CEntre for Research on Circular economy, Innovation and SMEs

# Working Paper Series

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The CEntre for Research on Circular economy, Innovation and SMEs (CERCIS) is part of the Department of Economics and Management at University of Ferrara and, in particular, of the departmental development program funded by the Italian Ministry of Education, University and Research (MIUR) on a competitive basis for the period 2018–2022 to promote excellence in education and research ("Dipartimenti di Eccellenza"). The Department of Economics and Management is one of the 18 Departments funded in the Scientific Domain of Economics and Statistics at a national level.

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Semptember, 2020
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# Heterogeneity, space and non-linearity in income-waste relation: A non-constant elasticity model

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**Abstract**

The paper presents an alternative approach to analyze decoupling in municipal solid waste and economic activity production. The methodology consists in the generalization of the functional form of the statistical model of the environmental Kuznets curve. To avoid the limitation of one single alternative hypothesis, we developed a small set of alternatives, according to the signs and significance of estimates. We tested the model for all available categories of municipal solid waste in Italian provinces, total generation, metal, organic, paper, plastic, electric, selective, wood and textile. The desire to develop an alternative approach resulted from inconsistency in past studies. Results from similar statistical approaches and models provided contradictory findings for Europe and other regions. The results from our approach suggest that economic activity and municipal solid waste are not linearly correlated neither are they (yet) decoupled. Economic activity tends to increase the rigidity of impact.

**Keywords:** Municipal waste management; Income levels; Spatial econometrics

# 1. Introduction

Municipal Solid waste (MSW) is an inevitable by-product of human activity (Periathamby, 2011). It amounts to approximately 10% of total waste generation (WG) in European countries (Mourelatou, 2018). Still, the Waste Framework Directive of 2008 made MSW management a priority, due to the link with consumption and income levels. The matter is even more relevant in developing countries as stated in the World Bank report "What a waste" (Hoornweg & Perinaz, 2012): it highlighted that damages associated with the long-term production of urban waste are severely undervalued and should not be ignored. Moreover, increasing urbanization and densification of urban areas will have a remarkable impact on economic development and therefore, on waste patterns.

Many events have fuelled the interest in effective and efficient municipal waste strategies such as the waste crisis of Naples, Rome and Milan (Italy) since 1994 (Di Nola et al., 2018). Over the past decades, several aspects related to the topic of municipal waste generation and management have been studied by economists such as illegal dumping (Chifari et al., 2017; D'Amato, Mazzanti, Nicolli, & Zoli, 2018; Sotamenou, De Jaeger, & Rousseau, 2019), driving factors of municipal waste generation (Jaligot & Chenal, 2018; Mazzanti et al., 2008), and waste collection pricing (Fusco & Allegrini, 2019; Mazzanti et al., 2012).

Current waste policies differ between countries and regions. In Italy waste policies are developed at the regional and municipal level. According to ISPRA1 classification, MWG can be divided into four categories: 1) household waste (incl. bulky waste), 2) non-hazardous matter derived from urban economic activity, 3) street-cleaning derivatives, and 4) waste from cemeteries. These data represent the amounts of waste before any treatment occurs: incineration, landfill or recycle. However, due to the transition towards a circular economy, waste is no longer seen strictly as a "bad". For example, Nelles, Grünes, and Morscheck (2016) describe the transformation from waste management to resource management in Germany. Whilst waste becomes a valuable resource, it is still associated with several negative externalities and it is not clear whether MWS will be beneficial for welfare (Korhonen et al., 2018). The decision 2000/532/Ce[2] divided the four in 37 groups according to material composition. Focusing on "sorted" fraction, we can find paper, glass, plastics, metal, wood, organic, textile; the other are mainly registered within the group "selective". Our analysis will focus mainly on these categories.

Since waste and pollution in general is identified as a general by-product of economic activity, national product-waste has been regarded as a topical research matter. Several papers links MSW with GDP. The importance to study this relation is highlighted by the idea that economic activity might reduce negative externalities while still increase wellbeing. The phenomenon is called decoupling and it is frequently studied through the estimation of environmental Kutzets curves (UNEP, 2011). The Environmental Kuznets Curve (EKC) is a hypothesized relationship between various indicators of environmental degradation and income per capita. In the early stages of development, degradation and pollution increase, possibly at lower rates than economic growth. This is called relative decoupling. Beyond a level of income per capita named "tipping point", the trend reverses. At this point, every level of economic growth is expected to reduce pollution. This implies that the environmental impact indicator is an inverted U-shaped function of income per capita, as shown in Fig. 1. Typically, the logarithm of the indicator is modelled as a quadratic function of the logarithm of income (Stern, 2004). However, several critiques of the EKC have been formulated ranging from low quality data sources, inadequate econometric modelling and failure to include feedback loops into account which would allow environmental quality levels to influence economic growth (Lieb, 2004; Perman & Stern, 2003; Seppälä et al., 2001; Uchiyama, 2016).

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[1] 1 http://www.catasto-ri uti.isprambiente.it/index.php?pg=ru

[2] https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex%3A32000D0532

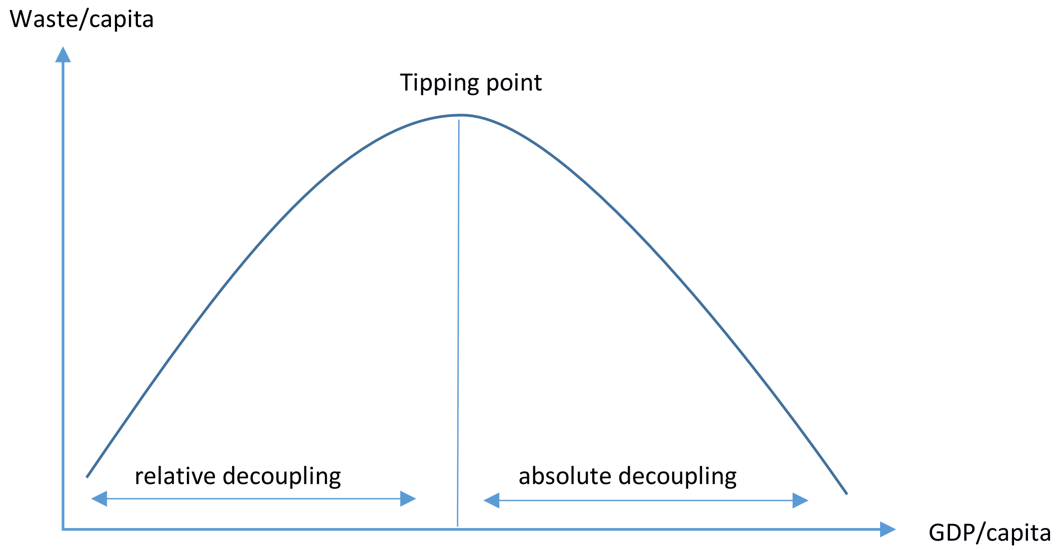


*Figure 1: The inverted U functional form and definition of tipping point*

Recycling is typically referred to as one of the strategies to move from a linear to a circular economy (Alaerts et al., 2019), the capability to recycle a significant part of MSW is certainly not the only condition needed to achieve a strictly circular economy. Waste is indeed an acceptable category in linear economy. The impasse can be synthesized as "to recycle or not to recycle", as "produce less waste", from waste hierarchy and "keep producing waste" as resources containing secondary products. It is then important for both visions of the circular economy to understand the interaction of economic activity and MSW. We believe previous studies managed sparsely to account for two factors. When searching for tipping points most authors model the model but overcame the heterogeneity effects. We believe that results might be affected by the use of both heterogeneity and tipping points. Italy provides an interesting case study due to the level of heterogeneity of the panel in such a small territory. Furthermore, we intend to deepen a case which has produced some inconsistency using the EKC hypothesis. To produce innovation in this case, we apply the spatial parametric approach.

In order to avoid selection bias and omitted variables, other variables are also included such tourism, population density and occupation. To check the robustness of this approach, a sensitivity analysis for the main parameters is performed. Finally, in the discussion section the main implications of the findings are highlighted, Policy comments are added.

# 2. Literature

| Reference | Framework, Location | Outcome |
|---|---|---|
| (Seppälä et al., 2001) | EKC, OECD | No tipping point |
| (Liu, 2008) | EKC, China | No tipping point |
| (Mazzanti & Zoboli, 2008) | EKC and Convergence, EU28 | Tipping point found for landfill |
| (Mazzanti et al., 2009) | EKC, Italy | Partially rejected[3] |
| (Mazzanti & Zoboli, 2009) | EKC, EU28 | Tipping point (landfill), linear relation (Total) |
| (Chen, 2010) | EKC-N, China | Two tipping points found |

[3] Valid for land-fill, linear for total on EU.

| | | |
|---|---|---|
| (Yamamoto et al., 2011) | EKC, Japan | Tipping point found |
| (Hossain & Miyata, 2012) | Data analysis, Japan | Relative decoupling |
| (Mazzanti et al., 2012) | Convergence, Italy | Convergence found |
| (Khajuria et al., 2012) | EKC, Japan | Tipping point found |
| (Trujillo et al., 2013) | EKC, Colombia | Tipping point, landfill |
| (X. Chen et al., 2014) | Data analysis, China | Absolute decoupling |
| (Arbulú et al., 2015) | EKC, EU28 | Tipping point found |
| (Ichinose et al., 2015) | EKC, Japan | Tipping point found |
| (Wu et al., 2015) | EKC, China | Tipping point found |
| (Montevecchi, 2016) | Policy<br>Analysis, North Italy | Tipping point found for property taxes to waste production |
| (Gnonlonfin et al., 2017) | EKC, Mediterranean panel | No Tipping point |
| (Ercolano et al., 2018) | EKC, Lombardy (Italy) | Tipping point (Referring to taxes as ex.) |
| (Jaligot & Chenal, 2018) | EKC-N, Switzerland | No tipping point found |
| (Gui et al., 2019) | EKC, China | Tipping point not found |

*Table 1: Overview of studies regarding the link between MSW and income levels*

Past studies focusing on decoupling between economic growth and municipal waste reveal two aspects: first, (tipping point is not always existent) decoupling in MSW is not always achieved; second, for many regions the results are at best inconclusive. These limitations emerge from an extensive literature review. Twenty articles around decoupling and MSW have been found from this search in the e-libraries of Science Direct and Scopus. The outcomes are summarized in table 1. We found that studies for European countries do not seem to produce homogeneous results. These studies use one main approach: testing the validity of the environmental Kuznets Curve (EKC) with two functional forms and other proxy variables. It seems these studies do not converge on the applicability of EKC for MSW. Each study adapted the exact specification of the econometric model to reflect the specific context: e.g. tourism, policy enforcement and so on. In most of the articles, H0 represents the EKC hypothesis: this is possible when all the estimates of the functional forms are significant. The hypothesis is rejected entirely for insignificance of one estimate. We constructed the table 1 in such manner: the methodology and the geographical reference of each study is listed in the column denoted “Framework”, while the “results” of each paper can be seen at the column denoted “Outcome”. We collected articles in chronological order. The table focuses on references on municipal solid waste and economic activity. We see that changing locality condition; same model might have different outcomes. Nevertheless, three main methodologies have been applied to the field. A more qualitative one based on plotting and trends interpretations. The second one uses convergence; this methodology aims to capture trends among changes of rate. When trends are negative, then changes in waste production converge to zero. In other words, proving convergence is equal as finding relative decoupling. This is an alternative approach without strict tipping points. Last is the application of functional forms to test EKC hypothesis. In this case linear quantities are used for a linear regression are the previous. In some cases, it is probably related to better information. For instance, Japan has repeated positive findings for decoupling. China started with negative decoupling (Liu, 2008), and according to the region the opposite (Chen, 2010; Wu et al., 2015). Europe had for instance unclear patterns, probably due to heterogeneity between and within European nations. The Italian case was one of the most studied. Tipping points and therefore decoupling have been tested on total waste generation and waste shipped to landfill. Results suggest that Economic cycle might affect management, but not production of waste. These two are necessarily interlinked due to the emergence of circular economy. For hierarchical reasons, we should reduce non-recyclable waste. On the other hand, recovering and recycling must relate production of waste.

Testing for tipping points requires the use of models able to capture first moments between two variables. Previous studies called these models functional forms (FF). These are a mathematical formula that plot shapes like a bell “U”, an “S”, a “N” etc. The choice of the model is related to the form of tipping points the author intends to test. Each FF contains implicitly a maximum and/or a minimum.

The U bell functional form has one tipping point and can be reverse, as shown in fig. 1. This is the preferred FF for EKC. The “S” curve is commonly known as logistic, geometric or sigmoid curve. In economics is used for predicting trends (Cramer, 2005). The “N” functional form extrapolates from data two tipping points; it resembles one “U” and one inverted “U” altogether (Jaligot & Chenal, 2018). Their purpose is to capture potential decoupling patterns in (panel)data (Gnonlonfin et al., 2017; Gui et al., 2019; Mazzanti et al., 2012; Mazzanti & Zoboli, 2008, 2009; Seppälä et al., 2001). However, some of these articles rejected the H0 from the statistical tests over the functional form (Gui et al., 2019; Mazzanti & Zoboli, 2009; Seppälä et al., 2001). The state of art can be summarized in one question: does the EKC-hypothesis apply to the link between MSW and income? As it appears from tab. 1, two possible answers have been provided. One is yes it does, but not for all regions. When the hypothesis seems to hold, income per capita appears to be statically significant as driver to promote decoupling. However, acceptance of EKC is debated by environmental economists (Seppälä et al., 2001; Stern, 2017). The second answer is no, with most of the time acceptance that just a linear form can appear (Jaligot & Chenal, 2018; Liu, 2008; Mazzanti & Zoboli, 2009).

We stylized above the main features of MSW/income literature. We highlighted the limitation of splitting analysis of heterogeneity and functional forms approach. When assessing heterogeneity, functional form might be a secondary issue, leaving out information. We can seemingly state the same for functional forms. Spatial regression can deal with both problems. This methodology might cover an important hole in literature. Spatial approach and EKC does not count many works. In further sections, we will link these two. In the next one, the theoretical framework is analysed. The heterogeneity component will be presented in data section. We will start with the relation that functional forms have with the econometric models and therefore tipping points.

# 3. Methodology

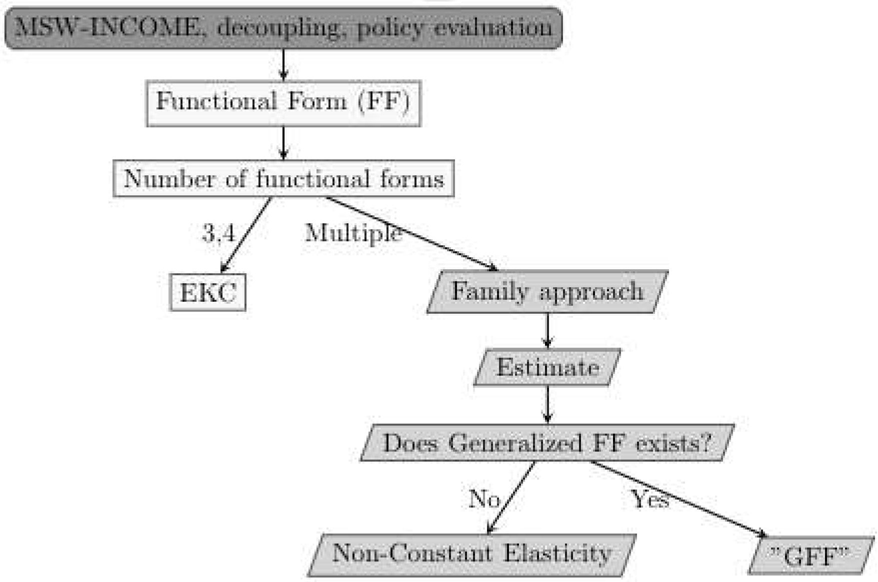


*Figure 2: Methodology map*

When considered in its totality, literature around MSW and income has produced inconclusive results. We believe one of its weak points is the use of functional form and the binary hypothesis approach of EKC literature. The approach used in reported articles is to not reject hypothesis 0 (EKC) or accept H1, based on statistical significance. This first point can be tackled by a multi-functional form approach: considering many functional forms at time. A second limitation is the rigidity of alternative hypothesis. Mainstream analysis bases its functional form on the significance of the estimates of a polynomial equation. For example, the bell shape is a second order polynomial such $a+bx+cx^2$. Insignificance of the estimate “c” means the rejection of the bell shape and emerging of linear FF. Similarly, “N” shape is a trinomial such $a+bx+cx^2+dx^3$: insignificance of d would underpin the “U” form; insignificance of both “c” and “d” means linear relation between the exogenous variable and the endogenous one. In case the third-grade estimates fail, the second order is accepted. In case the second order element is statistically insignificant, linear relation is assumed, at least for the panel-data under observation. Our approach is designed to deal with the two limitations considered above. The first weakness is dealt with by using a family approach, while the second one is dealt with a decision tree of alternatives. With a family approach, we imply that we use a “family” of functional forms (FF), i.e. a group of functional forms at the same time. If there exists an innumerable set of FFs, an appropriate approach may consider multiple FF. The heterogeneous component of the analysis might consider different FF according to spatial unities such as provinces or regions. Such generalization is influenced by the study of circular economy and the separation of waste and externalities (George et al., 2015). We will consider both situations at the same time. The first one will be considered by the generalization of the exponential components. We tried to account for provincial heterogeneity of FF using fixed effects. The generalization in family of FFs is the alternative step in testing the applicability of the EKC. Fig.2 provides a step-by-step of the alternative path. The lighter shapes are current state of art covered by the articles explained before. The darker ones highlight the contribution of this paper. The approach will be the following. The generalization represents a family of FF. Since there exists a difference between estimates and FF, a condition of existence is derived mathematically. This step is crucial as it can produce two outcomes. The "family" that is described here scopes limited cases and ignores possible interactions between variables. Thus, it is still fair to assume that other FFs exists. In case the estimates are outside the domain of possible solutions, the FF is not inside this family. Even if our estimates are significant, it is still possible to interpret the results in another way.

The generalization of FFs can be resumed in such manner: functional forms vary across countries. Our family of FF starts by a non-specified exponent in the EKC framework. For instance, the classical “U” can be generalized as:

$$y = ax + bx^c \tag{1}$$

Literature has applied the “N” functional form, based on a polynomial of order three (2). In this case the generalization appears as such:

$$y = ax + bx^c + dx^f \tag{2}$$

These equations can represent the FFs so far analysed in the existing literature. By generalizing “c” and “f”, other can be represented. We call this a “family” FF. It must be said that this is family can represent a limited number of shapes, as many other can be represented. The “Y” stands for the set of dependent variables. In the context of income/waste relation is usually MSW per capita. The “X” is the independent variable that is the focus of the study, which in this case is taken as income per capita. A third group of exogenous variables, usually as denoted as Z, is often used to reflect control variables such as tourism, policy measures or temporal effects. For simplicity, we focus on the economic covariate X and add the control variables Z later.

It is possible to see in equation 1 that "a" and "b" must be estimated jointly. In equation 2 all variables must be estimated altogether. In a large part of the literature, researchers simply assume that c is equal to two, implying a quadratic form. However, this assumption lacks sufficient motivation. Thus, we look, for instance at the first and second derivative of the tipping point, which is what most of the studies focus on. The tipping point is defined by putting the first derivate with respect to x of the y function equal to zero. Based on equation (1), this leads to the following expression of the tipping point

$$\hat{x} = \left(-\frac{a}{bc}\right)^{\frac{1}{c-1}} \tag{3}$$

This tipping point is one time derivable on “a”, while is convex in “b”. This is interesting because the sign of “b” determines the convexity of the “U” shape in the classical EKC. We cannot say the same for the parameter “c”. For instance, in case c is less than 1, both moments are positive in sign. In case c is more than one, it means that the tipping point is concave with c. The information of "c" is important as it gives the dimension of the tipping point, together with "a".

The possible determination of the statistical model can be derived from the logarithmic transformation of the first generalization (equation (1)). For simplicity we do not retain Z from the original model.

$$ln(y - ax) = ln(b) + cln\,(x)$$
$$\frac{ln(y)}{ln(a) + ln(x)} = ln\,(b) + cln(x)$$
$$ln(y) = ln(a + b) + ln(a^c + b)ln\,(x) + cln^2(x) \tag{4}$$

The second generalization has a similar process of determination. We will start from equation (2) and follow similar procedure of the former. As It is possible to see from (5), the changes are trivially similar. The main difference is that here we find the third grade $x^3$ translated to $ln^3(x)$.

$$ln(y - ax) = ln(bx^c + dx^f)$$
$$\frac{ln\,(y)}{ln\,(a)\ + ln\,(x)} = [ln\ \ (b)\ + cln(x)][ln\,(d)\ + fln(x)]$$
$$\begin{aligned} ln\,ln\,(y)\ &= ln(a + b + d) + [ln(a + b + f) + ln(a + b + d) + ln\,(b + d)]ln(x) \\ &+ [ln(c + d) + ln(a + c + f) + ln(b + f)]ln^2(x) + ln\,ln\,(c + f)\,ln^3(x) \end{aligned} \tag{5}$$

The generalization of FF must be then translated to a statistical model. This step allows hypothesis testing for the existence of a FF. The framework requires the establishment of vectors and matrixes for variables and regressors. For instance, the matrix $X=\{ln(x\}, ln^2(x\}, ln^3(x\})$ collects the independent variable of economic activity. Vector $\beta$ comprises the regressor of independent to dependent variable. This has length equal to the number of grades we are referring in mathematical model, For instance, the maximum number of functional forms is taken by the FF resembling the N form. This has a third degrees polynomial, therefore $\beta$ has length of three. Its members are the following: $\beta_1=\{ln(a+b+f)+ln(a+b+d)+ln(b+d)\}$, $\beta_2=\{ln(c+d)+ln(a+c+f)+ln(b+f)\}$, and $\beta_3=\{ln(c+f)\}$. The statistical model that aggregates the economic variables in X and the socio-economic ones in Z. the Dependent variable Y comprise the logarithm of a waste flow per capita. Such a model links GDP per capita with MSW per capita, while controlling for other socio-economic drivers. We employ the datasets provided by ISPRA for municipal waste generation. On the other hand, we used EUROSTAT[4] database for GDP. Socio-economic drivers have been extracted from ISTAT[5]. This study will focus on the level of Italian provinces, which corresponds to Nuts 3 in the EUROSTAT classification. A province is an institutional level that is between regions and municipal districts of cities in terms of hierarchy. They do not have relevant policy powers but are indeed useful for data analysis as they aggregate many municipal zones.

$$Y_{it} = \alpha_i + X_{it}\beta + Z_{it}\gamma + \varepsilon_{it} \tag{6}$$

It must be said that this framework is not general and is specific for any case under study. For instance, in case no functional form is captured but estimates are significant, we believe there may exists another explanation. When estimating EKC, the researcher is interested in finding a tipping point. This happens when at least the order two polynomial of the mainstream model is significant. In case it is, the marginal effects are linearly dependent to economic activity:

$$\frac{\partial y}{\partial x} = a + 2bx + 3cx^2 \tag{7}$$

The tipping point reflects the point where marginal effect is equal to zero. In other words when marginal utility generated by economic activity is equal to its marginal disutility. When interpreting them in percentage we refer to elasticity, which in this case, is calculated in such way:

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[4] https://ec.europa.eu/eurostat

[5] https://www.istat.it/en/

$$\eta_{EKC} = \frac{\partial lny}{\partial lnx} = \frac{\partial y}{\partial x}\frac{x}{y} = \frac{1}{y}(ax + 2bx^2 + 3cx^3) \quad (8)$$

This percentage is then varying per each level of both income and MSW. In our model this quantity is strictly dependent on economic activity:

$$\eta_{FF} = \frac{\partial lny}{\partial lnx} = \beta_1 + \beta_2\, ln\,(x)\ + \beta_3 ln(x) \quad (9)$$

In this case elasticity is to be strictly endogenous to economic activity. Elasticity is an intuitive measure of the responsiveness of a variable to the change of another. For instance, MSW is elastic to economic activity when $\eta_{FF}$ lays outside the interval [-1,1]. Within it, MSW would be rigid to economic activity. When adding spatial heterogeneity, the statistical model must comprise weight matrixes. Statistical model in this case comprises a spatial lag of the dependent matrix:

$$Y_{it} = \lambda W_i Y_{it} + \alpha_i + X_{it}\beta + Z_{it}\gamma + \varepsilon_{it} \quad (10)$$

The lag $\lambda W_i Y_{it}$ indicates the effect that surrounding areas have on current province. The assumption that spatial dependence affects elasticity highlights variability due to spatial frame. In this case elasticity would vary according to socio-economic factors and spatial interactions. In this case, the model might explain different spatial heterogeneity as interaction between spatial framework and socio-economic dynamics. In this case, elasticity will follow a different definition.

$$\eta_t^{vul} = \sum_{\forall i}(I_i - \lambda W_i)\frac{\partial Y_{it}}{\partial X_{it}} \quad (11)$$

According to the spatial analysis, elasticity estimated within one province might be affected by both inner and outer economic activity. The measure use to account both is called vulnerability effect (Kelejian & Piras, 2017). We calculated elasticity as vulnerability in equation 11. The reporting of such measure accounts for the complexity that can arise from a spatial econometric problem. When estimates are “vulnerable”, policymaking should anticipate the effect to surrounding areas. In this case, since elasticity would be endogenous not only to inner economic activity, but also to surrounding socio-economic performances. In case the estimate of lambda is high (the bounds are [-1,1]) surrounding areas effect are predominant, thus there exists a high chance of contagion, nevertheless the inner activity. In case it is contained to a value far from bound but not near zero, surrounding effects are added to the inner ones. In case it is near zero or even insignificant, surrounding effect are negligible if not null.

Following section will provide a data summary. We will present the panel we refer to in calculation. Before the test for the presence of any FF, we need to assess data structure. Since we expect spatial dependence, Moran test is provided according each time and variable. We will then apply tests for autocorrelation, model selection and robustness checks. According to the result we will then calibrate the model to estimate in subsequent section.

# 4. Data

A general summary of the variables is reported on tab. 2. For our analysis, we used a panel dataset with 103 Italian provinces. The dataset covers fifteen years (2001-2016. Note that during this time frame several institutional reforms had an impact the exact division of the Italian provinces. Due to the reforms of 2007 and 2010 the number of provinces increased from 103 to 107 and 110 respectively. For this paper, however, we will keep the initial territorial division of 2000. The dataset is generated by combining three open-access datasets: Eurostat, ISPRA and ISTAT databases. From the first we collected the socio-economic variables such as density, occupation, GDP per capita actualized to 2010.

The data comprises the total flow of MSW and all collected sub-flows[6] from ISPRA dataset. The last database provided shapefiles for spatial analysis and touristic data.

*Table 2: Summary Statistics*

| Variables | N | Mean | SD | Min | Q1 | Median | Q3 | Max |
|---|---|---|---|---|---|---|---|---|
| MSW.CAPITA | 1648 | 520.30 | 101.19 | 289.42 | 454.18 | 499.18 | 580.35 | 864.90 |
| GDP.CAPITA | 1648 | 24304.37 | 6379.05 | 11800.00 | 18600.00 | 24500.00 | 28900.00 | 52400.00 |
| OCCUPATION | 1648 | 0.45 | 0.33 | 0.01 | 0.32 | 0.40 | 0.47 | 0.51 |
| DENSITY | 1648 | 251.91 | 335.14 | 31.04 | 107.65 | 176.31 | 275.86 | 2687.40 |
| PAPER | 1648 | 45.53 | 34.39 | 0.00 | 22.15 | 44.64 | 61.52 | 400.40 |
| ORGANIC | 1648 | 61.75 | 50.84 | 0.00 | 14.78 | 54.28 | 100.94 | 245.50 |
| WOOD | 1648 | 10.47 | 10.42 | 0.00 | 1.69 | 8.60 | 16.51 | 72.37 |
| METAL | 1648 | 5.82 | 5.20 | 0.00 | 1.71 | 4.81 | 8.26 | 37.88 |
| PLASTIC | 1648 | 11.24 | 9.23 | 0.00 | 4.04 | 8.68 | 16.51 | 50.57 |
| RAEE | 1648 | 2.95 | 2.25 | 0.00 | 1.30 | 2.52 | 4.43 | 25.00 |
| SELECTIVE | 1648 | 0.58 | 1.03 | 0.00 | 0.06 | 0.41 | 0.83 | 22.48 |
| TEXTILE | 1648 | 1.45 | 1.76 | 0.00 | 0.43 | 1.32 | 1.98 | 30.21 |
| GLASS | 1648 | 24.09 | 15.47 | 0.00 | 10.44 | 23.40 | 36.23 | 113.20 |
| TOURISM | 1648 | 1381447 | 2458764 | 41505 | 290029 | 586640 | 1247583 | 17383151 |

For MSW generation related variables we used the ISPRA[7] database, control variables and spatial data were downloaded from ISTAT[8]. All waste variables are measured in kilograms (KG) per capita. MSW.CAPITA represents the sum of all separated and unseparated classes of waste. PAPER is the collection of paper-made objects: it comprehends paper packaging. ORGANIC accounts for discarded food, collected in separate bins. WOOD refers to the rest of garden cleaning. METAL refers to all metal-made waste, such as cans or plugs. PLASTIC is the collection of all recyclable plastics: for instance, it contains plastic packaging. RAEE represents the collection of waste from household electrical equipment; it is commonly known as Waste from Electronics and Electrical Equipment (WEEE). SELECTIVE is the aggregate of different collections that require a unique class, such as exhausted batteries, medicines. Finally, GDP per capita was taken from Eurostat[9]. Missing data from ISPRA are converted in zeroes. In case a province did not have a collection system for a waste class, 0 was reported as collected quantity. We interpolated the quantity to 0.0001 in order to extend the time dimension of MSW.CAPITA to all other variables. In this way we avoided to take the logarithm of a null quantity[10]. Similar approach was used by Gnonlonfin et al. (2017). The definition of each waste flow conforms to the EU commission decision of 3 May 2000. We represented the flow data within the appendix sections.

The exogenous variables can be divided in two main groups: GDP and its polynomial structure ($X_{1:3}$), and set of socio-economic variables ($Z_{1:3}$). The second group is composed of the potential drivers of MSW typically accounted for in the literature (Ercolano et al., 2018; Mazzanti & Zoboli, 2009). $Z_1$

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[6] A complete definition of nomenclatures used by ISPRA to define flows is provided in appendix

[7] www.isprambiente.gov.it/it

[8] https://www.istat.it/en/

[9] https://ec.europa.eu/eurostat/home?

[10] We run the regression while dropping increasing numbers of lines from the dataset: apparently, most of zeros were at start years, probably for implementation of policy. We dropped from 2001 to 2003 and from 2014 to 2016, reducing the convergence rate from T/N=0.145 to 0.087. The results show minor loss of significance, but sings remain the same and values are close to the reported.

represents Population density defined as the average residents per year (T) divided by the surface area of the province in km$^2$ (S). $Z_2$ equals Tourism density as the number of days of tourists used hotels, AIRBNB, hostels, etc. it is calculated by ISTAT by the accommodation tax system. We weighted to the area of its province to create touristic density. Finally, $Z_3$ is the occupation rate as the number of occupied population resident within the region divided by the total number of residents.

Within the dataset the average income per capita is 24 304 euros, while the total MSW per capita is 520 kg. The maximum values for income and MSW per capita were 52 400 euros and almost 865 kg respectively. The largest category recovered is organic waste, while the maximum registered is paper. Within the socio-economic variables it is possible to see that average density is almost 252 habitants per km$^2$. The average number of annual tourism visits is 1 381 448 over all provinces with a maximum of 17383151 visitors in 2005 within the province of Rome.

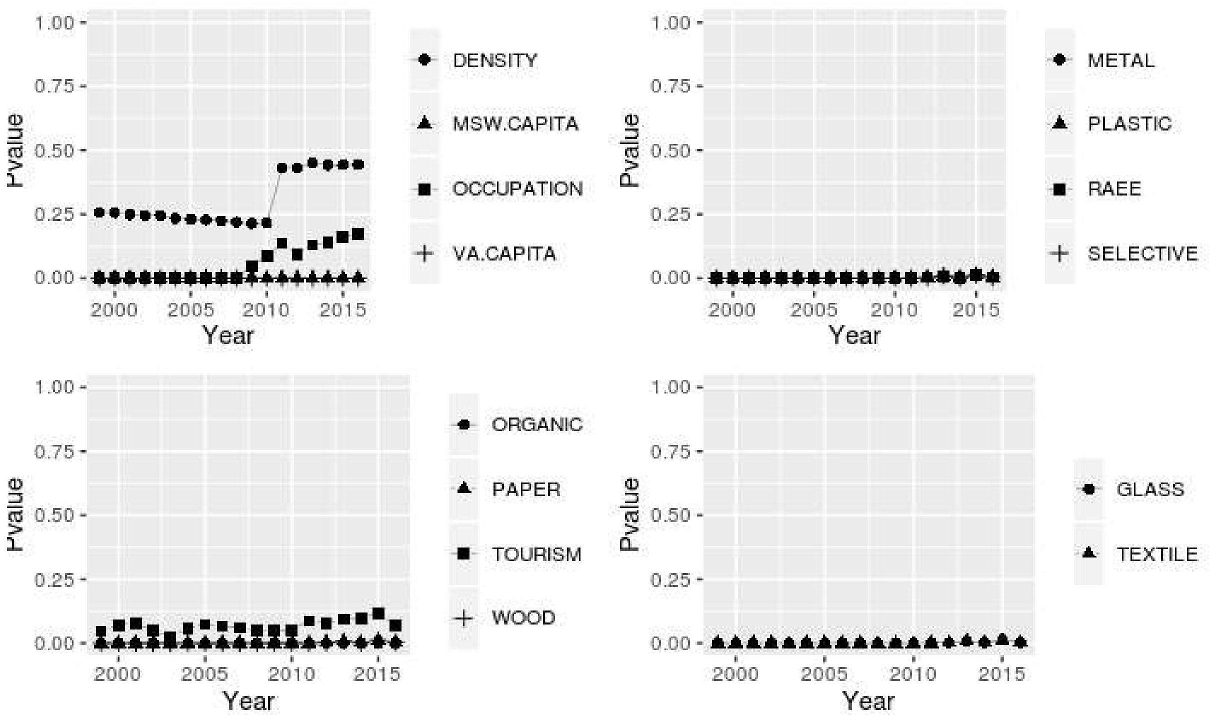


*Figure 3: Moran p-value according to year*

To integrate the spatial dimension in our regressions, we first generate a normalized spatial weight matrix (W) containing the relevant spatial information. The matrix is first set up as a binary matrix where each cell has a value of 1 or 0, with rows “i” and columns “j” as the number of provinces. The cell $w_{ij}$ contains the value 1 when provinces “i” and “j” share common border and 0 in the opposite case. Next the matrix is row-normalized by dividing each $w_{ij}$ is by the number of cells equivalent to 1 in each row. In this form, neighboring provinces will receive $w_{i;j} = 1/k$ where k is the number of neighboring provinces. Islands are isolated and thus their provinces can interact only with each other. Only one weight matrix is used.

We treated all variables with the Moran test to spot spatial dependence. The test comprehends the calculation of the Moran I and its p-value. The former can vary from -1 to 1. When equal to zero, it represents a variable distributed randomly. We used p-value obtained in the Moran’s I test for values over 0.1 we could not reject the null hypothesis of spatial interaction. We plotted the results of the test according to each year in Fig. 3. Every group variable relates differently with the spatial lag. Thus, each model requires a different setting of autocorrelation. For instance, we cannot assume randomness in waste generation; in other words, areas tend to have similar waste patterns. Most of waste patterns appear follow this pattern along with tourism density. Interestingly, population density appeared more random after the reform of 2011. At last, during economic crisis “surge” in randomness affected density and occupation, probably due to large movement in resident population. From these results it appears that we need to add a second lag to the model for socio-economic drivers.

After the selection of spatial matrix and Moran test, we had to determine the models to estimate. Critical aspects under analysis where temporal, local cross-sectional, errors and lags dependence and fixed effect selection. We reported the results of our tests in table 5 in appendix. The general model of equation (6) was treated for serial correlation in idiosyncratic component of errors. According to our results our model might efficiently use data using individual fixed effects as well as two-ways and spatial lags. Results show that the tests for local cross-sectional dependence are positive. We tested for spatial dependence in errors; since the Moran test does not have high p-value, we decided to use the error spatial model for all categories. The dummies for time and individuals have been tested. We chose to adopt the individual effect to avoid selection bias for redundancy. Since we found spatial interaction for socio-economic components, we included spatial lags of our socio-economic variables in the model. The model to be estimated is then the following:

$$\begin{gathered} Y_{it} = \alpha_i + \lambda W Y_{it} + X_{it}\beta + Z_{it}\gamma + W Z_{it}\delta + u_{it} \\ u_{it} = (I - \varrho W)\varepsilon_{it} \end{gathered} \tag{10}$$

Vectors α,β,γ,δ and the value of ρ and λ need to be estimated. We assumed normality for errors ε for simplicity. It is necessary to point out some complex aspects that arose during data analysis. According to the data set provided, most categories were registered as zero kg the first years or recovery. This notation can produce some complication in data analysis: logarithm transformation required interpolation of data. Another option is removed lines where such matter occurs. We preferred to choose the first in order to gain as much convergence as possible for maximum likelihood (ML) and generalized moments (GM) estimation. From model selection test, ML and GM displayed similar efficiency. Hence, we choose to use for all except glass the first method. The choice is supported by the outcomes of Hausman’s test. As it possible to see in Table 5, Glass is the only material to not support the ML. The vector δ contains the estimates of the spatial lags of socio-economic variables. These estimates measure the impact that surrounding’s socio-economic variables have on the generation of MSW. The error parameter ρ indicates presence of spatial autocorrelation and it is generally named nuisance parameter (Anselin, 2003). The interpretation of parameter β varies according to the sign of its estimate. In case the estimates are all positive, a FF from table 3 can explain income-waste dynamics. In case estimates violate such condition but are is still statistically significant, no known FF can be identified; hence, economic activity is variably elastic to MSW. More specifically, elasticity of economic activity to MSW changes according to the level of the first. As expressed in equation 9, the estimates of $\beta_1$ represents elasticity at very low values of GDP per capita. The others two determine the speed of change according to income, and the direction according to the sign. For instance, a negative value of $\beta_2$ represents a negative impact of economic activity to elasticity. The third value $\beta_3$ in this case is a second derivative, so can be interpreted as a “speed of speed” or in other words acceleration of change. This model is useful to understand heterogeneity. Each estimate determines one aspect of variable elasticity. Firstly, interaction between economic activity and waste production is not constant but changes across the spectrum as told by the first two β. Secondly, we can infer how it varies across GDP per capita spectrum. Second and third β suggest that this variation might be steep or rather flat. In the first case, heterogeneity is large. Thus, elasticity might vary greatly according to GDP per capita. When it their value is near to zero or statistically insignificant, heterogeneity of elasticity is minimal across GDP per capita levels. To summarize, the significance of these three β signify some level of variability of elasticity.

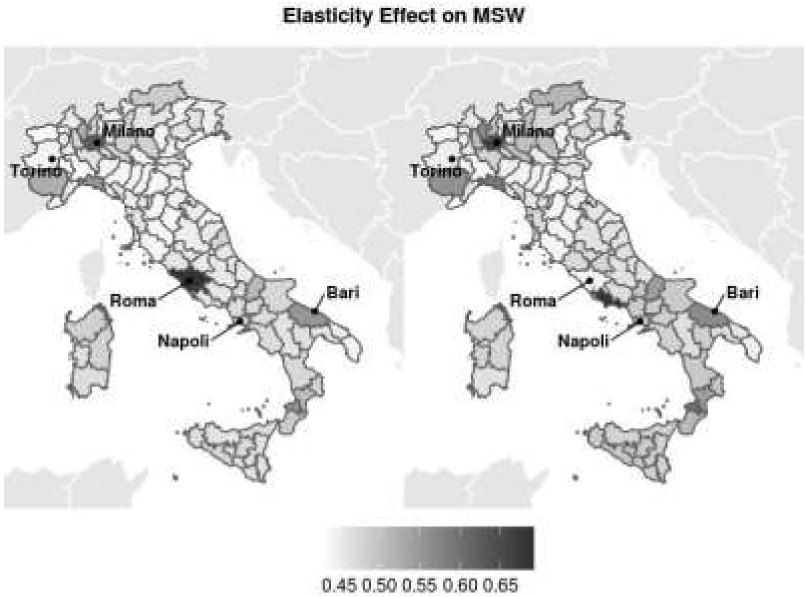


*Figure 4: Vulnerability effect of each province 2008-2015*

# 5. Results

Nine ML and one GM models have been estimated. Economic activity results significant with high value in eight of them. Socio-economic variables such as occupation, population density and tourism visits (q) were mostly consistent. According to $R^2$ the best fitting models are glass, total MSW and paper; the least was RAEE (WEEE). The model estimating MSW generation had the smallest residual sum of squares (SSR) and total sum of squares (TSS). To test the consistency of results to data manipulation in section 3, we test the sensitivity by dropping data for some years. We removed 1999 until 2003, where data reported the zeroes. Results show some overall loss in significance as expected, but no change in signs. We reported the results in tab.3. We find that results vary greatly across the various sub-flows. This variability suggest that some are rather dependent to economic activity rather than other. Furthermore, variability is greater in some. High value of $\beta$ values indicate that sensitivity of scale is lost at very low levels of income, when $\beta_2$ is negative. This is the case, for instance, for Glass, total MSW, organic, paper, RAEE, textile and wood. The $\beta_1$ value is high in all estimations and indicate that impact on economic activity is very elastic at low level of income. In case $\beta_1$ sign is positive but $\beta_2$ is negative, is means that elasticity reduces as economic activity rises. Furthermore, this change in elasticity is more sudden as $\beta_3$ rises. We can classify recovered materials according to this estimate in three main categories. The first relates no significant impact of economic activity on waste generation. Results suggest that glass, metal, paper, selective waste and RAEE (WEEE) are not affected by local economy. The second comprise those positively elastic impact at low economic activity but become rigid steadily or suddenly (according to $\beta_3$) inelastic with economic growth: plastics appear to fit in this category. Lastly, those negatively elastic impact at low economic activity, but become rigid steadily or suddenly (according to $\beta_3$) inelastic with economic growth: total MSW, textile, wood and organic seems to represent this category. Variability is very high in textile and wood. This means that elasticity vary greatly from low income provinces to high. In this case, low class regions might have strong reduction as income rises. Since variation of variation has similar tendency, we expect the change to halt fast. Therefore, variability cease at very low level of income. After that moment, percentage variation of economic activity affects textile and wood waste in a similar percentage. Plastics and total MSW in the other hand act very differently. Elasticity varies slowly per GDP levels. Heterogeneity across provinces and economic activity is therefore greater and does not settle as the previous. While per capita disposal of wood might be similar between average and high-income regions, it is not correct for plastics. Total MSW represent the total flow of the others. It has the variability of plastics and the signs of wood or

*Table 3: model estimation*

| Estimates | Glass | Metal | MSW | Organic | Paper | Plastic | Raee | Selective | Textile | Wood |
|---|---|---|---|---|---|---|---|---|---|---|
| e | | | | | | 0.807*** | -0.606*** | | | |
| | | | | | | 0.013 | 0.039 | | | |
| lambda | 0.739*** | 0.292*** | 0.492*** | 0.505*** | 0.461*** | -0.717*** | 0.744*** | 0.406*** | 0.328*** | 0.375*** |
| | 0.031 | 0.028 | 0.023 | 0.023 | 0.021 | 0.029 | 0.021 | 0.026 | 0.028 | 0.026 |
| ln(GDP/CAP) | -9.708 | -11.044 | -3.407** | -80.557* | 2.754 | 17.049* | -0.398 | 6.62 | -140.423** | -92.454* |
| | 5.987 | 27.406 | 1.055 | 40.176 | 5.707 | 7.68 | 41.091 | 28.762 | 44.896 | 38.608 |
| $\ln^2(GDP/CAP)$ | 1.165. | 1.615 | 0.4*** | 8.535. | -0.374 | -1.934* | 0.059 | -1.072 | 16.723** | 11.34* |
| | 0.686 | 3.131 | 0.12 | 4.58 | 0.651 | 0.884 | 4.659 | 3.286 | 5.129 | 4.41 |
| $\ln^3(GDP/CAP)$ | -0.042 | -0.068 | -0.015*** | -0.283. | 0.022 | 0.076* | -0.001 | 0.053 | -0.645*** | -0.442** |
| | 0.026 | 0.118 | 0.005 | 0.172 | 0.025 | 0.033 | 0.174 | 0.124 | 0.193 | 0.166 |
| OCCUP | 0.07* | 0.127 | 0.014* | -0.033 | -0.067* | -0.05 | -0.404 | 0.08 | 0.241 | -0.143 |
| | 0.035 | 0.144 | 0.006 | 0.212 | 0.03 | 0.059 | 0.247 | 0.151 | 0.236 | 0.203 |
| Neight. OCC | -0.094* | -0.565* | -0.03** | 1.593*** | 0.146** | 0.239** | -1.073* | -0.546* | -1.15** | -0.469 |
| | 0.043 | 0.258 | 0.01 | 0.368 | 0.052 | 0.087 | 0.492 | 0.271 | 0.423 | 0.364 |
| DENS | -0.007 | 0.003 | 0.01* | 0.063 | 0.056* | 0.009 | 0.369** | 0.041 | 0.14 | 0.189 |
| | 0.027 | 0.108 | 0.004 | 0.16 | 0.023 | 0.035 | 0.135 | 0.113 | 0.176 | 0.152 |
| TOUR | 0.24*** | -0.331. | 0.01 | -0.146 | 0.091* | 0.128* | 0.892*** | 0.7*** | 0.494. | -0.748** |
| | 0.044 | 0.17 | 0.007 | 0.25 | 0.036 | 0.059 | 0.258 | 0.178 | 0.279 | 0.24 |
| Neight. TOUR | -0.011 | 0.066 | 0.028*** | 0.185 | -0.346*** | -0.339*** | 1.022** | -0.121 | 0.822* | 0.149 |
| | 0.012 | 0.222 | 0.008 | 0.319 | 0.046 | 0.077 | 0.321 | 0.234 | 0.366 | 0.313 |
| ssr | 695800.432 | 2896.385 | 4.419 | 6428.364 | 127.849 | 572.407 | 12187.491 | 3190.924 | 7772.944 | 5749.734 |
| tss | 4784.046 | 8347.696 | 58.897 | 22930.623 | 4856.977 | 5142.048 | 17076.04 | 19456.131 | 20886.528 | 20426.65 |
| $R^2$ | 0.678 | 0.653 | 0.925 | 0.72 | 0.974 | 0.889 | 0.286 | 0.836 | 0.628 | 0.719 |

textile. This means that composition of waste varies greatly according too income but not in absolute terms. As presented in data, richer provinces produce relatively more waste than poorer ones.

Since estimates are high in the $\beta$ vector, we expect that impact of economic activity is rigid to municipal solid waste. Unless we count purely virtual tipping points in our estimates (we found $e^{13}$ for plastics, which is more than 400000 euros per capita), the sign of elasticity never changes. With this we mean that the estimates signs are like a standard EKC problem: $\beta_2$ does never have the same sign. In this application the tipping point expresses the point where elasticity is equal to zero. The results do not underpin the hypothesis of weak or strong decoupling. If we take only total economic activity, MSW will probably not respond to its changes after a certain point. As equation 9 *points out*, we could prove the rigidity strictly dependent on economic activity; there is no feedback effect from the scale of MSW as in (8), unless we consider vulnerability.

Other socio-economic variables such as occupation on the other hand appear to affect generation of MSW per capita differently *ceteris paribus.* For instance, plastic waste generation is positively affected by tourism rates, indicating a vulnerability of the sector to waste intensity. This intensity is probably strictly endogenous in each province, as the spatial lag is statistically insignificant. The same could not be said for glass and paper generation, which have negative impact from surrounding provinces tourism. Density affect positively waste generation in almost all cases. Different signs in spatial lags may indicate spatial heterogeneity in their impact on MSW generation. Such phenomenon falls in the definition of previously explained vulnerability (Kelejian & Piras, 2017). In this case it indicates that the total impact on MSW is affected by surroundings areas. This seems intuitive with tourisms, as it is rather common to find travelers that visit more than one city in a single region. In case we embody the spatial effect, the results appear different as plotted on Fig. 4. When considered as endogenous to one province, elasticity is negative, but when all effects are added, it emerges as positive. Apparently, Italy seems to have similar vulnerabilities between each province. Given spatial interaction, the peak from Rome translated to south in the province of Latina due to spatial proximity. Despite being both rich cities, Milano (Milan) and Torino (Turin) experience different scenario. Surrounded by other rich provinces, the one of Milan is the second highest in Italy for vulnerability. Given the general growth of these areas, vulnerability tend to be higher on average. On the other side, southern provinces do not suffer from the same vulnerability, but Bari for instance, register a high value. A second aspect arises from this figure. We have explained before that composition of waste changes greatly according to GDP per capita level. If considering spatial interaction too, heterogeneity is not fixed. It varies across time. This outcome is rather complex to interpret, as it assumes that elasticity varies according to the interaction of exogenous and endogenous factors.

# 6. Discussion

MSW management and its economic and environmental impacts have produced a prolific literature. Despite the advancement made by these fields, it still covers important size of journals and news. In this article a study on MSW-GDP per capita is made. The generalization of FF and the findings of income-based heterogeneity in elasticity constitutes one novelty in the current debate on tipping points. We concluded from the results that instead of changing sign in impact or reaching a maximum point, MSW generation becomes more rigid as economic activity grows. The second novelty is the approach that underpins such a conclusion. The standard FF approach is modified to contain a set of alterative hypotheses instead of one. We were not able to find a FF that fits all. Still, we manage to interpret the results referring to elasticity. From our preliminary results, it appears that MSW elasticity to economic activity varies. Furthermore, it appears to tend to zero. We interpreted this rigidity to be directly induced by economic growth. The results show the presence of vulnerability. These estimates do not consider on the other hand the policy performance developed by each zone. For instance, despite Milan is one of the most vulnerable provinces, its waste recovering performances are acceptable. It is not possible to say the same about Rome, where vulnerability is even. It is possible to see that in a wide perspective. *Ceteris paribus* the level of expenditures per capita, provinces with high vulnerability may have lower policy performances. The results of vulnerability analysis provide a more systematic effect perceived by one area. Italy represent for instance the classical example of spatially heterogeneous economic performance. In case both economic heterogeneity and non-linear elasticity hold, environmental and spatial policies such as decentralization should be considered altogether. Furthermore, inelastic impact of total economic activity on waste does not mean per se decoupling. Structural changes within economic system can still affect the MSW production. For instance, tourism exercise a significant and positive effect on production. Thus, tourism attraction policies could indirectly foster increases in MSW rates, *ceteris paribus*.

The difference with previous studies is the interaction between spatial framework and EKC hypothesis discussion. This article proposes a novel approach by dealing with both matters. We highlighted the possibility that more than one FF arises, if not null. Enlarging the scope of approach, we tried to assess the question of why absolute decoupling does not appear in MSW. Given the differentiation of flows and spatial approach, we might have a possible explanation. Each economic level might have different cohorts of waste flows. While some almost similar dynamics, other vary greatly. Here lays the importance of non-constant elasticity. A linear framework might have captured different tipping points, but not necessarily the differences among level of GDP per capita. Furthermore, other aspects intervene. Economic cycle is affected by location and endogenous variables. This is a reason to use spatial models for EKC. We then used this interaction to highlight the complex relation between elasticity and income. Some regions have higher spatial interactions. Keeping all constant, Provinces pulled by a complex net must consider secondary effects when planning for disposal. This is a crucial aspect for policy making. Since each province has different GDP per capita levels, waste compositions vary. Since this varies, uses of incineration, landfill or recycling is strictly dependent on which waste composition emerge in one province. This heterogeneity of composition might be one of the drivers of circular policy. High level of separation allows for better targeting for recycling. On the contrary, it is impossible to recover materials or reuse some commodities without dividing them. Decentralization of policy might rule out heterogeneity of flows if waste separation fuels circular policies. Otherwise, materials are lost in the process. Furthermore, interaction between areas are relevant to assess possible changes in flows.

Another aspect we need to report is the time-varying spatial dependence registered in Moran test. Such matter would require an extension (Lee & Li, 2017), but should be covered by a separated study, given its complexity. Furthermore, since clustering on provinces clear out many information that are available at regional level, we used variables which were available but still consistent with literature. Given the heterogeneity of materials and utility that each good provides, it is possible that other variables outside the available ones can add interesting knowledge to the field.

# 7. Conclusion

This work analyzed the relation of MSW-Income using a spatial panel data approach. We presented the relevant literature and highlighted the main gaps. Among these we find the lack of a general approach for FF and limited used of spatial framework, despite data evidence. We then approached the problem by dealing with both matters. Thus, we firstly classified FF and how they may arise in data estimation. We link this approach to the interest of tipping points. We used data for total MSW and its sub-flows to understand whether income affects each flow differently. Data pictures Italian provinces from 2001 to 2016. Socio-economic variables comprise tourism, density, and occupation levels. Since pre-selection test and Moran test underpinned spatial frameworks, we treated the model for spatial lags in dependent and some independent variables. The model estimation suggested the inexistence on any FF but the presence of varying elasticity. The main reasons of changes are related to spatial interaction, economic activity, and type of waste. Results suggest that GDP per capital level affect the composition of waste flow. Hence, elasticity varies according to relatively to waste type and economic variables. We

found that economic activity might be relevant in some cases only at very low level. In other cases, elasticity varied greatly according to economic activity.
Heterogeneity is evident when plotting vulnerability on a map. Elasticity changes in time according to this complex set of variables. Results are relevant for institutional approach to circularity. Decentralization might be an effective as Italy is characterized by high level of heterogeneity. Nevertheless, we cannot explain if separation positively affect circular policies. It is a *conditio sine qua non* material recovery and commodity reuse cannot arise. Nevertheless, some flows seem to reach very lo levels of elasticity at low income. Those flows could easily be managed, as they will not change according to relative economic growth. This is a relevant gap that further works might cover. We found the results for spatial correlation of Moran tests relevant too. Since they vary across time, there might be evidence for structural breaks. We did not test the data for those. Results of spatial breaks are not common in this literature.

Our work has sheds light on how socio-economic activity might have non-linear effects on waste productions. The novelty introduced might be useful for other studies in economics as more works start to address complexity. The necessary step after this is to produce a synthetic approach and intuitively valid for the community. We clarified the presence of heterogeneity both on economic and spatial correlation and how these two interacts. Nevertheless, this framework aims to solve the gaps by enlarging the scope. The focus on mass dynamics rather than mainstream linear approach might aggregate the benefits of wider scope with the synthesis of linear models.

# Appendix

## Material cycle in MSW and data

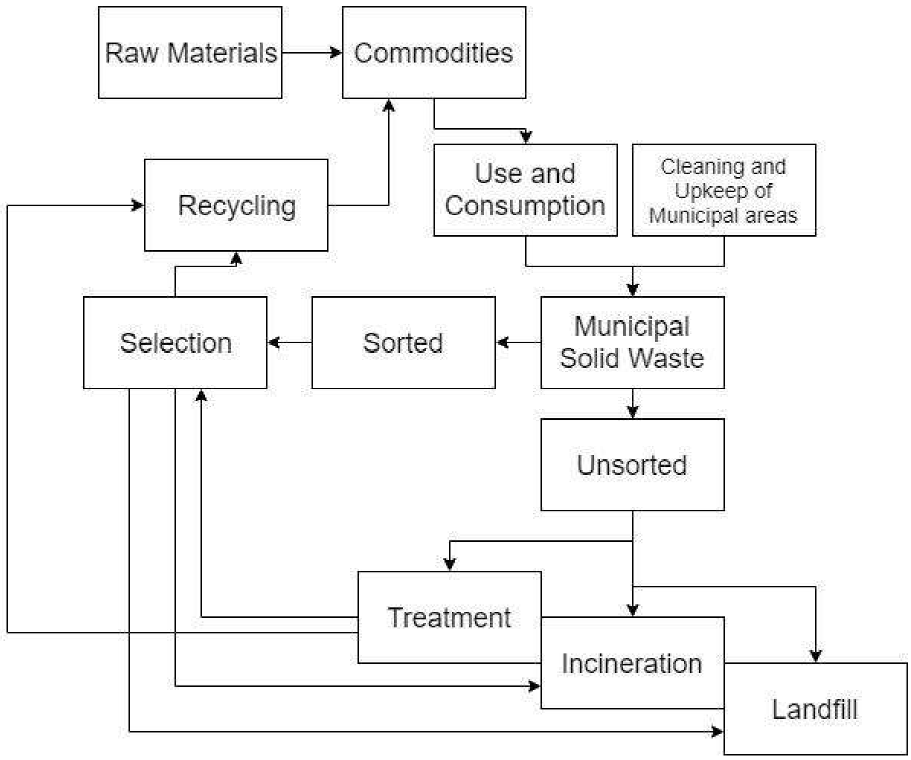


*Figure 5: Material Flow Chart*[11]

Cited literature tends to apply various definitions of MSW without a debug of its composition or direction in material chain. It represents the sum of sorted and unsorted flows. These defined after collection from bins, door to door and other policies. At this point, both can either be incinerated, landfilled, or processed for recycling. ISPRA does not divide at this point which form of incineration, as for energy or plain substitution for landfill. Furthermore, recycling is indeed unclear. Clothes are usually reused for secondary sells or donations after the sanitary procedures. Other flows might be recycled in the sense of material recovery. Therefore, WEEE might be treated to extract precious materials and so on. Confusion of these two terms is evident in this case, and caution is needed when applying such data. In our case, we mainly focused on total collection and sorted ones. We left out the unsorted one.

## Tipping points and possible functional Forms

In this section we briefly present how first, and second moment change according to each parameter change. We refer to the equation for family of FF where the first polynomial is used. It takes such form:

$$y = ax + bx^c$$

Results are reported in table X are theoretical examination. It must be noted that complexity arises as each parameter is presented. Tipping points "x" in FF is strictly positive on "a". This is trivial as it represents the parameter of interaction between linear independent variable and dependent one. Hence, we have positive signs of both moments of "x" for "a". Parameter "b" is convex to its tipping point. This is where we can fine two different FF: either U or its inverted shape. Its signs are different. Last parameter we considered is "c". Here, the number of functional forms is the maximum reported in literature. Non linearities are evident as the value of "c" are influencing the sign of first moment. Tipping

[11] Translated by the authors from ISPRA Website

point of X is strictly linear to “c” when its values are less than one. In other cases, it is concave, denoting other non-linearities. Outside “N” structural forms of c<1, we cannot find examples in literature where this has different values.

*Table 4: First and second moments of the tipping point*

| | First derivative | Second derivative |
|---|---|---|
| a | $\hat{x}_a = \hat{x}\frac{1}{a(c-1)} > 0$ | $\hat{x}_{aa} = -(c-2)\hat{x}\frac{1}{a^2(c-1)^2} \quad c < 2, \hat{x}_{aa} < 0 \; c \geq 2, \hat{x}_{aa} \geq 0$ |
| b | $\hat{x}_b = -\hat{x}\frac{1}{b(c-1)} < 0$ | $\hat{x}_{bb} = c\hat{x}\frac{1}{b^2(c-1)^2} > 0$ |
| c | $\hat{x}_c = -\frac{ln\,(\hat{x})\hat{x}}{c-1} = \{c < 1, \hat{X}_c > 0 \; c > 1, \hat{X}_c < 0$ | $\hat{x}_{cc} = \left[\hat{x}ln(\hat{x})\frac{2}{(c-1)^2} + \hat{x}ln(\hat{x})\frac{1}{(c-1)} + \frac{1}{c^2(c-1)^2} + \frac{1}{c^2(c-1)} + \frac{2}{c(c-1)^2}\right] > 0$ |

In tab X we then synthesized how composition of these three parameters might plot different functional forms. We refer to the equation (1). This is the first generalization. It assumes that the exponent “c” might be different from 2, differently from what literature states. We can count more than ten theoretical functional forms. According to literature references, only three might represent waste income dynamics. We therefore plotted the main features. The most important changes might be captured according to c variation. The assumption that is strictly equal to two is probably limiting. According to this premise, we therefore established our approach of multiple FF or family approach.

*Table 5: All possible shapes that generalized FF take*

| | c = 0 | 0 > c > 1 | c < 0 | c > 1 |
|---|---|---|---|---|
| a < 0 b < 0 | Negative linear | Negative log | Negative linear | Exponential Negative |
| a > 0 b > 0 | Positive linear | Positive log | Positive linear | Exponential Positive |
| a > 0 b < 0 | Positive linear | "U" shape<br>Fast turning | Hyperbolic<br>3rd, 4th with 1st quadrant | Inverted "U" |
| a < 0 b > 0 | Negative linear | Inverted "U"<br>Fast turning | Hyperbolic<br>2nd, 4th with 1st quadrant | "U" |
| a = 0 b > 0 | No relation | Positive log | Hyperbolic 1th or 2th quadrant | Exponential Positive |
| a = 0 b < 0 | No relation | Negative log | Hyperbolic 3th or 4th quadrant | Exponential Negative |

## Table of model tests

In this section we shortly resumed table 6 for pre-selection tests. We tested for serial correlation (Breusch-Godfrey/Wooldridge), local cross-sectional dependence (Pesaran CD), Lagrange multipliers and their robust counterparts, five different Hausman tests and finally Honda tests for panel balance. Hausmann tests were divided in: ML individual (1), time (2) and two-ways (3) effect then GM time (4) and individual (5). The tests have a null hypothesis of fixed effect inconsistency versus an alternative of random effects inconsistency. These tests are relevant as the convergence rate of our model is not high. Low convergence in estimation make random effect regressors less efficient than fixed effect. In most articles we cited, both models are estimated. Local cross-sectional dependence represents a different definition of spatial dependence. The main purpose of the CD is to test dependence between observation. It can test global dependence without a spatial matrix or any weight matrix and local with one. We tested here for the second one with proof of presence. The difference with Moran I is the time frame. Pesaran CD can scope for local dependence across a timeline. The latter is strictly cross-sectional. To select the spatial lag, we used the Lagrange Multipliers. The robustness allows to rule out possible individual effects. Despite a change in magnitude of p-value, we register no change in test results apart from Glass. Honda tests are used to rule out inefficient fixed effect. When the p-value is above 0.1, we will consider the treated effect as inefficient.

*Table 6: Model Selection tests*

| Test | MSW.CAPITA | PAPER | ORGANIC | WOOD | METAL | PLASTIC | RAEE | SELECTIVE | TEXTILE | GLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| Breusch-Godfrey/Wooldridge test for serial correlation in panel models | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** |
| Pesaran CD test for local cross-sectional dependence in panels | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0.033** | 0*** |
| LM test for spatial error dependence | 0.005*** | 0*** | 0*** | 0*** | 0.056** | 0*** | 0*** | 0*** | 0.004*** | 0.292** |
| LM test for spatial lag dependence | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0.408** | 0*** | 0.013** |
| Locally robust LM test for spatial error dependence sub spatial lag | 0.083** | 0*** | 0*** | 0.06** | 0.001*** | 0*** | 0*** | 0*** | 0*** | 0*** |
| Locally robust LM test for spatial lag dependence sub spatial error | 0*** | 0*** | 0.001*** | 0.005*** | 0*** | 0*** | 0.001*** | 0.977** | 0*** | 0.099** |
| Hausman test for spatial models (1) | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0.023** | 0*** | 0.162** | 0*** |
| Hausman test for spatial models (2) | 0*** | 0.005*** | 0*** | 0*** | 0*** | 0.041** | 0*** | 0.475** | 0*** | 0*** |
| Hausman test for spatial models (3) | 0*** | 0*** | 0*** | 0*** | 0.914** | 0.099** | 0.673** | 0.033** | 0*** | 0.041** |
| Hausman test for spatial models (4) | 0*** | 0*** | 0*** | 0.002*** | 0*** | 0.915** | 0*** | 0*** | 0.009*** | 0*** |
| Hausman test for spatial models (5) | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** |
| Lagrange Multiplier Test (Honda) for unbalanced panels | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** |
| Lagrange Multiplier Test (Honda) for balanced panels | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** |
| Lagrange Multiplier Test time effects (Honda) for unbalanced panels | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** | 0*** |

# References


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