has to be taken into consideration when analyzing landfill taxes' impact on recycling.

Going forward, composting (and consequently mechanical-biological treatment) is consciously left out of the analysis. The reason behind this is both due to the particular characteristics of biodegradable waste and the purpose of the study. Firstly, while composting biodegradable waste is clearly preferable, it does not save virgin materials to the same extent as does recycling of separately collected waste. Additionally, combustion or landfilling of biodegradable waste

do not cause the same negative environmental impacts as does other types of waste, since it, per definition, is entirely made of natural materials. Thus, the overall environmental impact of 'mishandling' of biodegradable waste is of smaller consequence compared to other waste types, and subsequently less crucial for policymakers (Kopnina 2012). Secondly, composting is not explicitly incorporated in the EU's waste hierarchy. Since the aim of this paper is to investigate the effectiveness of landfill taxes in aligning waste management with the sentiment of the hierarchy, composting is here excluded (2008/98/EC).

Below are descriptions of each of the analyzed disposal options' (landfilling, incineration and recycling) characteristics, starting with landfill sites.

2.2.1 Landfill Sites

Landfilling of waste is the waste management practice wherein solid waste is disposed of in the ground. According to the OECD, landfilling of waste is the following:

"Landfill is defined as a deposit of waste into or onto land, including specially engineered landfill, and temporary storage over one year on permanent sites. The definition covers both landfill in internal sites (i.e. where a generator of waste is carrying out its own waste disposal at the place of generation) and in external sites." (OECD 2020a)

The practice to landfill waste has long been the primary and dominating waste disposal alternative globally, and still is in many parts of the world (Kaza et al. 2018). One reason for this is the fact that all waste can be landfilled. However, during the last couple of decades, some waste flows in Europe have been redirected to other types of treatment alternatives, following policy implementations such as the Waste hierarchy (more on this below) (see Figure 2.2). But landfilling is still widely utilized, especially for hazardous- and mixed waste. Within the EU, landfill sites are divided into three classes: (1) landfills for hazardous waste, (2) landfills for non-hazardous waste, and (3) landfills for inert waste (European Commission 2019). Municipal solid waste is primarily disposed of in the first and second classes of landfills.

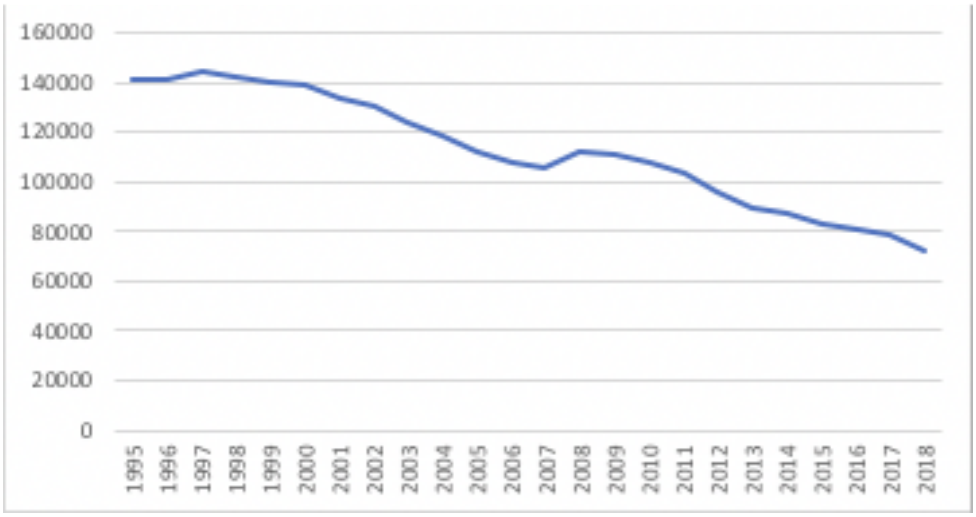


Figure 2.2 Amount of waste landfilled for the aggregated sample 1995-2018, in thousands of tons. Source: OECD, 2020a, data set titled 'Landfill'. Author's own rendition of the data.

The primary motivations for the efforts to reallocate waste from landfill sites, are environmental- and health concerns (i.e. not primarily economical) (20018/98/EC). From the point of view of the environment, landfilling is determined to be the worst waste disposal

option, especially older landfill sites. According to previous research in general, the main external concerns of landfill sites are global air pollutants, leachate and so called disamenities (Eshet 2006). Leachate is water, for example from rainfall, that travels through the landfill site – carrying with it hazardous substances – and seeps out into the ground below (Cambridge University Press 2020). So called leachate lakes have often formed below sites. However, leachate is considered less of a problem in modern landfill sites with a bottom barrier to enable collection and purification of the contaminated waste (Avfall Sverige 2018). With disamenities, research is referring to the overall welfare impacts on the people living in the surrounding area of the facility. Different papers highlight different aspects contributing to the disamenities of the facilities, but the most frequently voiced concerns are odor, visual intrusion, wind-blown litter, increased traffic and vermin (Eshet 2006). Lastly, a noteworthy disadvantage of landfill sites compared to other treatment options, is the amount of space necessary to operate such facilities.

2.2.2. Waste Incineration Plants

The primary waste disposal alternative to landfill sites is waste incineration plants, since the majority of waste types can also be combusted. Within these plants the waste is incinerated, transforming it into byproducts such as ash and smoke. The materials that cannot be combusted - mainly porcelain, and metals - are referred to as slag (Avfall Sverige 2018). Some plants recover the energy produced through combustion and transform it into heat and electricity. The European Commission has defined waste incineration plants as follows:

"'Waste incineration plant' means any stationary or mobile technical unit and equipment dedicated to the thermal treatment of waste, with or without recovery of the combustion heat generated, through the incineration by oxidation of waste as well as other thermal treatment processes, such as pyrolysis, gasification or plasma process, if the substances resulting from the treatment are subsequently incinerated." (2010/75/EU).

Compared to landfill sites, combustion plants are generally deemed more environmentally friendly, require less space, and have the ability to recover more energy. The majority of waste incineration plants in Europe have the ability to recover energy, since it is this factor that ranks them higher than landfill sites in the Waste Hierarchy (classifies them as 'recovery') (2008/98/EC). On the other hand, waste incineration causes external costs via air pollutants generated through the combustion process, for example particles like NOx, dioxins and SO2. NOx has been found to be the root cause of approximately 70% of the total health costs from waste combustion (Eshet et al. 2006). For this reason, it is unclear which of the two – landfilling and incineration – is better for human health. Moreover, waste incineration shares a lot of the disamenities found in landfill sites, such as odor, visual intrusion, noise and increased traffic. However, in this paper, the ranking provided by the Waste Hierarchy is taken as given, and incineration is thus posited to be the 'better' option in relation to landfilling.

2.2.3. Recycling of Waste

"Recycling is defined as any reprocessing of material in a production process that diverts it from the waste stream, except reuse as fuel. Both reprocessing as the same type of product, and for different purposes are included. Direct recycling within industrial plants at the place of generation are excluded." (OECD 2020c).

Recycling is broadly accepted as the most environmentally friendly treatment of waste already generated (i.e. not counting measures to diminish the amount of waste in the first place)

(2008/98/EC). The primary advantage of recycling is the decreased demand for virgin materials (newly sourced resources for production) due to the reuse of old materials through recycling.

For this reason, it is ranked above both landfilling and waste incineration in the waste hierarchy. However, as previously stated, the waste hierarchy have a strong environmental focus. Thus, research on waste management have shown that recycling does exhibit some disadvantages in certain areas, compared to other treatment options. First and foremost, recycling of waste is transport heavy. Collecting waste separately (after, e.g., households have sorted them) or, alternatively, collecting mixed waste that is later sorted and transported separately to different recycling facilities, naturally requires more traffic than most other disposal options (BiPRO/CRI 2015). For similar reasons, recycling has relatively expensive operational costs, albeit lower fixed costs, compared to landfill and incineration (Eunomia Research & Consulting Ltd 2000).

Furthermore, not all waste types are (at present) possible to recycle, and thus has to be treated using alternative methods. The materials most apt for recycling are; paper and cardboard, plastic, metal, waste electrical and electronic equipment (WEEE), wood, glass, textiles, and bricks and inert waste (ISM Waste and Recycling 2020).

2.3. Waste Policy

2.3.1 Waste Policy Theory

The waste sector is a part of the environmental sector, since the management of waste (or the lack thereof) have large impacts on the environment, primarily through greenhouse gas (GHG) emissions (Department of Environmental, Food, and Rural Affairs 2011). Environmental impact, in turn, is a kind of externality, meaning "[...] situations when the effect of production of consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided." (OECD 2003). In the case of waste, this environmental externality is negative. Left alone, the nature of the environmental externality would lead to a so-called market failure, wherein the environmental cost produced by the waste sector outweighs the benefits reaped by its operators. Utility- and profit maximization are no longer sufficient instruments to ensure economic efficiency since there are, in the case of market failure, utilities (and disutilities) left outside the transactions. Thus, to properly account for market failures of this kind, policy implementations are warranted, and subsequently widespread (SOU 2017:83). The most commonly employed instruments regarding landfill diversion are landfill taxation and landfill bans.

Bans are a type of quantity-based rules, while taxes are financial instruments. Both of these types can achieve socio economic efficiency, however financial instruments have an advantage because they circumvent the informational problem with optimal regulation that quantity-based firm-specific regulation requires. This they do by allowing each individual to decide for themselves whether a certain activity is worthwhile or not based on their present financial incentives. For these instruments to be socioeconomically efficient, the level of the environmental tax should be the point where the additional marginal cost for the taxpayer is equal to the value of the marginal environmental damage for society at large. Thus, to determine socio economic efficiency, marginal costs and -benefits must be known. Unfortunately, this is difficult when analyzing environmental impact, since ecological processes are complex, and it is difficult to "put a price" on such effects.

As a second-best, instruments can be designed to be cost efficient instead, i.e. the cost of the project is in focus rather than societal utility. Environmental taxes can, in this way, be designed

so that the marginal costs of the operators in question equalizes. Alternatively, as is the case with landfill taxes, they can raise the marginal cost of one option (landfilling) in relation to the rest. Thus, the idea behind landfill taxes it that the cost increase of landfilling waste (induced by the need to pay taxes) makes it relatively cheaper to treat waste using alternative options, and waste is in this way diverted from landfill sites. (SOU 2017:83) However, some researchers argue that this mechanism mainly raises revenue, and not actually diverts waste streams.

A brief account of European waste management policies will be given below, starting with the overarching EU waste directives, followed by the implementation of waste bans and taxes.

2.3.2. EU Waste Policy

The European Union has during the last 30 years put waste management and recycling high up on the agenda. With the goal of turning its member states into resource efficient societies where waste is avoided and the unavoidable waste is used as a resource, the EU have implemented a series of environmental action plans and legislations to deal with the issue. The aim is to reduce the environmental- and health impact of waste and to minimize the extraction of additional raw materials. Over the last decades, as the European societies have gotten wealthier and the amount of waste being generated has been continuously increasing, the European Union has identified, with the *Sixth Environment Action Program* (2002-2012), waste prevention and management as one of the top four priorities when it comes to environmental challenges (European Union 2010).

The cornerstone of the EU's waste policy is the *Waste Framework Directive* that was adopted in 1975 together with the *Hazardous Waste Directive* and the *Waste Shipment Regulation*. The directive defined the basic regulatory structure on waste and brought up the issue of the environmental impact of waste and how to ensure a safe disposal of it. The directive did however not specify any environmental emission parameters regarding the different acceptable waste management options - landfilling, waste incineration and recycling (1975/442/EEC). Regulations on these waste treatments were instead partly taken into account in 2000 with the *Waste Incineration Directive* (2000/76/EC) and in 1999 when the *Landfill Directive* (1999/31/EC) was adopted. Apart from this, the European Commission did in 1996 develop the *Waste Strategy Communication* to improve waste management and promote recycling and energy recovering of waste over the disposal of waste. With the Waste Strategy Communication, the hierarchy of waste (see 1.1) was reinforced and has ever since been used by the European Union as the prioritization strategy of waste streams (European Commission 2005).

In 2005, the *Waste Framework Directive* was revised and modernized. It shifted focus from seeing waste as an unwanted burden to seeing it as a valuable resource. The new main objective of the framework was to work towards a circular economy. This included, but was not limited to, stimulating innovation in recycling, limit the use of landfill, improve waste management and try to change consumer behavior. The revised version put up targets for the EU member states to achieve, such as the target goal of reaching a 50 % recycling rate of their municipal waste by 2020 (European Commission 2011).

In 2008, the Waste Framework Directive was revised once more with updated targets to the year 2035 (2008/98/EC), and in 2015 the Circular Economy Action Plan was introduced which included even more long-term goals for the EU's Waste Management (European Commission 2015).

The European Union's Waste Policies

1975	Waste Framework Directive
	Hazardous Waste Directive
	Waste Shipment Regulation
1996	Waste Strategy Communication
1999	Landfill Directive
2000	Waste Framework Directive, updated and modernized
2008	Waste Framework Directive, revised with goals for 2035
2015	Circular Economy Action Plan

2.3.2.1. Landfill

As mentioned above, the European Union adopted the Landfill Directive in 1999, which deemed the landfilling of waste as the least desirable waste management option. The directive banned certain types of waste from being landfilled, such as liquid waste, flammable waste, hospital waste and used tires. The directive also set up a permit system for the operation of landfill sites, where certain criteria had to be fulfilled to get an operational permit. These requirements were not particularly detailed, however. The application had to include the following information (non-exclusive) (1999/31/EC):

- The proposed methods for pollution prevention and abatement
- The proposed monitoring, operation and control plan
- The plan for closure and aftercare procedures
- An impact assessment study

As with many environmental legislations, the Landfill Directive has in some areas of the European Union suffered from bad implementation. Waste has historically been deprioritized in politics and legislations has not always resulted in action and environmental change. Even though there are no exact inventory on how many illegal landfills are in operation in Europe at present, there are reasons to believe they exist to an extent. This includes landfill sites that are non-authorized, or sites that are authorized but badly managed with negative consequences to the environment (European Commission 2005).

Apart from the EU Landfill Directive from 1999, further requirements and regulations on landfill sites have been left for the individual member states to decide upon. As noted previously, one instrument widely used is *landfill taxation*. The purpose of the taxes is to shift financial incentives from landfilling of waste towards other waste streams higher up in the waste hierarchy. These taxes can take various forms. The most common policy is to have a general landfill tax per ton of waste. In 2017, Austria was the country with the highest tax, amounting to 84,53 EUR/ton. Some countries, such as Italy and Spain, have within-country-differences as the tax levels are decided on a regional level. In the former, the tax on landfilling spanned from 5,2 EUR/ton to 25,85 EUR/ton in 2017 (European Environment Agency 2016).

Not only taxes, but also *landfill bans* are widely used as a waste policy within the European Union's member states. In 2017, 19 out of the 28 member states had implemented one or more

bans on landfilling. These bans are usually regulations on either landfilling of combustible waste, landfilling of biodegradable waste (including organic waste), landfilling of untreated waste or landfilling of waste with high calorific values (European Environment Agency 2016).

2.3.2.2. Waste Incineration

In 2000, the *Waste Incineration Directive* was adopted in all member states of the European Union. Its aim is to reduce the negative effects to the environment caused by waste incineration. Particularly, this means that the pollution created during incineration should cause less damage to the groundwater, soil and air (2000/76/EC).

The Directive consists of emission limit values for pollutants to air such as hydrogen chloride (HCI), heavy metals, Sulphur dioxide (SO2), nitrogen oxides (NOx) and hydrogen fluoride (HF) (ibid). Furthermore, the Directive consists of technical requirements on e.g. monitoring and measuring. Additional to the Waste Incineration Directive, four member states of the European Union have chosen to implement national incineration taxes, namely Austria, Belgium, Denmark and Sweden (European Environmental Agency 2013a/b/d/v).

3. Previous Research

Since this paper focuses on waste flows and the impact waste policies (primarily landfill taxes) have on these, an account for previous research on the relative desirability and trade-offs between the different waste treatment options will not be accounted for. This includes papers on their documented environmental effects, a research area which take up a considerable chunk of the waste management field. On the contrary, as laid out above, the European waste hierarchy is here merely accepted as the "right" ranking of waste disposal options. Instead, investigation is on whether instruments employed to enforce this hierarchy in practice, such as the landfill tax, actually manage to do so. Furthermore, papers analyzing instrumental effects on industrial, construction, or other waste not included in the definition of municipal solid waste are also excluded. Despite the fact that the different waste types by and large are treated in the same manner, differences exist and studies on waste from separate origins are thus commonly kept apart.

Following this, the current section is a brief account of previous research on the determinants of municipal waste generation, the effect of waste management policies and other determinants on landfill diversion, and the relationships between the different waste treatment alternatives.

3.1. Municipal Waste Determinants

The generation of municipal waste is increasing over time. Moreover, richer countries generally produce more waste than their poorer counterparts. A study on Dutch regions found that higher levels of GDP per capita caused a raise in the amount of per capita waste (Barterlings et al. 2005). Similarly, richer areas with larger service sectors have been found to generate more waste than poorer regions with more prominent manufacturing sectors (Mazzanti and Zoboli 2008). Thus, Mazzanti and Zoboli, in their study of European countries from 2008, found that economic growth, population density and the share of manufacturing had significant effects on a region's waste generation. Where the prior two drive waste generation, and the latter showcases a negative impact (Mazzanti and Zoboli 2008).

On the other hand, research investigating a potential trend in line with the Environmental Kuznets Curve for waste generation (Waste Kuznets Curve) have found a relative delinking between waste generation and economic drivers. Meaning that the relationship curves at a certain point, where the economic variable continues its upward trend, but the growth of the

waste generation diminishes somewhat. However, at present the presence of a Waste Kuznets Curve is not established, and economic drivers continually exhibit a positive correlation with waste generation (Mazzanti and Zoboli 2009).

3.2. Landfill Diversion Determinants

Similar drivers connected to municipal waste generation have been found to impact also the way in which waste is managed. Particularly, population density significantly affects the amount of waste landfilled. Both variables are negatively correlated with landfilling, as is to be expected. The more densely populated an area is, the scarcer and more valuable is land. Consequently, the opportunity cost of land rises, making landfilling – the most space-demanding treatment option – less amicable. In addition, population density also enhances negative disamenity effects such as odor, as an increased number of individuals are exposed to them (Mazzanti and Zoboli 2008).

Furthermore, while previous research has found economic drivers to also affect landfilling of waste, the relationship seems to be the opposite in comparison to waste generation; rising income significantly and negatively affects the amount of waste landfilled (Mazzanti and Zoboli 2009).

3.3. The Impact of Landfill Policies

The effect of landfill policies has been investigated extensively since the United Kingdom's noted implementation of a landfill tax in 1996. For example, one study from 2003 investigating said tax (Martin and Scott 2003), concluded that the tax contributed to increased recycling, but not a decrease in the amount of waste generated nor its reuse. Similarly, Barterlings et al. (2005), using a panel data set of Dutch regions, found that a landfill tax in the Netherlands increased the recycling share, but had no effect on the amount of waste produced. The authors argue that the increased waste disposal costs due to the implementation of a landfill tax does not directly affect the principal generators of waste (the households for municipal waste), and thus the effect on waste generation is limited. Mazzanti et al. reached the same conclusion, the implementation of a landfill tax did not decrease waste generation (Mazzanti et al. 2012). Moreover, Mazzanti, together with Nicolli (2013), empirically showed that landfill taxes in Italy did divert waste treatment away from landfill sites. This paper also found a larger effect on increased incineration, compared to recycling, following tax implementation. The study indicated that existing incineration plants contributed to landfill diversion via "lock-in" effects from large investments in incineration plants on the regional level. An effect not found to exist to the same degree when it comes to recycling practices, as these require less initial investment. Additional reports have argued along these lines; that decreased landfilling has a larger effect on waste incineration (provided there's existing incineration capacity) than recycling, to make use of all incineration capacity and because all waste can be incinerated as opposed to recycled (Zero Waste Europe 2015).

Generally, waste policy effects on incineration of waste, especially waste policies targeting landfilling of waste, have found to impact incineration positively. Landfill policies significantly decrease landfilling and increase incineration (Mazzanti and Zoboli 2008).

As the papers mentioned above indicate, research investigating the effect of landfill policy implementations have mainly been conducted on a within-country scale, due to limitations to cross-country data. However, some international studies exist, primarily by Mazzanti (2009) and Papineschi et al. (2019). Mazzanti (2009), conducting analysis on EU25, provide evidence in line with the country-specific reports: waste policy is a significant driver of landfill diversion.

However, while the study is conducted on EU as a whole, the policy instruments utilized are, for example, EU policy transcendence into national regulations, not landfill taxes per se. Furthermore, it does not investigate the effect on incineration. Regarding, Papineschi et al. (2019), the study fail to detect any significant effects of landfill policies (tax and ban) on biodegradable waste on waste generation, and of an incineration tax on either waste generation or recycling. However, landfill bans on biodegradable and combustible waste is found to significantly and positively impact a country's recycling rate, indicating successful landfill diversion. The paper concludes that landfills taxes and bans appear to have successfully contributed to landfill diversion in the analyzed regions (Åland, Denmark, Faroe Islands, Finland, Greenland, Iceland, Norway and Sweden) (Papineschi et al. 2019).

Going beyond the study on Nordic waste regulations (Papineschi et al. 2019), papers on effects from landfill bans and/or waste incineration taxes on waste flows are limited. Landfill bans have been found to impact waste generation and landfill diversion similar to landfill taxes, i.e. with limited impact on the generation of waste but successful diversion from landfilling. In particular, landfill bans positively correlates with increased waste incineration (Zero Waste Europe 2015). Waste incineration taxes, on the other hand, are noted to have limited effects in previous research. A plausible explanation for this is posited to be rather scarce data availability following limited practical application of the instrument. However, some papers indicate successful diversion toward higher ranked waste treatment options such as recycling, if paired with sufficient landfill policies (e.g. landfill taxation) (SOU 2017:83).

Moreover, waste policy research is even scarcer outside of Europe. A noteworthy mention is an empirical study on waste taxation in Japan (Sasao 2014). The study investigated the effect on MSW generation, but only found a negligible effect. The author's held the low tax rate as a possible explanation for the lack of impact.

Thus, the literature on single-country cases has concluded (rather unanimously and unsurprisingly) that landfill policies do not lead to a decrease in the amount of waste generated, but divert the treatment of waste away from landfill sites toward other means of waste treatment, primarily waste incineration. On the other hand, cross-country studies on landfill taxes in a European setting are scarce, and with limited results (Papineschi et al. 2019). The slightly more ambiguous effect of landfill policies on the recycling rate of municipal waste is posited to stem from the somewhat different waste management characteristics of recycling, as previously mentioned (Barterlings et al. 2005). Consequently, following is a depiction of previous research on the determinants of the recycling rate of municipal (household) waste.

3.4. Recycling Rate Determinants

Recycling of waste is generally viewed as the most optimal treatment of generated waste. Consequently, a lot of effort have been devoted into investigating recycling behavior to enable the design of efficient recycling policies. Overall, the research field has found that convenience play a big part in determining recycling behavior (Barr et al. 2003; Martin et al. 2006). Especially in the form of the availability of recycling stations (Lange et al 2014, Zhang et al 2016). The importance of convenience goes together with the thought of decreased diversion incentives mentioned in the previous paragraph.

Research on recycling behavior have not been able to determine one "optimal" design for waste collection to induce recycling. However, there is a fairly strong consensus that separate collection is generally preferable (European Commission 2015). Other aspects that have been

found to affect recycling behavior are peer influence, moral motives and the felt ability to positively affect the environment.

4. Method

4.1 Empirical Strategy

Due to the quantitative and empirical nature of the research question, an econometric approach will be used in order to try and gauge out the impact of landfill taxation. In particular, the analysis will be conducted using estimations in the form of multiple linear regressions (MLRs). The basis of this choice is that it is the most common and widely accepted research method when conducting quantitative studies. Furthermore, panel data is particularly well suited for policy variable investigations, due to the ability to incorporate observations both before and after policy implementations and/or changes (Woolridge 2013). To enable the investigation of a more granular effect between landfill taxes and waste flows and circumvent potential (and probable) differences in observations because of individual laws and institutions due to the national scale of the study, time-invariant, country-specific characteristics will be controlled for. The regression functions employed are based off of a model presented in the aforementioned study by Barterlings et al. (2005), where the authors investigated the effectiveness of landfill taxes in the Netherlands. Specifically, the authors divided the study of the Dutch landfill tax into two separate regression functions following the responsibility structure of waste management; i.e. that it is primarily households that are responsible for the choice between recycling and disposal (in Barterlings' et al. report defined as the total of landfilling and incineration), while municipalities ultimately decide over the allocation between the two disposal options; landfilling and incineration. This is true not only for the Netherlands, but all countries incorporated in the present analysis (Eunomia Research and Consulting Ltd 2000).

4.1.1. Hypotheses

Taking cue from this structure, the current paper will divide the research question – *How has the implementation of a landfill tax affected the allocation of waste between different waste treatment options?*– into three hypotheses, in order to capture the specific effects per waste treatment alternative, as well as account for the overall responsibility characteristics of waste management schemes. The hypotheses are depicted below.

Hypothesis 1: The implementation of a landfill tax has led to a relative decrease in waste supply for landfilling of waste.

Hypothesis 2: The implementation of a landfill tax has led to a relative increase in waste supply for the incineration of waste.

Hypothesis 3: The implementation of a landfill tax has led to a relative increase in waste supply for the recycling of waste.

4.1.2. Regression Functions

Noting that the empirical model of Barterlings et al. (2005) share several similarities with the model and research question of this study, the multiple linear regression functions relating to each hypothesis, too, are designed in a similar way. The dependent variables represent the change in thousands of tons of waste going to each waste treatment alternative, for a one-unit change in the independent variable(s). An important distinction, however, between the structure of the two studies is that the present one operates on a cross-country level, while the previous

study investigated the effect on a landfill tax in a within-country context. Adjustments to the models have been made accordingly. The current regression functions are designed as follows:

Regression 1:
$$Landfilling_{it} = W_{it} + X_{it} + t_t + e_{it}$$

Regression 2:
$$Incineration_{it} = W_{it} + X_{it} + t_t + e_{it}$$

Regression 3:
$$Recycling_{it} = W_{it} + X_{it} + t_t + e_{it}$$

Where W is a set of waste policy indicators and treatment options, namely; tax on landfilled waste, tax on incinerated waste, ban on landfilled waste, total amount of municipal waste generated, total amount of recycled waste, total amount of incinerated waste and number of landfill facilities. X is a set of geographical and economic determinants: GDP per capita, household spending, population, population density, number of single person households and EU membership. T represents a time trend, and e is the residual term. A full list of the variables included can be found in Table 4.1

Table 4.1: *Summary Statistics of data set*

	N	Mean	Std. Dev	Min	Max
Landfill Ban	460	0.44	0.50	0	1
EU member	460	0.88	0.33	0	1
GDP**	460	13579.62	39836.46	373.00	224515.8
Incineration	460	106.11	105.75	0	439.23
Incineration tax	460	2.76	9.41	0	54.16
Landfill	460	201.88	134.20	1.27	552.31
Landfill tax	460	21.73	29.83	0	127.03
Municipal Waste*	460	486.29	121.15	247.71	830.75
Population	460	2.02e+07	2.40e+07	424699	8.27e+07
Population density	460	137.99	109.55	16.96	508.45
Singl.person hh*	460	140.32	46.56	53.16	340.03
Recycling*	460	99.88	69.25	0	311.11
Year	460	2007.5	5.77	1998	2017
Inc.facilities*	334	3.31	7.50	0	75.29
Landfill facilities*	329	19.46	16.76	0	86.17
Dispfac*	329	22.72	18.41	1.04	90.61
EPSI	287	2.45	0.81	0.52	4.13
Recycling facilities*	202	85.76	66.56	0.746	302.81

** Measured in per million capita, ** Measured in USD, constant prices*
Taxes measured in EUR/tonne, constant prices
Sources: OECD, Eurostat

Since the allocation of waste supply is up to the local authorities, the effect of landfill taxation on the amount of waste landfilled and the amount of waste incinerated is direct and expected to be significant. Implementing a landfill tax makes landfilling of waste relatively more expensive, consequently incentivizing municipalities to reallocate the disposed waste to, first and foremost,

incineration plants. Other variables affecting this decision is primarily established incineration- and landfilling capacity and contracts, and laws and regulations regarding the disposal of waste.

The choice between recycling municipal waste, or disposing of it (in which the waste ultimately goes to either landfill sites or waste incineration plants) is, as stated in previous sections, by and large made by the households. Thus, the landfill tax' effect on the recycling rate is posited to be of an indirect nature; the increased landfill cost encourages municipalities to invest more in alternative waste disposal options, which in due time eases the act of recycling for the households. However, it can also be in the local authorities' interest to redirect more waste to incineration plants.

Additionally, there are a number of other factors (apart from the waste infrastructure and municipal encouragement) that determines households' recycling behavior, such as proximity to recycling stations, cost of recycling and concern for the environment. To try and account for these effects, the number of recycling facilities per 1 million inhabitants for each country is included, similar to Regression 1 and 2. Furthermore, an additional variable retrieved from an OECD index data set titled 'Environmental Policy Stringency Index' to be used as a proxy for the general environmental concern for each country.

4.2. Econometric Considerations

4.2.1. Fixed effects vs. Random Effects

When conducting a study on a country-level basis, differences between the observed units (countries) are expected to be significant. In order to obtain as unbiased estimates as possible, it is thus critical to control for these country-specific differences to the best ability. The present study makes use of fixed effects (FE). Random effects (RE) is rarely employed for cross-sectional analysis of such vast geographical areas as countries. The key issues that determines whether FE or RE should be used is if one can, with some level of confidence, assume that the time-invariant unobservable determinants are uncorrelated with all the explanatory variables in all time periods. Thus, for country-level analysis it is not feasible to treat the sample as a random sample from a larger population, since the entire state can either be viewed as the entire population, or alternatively as a sample of, say, the world population. But since the country is specified in advance, it cannot be said to be random. In these instances, FE is a better estimate than RE (Woolridge 2013).

4.2.2. F-test

To confirm that it would be a better fit estimating our model with FE rather than pooled OLS, we conducted an F-test on the respective LSVD-regressions (*the least square dummy variable model).* This to test to hypotheses that the countries (thereof country dummies) does not have a joint effect on the dependent variables. $H_0 = d_1 = \cdots = d_{23} = 0$. The alternative hypotheses is that at least one of the countries does have an effect. On all three regressions, we were able to reject the null hypothesis on a 1% significance level, meaning that our country dummies are jointly statistically significant in all our regression equations. See F-test in Appendix. The use of fixed effects therefore improves the goodness-of-fit of our data and is a more suitable option of model than pooled OLS.

4.2.3. Heteroskedasticity

For the fixed-effects analysis to provide the best linear unbiased estimators, the regressions' residuals should be constant (homoskedastic) over time. If they are not, the model is said to suffer from heteroskedasticity, i.e. non-constant residuals over time. The presence of heteroskedasticity does not bias the estimates, but it does make them less efficient.

Heteroskedasticity is a common issue in regression analysis, and so the models employed in this paper were tested for it. (Hayes 2019). In Stata, heteroskedasticity cannot be tested on a within fixed effects model (xtreg). To circumvent this, the Breusch-Pagan test was applied to the equivalent dummy-fixed effects model. The results from the tests for the respective regressions (Regression 1, Regression 2, and Regression 3) indicated heteroskedasticity. Following this, cluster robust standard errors have been added to the final model for all three regressions.

4.2.4. Serial correlation

Serial correlation can be an issue in panel data analysis, especially with panel data over a longer time period. This relates to the present analysis, as it employs a data panel stretching over a 20-year time period. To test for the prevalence of serial correlation, Woolridge's test for autocorrelation was used. The test indicated the existence of serial correlation for all three regressions. Fortunately, the inclusion of cluster robust standard errors solves also this issue.

5. Data

5.1. Data Description

Our main data is a panel dataset from the OECD titled '*Municipal waste, Generation and Treatment*', covering 23 OECD countries for the period 1998 to 2017 (20 years in total).

Units

The 23 units (countries) from the OECD data included in the analysis (and thus the data sets) are: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland and United Kingdom. These countries are chosen out of the total 28 OECD countries included in the data sets on the basis that they are member states of the European Union. As accounted for previously, this study takes cue from the EU's Waste Hierarchy and overall efforts towards landfill diversion, to investigate this efforts (by studying the most widely applied policy instrument - waste taxation) it makes sense to only incorporate EU member states. Furthermore, waste management is a highly dynamic and complex area, with differences both at the national and even regional scales. Thus, when conducting a cross-country analysis, it is important to try and limit these discrepancies as far as possible. One way of doing this is to confide the study within a context of the European Union, since EU member states share a lot of common guidelines in the waste management area. Finally, to enable a higher quality analysis by controlling for potentially important variables, complementary data sets from the EU's own statistical database Eurostat was incorporated. Limiting the study to EU countries enabled the use of these data sets.

Time Period

The time period was chosen for three reasons; waste management policies, data availability, and sample size. Despite a moderate prevalence of missing observations for the beginning years of the time period, 1998 was decided upon as a starting point to maximize the number of observations in the sample. Moreover, the 1990's is also the decade wherein environmental policies - particularly within the field of waste management - increased in number. In order to include, primarily, the Landfill Directive (1999) in the sample, 1998 was ultimately decided upon. The starting point is considered as a reasonable balance between sample size and data availability. Since the main data sets used in the analyses all end in 2017, the data availability alone determined the end of the panel.

The chosen sample consequently includes 460 observations – one observation per country and year. The data sets cover the following waste management areas: (i) municipal waste generated, (ii) amount of waste landfilled, (iii) amount of waste incinerated, (iv) and recycling. The reported unit for all four data sets are thousands tons. In addition to the waste management areas, the analysis also make use of OECD data sets covering the following aspects: (i) population, (ii) GDP per head of population in USD constant prices, (iii) final expenditure of household consumption, and (iv) environmental policy.

5.2. Variable Description

5.2.1. Dependent Variables

Following the design outlined under the method section, the analysis includes three dependent variables, for three separate regression analyses. The variables are retrieved from the municipal waste data set provided by OECD described above. To mitigate large differences in the reported values for each country, the values retrieved from the data set was divided by each respective country's population divided by one million. Thus, the observations used in the regression function is the amount landfilled waste per 1 000 000 inhabitants, for each country and year. This computation was applied for all variables employed in the present analysis except the dummy variables (landfill bans and EU membership), tax variables, GDP per capita, population, population density and time trend variable. The dependent variables are described below.

Dependent variable 1: The amount of waste landfilled per country and year
The first dependent variable shows the amount of landfilled waste per country and year, in thousand tons. The specific data set used is titled 'Landfilling' (OECD 2020b).

Dependent variable 2: The amount of waste incinerated per country and year
The dependent variable in the second regression function depicts the amount of waste incinerated in a country for a specific year, in thousands tons. The variable is based of off the OECD panel data set titled 'Total Incineration' (OECD 2020d). These values are the total amount of waste incinerated in a country, i.e. it includes combusted waste from both waste incineration plants with energy recovery and waste incineration plants without energy recovery. This particular data set is chosen over the other two describing a country's level of incineration ('incineration with energy recovery' and 'incineration without energy recovery') primarily because the aim of the study is to investigate how a tax on landfilled waste affects a country's reliance on waste incineration, regardless of whether these plants converts the waste to energy or not. Moreover, out of the chosen sample, only five countries have waste incineration plants without energy recovery. Of course, it is possible that the effect differs depending on a facility's energy recovery. This potential effect is not taken into account in the present analysis.

Dependent variable 3: The amount recycled waste per country and year
The third dependent variable represents the amount of waste recycled in a country for a given year, in thousands of tons. This variable is based off of the OECD data set 'Recycling' (OECD 2020c).

5.2.2. Independent variables

Landfill tax and Incineration Tax
Landfill tax as the main regressor. Incineration tax as one of the control variables. These variables depict the landfill tax- and incineration tax per ton, in euro, per country in a specific year. The taxes are in constant prices with 2015 as the base year. Data was collected from the European Environment Agency's country reports on Municipal Waste Management in the

respective countries (European Environmental Agency 2013a/b/c/d/e/f/g/h/i/j/k/l/m/n/o/p/q/r/s/t/u/v; European Environmental Agency 2014; Coppola 2019). In the case of the landfill tax in Italy and Belgium, a weighted country average was used as the tax level varies between regions in these countries.

Landfill ban

The landfill ban variable is a dummy that takes the value 1 when a country implements a landfill ban, starting with the year of implementation if the date of implementation is in the first half of said year (before July 31st), and the year after if the date of implementation is in the second half of said year (after July 31st). Thus, the dummy takes the value 0 for all countries in the sample before the implementation of a landfill ban, as well as for all countries that does not implement a ban at any time during the sample period. A report by the Confederation of European Waste-to-Energy Plants (CEWEP) was utilized for information on ban implementation (CEWEP 2017).

Number of landfill facilities

This variable depicts the number of landfill facilities per country in a specific year. The observations are retrieved from a data set over waste treatment facilities provided by Eurostat (Eurostat 2020a). Unfortunately, due to lack of acceptable data sets, only data for every other year between 2004 and 2016 was obtained. Despite this shortage, the variable was deemed important enough to validate inclusion in the regression models. The reason for this is that it is here posited that the existing capacity in a country to dispose of waste via landfilling has a direct effect on the amount of waste actually being landfilled. In order to increase the number of observations, the missing values was treated through imputation. Half the total difference between two years with data was added (or subtracted) to all the years with missing values in between (i.e. 2007, 2009, 2011, 2013 and 2015). Furthermore, the values of 2004 and 2016 was brought back and forward, respectively, to the years of 2003 and 2017. This is a common tactic for imputation.

Number of waste incineration facilities

This variable depicts the number of waste incineration facilities per country in a specific year. The variable is retrieved from the waste treatment facility data set from Eurostat (2020a). Similar to the data on the number of landfill facilities, it only has values for every other year between 2004 and 2016. However, this variable, too, was deemed necessary for the regression functions and has thus been included despite a fair amount of missing values. The motivation for the inclusion is the same as for landfill facilities; it is posited that the number of waste incineration facilities operating in a given year directly impacts the amount of waste incinerated for that year. The same data imputations as for the variable depicting the number of landfill facilities was applied.

Number of recycling facilities

This variable depicts the number of recycling facilities per country in a specific year. The variable is retrieved from the data set of waste treatment facilities by Eurostat (2020a). As with the other two variables over the number of waste treatment facilities, Eurostat's data for recycling facilities only has values for every other year. Moreover, this particular variable only had data from 2009 to 2016. Again, the potential omitted variable bias of the estimates from not controlling for the number of recycling facilities was concluded to outweigh the inherent uncertainty of the variable due to missing values. This because the number of recycling facilities available have been found to affect households propensity to recycle in previous papers (Zhang et al. 2016). The availability of recycling stations makes it easier to recycle, and hence increases

the conceived convenience to do so. Thus, the variable was included in the analysis. The same data imputations undertaken for the other data sets over number of waste treatment facilities was applied.

Municipal waste generation
Municipal waste generation is the aggregated amount of generated municipal waste for each country in a given year. The variable is a part of the main data set employed in this paper, produced by OECD (OECD 2020a). Thus, it covers all the years in the sample, 1998-2017.

Population
Population reports the size of the population for each country in a specific year. The data is retrieved from a data set provided by OECD (2019d).

Population density
In order to control for each country's different abilities to make use of landfill sites (as these require noteworthy amounts of space), a population density variable was computed. The population density values shows a country's population for a given year, divided by its total land area. The population values used are the same as the ones employed in the 'Population' variable (OECD 2019d). The countries' respective land areas was fetched from Worldometer (2020).

GDP per capita
Previous research has found a positive relationship between wealth and recycling. Higher income is also correlated with increased consumption and thus consequently increased waste generation. GDP per capita is currently used as a proxy to account for these relationships. The variable is based off of a data set provided by the OECD (2019b).

EU membership
The variable for EU membership is a dummy variable taking on the value 1 after a country become a member state of the European Union, and 0 before the country is a part of the EU. Despite the fact that all countries in the sample are EU member states today, the variable has been included to capture any possible effect on waste management for the countries joining the European Union sometime during the sample period in question. Notably, 8 countries in the sample became EU member states 2004. This is posited to have had an effect on these countries' waste management due to the EU's numerous waste management directives, particularly the Landfill Directive from 1999 here described under 'Conceptual Framework'.

Final expenditure of household consumption (household spending)
Household spending in million USD, constant prices with base year 2015. Data retrieved from OECD (2019c). As municipal waste primarily pertains to household waste, the households' consumption impacts how much waste is ultimately generated. Furthermore, it is an additional variable signalling the overall wealth of a country's population. Thus, this variable was included as a supplement and nuansation to both municipal waste generated and GDP per capita, as per previous research.

Single-person households
Number of private, single-person households, in thousands, between 2005-2017. To deal with the missing values for year 1998-2004, we calculated the average growth rate of the respective countries single-person households and estimated the values backwards. We did this as the data

set is continuous and the growth rate was fairly steady. Data retrieved from Eurostat (Eurostat 2020b).

The OECD Environmental Policy Stringency Index
OECD's Environmental Policy Stringency Index (EPSI) has been deployed as an additional data set, as a means to account for the chosen countries' environmental policies not captured by the abovementioned waste management indicators (OECD 2017). Here, stringency is the degree to which environmental policies put an explicit or implicit price on environmentally harmful behavior. The index represents a comparable measure of the stringency between countries. The data set covers the time period 1990 to 2015, and consists of 28 OECD countries and 6 BRIICS countries. Consequently, the sample for the environmental policy variable is two years short compared to the other data sets. Furthermore, out of the 28 OECD countries included in the index, only 19 coincide with the present analysis. The countries studied in this report, but not incorporated in EPSI, are Estonia, Latvia, Lithuania and Luxembourg.

Despite the limitations, this index was deemed adequate and thus incorporated into the analysis. The major arguments for this decision was the necessity to control for additional environmental policies to reduce omitted variable bias in the analysis, as these are likely to affect not least the recycling behavior in a nation. Due to a lack of sufficient data sets, especially for the time period in question, the Environmental Policy Stringency Index was chosen since this index is produced by the OECD - same as the main data sets, thus securing consistency in the collection of data - and covers almost the entire period of interest.

Year (Time trend)
Looking at the data, it is evident that a multitude of the incorporated waste variables exhibit a positive trend over time, examples being the amount of waste generated and the amount of waste recycled. In order to avoid a potential spurious regression problem, i.e. inflating the true correlation between the variables by their common positive trends, a time trend will be incorporated into the model. This variable is titled 'year', and increases by one integer for each consecutive year, starting in 1998. The underlying assumption thus being that the trend going forward will continue at the same (or similar) rate, since the regression design is linear (Woolridge 2013).

6. Results
In this section, the results from the regression analyses is presented and discussed. The results for each regression function are presented individually, starting with the regression on the effect of landfill tax implementation on the amount of waste landfilled.

6.1. Regression 1. The Relationship between Landfill Taxes and Landfilling of Waste
As can be deduced from Table 6.1 (FE, base), the existence of a landfill tax is negatively correlated with the amount of waste treated in landfill sites. This result is in line with previous research, and also what was expected a priori to running the regressions. The effect decreases once control variables and fixed effects are included, indicating a biased first estimate. Without control variables, a €1 increase of the landfill tax was estimated to lead to a decrease of a country's landfilled waste by approximately 3.49 ton per 1 million inhabitants. After adding variables controlling for other waste treatment options and waste policies (FE, waste control), this estimated value decreased to -1.01 ton landfilled waste per 1 million inhabitants. This decrease indicates that the original estimate was upward biased due to the fact that it took up effect from the omitted variables. It is plausible that the availability of alternative waste

treatment options as well as additional waste treatment policies all have an effect on the amount of waste treated in landfill sites. As a third step, the additional socioeconomic control variables was added. These variables was chosen based on previous research and reasoning, and represent a set of geographical and economic factors, such as GDP per capita. Now, the estimated effect of the landfill tax decreased further (-0.85 ton), as compared to the model without geographical and economic control variables (FE). Thus, omitting these controls seem to have biased the estimate downward. This is in line with what was argued earlier in the paper, as, for example, EU membership and a time trend were posited to inhibit the landfilling of waste, a negative effect taken up by the landfill tax estimate in the model with only waste related control variables. On the other hand, it also rendered the coefficient insignificant, with a p-value of 0.149. Furthermore, the coefficient remained insignificant also after adding cluster robust standard errors, indicating that landfill taxes do not really divert waste from being landfilled. The cluster robust standard errors were included following the prevalence of heteroskedasticity and autocorrelation found in pre-analysis.

After adding these standard errors, the only variables showcasing a significant relationship with the amount of waste landfilled are the amount of waste incinerated, recycled and generated. The coefficients of these variables all have the expected signs, i.e. negative for waste incineration and recycling, and positive for municipal waste generation (see Table 6.2). This is what's expected since the waste treated through combustion or recycling cannot be treated via landfilling, and thus this effectively diminishes the amount of waste landfilled. Additionally, the more municipal waste being generated, the more waste has to be treated, partly via landfilling.

Table 6.1: *Results of the dependent variable Landfill Tax, on the regressions on Landfill per capita, Incineration per capita and Recycling per capita (p-value in parenthesis).*

	(1)	(2)	(3)
	Landfill	Incineration	Recycling
Pooled OLS, base	-2.701	1.9714	0.8989
	(0.000)	(0.000)	(0.000)
Pooled OLS, waste control	-0.5781	-0.2621	-0.2891
	(0.000)	(0.002)	(0.000)
Pooled OLS	-1.1839	-0.1222	-0.643
	(0.00)	(0.343)	(0.000)
FE, base	-3.4896	1.805	0.7506
	(0.003)	(0.007)	(0.001)
FE, waste control	-1.011	0.8861	0.2294
	(0.92)	(0.004)	(0.380)
FE	-0.8456	0.784	-0.2965
	(0.151)	(0.013)	(0.495)

Table 6.2: *Regression 1, 2 and 3*

	(1)	(2)	(3)
	Landfill	Incineration	Recycling
Landfill tax	-0.8456	0.7844**	-0.2965
	(0.568)	(0.2889)	(0.426)
Incineration tax	-0.048	0.08369	0.0921
	(0.217)	(0.1359)	(0.097)
year	1.2290	0.4086	-1.3167
	(2.662)	(1.317)	(2.332)
Household spending	-0.0039	0.0019	0.0033
	(0.003)	(0.001)	(0.0033)
GDP	0.00079	0.00088	0.0081
	(0.0015)	(0.0001)	(0.017)
Municipal Waste	0.6639***	0.3319**	0.4095*
	(0.173)	(0.1521)	(0.2161)
Population density	1.262	0.3357	-2.6266
	(1.724)	(1.033)	(1.832)
Population	0.00000307	0.00000292	0.000000841*
	(0.000)	(0.000)	(0.000)
Singl.person hh	-0.5494	-0.2339**	0.1321
	(0.354)	(0.111)	(0.348)
Incineration	-0.9442***		-0.4623***
	(0.131)		(0.147)
Landfill		-0.4734***	-0.4208***
		(0.116)	(0.139)
Landfill Ban	-8.890	-2.6776	33.5899**
	(26.651)	(11.083)	(14.751)
EPSI			4.4763
			(6.499)
EU member	0.4970	.	-8.714
	(11.119)		(6.294)
Dispfac			-0.3672
			(0.450)
Recycling facilities			0.0106
			(0.023)
Recycling	-0.6197**	-0.3814**	
	(0.1754	(0.1604)	
Landfill facilities	-0.2687		
	(0.287)		
Inc.facilities		0.1243	
		(0.249)	
Constant	-2311.611	-868.76	2735.369
	(5203.463)	(2571.606)	(4574.518)
Observations	301	308	67
Adjusted R-squared	0.785	0.707	0.490
F	143.4	66.29	.
df_m	13	13	13
df_r	22	22	18

Standard errors in parentheses

Independent variables measured in per million capita

**p<0.10, **p<0.05, ***p<0.01*

6.2. Regression 2. The relationship between landfill taxes and waste incineration

When only regressing the relationship between landfill taxes and the amount of waste combusted in incineration facilities (FE, base), the estimate showcases a large positive correlation. Namely, that a €1 increase in the landfill tax leads to an increase in the amount of incinerated waste by approximately 1.81 ton per 1 million inhabitants. This result is significant at the 1%-level. However, as with the regression function on landfilled waste (Regression 1), it suffers from severe omitted variable bias. To mitigate this problem additional explanatory waste variables was added. This decreased the magnitude of the estimate (to 0.77 ton per 1 million inhabitants) and the significance, this result was fairly intact after adding the same geographical and economic controls as in Regression 1. However, the level of significance decreased slightly once correction for heteroskedasticity and autocorrelation was made. Specifically, the results indicate that an increase by €1 of a landfill tax increases the amount of waste incinerated by approximately 0.78 ton per 1 million individuals. Equivalently, this translates into an increase of 0,078 hg per person. With a p-value of 0.013, this positive effect of landfill taxes is significant at the 5% level.

Furthermore, the amount of waste treated in landfill sites and recycling stations both decreases the amount of waste incinerated, seeing as the sign of these coefficients are negative. These effects, too, are significant, the amount of waste landfilled at the 1%-level, and the amount of waste recycled at the 5%-level.

Looking at our control variables, only two have a significant relationship with the dependent variable; the amount of municipal waste generated per country and year, and the number of single person households per country. As is to be expected, the relationship between municipal waste and incineration is positive, indicating that an increase in the amount of municipal waste generated in turn raises the amount of waste incinerated. Specifically, an increase of 1 ton municipal waste, raises the amount of waste incinerated by approximately 0.33 tons per 1 million individuals. The number of single person households, on the other hand, exhibits a negative effect on waste incineration. An increase of 1000 single person households decrease the amount of waste incinerated with 0.23 ton per 1 million individuals. A probable reason for this negative relationship is that smaller households generates less waste.

As for the rest of the control variables, none is significant, but they all exhibit the expected signs, with the exception of ban on combustible waste and the EU dummy. As argued in previous sections, both these variables are posited to have a positive relationship with the amount of waste incinerated. The landfill ban on combustible waste because waste that is not allowed to be landfilled still has to be treated, and the main alternative to landfill sites are waste incineration plants. Furthermore, combustible waste is extra probable to be diverted to waste incineration plants in particular, due to the characteristics of the waste: it cannot be recycled or composted, and it is not forbidden from incineration (as hazardous waste might be). Thus, a negative relationship between a ban on the landfilling of combustible waste is perplexing. Moreover, being a member of the European Union should lead to an increase in the amount of waste treated through combustion due to the EU's waste hierarchy and, in general, positive perception of waste incineration. Worth highlighting again, however, is that neither of these variables are significant and that their sign, thus, should be treated with caution.

6.3. Regression 3. The relationship between landfill taxes and recycling of waste

A first check of the relationship between the amount of waste recycled and taxation of landfilled waste provides expected estimates - the relationship is positive and significant. However, after adding additional waste variables (alternative treatment options and policies), the sign of the estimate turns negative. The sign stays negative in all the subsequent models, i.e. after adding geographical and economic control variables and standard cluster robust errors. Even though this seemingly indicates that the relationship might indeed be negative, the results should be handled with caution since it goes against findings of previous papers, and also what one would logically believe. Furthermore, the estimates for the fixed effects models (with and without cluster robust standard errors) are both insignificant, and the standard errors for the final model (FE) are of a larger absolute magnitude than the indicated coefficient itself. These aspects underline the implausibility and high variability of the reported results.

Together with the final models of Regression 1-2, the results of Regression 3, Model 4, can be viewed in its entirety in Table 6.2. As with the other regressions, the variables depicting the amount of waste treated by alternative waste treatment options (through incineration and landfilling in the case of recycling) have negative signs and significant results. An increase of landfilled and incinerated waste with 1 ton decreases the amount of waste recycled by 0.42 tons and 0.46 tons, respectively. The consistent significance and negative relationship between the alternative waste treatment options within all three regressions is reassuring. It signals that the model design works fairly well.

The remaining variables with significant p-values are municipal waste generation, population and a landfill ban on total waste. Since the regression includes the ban-dummy consisting of all implemented bans in the sample, the estimated coefficient indicates the effect of bans on combustible-, biodegradable-, untreated-, and general waste. Specifically, this effect is an increase in the amount of waste recycled by, approximately, 33.59 tons per 1 million inhabitants due to the implementation of a ban on landfilling of waste. This effect is clearly large and would provide substantial support for the implementation of bans on landfilled waste to induce recycling, were it possible to confidently proclaim its credibility. However, the coefficients standard error is fairly large (14.751), and the power of Regression 3 quite low, with only 67 observations following a problem with missing values.

As can be seen in Table 6.1, the model specifications (base, waste control, and full model) were also conducted using pooled OLS regressions. This was done mostly for comparison purposes. The results between the pooled OLS and the FE functions are fairly similar in terms of magnitude. On the other hand, pooled OLS showed significant results also after adding socioeconomic controls, as opposed to the FE specification. However, according to the tests and argumentation laid out under ‘Method’, the fixed effects coefficients are ultimately regarded as the results of the empirical analysis.

6.4. Summary

To summarize the findings from the conducted regression analyses, only one out of the three a priori posited Hypotheses held up empirically (Hypothesis 2). Namely, it was found that landfill taxation increases the amount of waste treated in incineration plants. In particular, a €1 increase in the tax rate increases the amount of waste incinerated by approximately 0.78 tons, results significant at the 5%-level. Any significant relationship between landfill taxation was not found for any of the other two waste treatment alternatives, and thus the results showed no support for Hypothesis 1 or Hypothesis 3. Regarding the remaining independent variables, the

alternative treatment options to the dependent variables was found to exhibit negative and significant relationships throughout the regressions. On the other hand, municipal waste generation seem to positively and significantly affect all three treatment options. In regard to recycling (Regression 3), having a landfill ban was found to significantly and greatly contributed to the recycling rate.

6.5. Robustness Checks

To check the robustness and validity of our results, we conducted two robustness checks to see whether we would be able to confirm our findings.

First, we re-ran the regressions with seven additional years in the data set, including observations from 1990-1997 as well as our initial observations from 1998-2017. We found that the results of the control variables were relatively robust throughout the three different regressions. See Robustness Checks in Appendix. The effect of the landfill tax on the dependent variables was also found to be robust (but still insignificant) on the regressions on Landfilling of waste and Recycling of waste. In the regression on waste incineration, however, the landfill tax decreased from 73 to 17, going from being significant on the 5% level to being insignificant. This finding is non-robust to our presented results and is thus a reason to doubt the validity of our finding on the incineration regression. One possible explanation to the decreased significance of the variable is the weaker data set of the extended regression. If this is the explanation to the non- robustness, there is no reason for concern.

Secondly, we conducted a robustness check by reducing the data set with the countries that had not been part of the European Union before June 1, 2004. This to evaluate whether our findings are robust when including less observations in our regressions. The excluded countries are the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic and Slovenia. As this exclusion is non-random we expected a slight bias in some of the waste treatment coefficients as non-EU member states tend to score lower on environmental indexes. The check shows quite robust results on all three regressions. The biggest - and potentially worrisome-deviationsfromthemainregressionsisthesignificancelevelofthelandfilltax. In the regression on landfilling the tax changed from being insignificant to being significant on a 5% level. A possible explanation to this could be that member states that have been under the influence of the Waste Framework Directive for a longer time could have had the opportunity to better comply to the policies. This in turn could mean that they have implemented more optimally designed landfill taxes and thus gotten a more significant result.

7. Discussion

7.1. The Effect of Landfill Taxation

The main explanatory variable – the landfill tax – is only statistically significant in one of the three regression functions, namely the one on the amount of waste incinerated. Hence, only Hypothesis 2 was found to be true. The positive relationship with incinerated waste is in line with previous research, as well as one of the main purposes for the implementation of such a tax (the other being raising revenue). As laid out above, the point of the tax is to make landfilling relatively more expensive compared to the other two waste treatment options, and consequently divert waste flows from landfill sites. Thus, if the tax works, a positive relationship between the tax and the amount of waste incinerated should be discernible, as was found here. However, due to the same logic, this relationship should also exist between the landfill tax and the amount of waste recycled. Furthermore, the waste diverted to these two treatment options should in turn mean that there is a negative relationship present between the landfill tax and the amount of landfilled waste. Neither of these effects could be found in the undertaken analysis.

Regarding the relationship between the landfill tax and the recycling rate, the insignificant result is not entirely out of line with previous research. As stated earlier in the paper, there's less consensus in the research field when it comes to the relationship between landfill policies and the recycling rate. Some papers have indeed reported an increase in the amount of waste recycled due to landfill taxation (Barterlings et al. 2005; Martin and Scott 2003), while others have failed to find any significant relationship (Mazzanti and Nicolli 2013; Zero Waste Europe 2015; Papineschi 2019). The reason for this is probably the mentioned difference in the waste management structure for recycling compared to incineration and landfilling (Barterlings et al., 2005). Following this, the magnitude of the impact of the tax on the recycling rate was hypothesized to be smaller compared to the other regressions. Thus, the lack of a significant result may very well reflect reality.

However, this regression should be treated with some caution since acknowledged additional determinants of the recycling rate - convenience, cost and environmental concern - was only controlled for to a certain extent. While the number of recycling stations are included as a means to control for convenience of recycling (more stations per 1 million inhabitants indicating increased convenience), this variable exhibits a noteworthy number of missing values, and thus effectively decreases the efficiency of the model. Additionally, due to a lack of panel data on the disposal charge (cost) of recycling, it had to be omitted despite being possibly important. In conclusion, Regression 3 is posited to suffer from a higher degree of omitted variable bias and weaker statistical power, compared to Regression 1 and Regression 2.

Unfortunately, the indirect nature of the effect on the recycling rate is not something that can be theorized for the relationship between the landfill tax and the amount of landfilled waste. An insignificant coefficient is worthy of some scrutiny. The lack of effect is at odds with a majority of earlier papers (Barterlings et al. 2005; Martin and Scott 2003; Mazzanti and Nicolli 2013; Mazzanti and Zoboli 2008; Papineschi 2019), however previous research is not unanimous. As proposed by Sasao (2014), an explanation for the lackluster results could be that the landfill taxes, on an aggregate level in the sample, have failed to significantly contribute to landfill diversion following sub-optimal tax rates. On average, the tax rates in the sample could have been lower than the level necessary to increase the marginal cost of landfilling enough to divert waste streams from this option to alternatives. This would not go against the previous within-country studies, if the effect of taxes in countries where its impact has not already been investigated would prove to be inadequate. Unfortunately, acceptable panel data on the relative costs of the different waste treatment options was not possible to obtain. Consequently, this paper simply studies the effect of the marginal cost increase for landfilling that the taxes represent. Thus, it is difficult to conclude whether or not the increased costs - on average - was enough to incentivize reallocation of waste flows. Naturally, an improved model would account for such a variable.

What is cause for more concern is the fact that the significance of the tax differs between Regression 1 and Regression 3 on the one hand, and Regression 2 on the other. Would the above reasoning (sub-optimal tax rates) be the explanation for the lack of effect on landfilling and recycling, it is plausible to believe that it should dilute the effect also for incineration.

7.2. The Effect of Control Variables

Waste Related Control Variables

Contrary to prior beliefs, the waste policy and capacity variables included in the analyses - incineration tax, landfill ban on total waste and the number of treatment facilities - did not

provide significant results. With an exception for Regression 3, where the incineration tax was significant on 10%-level, and the landfill ban on 1%-level.

While the impact from the incineration tax was posited to be of some significance, the lack thereof is not entirely surprising nor cause for concern. As stated in 'Previous Research', the research on the effect of incineration taxes is both limited and inconclusive. Furthermore, only a minor number of countries had at some point during the sample period implemented a tax on incinerated waste, hence the underlying data for the variable might not have been sufficient[2]. However, this does not explain why the tax had a significant impact on the recycling rate, but not the remaining two treatment alternatives. At a first glance, it would be more plausible had the effect been for incineration. Or even landfilling, considering that all waste can be landfilled, while the same is not true for recycling. However, it is possible that countries that have implemented taxes on the incineration of waste also recycles more than the rest of the sample. The countries that have implemented incineration taxation have extensive incineration capacity in regard to the size of their domestic waste market. Along the same lines, it is possible that they could also have rather extensive recycling capabilities. In such a scenario, the increased correlation between waste incineration taxation and the recycling rate would not stem from the taxation's effect on the amount of recycling directly, but from an unobserved variable relating to the waste infrastructure within the countries in question. Further investigation on the matter is necessary to enable any conclusive inference.

That the number of landfill facilities did not prove to significantly affect the amount of waste landfilled goes against prior beliefs, but not necessarily prior research. For example, in the study on Dutch regions (after which the current paper modeled the regression functions), the variable representing landfill capacity also reported insignificant values (Barterlings et al., 2005). Despite this, it was included in the present analysis as omitting the capacity was believed to lead to a bias of the results. The logic is that the amount of waste treated via landfilling (or incineration or recycling) is ultimately dependent upon the number of landfill sites (or incineration plants or recycling stations) available and their capacity. Now, unlike the report from 2005, a variable directly depicting the available capacity (in tons) was not possible to employ due to lack of data. While such a variable was initially retrieved (for all three regressions), it was later dropped from the analysis due to too many missing values. Instead, the number of facilities was used as a proxy for the overall available capacity. Clearly, this method is second-best. The number of facilities does not say anything about the size of said facilities, and can thus lead to misleading results if a country with fewer facilities that are of a larger scale has a bigger overall treatment capacity compared to a country with more small-scale facilities. This is true for the facility-variable in all regressions (Regression 1, Regression 2, and Regression 3).

The non-significance of the remaining waste-related control variable, on the other hand, is more worrisome. According to prior research, landfill bans should impact landfill diversion in similar ways to landfill taxes (simultaneously referred to as 'landfill policies'), i.e. they should have significant effect on the diversion of waste from landfill sites (Mazzanti 2009; Mazzanti and Zoboli 2012; Papineschi 2019). As previously noted, no significant effect was found for the landfill tax, and a landfill ban on total waste only significantly impacted the amount of waste recycled. Furthermore, while taxes are simply financial instruments that increases the cost of a certain practice, landfill bans explicitly forbids the landfilling of certain types of waste. Thus,

[2] The countries that have had a tax on waste incineration sometime during the period in question are Austria, Belgium, Denmark and Sweden.

the implementation of a ban has been argued to impose an effect on landfilling of a larger magnitude, compared to taxes (Zero Waste Europe 2015). A diluted effect due to low tax rates (Sasao 2014) cannot be used as a possible explanation for the weak relationship between ban implementations and landfill diversion. However, it could be the case that the effect of some of the bans implemented from 1998-2017 had little to no effect on landfill diversion, either because of (1) too high gate values for TOC or calories which effectively diminishes the practical impact of such bans, (2) extensive exceptions for compliance or lagged implementation, or (3) bans only targeted for marginal waste types, which would dilute the overall effect. Following this, using an aggregate control variable for all types of bans on landfilled waste could lead to weak results as the aforementioned effects (or rather, lack thereof) would be picked up by the variable. To mitigate this issue, a regression only consisting of more targeted bans (i.e. logically posited to have a larger impact on diversion) could be a solution. Yet, the landfill ban did exhibit a significant and positive coefficient in Regression 3. However, due to aforementioned apprehensions in regard to this regression function, as well as the coefficients large standard error, its significance should be treated with caution.

Geographic and Socio-economic Control Variables

Moving on to the geographical- and socio-economic control variables, what stands out is (i) the lack of impact regarding population density, on the one hand, and (ii) the consistent significance of municipal waste generation and alternative treatment options on the other. As a number of earlier studies had noted the significance of a region's relative population density in regard to landfill diversion, this negative relationship was expected also in the present analysis. In addition, such negative correlation is logical following the fact that landfilling is the most space demanding treatment alternative, and the opportunity cost of land increases with increased population density. While the population density variable's lack of effect might cause some worry, the consistent significance and negative coefficients of the amount of waste treated via alternative treatment options in all three regressions, for all model specifications and robustness tests, speaks in favor of the model design. That, for example, the amount of waste landfilled have a significant decreasing impact on the amount of waste incinerated is both in line with previous research, and what one would generally believe. Waste treated in one facility cannot possibly be treated in another as well, and thus effectively decreases the amount of waste that initially could have been disposed of using an alternative method.

7.3. Limitations to the Model

The robustness tests indicate somewhat non-robust results. There are several possible explanations for why this is the case, most of which can be grouped into two areas; the lack of robustness could either stem from a misspecification of the model design, or flaws within the employed data set.

7.3.1. Model Design

As is commonly known, the best way to confidently infer any causal relationships is by undertaking investigations in experimental settings, so called Randomized Control Trials (RCTs). However, this type of setting is rarely an available option when studying macroeconomic effects, such as the impact of environmental taxation. Arguably, a fixed effects function specification can in this particular case be classified as a second best. As explored in greater detail under 'Method', leveraging panel data for policy analysis is particularly suitable since it allows for 'pre-' and 'post-treatment' observations. Furthermore, the implementation of fixed effects limits omitted variable bias by controlling for time-invariant omitted variables. Furthermore, following intuitive argument fixed effects estimation proved a better fit to the regression functions in question, compared to random effects. The models should consequently

provide the best linear unbiased estimates after correcting for heteroskedasticity and serial correlation via cluster robust standard errors. However, some potential issues remain.

For the regressions to provide adequate estimations, it is important that they fulfill the underlying assumptions. The most critical assumption states that the mean value of the error term conditional on the explanatory variables should be equal to zero (zero conditional mean assumption). Simply put, there should be no dependencies (on average) between the residuals and the regressors in the model, for all time periods (Woolridge 2013). Ergo, related omitted variables would violate this assumption. Naturally, this proves an issue for all non-experimental econometric analyses, including this one. While all recognized determinants according to previous research have been included in the models (Barterlings et al 2005; Lange et al. 2014; Mazzanti and Zoboli 2009; Zhang et al. 2016), a risk for assumption violation remains. Primarily, a potential omitted variable would be the trade of waste. Especially within the European Union, which is the world's largest exporter of non-hazardous waste (European Commission 2015). The shipment of waste, in turn, affects the amount of waste treated in the respective countries' treatment facilities. Unfortunately, sufficient data for a waste shipment variable was not obtained.

Moreover, there is a possibility that the treatment facility variable would describe reality better (and thus provide results closer to the 'true' values) had it been designed with a lag. It is reasonable to believe that the waste flows for year t depends on the treatment capacity the year before (t-1) for each respective alternative. If this is indeed the case, the zero conditional mean assumption would be violated (Woolridge 2013). The reason the variable was not lagged in the present analysis is, again, that it depicts the number of facilities and not capacity in tons. As they say, a treatment facility is not built in a day. Furthermore, along these lines, allocation probably also depends on the decision to establish new facilities, since the construction of new facilities are undertaken on the premise of future waste flows. But since the data set employed only depicted facilities in operation, it was deemed better to strictly model the function based on the capacity for the year in question and not assume the magnitude of a potential lagged effect. However, it could be worthwhile investigating this issue further.

Finally, despite the necessity of cluster robust standard errors, the clusters might lead to inconsistency due to the relatively small number of clusters (20 time period clusters, or 23 country clusters). As is common in the wonderful world of regression analysis, there is no clear rule declaring at what point the number of clusters induces inconsistency, but Cameron and Miller (2015) indicated that there should be at least 20 clusters. Seeing as the present regression functions have at most 23 clusters (for Regression 1 and Regression 2), and at the lowest 19 (for Regression 3, due to missing values), a resulting inconsistency might very well be an unmitigated issue.

7.3.2. Data

As waste management is a relatively new area within Europe and the European Union, the development of systems on how to measure different waste streams has been under constant development during the last 20 years. This has resulted in both within- and between country differences in how waste is - and have been - measured. Though the data being used in the analysis is primarily from the OECD and Eurostat - two reliable sources - there are reasons to believe the data is not always consistent. One example is the data on number of recycling facilities in the United Kingdom. In 2009 the number was measured to 18 853 recycling facilities and only three years later to 2 530. Not only is this a giant leap under the course of only three years - it is also a counterintuitive development of recycling facilities. After adjusting

our data set for obvious measurement errors, we have however decided to stick with the data from OECD and Eurostat despite the believed limitation and probable inconsistency in the data. As with the limitation above, one further result of waste management being a relatively newly prioritized area within the European Union and its member states, is that there is a lack of data in several variables included in our regression. This is especially true with the variables on disposal facilities. Because of this, it will be harder to draw conclusions from our regressions since the statistical power will be weakened. We have also omitted a couple of variables we initially planned to include in our regression, such as waste collection schemes, since we could not obtain any panel data on this and the fixed effects model partials out time-invariant variables.

8. Conclusion

Within the context of a transition into a new decade, as well as the end to the first stretch of the European Union's Circular Economy Action Plan (within which waste has been highlighted as an asset instead of, well, waste) this paper set out to empirically investigate the effectiveness of previous waste policies. Specifically, the effect on waste treatment of landfill taxation, as it is the most broadly implemented waste management tool in the region. The motivation for the investigation was that a documented effect from empirical analysis would help enable more sound decision-making for future policies, and subsequently improve waste management practices.

In order to achieve this, three fixed effects regression functions were developed. The regression functions each investigated the relationship between landfill taxation and the amount of waste landfilled, -incinerated and -recycled. The amount of waste treated via the respective treatment alternatives was employed as the explained variables following the purpose of landfill taxation. The idea behind the taxes is to raise the marginal cost of landfilled waste enough to equalize the environmental externalities of the practice, and shift waste streams away from landfill sites toward alternative disposal options. Thus, in order to investigate the effectiveness of landfill taxation as a waste management instrument, it is suitable to study its impact on waste flow allocation. This effect has previously been investigated in several single-country contexts, notably in the United Kingdom, the Netherlands and Italy. These papers found that landfill taxes didn't affect the generation of waste, but were successful in diverting it from landfill sites to alternative options. To enrich the empirical foundation for waste policies and increase the generalizability of the results, this paper investigated said relationship on a cross-country level, using a panel data set of 23 European Union member states over a period of 20 years (1998-2017).

The results from the empirical analysis in the present paper did not find a significant effect of landfill taxation on the amount of waste landfilled or the amount of waste recycled. These findings (or rather lack thereof) hence goes against the general findings of previous research. On the other hand, in line with earlier papers, a positive relationship between the amount of waste treated via combustion was found. In particular, a €1 increase in the value of the landfill tax would lead to an increase in the amount of waste incinerated by 0.78 tons per 1 million individuals, ceteris paribus.

However, despite rigorous panel datasets and applicable model design, the presented results should be treated with care. While a number of variables proved to be highly robust, the regression functions overall indicated some weaknesses in undertaken robustness tests. Specifically, the relationship between recycling and landfill taxation would be advantageous to view with some apprehension. The number of observations, and thus the statistical power, of

this particular regression (Regression 3) is lower compared to the remaining two following a higher degree of missing values. While the aim of this study was to determine the effect on waste allocation following landfill taxation, the analysis did not prove robust enough to confidently be able to declare the nature of these relationships. Thus, to sufficiently provide an empirical foundation for future policies, it would be wise to explore the area further via additional investigations. Future research on the area would probably benefit from better quality data on the countries' waste treatment capacities as well as from including variables that sufficiently accounts for trade in waste and the cost of the respective waste treatment alternatives. Due to lack of acceptable panel data for these variables, the present paper was not able to take these aspects into account. This led to some ambiguities in the obtained results, which consequently should not be seen as the whole truth, but rather as complementary to previous research in the field, and as a starting point for more investigations going forward.

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10. Appendix

Table 1, Appendix: *Robustness test on the Landfill model with 1) additional years and 2) reduced amount of countries*

	(0)	(1)	(2)
	Model	Rob.test 1	Rob.test 2
Landfill tax	-0.8456	-0.5754	-1.3131**
	(0.568)	(0.386)	(0.630)
Incineration tax	-0.048	0.0319	0.2645
	(0.217)	(0.2133)	(0.196)
year	1.2290	1.0508	0.1146
	(2.662)	(2.573)	(3.243)
Household spending	-0.0039	-0.0066	-0.0034
	(0.003)	(0.004)	(0.0045)
GDP	0.00079	0.0025	0.0017
	(0.0015)	(0.0015)	(0.0014)
Municipal Waste	0.6639***	0.7652***	0.5138*
	(0.173)	(0.119)	(0.269)
Population density	1.262	1.7740*	1.2149
	(1.724)	(0.931)	(2.116)
Population	0.00000307	0.00000518	0.000000219
	(0.000)	(0.000)	(0.000)
Singl.person hh	-0.5494	-0.3913	0.0278
	(0.354)	(0.228)	(0.233)
Incineration	-0.9442***	-0.9055***	-0.9106***
	(0.131)	(0.101)	(0.218)
Landfill			
Landfill Ban	-8.890	-29.463	6.0084
	(26.651)	(20.882)	(10.745)
EPSI			
EU member	0.4970	-0.0789	(omitted)
	(11.119)	(13.562)	
Dispfac			
Recycling facilities			
Recycling	-0.6197**	-0.7346***	-0.6492**
	(0.1754	(0.1498)	(0.235)
Landfill facilities	-0.2687	-0.3652	-0.2324
	(0.287)	(0.271)	(0.348)
Inc.facilities			
Constant	-2311.611	-2156.186	-197.8375
	(5203.463)	(5165.027)	(6313.603))
Observations	301	293	194

Standard errors in parentheses

Independent variables measured in per million capita

**p<0.10, **p<0.05, ***p<0.01*

Table 2, Appendix: *Robustness test on the Incineration model with 1) additional years and 2) reduced amount of countries*

	(0)	(1)	(2)
	Model	Rob.test 1	Rob.test 2
Landfill tax	0.7844**	0.1722	0.7136**
	(0.2889)	(0.261)	(0.340)
Incineration tax	0.08369	0.0733	0.1001
	(0.1359)	(0.103)	(0.135)
year	0.4086	1.4006	1.4680
	(1.317)	(1.850)	(1.398)
Household spending	0.0019	-0.00026	0.0025*
	(0.001)	(0.0028)	(0.0014)
GDP	0.00088	0.0017	0.0004
	(0.0001)	(0.001)	(0.0008)
Municipal Waste	0.3319**	0.3691**	0.2467
	(0.1521)	(0.178)	(0.159)
Population density	0.3357	0.1682	-0.6043
	(1.033)	(0.529)	(1.055)
Population	0.00000292	0.00000023	0.000000296
	(0.000)	(0.000)	(0.000)
Singl.person hh	-0.2339**	-0.3131**	-0.4377***
	(0.111)	(0.156)	(0.137)
Incineration			
Landfill	-0.4734***	-0.5544***	-0.4174***
	(0.116)	(0.124)	(0.130)
Landfill Ban	-2.6776	-12.301	7.6107
	(11.083)	(11.030)	(9.634)
EPSI			
EU member	(omitted)	-8.2005	(omitted)
		(9.163)	
Dispfac			
Recycling facilities			
Recycling	-0.3814**	-0.4406**	-0.5529***
	(0.1604)	(0.164)	(0.184)
Landfill facilities			
Inc.facilities	0.1243	-0.0266	-0.0328
	(0.249)	(0.184)	(0.212)
Constant	-868.76	-2714.695	-2780.65
	(2571.606)	(3665.873)	(2685.716)
Observations	308	297	199

Standard errors in parentheses

Independent variables measured in per million capita

$^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$

Table 3, Appendix: *Robustness test on the Recycling model with 1) additional years and 2) reduced amount of countries*

	(0)	(1)	(2)
	Model	Rob.test 1	Rob.test 2
Landfill tax	-0.2965	-0.2936	-0.2699
	(0.426)	(0.407)	(0.463)
Incineration tax	0.0921	0.2130	0.1255
	(0.097)	(0.125)	(0.076)
year	-1.3167	3.9027	-8.5809**
	(2.332)	(4.139)	(3.726)
Household spending	0.0033	-0.0024	0.0121**
	(0.0033)	(0.008)	(0.004)
GDP	0.0081	0.0017	-0,0486
	(0.017)	(0.004)	(0.035)
Municipal Waste	0.4095*	0.3534**	0.2927**
	(0.2161)	(0.175)	(0.149)
Population density	-2.6266	-2.594	-2.2992
	(1.832)	(1.683)	(2.056)
Population	0.000000841*	0.00000054	0.0000133**
	(0.000)	(0.000)	(0.00)
Singl.person hh	0.1321	-0.2333	0.6738**
	(0.348)	(0.426)	(0.326)
Incineration	-0.4623***	-0.3962**	-0.5353**
	(0.147)	(0.138)	(0.141)
Landfill	-0.4208***	-0.3416**	-0.3911***
	(0.139)	(0.153)	(0.122)
Landfill Ban	33.5899**	40.126***	(omitted)
	(14.751)	(8.857)	
EPSI	4.4763	10.4077	10.4963
	(6.499)	(8.047)	(8.337)
EU member	-8.714	(omitted)	(omitted)
	(6.294)		
Dispfac	-0.3672	0.5229	-0.8858
	(0.450)	(0.338)	(0.738)
Recycling facilities	0.0106	-0.0078	0.0283
	(0.023)	(0.036)	(0.025)
Recycling			
Landfill facilities			
Inc.facilities			
Constant	2735.369	-7587.283	17091.56
	(4574.518)	8175.003	(7370.737)
Observations	67	67	67

Standard errors in parentheses

Independent variables measured in per million capita

$^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$

F-test

Regression (1) on Landfilling

```
F( 14,     22) =  143.39
     Prob > F =    0.0000
```

Regression (2) on Incineration

```
F( 14,     22) =   66.29
     Prob > F =    0.0000
```

Regression (3) on Recycling

```
F( 14,     18) = 1.5e+07
     Prob > F =    0.0000
```

Breusch–Pagan test

Regression (1) on Landfilling

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of LF

         chi2(1)      =    12.38
         Prob > chi2  =   0.0004
```

Regression (2) on Incineration

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of incto

         chi2(1)      =     4.19
         Prob > chi2  =   0.0406
```

Regression (3) on Recycling

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of recyc

         chi2(1)      =     0.44
         Prob > chi2  =   0.5068
```