Relationship between Recycling Rate and Air Pollution in the State of Massachusetts

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Abstract

Recycling can be an effective tool for reducing waste generation, eliminating waste disposal sent in landfills and incinerators and reducing environmental pollution. Moreover, recycling is one way to achieve sustainable use of natural resources and to protect the environment and human health. However, the relationship between air pollution and recycling has been neglected in the previous economic studies. This study examines this relationship using panel data from a waste municipality survey in the state of Massachusetts during the period 2009-2012. In addition, the analysis considers economic factors, as unemployment rate and income per capita, meteorological variables, as well as, it accounts for additional municipality characteristics, such as population density and trash collection services. The approach followed is a fixed effects model which controls for stable time invariant characteristics of the municipalities, thereby eliminating potentially large sources of bias. The findings support that a negative relationship between recycling rate and particulate particles in the air of 2.5 micrometres or less in size ($PM_{2.5}$) is present.

Keywords: Air Pollution, Data, Municipality Survey, Recycling, Solid waste services, Stochastic Frontier Analysis

JEL Codes: Q50, Q53

1. Introduction

Recycling is the process of collecting and processing materials that would otherwise be thrown away as trash and turning them into new products. According to the U.S. Environmental Protection Agency (EPA), recycling helps the economy and the environment (EPA, 2007; 2009). Manufacturing products from recycled materials consume less energy and produce less pollution than producing the same items from virgin materials. Reducing the use of virgin materials conserves natural resources like trees, water and minerals. In addition, by reducing the amount of waste sent to landfills and incinerators the air quality is improved.

The environmental economics literature pays attention to the waste management services cost structure rather than to the relationship between pollution, waste management and recycling. Numerous scientific studies have linked particle pollution exposure to a variety of negative outcomes, including premature death for people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms (Seaton et al., 1995; Nel et al., 1998; Harrison and Yin, 2000; Vrijheid, 2000; Li et al., 2002; Li et al., 2003; Sarnat et al., 2005).

This paper proposes an econometric model to test and describe how municipal recycling rate is associated to air pollution, and specifically to particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$). $PM_{2.5}$ is one of the six most common air pollutants including CO, SO_2, NO_X, Lead and Ground-Level Ozone. The paper focuses on $PM_{2.,5}$ as it is better monitored than other pollutants (21 monitoring stations vs 7) throughout the state of Massachusetts, for which this analysis is done. Data on recycling is obtained for 325 municipalities and cities in the state of Massachusetts from municipality surveys during the period 2009-2012.

The first contribution is that it is the first study which examines the relationship between recycling and air pollution. Another contribution is that the analysis expands on the cross-sectional data analysis of Hirsch (1965) and Bel and Fageda (2010) and relies on panel data. Cross-sectional data, used in previous studies, are likely to lead to biased estimates due to unobservable characteristics which are correlated both with pollution and recycling. Panel data makes it possible to control for unobserved cross section heterogeneity, i.e. taking into account unobserved individual or time effects, such as years, by including them in the model (Wooldridge, 2010). In addition, this study considers additional factors, including income per capita, population density, trash collection services and Pay-as-you-Throw (PAYT) program. The overall results show that recycling improves air quality by reducing $PM_{2.5}$ pollutant emissions.

The structure of the paper is as follows. The second section presents the literature review. It reviews theoretical and empirical studies on solid waste management. Section three presents the data; section four discusses the methodology used in the analysis of solid waste services, while in section five the empirical results and recommendations are reported and discussed. In section six the conclusions are presented.

2. Literature review

This section presents previous research studies on recycling, disposal, waste management costs and recycling programs from the economics field. These studies do not examine the relationship between air pollution and recycling; however are discussed here because these are closer to the analysis employed in this study.

One of the first studies employed the relationship between recycling and disposal in a theoretical framework is by Smith (1972) who treats recycling as a reprocessing of the residue from consumption. The reprocessing activity represents a utility loss, i.e. a negative effect upon consumers' utility. Specifically, forcing consumers to retain pollutants such as aluminum cans or glass bottles can represent a loss of utility when disposal is considered a costly activity by the consumers. Consumers will bear these costs if there are returns in form of reduced pollution so they need to be informed of the returns in order to change their behaviour. On the other hand, Plourde (1972) treats recycling as a productive process intended to decrease the stock of pollution, which results from the accumulation of waste that accompanies production and consumption. The approach is different from Smith (1972), and uses a central planner optimization problem through taxation. Pollution, having undesirable effects on consumers, leads to a reallocation of resources to reduce its quantity. Neither of these papers provide empirical evidence.

A similar study with the current one is by Kinnaman et al. (2010); however the relationship between recycling and cost instead of air pollution is examined. Kinnaman et al. (2010) used Japanese data and fixed effects model in order to estimate the social cost of municipal waste management as a function of the recycling rate. Kinnaman et al. (2010) found a quadratic relationship between waste management costs and the recycling rate and more specifically an inverted U-shaped curve. Additionally the authors examine the relationship between municipal waste management cost and recycling rate for different product categories, finding mixed results, either linear or quadratic significant effects. Similarly to the research by Kinnaman et al. (2010), this study employs a fixed effects model.

A study which examines the recycling schemes and rates in the state of Massachusetts is by Russell (2011). Russell (2011) found that the type of collection, curbside, drop-off, single-stream, or pay-as-you-throw (PAYT), has an impact on the success of the recycling program. PAYT and single-stream systems were shown to increase recycling rates, while the residents who live in towns with drop-off programs actually recycle more material than those in towns with curbside service. According to a study released recently by the New York-based Green

Waste Solutions and the U.S. Environmental Protection Agency (EPA, 2010) local governments with PAYT programs produce 467 pounds of landfilled trash per capita per year, compared with 918 pounds in non-PAYT communities. In Massachusetts, cities and towns with PAYT programs produce approximately 0.56 tons of trash per household compared to 1.13 tons for non-PAYT communities. In addition, PAYT can be applied either on drop off or curbside service. It was noted, that drop off service is more efficient than curbside is. Roughly 45 per cent of the municipalities, employing PAYT program, offers only the drop off service, while the 37 per cent offers only the curbside service. Therefore, increasing the drop off service in municipalities following the PAYT system might improve the air quality. Furthermore, it was found that municipalities applying both drop off and curbside recycling collection services have a greater positive impact on air quality. So, another suggestion could be for municipalities to offer both services. The characteristics and the effects of the PAYT program are discussed in more details in the results part. A very similar study is by Kuhn and Schulz (2003) who found that environmental quality is negatively affected by the amount of waste dumped and the amount of resources extracted. In addition, the authors show that balanced sustainable growth is only possible if governmental policy ensures a recycling rate of 100%.

In line with these results, this study contributes to the literature of economics field by examining the relationship between air pollution and recycling controlling for various economic factors, meteorological data and other trash collection and recycling programs characteristics among others.

On the other hand, regarding the environmental engineering and chemistry literature a positive and significant association between particulate matter and landfilling has been found (Fitz and Bumiller, 2000; Stevenson, 2002; Chalvatzaki et al., 2010). Chalvatzaki et al. (2010) examining a landfill site in Crete of Greece found that particulate matter emissions are significant. Those emissions in landfills are the result of re-suspension from the disposed waste and other activities as composting, waste unloading and sorting and waste transport by trucks. These studies control additionally for weather conditions, such as temperature and wind speed. However, this study adds to this literature by accounting for additional demographic and economic factors, as well as, for trash and recycling programs.

3. Data

The data used in this study come from various sources. More specifically, the solid waste municipality survey, the recycling rates and the air pollution data for $PM_{2.5}$ can be found at the Massachusetts Department of Environmental Protection website for the period 2009-2012. $PM_{2.5}$ is measured as the average pollution over a yearly period. It should be noted that according to the US Environmental Protection Agency (EPA) there are no areas in the state of Massachusetts which violate the air quality standards regarding particulate matters. The municipal solid waste (MSW) recycling rate is calculated by the Massachusetts Department of Environmental Protection as:

$$MSW\ \ recycling\ \ rate = \frac{Total\ \ MSW\ \ recycled}{Total\ \ MSW\ \ generated} \tag{1}$$

Total MSW generated = MSW recycled + MSW disposed as trash. This ratio is calculated separately for different product but especially hazardous products, like batteries, computers and electronic equipment, and conversion factors are used to convert values into tons, so that they can be aggregated.

Particulate matter ($PM_{2.5}$) is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. According to EPA (2000) the principal sources of $PM_{2.5}$ emissions are miscellaneous sources, such as highway and off-road vehicles, waste disposal, industrial sources and fuel combustion at stationary sources such as apartment buildings, hospitals and office buildings. In addition, particulate matter emissions are generated by combustion devices used to reduce air emissions from landfills. Thus, on the one hand, particulate matter is emitted from landfills, while on the other hand are emitted through combustion process (EPA, 1995; 2008; Fitz and Bumiller, 2000; Stevenson, 2002; Psomopoulos et al., 2009; Koshy et al., 2009; Chalvatzaki et al., 2010).

Generally, the link between $PM_{2.5}$ and landfills is formed on the action of tipping waste which raises plumes of dust, notably on elevated ground, which are exposed to windy conditions, on the waste compaction by bulldozers and crushers. Finally $PM_{2.5}$ is formed on the stockpiles of soil and rubble required for daily waste coverage which are susceptible to re-suspension and dispersion by wind flow (Koshy et al., 2009; Chalvatzaki et al., 2010).

In map 1 the air monitoring stations for $PM_{2.5}$ are reported. Regarding mapping the $PM_{2.5}$ to each municipality, the following approach is followed. Firstly, the exact location of each monitoring station in terms of longitude and latitude coordinates is found. Secondly, the centroid coordinates of each municipality is given. The next step is to compute the nearest neighbours using geodetic distances, and specifically the Haversine formula[1] and matching each monitoring station to the closest centroid without imposing any restriction on how far from a monitoring station the municipality can be[2]. The reason why Haversine formula is preferred over the Euclidean is the following: Euclidean distance is a good approximation for

[1]Haversine formula has been used which is:
First step: R = 637100 (the Earth's radius in meters)
Second step: $\Delta latitude = latitude_1 - latitude_2$
Third step: $\Delta longitude = longitude_1 - longitude_2$
Fourth step: $a = \sin^2(\Delta latitude / 2) + \cos(latitude_1) \cdot \cos(latitude_2) \cdot \sin^2(\Delta longitude / 2)$
Fifth step: $c = 2 \cdot atan2(\sqrt{\alpha}, \sqrt{1-\alpha})$
Sixth step: $distance = R \cdot c$
[2]The results for specific distance between municipality and monitoring station using the inverse weighting distance ie.within 10 or 20 miles show the same negative relationship between recycling and air pollution; however the effects become stronger when a municipality is located closer to a monitoring station.

short distances, such as between cities, normally within 10-15 km. However, for longer distances, such as between counties, measures based on two dimensions, as the Euclidean distance, are no longer appropriate, since they fail to account for the curvature of the earth. (Robusto, 1957; Sinnott, 1984).

The population density has been retrieved from the Massachusetts Executive Office for Administration and Finance. The income per capita for each municipality comes from the Massachusetts Department of Revenue (DOR), while the unemployment rates have been retrieved from the Massachusetts Executive Office of Labor and Workforce Development. The meteorological data-average, minimum and maximum temperature, wind speed and precipitation- can be found at Tutiempo weather and the US National Climatic DataCenter (NCDC). The study period is 2009-2012 and the data are based on yearly frequency. Note that no day above the threshold triggering a smog alert was reported during the period examined. It should be noted, that the traffic volume counts could have been used, but the data are available only up to 2009. More specifically, the variables included in the model are: *Population Density*. This variable is derived by dividing the municipality population, which is included by itself, by the land area size. The second variable is the *Income per capita* for each municipality. The sign might be positive, as a higher income implies higher consumption and additional waste and pollution. However, based on the Environmental Kuznets Curve (EKC) hypothesis the relationship between air pollution and income can be an inverted U-shaped curve. *Unemployment rate* in each municipality is another variable used in the analysis. This can be negative as a higher unemployment rate implies less purchasing power; therefore less waste volume, as well as, less air emissions caused by transportation to work.

The next two variables are the *Reciprocal and Regional Program*: The former is a dummy taking the value 1 if there is a reciprocal program in the municipality and 0 otherwise. More precisely, this program refers to a reciprocal use agreement with other municipalities to allow their residents to deliver waste and problem materials to the municipality's permanent facilities and event collection sites. Similarly, *Regional program* is a dummy taking the value 1 if there is a regional program in the municipality and 0 otherwise. However, these variables are potentially endogenous. For this reason, initially the model is estimated without the potential endogenous variables and then including all of them. The next variables refer to *trash, yard* and *food waste service types*. These are categorical variables taking four values; if there is a drop off service, if there is curbside service if there are both services and neither of the above. In a curbside recycling program, recyclable materials, such as cans and bottles, are placed in special containers at the curb for pickup by a recycling truck. A drop off recycling program provides a centre where citizens can transport and drop off their recyclable materials. Where appropriate, the index of these variables is: 1 for curbside, 2 for drop-off and 3 for none of the above. Because reciprocal and regional program, as well as, trash, food and yard waste service type are possibly endogenous the estimates take place without and with them. *Meteorological data* are considered in the analysis too. It is expected that $PM_{2.5}$ is negatively associated to minimum temperature, precipitation and wind speed, while a positive sign is expected for average and maximum temperature (Tai et al., 2010; Chalvatzaki et al., 2010; Barmpadimos et al., 2012; Lecoeur et al., 2012; Tai et al., 2012). We obtain the average values over a year of the above meteorological variables. *Combustion*, is a dummy variable taking value 1 if there is a combustion-incineration plant in the municipality and 0 otherwise. It should be noted that the incineration process is not considered as recycling, but is a process which is used to minimise the generation of wastes and reduce landfilling. This variable is taken into consideration, because incinerators are one of the sources of $PM_{2.5}$ in Massachusetts (Massachusetts Department of Public Health, http://www.mass.gov/eohhs/gov/departments/dph/).

Landfill is a categorical variable taking four values; 1 for no-landfill in the specific municipality, 2 if both are private, 3 if one is private and 4 if both are public. This is measured to examine which regime-public or private- is more efficient in generating air quality, as in the literature used to examine the efficiency of waste management service costs (Hirsch, 1965; Kemper and Quigley, 1976; Collins and Downes, 1977; Bel and Fageda, 2010). *Municipality Type* is a dummy variable indicating whether the municipality is a city or a town. The distinction between a city and a town as defined in Massachusetts law is primarily related to the form of government that the municipality has chosen[3]. Finally, *PAYT* is considered in the analysis, which is a dummy variable taking value 1 if there is PAYT (Pay-as-you-throw) program and 0 otherwise. In PAYT program residents are charged for each community-issued bag or container of waste they set out for disposal, and the residents have a variety of bag and container sizes from which to choose.

In table 1, summary statistics separately for every year are reported after reweighting municipalities by their population size. The average recycling rate has increased by 3 percentage points from 2009 to 2012, while the average air pollution ($PM_{2.5}$) decreased from 2009 to 2012 by 12%. In addition, the income per capita and unemployment rate have increased and decreased respectively from 2009 to 2012. In figure 1 a scatter-plot is presented. Figure 1 shows the relationship between $PM_{2.5}$ and recycling rates, indicating a negative association. In addition, an outlier is observed in the right side of figure 1, was excluded, but this does alter the conclusion[4]. In map 2 the recycling rates at municipality level during 2009 are presented. Based on map 2, the majority of the municipalities located in western region are characterized

[3]More specifically, a town is governed under the Town Meeting or Representative Town Meeting form of government. A city has a council or board of aldermen and may or may not have a mayor, a city manager, or both (State Street Trust Company, 1922).

[4] It is decided to keep this outlier. It should be noticed that the change in coefficients are considerable very small ie. The coefficient of recycling rate on air pollution is -0.0210 without the outlier, while it becomes -0.0211 including the outlier.

by high recycling rates, while the municipalities located in the centre and north of the state are characterized by low recycling rates. The situation regarding the eastern part of the state of Massachusetts is mixed.

In table 2 the correlation matrix is presented. The correlation between total trash tonnage and $PM_{2.5}$ is positive but statistically insignificant. The correlation between population density and total trash tonnage is positive. Therefore, one assumption is that the higher the population density the higher the trash tonnage might be and so the higher the air pollution is expected to be from waste generation and landfilling depending on the recycling rates and traffic density among other factors. In addition, the relationship between recycling rates and income per capita is positive, indicating that the higher the income is the higher the recycling rates are expected to be.

4. Econometric framework

In this section the econometric framework followed in this study is presented. By including fixed effects (group dummies for municipalities), the average differences across municipalities in any observable or unobservable predictors are controlled. These differences can include traffic, industrial activity and other factors that might affect the dependent variable- air pollution emissions. If the regressions are estimated with plain ordinary least squares (OLS) then there is a great worry that omitted variable bias would result because unobservable factors can be correlated with the variables that are included in the regression. The fixed effect coefficients soak up all the across-group action. What is left over is the within-group action, which is what is desirable and the threat of omitted variable bias has been reduced a lot. The following fixed effects model is estimated:[5]

$$\ln pm_{ijt} = \beta_0 + \beta_1 \text{lnrec\_rate}_{it} + \gamma_z' \ln W_{it} + \delta_z' X_{it} + \mu_i + l_j + \theta_t + \varepsilon_{ijt} \qquad (2)$$

Variable *pm* is the $PM_{2.5}$ emissions, *rec_rate* is the recycling rate, subscript *i* represents the municipality, subscript *j* denotes the air pollution monitoring site for $PM_{2.5}$ and subscript *t* indicates the year. Vector *W* includes meteorological variables as minimum, maximum and average temperature, precipitation and wind speed. Vector *X* includes the additional factors presented in the data section (note all the quantitative variables are expressed in logarithms). Finally, the vector μ_i includes municipality dummy variables, while l_j and θ_t control for air pollution monitoring stations and year fixed effects respectively.

Initially, the regressions excludes the dummies for reciprocal and regional program and the dummies representing the trash, food and yard waste services, as those are potentially endogenous. In addition, this study aims to provide a detailed empirical analysis of the factors that determine air pollution levels through waste services, like curbside, drop-off, and meteorological data. More specifically, many factors contribute to the success of municipal recycling programs, both demographic as well as the type of program in place. There are several different types of recycling programs a town can implement, such as a curbside program, Pay-As-You-Throw (PAYT), or single stream program. Demographic factors, including population density, income, unemployment rate and location might have an impact on the local recycling rate and the air pollution.

In addition, a quadratic function of income per capita is included as in Grossman and Krueger (1993; 1995), Panayotou (1997) and Verneke and Clercq (2006) who examined the

[5] Based on Hausman test the fixed effects model is chosen.

Environmental Kuznets Curve (EKC) hypothesis. This hypothesis explores the relationship between air pollution and income. The above-mentioned studies found an inverted U-shaped curve, indicating that the positive relationship between air emissions and income is inverted after a given point of income. By studying all of these different factors, this study looks to determine what actions can be taken by towns to increase their residential recycling rates and improve air quality.

5. Empirical results

In table 3 the fixed effects estimates are reported. Based on Hausman test the fixed effects model over the random effects model is chosen. The relationship between recycling rate and $PM_{2.5}$ is negative and significant in both estimates and the coefficient ranges between -0.021 and -0.024. Thus, for a 1 per cent increase in recycling rates the air pollution is decreased by 0.021-0.024 per cent or 0.0017-0019 micrograms per cubic meter ($\mu g/m^3$). This relationship between air pollution and recycling can be explained by various factors. Firstly, recycling can be one of the most effective ways to reduce the reliance and waste on landfills. By recycling, natural resources are conserved and the amount of pollution released into the environment is reduced. Also the impacts of landfills are greater than simply the space they take up. As organic matter breaks down in a landfill, it produces air pollution. This is also confirmed by the total trash tonnage, which increases air pollution and it is significant in both estimates. Local and State governments have to set up efficient recycling programs to capture bottles, cans, paper and other materials that are dumped into the garbage. Secondly, manufacturing products from recycled materials often generate less air pollution than what would have been generated when the product was made from the original materials. For example each glass bottle recycled keeps valuable non-renewable resources such as bauxite, iron-ore and sand in the ground. Making new glass from recycled cullet saves energy because recycled glass melts at a lower temperature than virgin raw materials. Because the materials do not need to be heated as much, less energy is required in the manufacturing process. Also, because recycled glass takes less energy to manufacture, finite natural resources such as oil and coal are also conserved (Morris, 1996). Thirdly, recycling reduces the incineration process as this process is associated with generating energy and electricity by burning materials, through which air pollutants are emitted (Morris, 1996). Recycling waste materials conserves energy by replacing virgin raw materials in manufacturing products, thereby reducing acquisition of virgin materials from the natural environment. Recycling most materials from municipal solid waste saves on average three to five times more energy than does burning them for electricity (Morris, 1996).

The income per capita is reported in quadratic terms, since higher polynomial orders have been found insignificant. We find an inverted U-shaped curve of the relationship between income per capita and pollution, similar to other studies (Grossman and Krueger, 1993; 1995, Panayotou, 1997, Verneke and Clercq, 2006). More specifically, the turning points range between $23,000-$26,000 average municipal income. Shafik and Bandyopadhyay (1992) found that the turning points for sulphur dioxide and carbon monoxide emissions range between $2,200 and $14,400 in 2009 prices. Selden and Song (1994) estimated EKCs for sulphur dioxide, nitrogen oxides and carbon monoxide using longitudinal data on emissions in developed countries. They found turning points equal at $17,300 for sulphur dioxide, $22,300 for nitrogen oxides, and $11,100 for CO in 2009 prices. Grossman and Krueger (1993) report turning points equal at $8,900 and $11,060 in 2009 prices for sulphur dioxide and nitrogen oxides respectively using data from the Global Environmental Monitoring System (GEMS) in 126 cities in 74 countries.

Unemployment rate has a positive effect on air quality; a quadratic term was tested but was never significant. Similarly, for population density, the quadratic term was, as in other studies (Skene et al., 2010; Clark et al. 2011) not significant; therefore only the linear term is considered. The results show that population density leads to reduced air pollution. Regional transportation plans, public officials, and urban planners have been seeking to densify urban areas, using strategies referred to as “smart growth” or “livability.” They have claimed that densifying urban areas would lead to lower levels of air pollution, principally because it is believed to reduce travel by car.

From table 3 the PAYT seems to have a positive impact on air quality, where the air pollution is less by 0.026 per cent less in municipalities, which employ PAYT system in comparison to those which do not. It should be noted that the average recycling rate is 33.75 per cent in the municipalities, where the PAYT system is implemented. On the other hand the recycling rate in municipalities with no PAYT system is 25.68 per cent. In some communities, PAYT works on a per-container basis; households are charged for each bag or can of waste they generate. A few communities bill residents based on the weight of their trash. Either way, the system motivates people to recycle more and think about how to generate less waste in the first place. In addition, under PAYT, everyone pays only for what they generate so they do not have to subsidize for their neighbour’s wastefulness, as it happens in the fixed pricing systems. Thus, the findings support the design and implementation of the PAYT systems.

Towns and municipalities located in the western part of the state have lower air pollution concentration levels. In addition, when waste landfills are public or one of them is private, the air quality is improved. Studying the characteristics in specific municipalities, considering additional factors, such as the distance between municipality and the air monitoring station and meteorological data among others, these can be helpful in order to design the appropriate trash collection and recycling processes.

In this part some back of the envelope calculations are presented assuming that results imply causality. Lipfert et al. (2000) examined the effects of particulate matter on infant mortality using US data for 1990. More specifically, the elasticity of particulate matter with regard to infant mortality is 0.1181 for low birth weight (less than 2,500 kg) and 0.1217 for high birth weight (equal or more than 2,500 kg). Applying these estimates to our findings we find that the infant mortality would decreased by 0.0242 and 0.0256 per cent for low and high birth weight infants respectively if recycling rates increase by 1%. In other studies all-cause daily mortality is estimated to increase by 0.2-0.6% for a 10 μg/m^{3}increase in PM_{10} concentrations (WHO Regional Office for Europe, 2006; Samoli et al., 2008). Using these estimates the daily mortality is decreased by 0.0051-0.015% for a 1% increase in recycling rates. Other studies show that long-term exposure to $PM_{2.5}$ is associated with an increase in the long-term risk of cardiopulmonary and lung cancer mortality by 6-13% for a 10 μg/m^3 increase in $PM_{2.5}$ concentrations (Pope et al., 2002; Beelen et al., 2008; Krewski et al., 2009). Substituting in our estimates a 10% increase in recycling rates is associated with a decrease in the long-term risk of cardiopulmonary mortality by 1.26–2.74% per 10 μg/m^3.

6. Conclusions

This study examined the relationship between $PM_{2.5}$ air pollutant and recycling rate. A negative relationship between $PM_{2.5}$ and recycling rate has been found indicating that recycling can lead to air quality improvement. The reduction is 0.0017-0019 micrograms per cubic meter (μg/m^3) of $PM_{2.5}$ for a one percentage increase in recycling rates. Much of the energy and resources that are used to initially process a raw material only need to be used once when the raw materials are recycled, saving both energy and resources. In addition, many practices in USA and Europe include incineration processes. However, burning materials in order to generate electricity creates a demand for "waste" and discourages much needed efforts to conserve resources, reduce packaging and waste and encourage recycling. More than 90% of materials currently disposed in incinerators and landfills can be reused and recycled. Providing subsidies or incentives for incineration encourages local governments to destroy these materials, rather than investing on environmentally sound and energy conserving practices. In addition, increasing waste in landfills and incinerators pose considerable risk to the health and environment of neighbouring communities as well as that of the general population. Concluding, recycling can be an effective tool in the community for reducing waste generation, eliminating disposal and reducing air pollution. In addition, PAYT was found to be an important factor for air quality improvement. However, illegal dumping can be a disadvantage of PAYT. Thus, more attention should be paid on PAYT program, like the relation of its price with the fixed pricing system in the case where PAYT is absent. In parallel with the PAYT program and fixed pricing systems, the recycling prices and costs, trash delivery costs and generally the solid waste management expenditures can be examined.

It is suggested that the relationship between recycling rate and additional air pollutants, like SO_2, NO_X and CO_2 among others should be examined as the turning point may differ between pollutants. The reason is that the recycling process of each product is different and the air pollution for different pollutant might vary. In addition, whenever available, personal and household demographic and socio-economic characteristics can be considered for future research. In addition, the relationship between recycling and pollution can be examined also in line with, health effects including bronchitis, headaches, heart disease and cancer among others, health care costs, loss of productivity at work and human welfare impact.

Efforts should be prioritised by geographic area or resource, type of generator -residents, stores, industry- type of pollutant and cost to society. There should be state and federal identification, which supports and provides incentives for pollution prevention and recycling, considering also local legislation. A pollution prevention and recycling strategy, should be developed, which includes businesses, industries and governmental agencies in the community and establish targets for waste reduction which can be used by the private and public sector in the community.

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Appendix A

Massachusetts Department of Environmental Protection website (http://www.mass.gov/dep).

Massachusetts Department of Public Health (http://www.mass.gov/eohhs/gov/departments/dph/).

Massachusetts Executive Office for Administration and Finance(http://www.mass.gov/anf/research-and-tech).

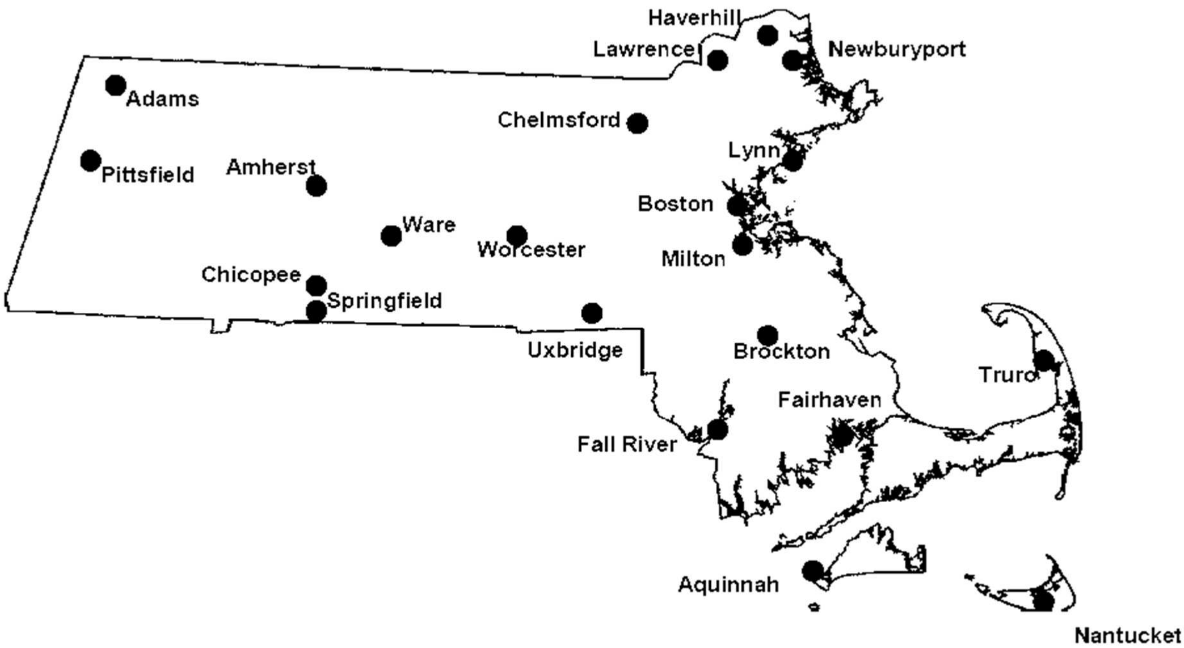
Massachusetts Department of Revenue (DOR) (http://www.mass.gov/dor/local-officials),

Massachusetts Executive Office of Labor and Workforce Development (http://www.mass.gov/lwd).

Tutiempo weather (http://www.tutiempo.net)

National ClimaticDataCenter (NCDC)(http://www.ncdc.noaa.gov).

Map 1. Massachusetts Air Monitoring Network for $PM_{2.5}$



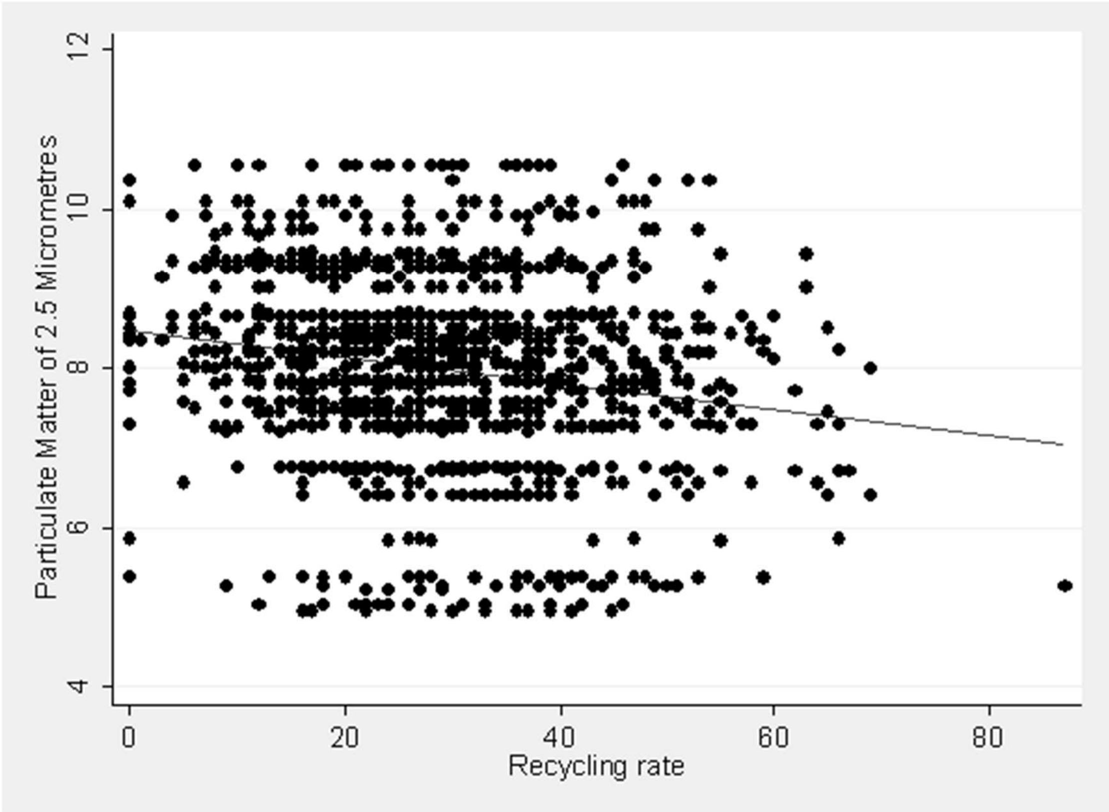
Source: Massachusetts Department of Environmental Protection website (http://www.mass.gov/dep).

Table 1. Summary Statistics

Variables		Period 2009-2012	Period 2009	Period 2010	Period 2011	Period 2012
$PM_{2.5}$($\mu g/m^3$)[1]	Mean	8.020	8.666	8.246	7.664	7.548
	Standard Deviation	0.611	0.608	0.621	0.618	0.580
Total Trash Tonnage	Mean	5930.131	5,023.165	6,196.451	6,544.734	6,385.21
	Standard Deviation	14,474.97	13,752.27	14,429.22	14,972.55	15,157.32
Recycling Rate	Mean	28.635	27.075	28.156	29.335	30.153
	Standard Deviation	6.257	6.882	6.704	5.949	6.297
Income Per Capita (2010 as baseline year)	Mean	35,347.43	32,465.55	35,391.79	36,210.97	37,344.69
	Standard Deviation	8,096.729	8,452.03	8,248.68	7,556.72	7,876.19
Unemployment Rate	Mean	7.238	7.827	8.057	7.079	6.588
	Standard Deviation	0.973	0.856	1.051	1.038	0.921
Average Temperature	Mean	12.082	9.043	13.901	14.638	10.700
	Standard Deviation	5.133	1.782	4.570	5.120	1.953
Precipitation	Mean	1,253.794	1,233.507	1,311.668	1,385.784	1,078.37
	Standard Deviation	190.605	97.681	166.563	115.894	205.823
Wind Speed	Mean	13.009	12.381	14.261	13.625	11.698
	Standard Deviation	3.496	2.864	3.541	4.096	2.670

$PM_{2.5}$ is measured in micrograms per cubic meter ($\mu g/m^3$), total trash tonnage in tonnes, temperature in fahrenheit, precipitation in in inches per 24-hour, wind speed in miles per hour (mph).

Figure 1. Scatter Plot of Recycling Rates and $PM_{2.5}$



Map 2. Municipal Recycling Rates 2009

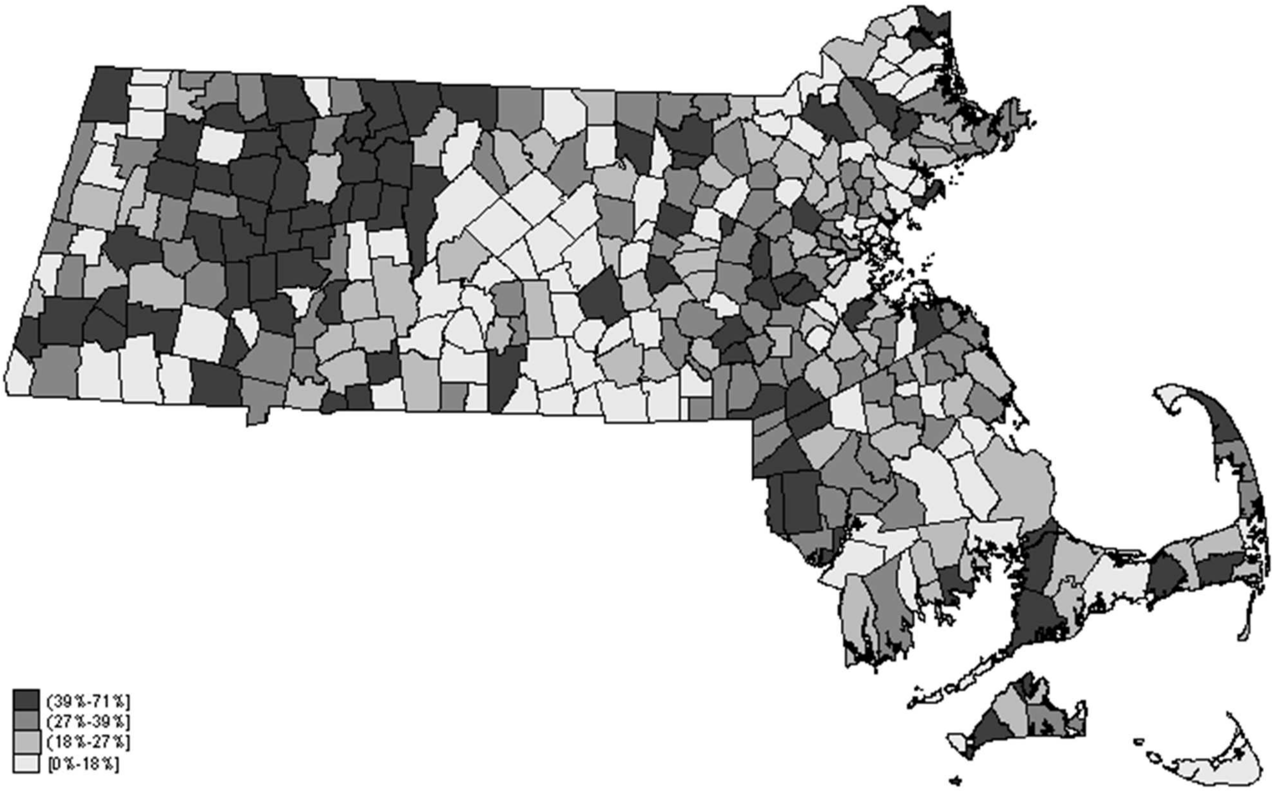


Table 2. Correlation Matrix

	$PM_{2.5}$	Total Trash Tonnage	Recycling Rate	Income Per Capita	Unemployment Rate
Total Trash Tonnage	0.0428 (0.3113)				
Recycling Rate	-0.1811 (0.0000)***	-0.1406 (0.0000)***			
Income Per Capita	-0.1195 (0.0000)***	-0.0697 (0.0299)**	0.2598 (0.0000)***		
Unemployment Rate	0.0785 (0.0054)***	0.0886 (0.0058)***	-0.1917 (0.0000)***	-0.4066 (0.0000)***	
Population Density	-0.0262 (0.3546)	0.5562 (0.0000)***	0.1722 (0.0000)***	-0.0697 (0.0129)**	0.0807 (0.0040)***

p-values in brackets, *** and ** denote significance at 1% and 5% level

Table 3. Regression Estimates of Equation (2) using Fixed Effects

Variables	**Fixed Effects Estimates**	**Fixed Effects Estimates†**
Constant	4.728 (1.892)**	5.431 (1.852)***
Recycling Rate	-0.0211 (0.0077)***	-0.0238 (0.0087)***
Total Trash Tonnage	0.0035 (0.0015)**	0.0042 (0.0018)**
Population Density	-0.0223 (0.0109)**	-0.0252 (0.0124)**
Income Per Capita	0.687 (0.328)**	0.986 (0.354)***
Income Per Capita Square	-0.0339 (0.0160)**	-0.0491 (0.0242)**
Unemployment Rate	-0.0807 (0.0328)**	-0.0993 (0.0337)***
Average Temperature	0.541 (0.193)***	0.751 (0.224)***
Minimum Temperature	-0.681 (0.204)***	-0.889 (0.234)***
Maximum Temperature	0.563 (0.230)**	0.806 (0.262)***
Precipitation	-0.194 (0.0287)***	-0.188 (0.0266)***
Wind Speed	-0.124 (0.0293)***	-0.138 (0.0685)**
PAYT		-0.0265 (0.0081)***
No. observations	1,274	1,116
R-square	0.2222	0.2866
Hausman test	112.75 [0.000]	103.85 [0.000]

Standard errors are between brackets, Standard errors clustered at municipality level
***, ** and * denote significance at 1%, 5% and 10% level.
The dependent variable is the logarithm of $PM_{2.5}$ and following variables are included as explanatory variables in the regression estimates: Combustion, Landfill, Municipality Type.
†Regressions include yard, food, trash waste services, reciprocal-regional program and PAYT