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Is Incineration Replacing Recycling?

Masashi Yamamoto and Thomas Kinnaman

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UNIVERSITY
OF TOYAMA
富山大学

FACULTY OF ECONOMICS
UNIVERSITY OF TOYAMA

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Masashi Yamamoto[*,†] Thomas Kinnaman[‡]

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Abstract

Recycling rates increased rapidly in the United States and across the developed world in the 1980s and 1990s but have remained relatively flat in many countries since about 2005. Could increases in incineration and a possible "feed the beast" mentality associated with efficient incineration make the recycling of some materials economically and perhaps environmentally obsolete? In this paper, a theoretical model is developed to better explain the possible trade-off. The model is then tested using novel data in Japan that includes both unused incineration capacity and recycling rates across municipalities and across time. Results suggest that, when controlling for other variables, excess incineration capacity indeed reduces recycling. These results suggest that future planned increases in recycling may be frustrated by increases in incineration.

Key words: matching, recycling, incineration, waste management policy

1 Introduction

When the "Renewable Energy Facility" opened in June of 2015 in West Palm Beach, Florida, it marked the first time in over 20 years that a new solid waste incinerator began operations in the United States. Although 87 incinerators currently operate in the United States, lingering worries from the late 1980's over dioxins and other airborne pollutants have led NIMBY groups and local politicians to oppose the construction of new incinerators in New York City, Baltimore, Seattle, and in many other places. New York City's last incinerator closed in 1992,

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[*] (Corresponding author) Professor, Center for Far Eastern Studies, University of Toyama, Address: 3190, Gofuku, Toyama, 930-8555, JAPAN. Email: `myam@eco.u-toyama.ac.jp`

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[‡] Professor, Bucknell University

and since 1996 the percentage of all waste incinerated in the United States has decreased from 16% to 12%.

Over this same timeframe, rapid technological advances have increased incineration rates in virtually all other developed countries. Across European OECD countries, the percentage of waste incinerated has increased from 14% in 1996 to 26% in 2017. This change has been led by Scandinavian countries such as Norway (from 13% to 53%), Finland (from 2% to 46%), and Estonia (from 0% to 58%), and by southern European countries such as Italy (from 5% to 20%) and Portugal (from less than 1% to 20%). Australia (11% to 30%) and South Korea (4% to 25%) have also increased their incineration rates over the past two decades, and Japan has sustained very high rates of incineration (77%).

The global increase in incineration sparks a new policy question. What are the future prospects for recycling? Recycling rates increased rapidly in the United States and across the developed world in the 1980s and 1990s but have remained relatively flat in many countries since about 2005. Could increases in incineration and a possible "feed the beast" mentality associated with efficient incineration make the recycling of some materials economically and perhaps environmentally obsolete?

This paper uses original data to test whether increases in incineration capacity reduce recycling rates. A model is first developed to better explain the possible trade-off. Added recycling is assumed to increase unused capacity at the incinerator, which is costly due to the technology associated with incineration. With this assumption, increases in incineration capacity are predicted to decrease recycling. The model is tested using novel data in Japan that includes both incineration capacity and recycling rates across municipalities and across time. Results suggest that, when controlling for other variables, excess capacity indeed reduces recycling. These results suggest that future planned increases in recycling may be frustrated by increases in incineration.

2 The Literature

We are aware of no papers that model or estimate the relationship between recycling and incineration. More common are papers that compare landfilling with incineration for waste disposal. For example, Dijkgraf and Vollebergh (2004) find that although the external costs of incineration are less than those for landfilling, the social costs of landfilling are lower than incineration due to large differences in private costs. Incineration is therefore a relatively expensive way for an economy to reduce carbon emissions. O'Donovan and Collins (2011) find incineration is associated with higher net benefits when compared to landfilling in Ireland - a country that has experienced a rapid increase in incineration. Differences in local economic and environmental conditions could be responsible for these differing conclusions. This paper does not contribute directly to this debate between landfilling and incineration. It does present one additional consequence of incineration not previously mentioned in the literature - that incineration may reduce recycling.

This paper also contributes to the literature estimating recycling rates. This literature suggests that differences in observed recycling rates can be explained not by differences in the explicit costs of recycling and other waste management processes but to differences in tastes and preferences of recycling households. The contingent valuation method estimates households are willing to pay an average of USD 5.61 per month for recycling services (Aadlan and Caplan, 2005). More recently, Koford *et al.* (2012) estimate household willingness to pay for recycling at USD 2.29 per month. The source of these household recycling benefits appears to be a desire to adhere to social recycling norms (Halvorsen, 2008). Abbot *et al.* (2013) examine counties in the United Kingdom and are unable to link differences in recycling rates to economic costs or recycling program attributes such and instead also find evidence of a social norm explaining recycling rates. If incineration is estimated to reduce recycling rates, then this paper contributes to this literature by identifying an economic factor as a determinant of recycling rates.

3 The Technology of Modern Incineration

The environmental risks associated with solid waste incineration became widely known in the late 1970's. The 1976 Seveso accident in Italy led to a thorough search across all industries to discover other sources of dioxins - a term that subsumes roughly 200 closely related airborne chemicals all dangerous to human health. By 1977, unacceptable levels of dioxins were detected in the fly ashes of a Dutch incinerator, and soon after dioxins were found in the ashes of incinerators in Canada, Switzerland, and Japan. These discoveries led to new public opposition to incinerators, new emission standards, and new research on methods to reduce dioxins from the air streams of incinerators.

At the time, pollution abatement technology at incinerators consisted solely of electrostatic precipitators - a relatively low cost filtration technology designed to remove fine dust particles from air streams. But these didn't work. Dioxins escaped, and releases of dioxins were found to be intensive when combustion temperatures fell between 200 and 600 degrees Celsius.

Furnace temperatures were thereafter raised to levels above 850 degrees Celsius, methods were developed to better trap fly ash, better clean the boilers, and remove dust. Abatement technology has also been added to reduce nitrogen oxides and other airborne pollutants. Periods of incinerator startup and shutdown, when furnace temperatures pass the dangerous 200 to 600 degree threshold, are minimized with steady supplies of waste. As a result, dioxin emissions from incinerators with modern abatement technologies are near zero and typically below ambient levels of dioxins in the atmosphere. A back-yard barbecue grill or home fire place releases more dioxins than a modern incinerator (Vehlow, 2012).

Modern incinerators may include not just the abatement technologies discussed above, but also include processes to generate electricity, provide district heating services to neighboring dwellings, to collect metals from ashes for recycling, and recycle slag to produce building tiles. The lifecycle environmental costs associated with these incinerators and all of their processes have been estimated in the literature. In terms of lifecycle carbon dioxide (CO2) emissions, incinerators generate CO2 during combustion, from transporting waste to the incinerator, and from the initial construction. CO2 is reduced via energy production and the recovery of recyclable metals from various ashes. The net lifecycle impact on CO2 depends upon the type of displaced energy source and can range from 382 to negative 303 kilograms of CO2 per ton of waste incinerated (Boesch *et al.*, 2014). Thus, if the energy generated by an incinerator displaces energy from a high carbon source such as coal, then an incinerator's lifecycle impact on CO2 is negative - it is a carbon sink. These lifecycle results from incineration systems are similar for environmental impacts other than carbon such as energy use, acidification, and nitrification. Thus, the initial environmental problems associated with incineration appear to have largely disappeared due to advances in technology. These advances may help explain the recent increase in incineration in many pro-green developed nations of the world other than the United States.

Lifecycle estimates of the emissions from recycling systems are also available but vary widely across the literature due to differences in recycling practices, assumed boundary conditions, and other aspects of the research (Cleary, 2009). Studies that are available suggest reductions in lifecycle emissions from recycling systems due mostly to the displacement of raw materials in production (Kinnaman *et al.*, 2014). Thus, recycling may remain an ecologically preferred option to incineration, but future lifecycle estimates of both incineration and recycling processes are likely to further clarify this question. If recycling is found to be the cleaner option, then the question of whether recent increases in incineration have served to reduce recycling becomes rather important from an environmental perspective.

4 Modeling Incineration Costs and Unused Incineration Capacity

Assume a large municipality is endowed with incineration and recycling technologies to manage a homogenous solid waste material generated by its residents. With no other disposal options, all exogenously determined waste ($\tilde{Q}$) must either be incinerated (with quantity Q_I) or recycled (with quantity Q_R), thus $Q_I + Q_R = \tilde{Q}$.

At some point in the past the municipality planned for waste disposal by investing in incineration facilities. These facilities have life spans of several decades[1]. The capacity of its incineration facilities is defined at $\overline{Q}$, where $\tilde{Q} < \overline{Q}$. In other words, municipal incineration

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[1] An incinerator in Japan has an average life expectancy of 30 years.

capacity exceeds the quantity of waste generated by its residents. Some degree of excess capacity is desired to account for uncertain changes in tastes, incomes and human populations over time.

But owing to the details of the incineration technology, too much excess capacity is costly. Excess capacity requires furnaces to run intermittently, which requires added processes to temporarily store waste and to periodically ignite and extinguish furnaces. Intermittence also complicates the process of removing pollutants and dioxins from the air stream and therefore increases costs. The incineration cost function is therefore defined over both the quantity of waste incinerated and the excess unused capacity (Q^E)

$$TC_I = W(Q_I) + E(Q^E), \tag{1}$$

where $W' > 0$, $E' > 0$, $W'' > 0$ and $E'' > 0$. Marginal costs associated with both incineration and excess capacity are positive and increasing.

Each municipality is also endowed with a recycling technology. Recycling diverts material from the incinerator by converting the waste material into an input to the production process. The total cost of recycling is given by,

$$TC_R = R(Q_R), \tag{2}$$

where the first and second derivatives are both positive. Note that $Q^E = \overline{Q} - \tilde{Q} + Q_R = \overline{Q} - Q_I$. Thus, increases in recycling contribute to excess capacity as recycling reduces the quantity incinerated.

The goal of the municipality is to choose the quantity incinerated to minimize the total costs of managing $\tilde{Q}$ units of waste material.

$$\min \; W(Q_I) + E(\overline{Q} - Q_I) + R(\tilde{Q} - Q_I) \tag{3}$$

The first-order condition from this minimization process is

$$W'(Q_I) = E'(\overline{Q} - Q_I) + R'(\tilde{Q} - Q_I). \tag{4}$$

The second-order condition for a cost-minimum is $W'' > -E'' - R''$, which is easily satisfied given that all these second-order effects are assumed positive.

The solution to the cost-minimization problem can be written as $Q_I = Q^*(\overline{Q}, \tilde{Q})$. Substituting this solution back into the first-order condition and differentiating with respect to $\overline{Q}$ allows us to solve for how an increase in excess capacity will affect the level of incineration. This comparative static is:

$$\frac{\partial Q_I}{\partial \overline{Q}} = \frac{E''}{(W'' + E'' + R'')}, \tag{5}$$

which is positive for a cost-minimizing municipality. Also, since $Q_R = \tilde{Q} - Q_I$, we have,

$$\frac{\partial Q_R}{\partial \overline{Q}} = -\frac{E''}{(W'' + E'' + R'')}, \tag{6}$$

which is negative. Thus, municipalities with incinerators with large excess capacity are predicted to have lower recycling rates than municipalities with incinerators with low levels of excess capacity.

This comparative static can also be represented graphically in Figures 1 and 2, where the quantity incinerated is measured along the horizontal axis. Recall that the capacity of the incinerator is represented by $\overline{Q}$ and the total quantity of municipal solid waste to manage is represented by $\tilde{Q}$. Illustrated in Figure 1 is the marginal cost of incineration (W'), the

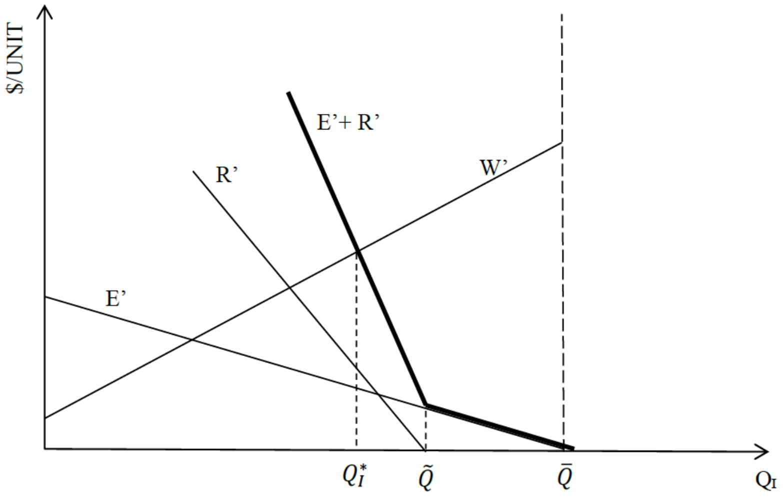

Figure 1: Costs of Incineration, Excess Capacity, and Recycling

marginal cost of excess capacity (E'), which rises with $\overline{Q} - Q_I$, and the marginal cost of recycling (R'), which rises with $\tilde{Q} - Q_I$. With incineration increasing along the horizontal axis, the slope of the recycling marginal cost curve is $-R'$ and the slope of the excess capacity marginal cost is $-E'$. The cost-minimizing quantity of incineration (Q_I^*) is determined by the intersection of W' and the sum of E' and R', the latter of which is illustrated in bold in Figure 1. The cost-minimizing quantity of recycling is $\tilde{Q} - Q_I^*$.

Figure 2 illustrates the effect of an exogenous increase in incinerator capacity holding constant the quantity of waste needing to be managed ($\tilde{Q}$). As capacity increases from $\overline{Q}$ to $\overline{Q}'$, the sum of the marginal costs associated with excess capacity and recycling ($E' + R'$) increases. The cost-minimizing quantity of incineration then increases to $Q_I^{*\prime}$ and that of recycling decreases.

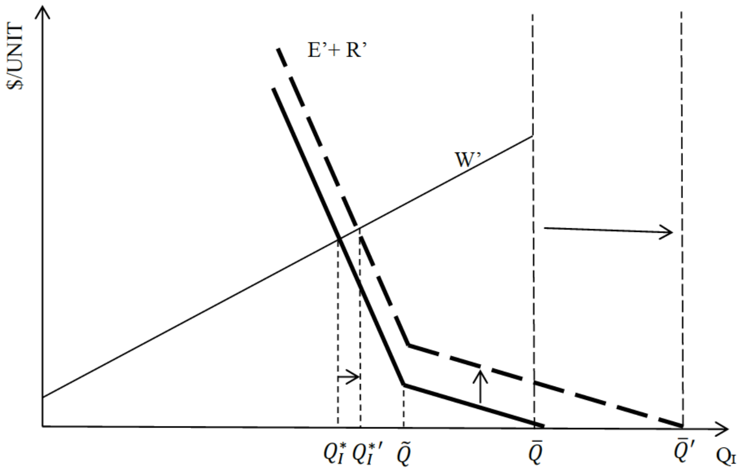

Figure 2: Optimal Incineration with Increased Excess Capacity

5 Empirical Analysis

5.1 The Emergence of Incineration in Japan

The model is tested using data from Japan. Japan incinerates nearly 80% of its waste - the next highest rate is less than 60% (by both Estonia and Norway). The transition from landfilling to incineration in Japan began in the 1960's during Japan's era of rapid economic growth when land became valuable and externalities associated with landfill disposed in congested areas became substantial. The Koto Ward in Tokyo famously banned waste originating in other wards from entering its landfills, and the Japanese media made the issue a national story. By 1971 the Tokyo Metropolitan Governor had to reluctantly declare that Tokyo was in a "War against Waste" (JMOE, 2014). Incineration became the favored alternative. Japan's initial incinerators were designed mainly to reduce the total volume of waste disposed at landfills by converting waste into ashes. The subsequent evolution in incineration has focused on reducing air emissions and other externalities. This evolution has yielded the technologies discussed above and a network of relatively clean incinerators located in and amongst large populations in city centers (Nagaoka and Ishii, 2016).

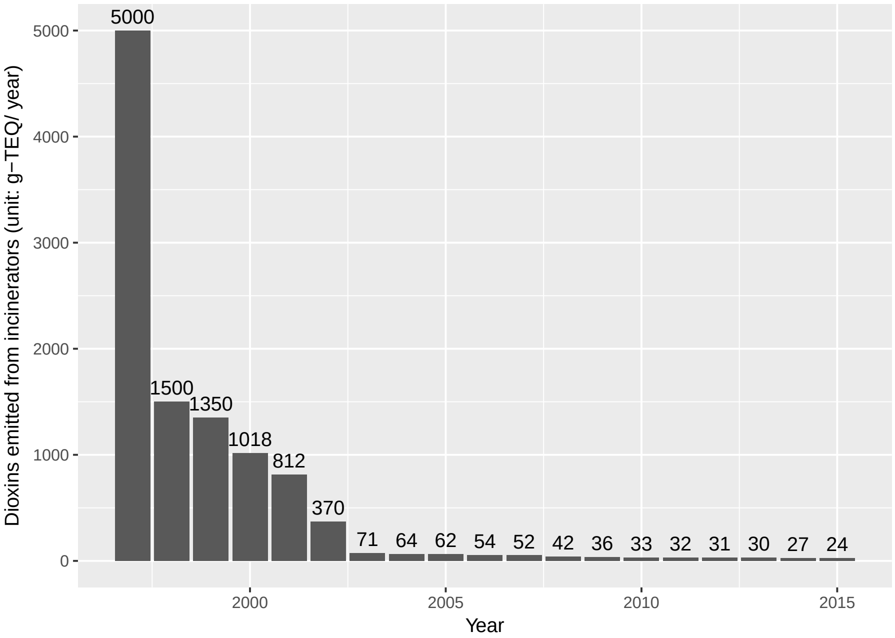

Figure 3: Dioxins Emitted from Incinerators

Source: JMOE website (`http://www.env.go.jp/recycle/dioxin/ippan/H28dioxin.pdf`)

When dioxins emerged as public health problem in the 1990's, Japanese incinerators were updated to burn at temperatures above 800 degrees Celsius and methods were developed to cool vapor outflow to less than 200 degrees Celsius as fast as possible. As a result, total dioxin emissions from all Japanese incinerators fell sharply. Figure 3 illustrates the quantity of dioxins emitted by Japanese incinerators each year from 1997 to 2015. Dioxins emitted from incinerators in 2015 represented only 0.5% of their 1997 total. Reducing dioxins was found to be most easily obtained with increases in the size of the incinerator. To encourage large emission-efficient incinerators, the Japanese Ministry of Environment began to subsidize the construction of large incinerators in the late 1990s. Over time, the total capacity of incinerators in Japan increased with the subsidy.

The emergence of large incinerators appears to have reduced dioxin emission. The excess capacity associated with these large incinerators may have also discouraged recycling. The next section describes the data and econometric model used to address this question.

5.2 Data

To estimate the model above, data are required on the excess incineration capacity and recycling rate across a sample of municipalities. Japan's Ministry of the Environment (2016) provides data on the total quantity of waste generated and the annual amount incinerated, landfilled, and recycled for each municipality in Japan from 2007 to 2014. The data also include each municipality's total incineration capacity. Excess incineration capacity is identified by subtracting the quantity incinerated from the total capacity.

The sample includes all municipalities in the Kanto region of Japan. The Kanto region consists of seven prefectures[2], including Tokyo, and is the most heavily populated region of Japan (43 million - roughly 25% of Japan's population). The left panel of Figure 4 provides a map of the Kanto region. The right panel in Figure 4 shows a close up of a few municipalities. The colored areas represent unique municipalities, and the dots denote the location of each incinerator.

Matching incinerators to municipalities in the data requires some attention. In many cases a single municipality, such as number 08202 in the right panel of Figure 4, is served by a single incinerator thus making the matching process trivial. In some cases, a (usually heavily populated) municipality such as number 08221 in Figure 4 is served by two or more

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[2] Each municipality in Japan belongs to one of the 47 prefectures. Note that Japan has the two-tier local government system.

incinerators. That municipality's recycling rate is matched with the average incineration rate and incineration capacity across these serving incinerators. If one incinerator serves two or more (usually small) municipalities, then these municipalities would have formed a Joint Waste Authority. In Figure 4, municipality 08212 and municipality 08255 share a single incinerator. The excess capacity at this single incinerator is then allocated to both municipalities in the Joint Waste Authority. Note that each of these municipalities will have generated its own unique recycling rate.

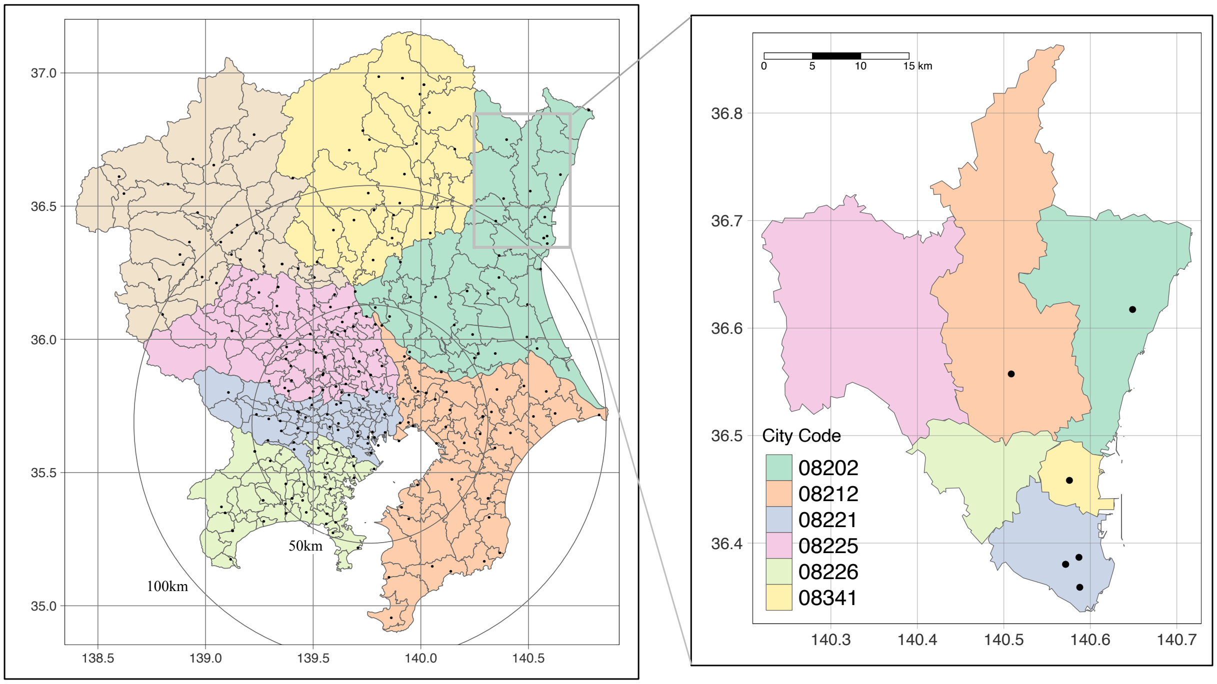

Figure 4: Plot of all sample (left) and selected area (right)

Note: The dots in both figure show the location of incinerators. Equi-distant circles in the left panel are 50km and 100km away from the central Tokyo.
Source: JMOE (2016)

Annual excess incineration capacity is defined as a proportion equal to one minus the ratio of the total annual quantity of waste incinerated to the annual incinerator capacity. Thus, an incinerator operating at 10% of total capacity will have excess capacity of 0.90. Recall that the theoretical model above predicts a negative relationship between excess incineration capacity and recycling rates. This negative relationship may not be constant across all possible measures of excess capacity. For example, any change in excess incineration capacity at an incinerator with already high excess capacity may affect recycling decisions differently than a similar change in excess capacity at an incinerator with already low excess capacity.

Table 1 provides summary statistics of each variable in the data set.

Table 1: Descriptive Statistics

	N	**Mean**	**St. Dev.**	**Min**	**Max**
Outocome variable					
Recycling rate (%)	2,158	22.280	8.755	0.000	77.748
Waste related variable					
Total volume of waste (ton / year)	2,159	41,238	93,938	91	1,330,563
Incinerator Capacity (ton / year)	2,155	68,501	95,248	0.000	1,271,200
Capacity-Waste Ratio	2,155	4.325	6.116	0.000	49.941
JWA dummy	2,159	0.622	0.485	0	1
Age of Incinerator (year)	2,159	18.781	8.262	0	42
sort number	2,159	12.742	4.037	2	24
Socio-economic variable					
Population (thousand person)	2,159	118.5	270.1	0.160	3,721.6
Population density (person / km^2)	2,159	2,475	2,921	51.136	14,020
Percent of over 65yrs	2,159	0.224	0.058	0.085	0.572
Average income (million JPY/ person)	2,159	3.160	0.453	2.104	5.031

Recall waste-related data is taken from JMOE (2016) and all the socioeconomic variables are obtained from the Ministry of Internal Affairs and Communications (2016). Our outcome variable is the recycling rate. The average recycling rate in Japanese municipalities in the sample is 22.28%, which is similar to the reported national recycling rate of 20%, and varies widely between zero and almost 78%. Our main treatment variable is the incineration capacity. We define capacity as the total capacity of all of the municipality's incinerators divided by the total amount of waste managed by the municipality. This capacity-to-waste ratio has a mean of 4.325 in the sample. By inverting this number, we see that the average municipality is utilizing roughly 25% of its incineration capacity. But the mean might not best capture the central tendency of this variable if the distribution is skewed[3].

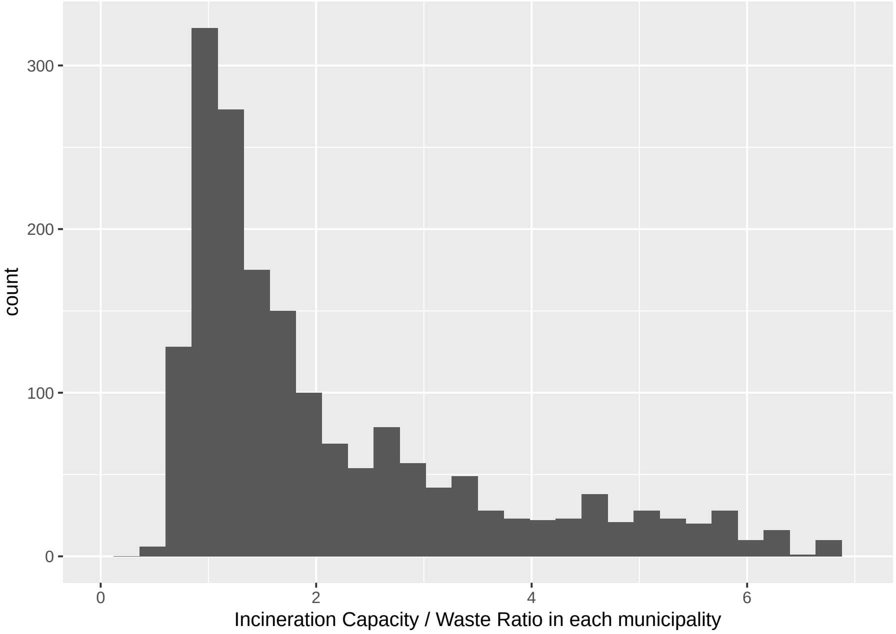

Figure 5: Histogram of capacity-to-waste ratio

Source: JMOE (2016)

Figure 5 illustrates the distribution of the capacity-to-waste ratio across municipalities and time in the data. A few municipalities have a ratio less than one suggesting they are managing more material than the capacity of their incinerator. These municipalities have incinerator facilities at full capacity and are using landfills and/or recycling to manage the remainder of their waste. The mode of the distribution is just above one. These municipalities have

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[3] Many incinerators have multiple furnaces, and the data report the daily capacity for each furnace. Annual incineration capacity is obtained by simply summing the daily capacities of each furnace and then multiplying by 280. Industry standards require incinerators to shut down operations for about 85 days per year for cleaning and maintenance.

incineration facilities that are at or near full capacity or are recycling and/or landfilling large quantities of waste. The ratio then increases to high values for other municipalities - these communities clearly have excess incineration capacity and may be not be recycling much. These municipalities would choose low recycling rates if incinerating recyclable materials increases incineration efficiency.

Other variables useful to the estimation process described below include per-capita income, population density, and the age of the furnace. In Japan, data on per capita income are not available at the municipality level. As a proxy for per capita income, we use the ratio of each municipality's overall taxable gain to the total number of the taxpayer (in million JPY per person). Although the overall mean of this proxy will not accurately represent per-capita income, this proxy is surely highly correlated with income. The average age of incinerators in our sample is 18.78 years, and about 67% of the incinerators in our sample employ more than one furnace.

5.3 Econometric Model

Recall that the theoretical model above predicts a negative relationship between excess incineration capacity and recycling rates. The skewed nature of the incineration-to-waste ratio suggests this relationship may not be linear. A threshold level of excess capacity might be crossed when any added excess capacity leads to the emergence of engineering challenges in terms of maintaining efficient treatment of incineration emissions. It is at this threshold and beyond when recyclable materials might provide helpful fuel to the incinerator.

Thus, fitting a smooth best-fit regression line through the data might do a poor job of explaining the marginal impact of excess capacity through this threshold[4]. We instead use the Rubin causal empirical matching model (Imbens and Wooldridge, 2009), which allows the marginal effect of excess incineration capacity on recycling to be estimated at any defined level of excess capacity. Following the logic of this model, we define the binary variable D_i to equal one if municipality i crosses some threshold and thus faces inefficient excess incineration capacity. Let R_i denote the observed recycling rate of municipality i facing this excess incineration capacity and R_j denote the recycling rate of an otherwise identical municipality but without excess capacity. The matching method reaches into the sample for a counterfactual version of of municipal i with a similar set of characteristics. Our interest, then, is to estimate the following mean difference of recycling rate between treated and control group;

$$\hat{\tau}|_{D=1} = \frac{1}{|N|} \sum_{i \in N} \left(R_i - \frac{1}{|J_i|} \sum_{j \in J_i} R_j \right), \tag{7}$$

where J_i is the set of counterfactual (comparison) units matched to unit i[5].

The challenge is finding matches for each municipality. One common method is to employ the “nearest-neighbor” matching - essentially looking for clones in the data. Rosenbaum and Rubin (1983) propose the use of a propensity score[6]. This propensity score allows matches to be made based on the weighted average of a collection of covariates. The observed characteristics of each municipality are reduced to a single scalar (the propensity score). Municipalities with the closest propensity scores become the candidates for a counterfactual match.

What level of capacity-to-waste ratio (C/W) will trigger the addition of recyclable ma-

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[4] Utilizing the within fixed-effects estimator on these panel data finds a 1% change in capacity reduces recycling rate by 0.11%. The estimated coefficient is significant at the 1% level (t=-3.14).

[5] In our case, we set $|J| = 1$ throughout the analysis.

[6] See Dehejia and Wahba (2002) for the algorithm of estimating the propensity score.

terials to improve the efficiency of incinerators? No single answer will suffice. Instead, we define three separate control ranges as defined in Table 2. For Control A, municipalities with capacity-to-waste ratios below 1.2 are defined as not having excess capacity. We then define 8 different treatment ranges, also listed in Table 2. Municipalities in each of these ranges is considered to have crossed the threshold and have excess capacity. Thus, we create 24 separate matched samples of municipalities with and without excess capacity.

Table 2: Distribution of Control and Treatment Group

Control	Number of Municipalities	Treatment	Number of Municipalities
Control A $\left(\frac{C}{W} < 1.2\right)$	338	$1.2 < \frac{C}{W} < 1.5$	245
		$1.5 < \frac{C}{W} < 1.8$	184
		$1.8 < \frac{C}{W} < 2.0$	86
Control B $\left(\frac{C}{W} < 1.5\right)$	471	$2.0 < \frac{C}{W} < 2.5$	136
		$2.5 < \frac{C}{W} < 3.0$	140
		$3.0 < \frac{C}{W} < 3.5$	96
Control C $\left(\frac{C}{W} < 2.0\right)$	616	$3.5 < \frac{C}{W} < 4.0$	52
		$4.0 < \frac{C}{W}$	600

The actual computation of the matching estimator below has been done by the `MatchIt` package developed by Ho *et al.* (2011). Each municipality is issued a propensity score. This score is based on that municipality's total waste, average age of incinerators, number of separate materials collected for recycling, whether or not the municipality is a member of a Joint Waste Authority (defined above), per-capita income, percentage of the population over 65 years of age, and population density. The nearest neighbor matching method is applied to these propensity scores. Once each municipality with no excess capacity is matched with a similar municipality with excess capacity, the process simply involves comparing the mean recycling rates from each of the two samples. The average difference in recycling rates can be attributed to the excess incineration capacity. A negative difference in means would suggest the excess capacity has reduced recycling rates.

Table 3: Estimation Results of $\hat{\tau}$ in (7)

		Control Group	
Treatment Groups	Control A ($C/W < 1.2$)	Control B ($C/W < 1.5$)	Control C ($C/W < 2.0$)
$1.2 < C/W < 1.5$	-3.28*** (0.76) Pairs = 245 (93 Extra in Control)	NA	NA
$1.5 < C/W < 1.8$	-2.43 (0.68) Pairs = 184 (154 Extra in Control)	0.8 (1.29) Pairs = 184 (284 Extra in Control)	NA
$1.8 < C/W < 2.0$	-6.94*** (1.20) Pairs = 86 (252 Extra in Control)	-6.02*** (1.06) Pairs = 86 (385 Extra in Control)	NA
$2.0 < C/W < 2.5$	-1.80** (0.87) Pairs = 136 (202 Extra in Control)	-2.13** (0.93) Pairs = 136 (335 Extra in Control)	-2.23* (1.21) Pairs = 136 (480 Extra in Control)
$2.5 < C/W < 3.0$	-5.1*** (0.86) Pairs = 140 (198 Extra in Control)	-6.67*** (1.01) Pairs = 140 (331 Extra in Control)	-5.91*** (0.92) Pairs = 140 (476 Extra in Control)
$3.0 < C/W < 3.5$	-6.01*** (1.10) Pairs = 96 (242 Extra in Control)	-7.17*** (1.00) Pairs = 96 (375 Extra in Control)	-7.80*** (1.03) Pairs = 96 (520 Extra in Control)
$3.5 < C/W < 4.0$	-5.26*** (1.73) Pairs = 52 (286 Extra in Control)	-1.20** (0.51) Pairs = 52 (419 Extra in Control)	2.15* (1.20) Pairs = 52 (564 Extra in Control)
$4.0 < C/W$	-3.08*** (0.72) Pairs = 338 (262 Extra in Treated)	-2.26*** (0.59) Pairs = 471 (130 Extra in Treated)	-1.48*** (0.51) Pairs = 601 (15 Extra in Control)

Note: Estimate is mean difference of recycling rate of treatment group and control group

Table 3 provides the difference in means for each treatment and control pairing together with the standard error. Also in each block of this table are the number of matched pairs for each estimate and the number of unused observations. For example, when the control group is defined by a capacity-to-waste (C/W) ration of less than 1.2, and the treatment group is comprised of municipalities with a capacity-to-waste ratio of between 1.2 and 1.5, then the data provided 245 matched pairs. All observations from the treatment group were included, and 93 observations in the control group were not used. The estimated difference in recycling rates between these two groups was 3.28%. The standard error suggests this difference is different than zero. Thus, treated municipalities with C/W between 1.2 and 1.5 recycle less. Recall that these treated municipalities feature incinerators with more excess capacity than in municipalities in the control group. This result is consistent with the theory presented above. In general, average recycling rates in control groups are less than average recycling rates in treated groups throughout the various combinations represented in the table. In some cases this difference climbs to 6% and more.

Perhaps the set of results that best capture the impact of excess capacity on recycling rates are portrayed in the final row of Table 3. Treated municipalities in this row have C/W values of greater than 4 suggesting that, even if they incinerate 100% of the total waste they manage, they would only be using 25% of their incineration capacity or less. Thus, we are comparing the municipalities with the most capacity with those with the least capacity. Note also that the number of matched pairs is large in this row. Pairs are large because there are many municipalities in the sample with $C/W > 4$ and many municipalities with C/W below 1.2, 1.5, or 2.0 (the three control groups). Results in this row suggest that excess capacity in the extreme reduces recycling rates by 3.08%, 2.26%, or 1.48% depending upon the control

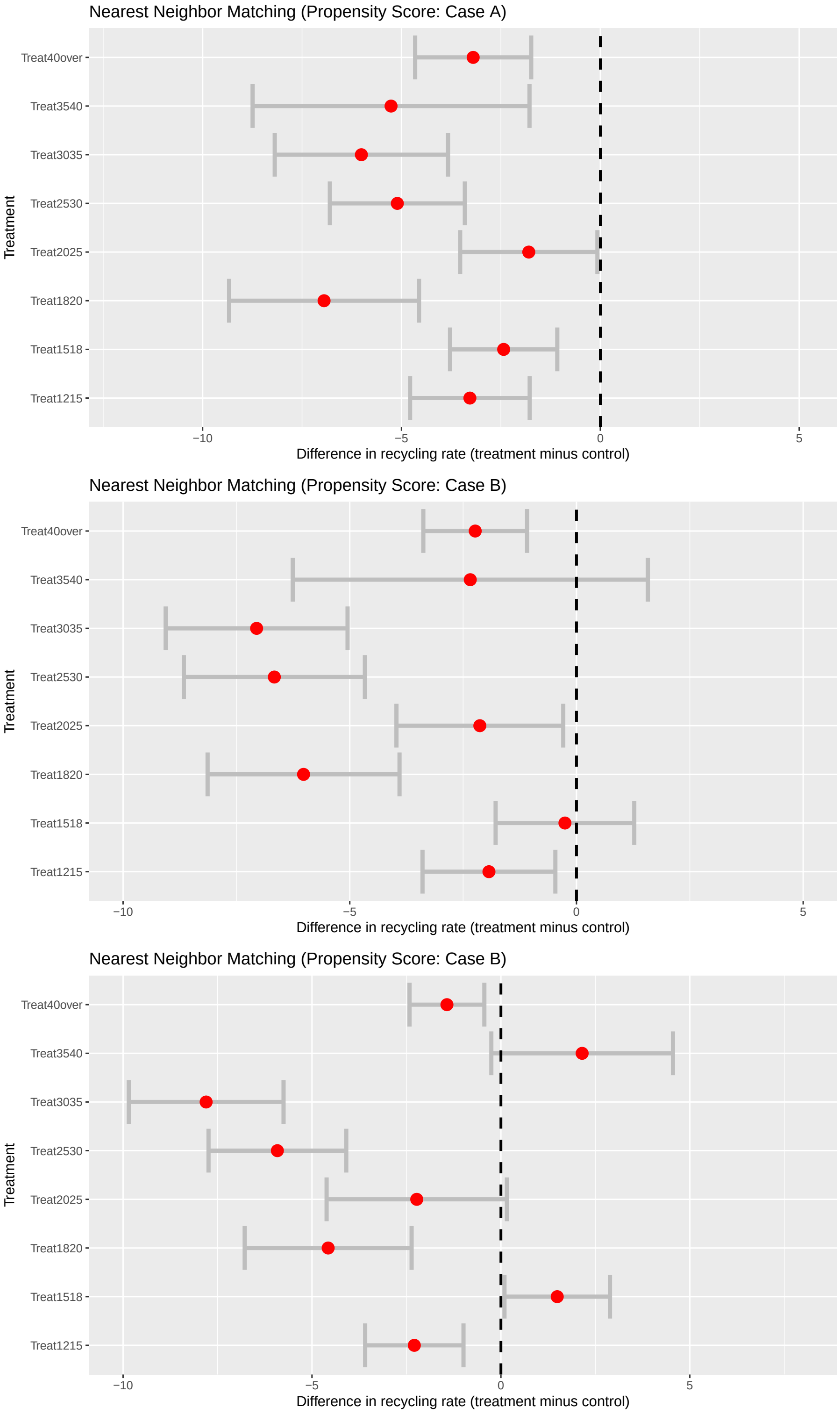

Figure 6: Point estimates and confidence intervals of t-test

group considered. Note that large numbers of pairs are not necessarily desirable. Every treated municipality needs to be matched with a municipality in the control group. When extra unused municipalities in the control group are unused, then the matching process would have had more choices for finding good matches.

Figure 6 offers a visual explanation of these results by illustrating the estimated changes in means (the red dots) with their 95% confidence intervals. In almost all cases, the average recycling rate decreases for the treated group of municipalities with large incineration capacities. This decrease in recycling rates seems to increase as the capacity-to-waste ratio used to define each treatment group increases (seen by reading the table from bottom to top). But this trend does not continue into the treated group defined by a capacity-to-waste ratio above 4 where the number of matched pairs changes abruptly.

6 Implications and Conclusions

These estimates above suggest that relatively high excess capacity contributes to reduce up to 7% in the recycling rate. This number is quite large given that the average recycling rate in Japan is about 20%. Even a 5% change in the recycling rate represents a fourth of all recycling. Thus, the magnitude of these results is rather substantial. Policymakers may have been unaware that large incinerations operating a low capacities appear to be affecting recycling decisions of municipalities.

This paper estimates that incineration capacity affects recycling rates. We are aware of no previous paper that has analyzed this “cannibalism” effect between incineration and recycling. We believe the implications of this analysis is important. Many developed countries are currently attempting to achieve high recycling rates. Many countries are also investing in new high-capacity incineration capabilities. These two goals appear to be inconsistent with each other. Although we are unable to find a headline that states that incinerators are burning recycled materials over the time studies by this paper, the perhaps unexpected tradeoff appears in the data.

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