Industrial waste, green taxes and environmental policies in a regional perspective

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ABSTRACT
This paper analyses the effectiveness of regional governments’ environmental taxes and policies in reducing industrial waste. We propose a spatial and dynamic model for the Spanish regions during the period 1999–2017. The results suggest that there are spatial and dynamic components in the generation of industrial waste; and that the specific environmental tax policy applied to industrial waste is not very effective, although the induced effect of these taxes and other environmental policies reduces the waste generation. Our model also suggests a relative decoupling between growth and waste, although many regions are still far from the waste Kuznets curve (WKC) turning point.

KEYWORDS
industrial waste; waste tax; environmental policy; spatial effects; dynamic model; region

INTRODUCTION
Since the mid- to late 1980s, the presence of tax instruments such as taxes on industrial waste (i.e., landfill taxes, incineration taxes, etc.) has been continuously strengthened in environmental policies (Organisation for Economic Co-operation and Development (OECD), 1994; European Environment Agency (EEA), 2016b), by both central and sub-central governments (e.g., United States and Australia, or in the European Union (EU), Belgium and Spain). However, unlike what happens with urban waste,1 there is little empirical evidence to analyse the effects of these tax policies on the industrial sector. Most studies of industrial environmental damage have analysed the effects of economic growth or economies of scale on the environment, and the role played by the stringency of environmental policy, including taxation, among other economic aspects, but focusing on water pollution or atmospheric emissions (e.g., Cheng et al., 2016; Hettige et al., 2000; Liu et al., 2017; Morgenstern et al., 2002; Wang, 2000; Wang & Jin, 2007; and Xiong et al., 2018), rather than on solid industrial waste.

However, in more or less developed economies where sustainability, industrial waste generation is an important problem which merits specific analysis, separately from urban waste and pollution in general, as it may respond to different forces and behave differently, given the specific characteristics of this type of waste. On one hand, industrial waste is the largest source of total waste generation (EEA, 2019), and is also more dangerous, as much of it is classified as toxic and hazardous, and may be harmful to human health (EEA, 2016a; Glover, 2017). Also, industrial waste, once generated, is processed very differently from urban waste: it may require specific disposal methods, and often the large industries generating this waste are also responsible for eliminating or recycling it (McGlinn, 2000). In fact, the EEA itself regards industrial waste as distinct from urban waste, and treats it separately, and as OECD (2015) points out, a specific and complex set of environmental policies has been configured for the industrial sector. Meanwhile, industrial waste generation presents greater territorial heterogeneity than urban waste, as it depends on how industrialized a region is, and what industries operate there (Boschma, 2015). There is also greater spatial correlation of this waste, given that industrial specialization and economic development have a strongly territorial dimension, linked to the
development of industrial clusters (Battaglia et al., 2012). And the relative low or high stringency of environmental regulations can generate spillover effects, given that they affect how attractive a region is as a destination for factors of production and economic agents, and even for industrial waste itself. In fact, there is a vast debate on fiscal federalism relating to the tax competition processes which may arise among regions due to the undesirable effects of environmental policy on growth, employment, well-being and environmental damage (e.g., Dou & Han, 2019; Kunce & Shogren, 2005; Levinson, 2003; Metcalf & Stock, 2020). However, many studies do not find evidence of a competitive environmental tax exemption phenomenon (Fredriksson, 2000), and in some cases the literature even shows a race to the top in taxation (Levinson, 1996a; Millimet, 2003), as predicted in the theoretical models of Markusen et al. (1995) and Glazer (1999).

As far as we know, only three econometric papers analyse the relationship between taxing solid industrial waste and its generation (Deyle & Bretschneider, 1990; Sigman, 1996; Sasao, 2014b), although none properly takes into account two aspects which are fundamental to its study: (1) the spatial dependence between regions – in other words, the fact that public policies, industrial specialization and economic development have a strongly spatial dimension, which can also extend over time; and (2) that reducing industrial waste generation is costly and requires an investment process which can be time-consuming (Sasao, 2014a). For that reason, this paper will analyse the effectiveness at the regional level of environmental policy, including taxes, in reducing solid industrial waste, simultaneously taking into account these two aspects in the econometric specification, which have not been considered in the literature to date. So this paper not only contributes to covering the huge gap on this subject at the international level, but from a methodological perspective, this article represents an advance with respect to Deyle and Bretschneider (1990), Sigman (1996) and Sasao (2014b), as for the first time in the literature it considers the spatial dimension and dynamic component of the problem. To do this, we perform a maximum likelihood estimate using spatial econometrics techniques, specifically a dynamic spatial Durbin model (SDM), which considers both spatial (contemporary and non-contemporary) and dynamic effects, as well as including fixed effects and taking into account the possible existence of endogenous variables. Our analysis also considers other explanatory factors such as the regional productive structure, the intensity of the factors of production used by industry, certain regional socioeconomic characteristics, and business costs relating to industrial waste management and the environment in general responding to the implicit demands of environmental policy in those Autonomous Communities (ACs).

This study was conducted for the 17 Spanish ACs in the period 1999–2017, so it is also the first to analyse industrial waste generation in Spain using spatial econometrics procedures. The gradual introduction of environmental taxes, such as industrial waste taxes, by some Spanish ACs over the last two decades, the diversity of their design, and the disparity of the socioeconomic and demographic characteristics of the Spanish ACs provide a suitable scenario for this study because they form practically a natural experiment on environmental policy on industrial waste.

Our results show that there is a spatial and dynamic component in industrial waste generation in Spain, and that although environmental tax policy is quantitatively not very effective in reducing industrial waste, the induced effect of these taxes and other environmental regulations on firms (i.e., investment costs, and especially the operating costs of environmental policy for industries) does seem to achieve this aim. This result suggests that rather than just one environmental policy, it would be advisable to implement a range of policies to reduce the environmental damage associated with industrial waste generation (OECD, 1994). The other groups of variables considered in this analysis are also found to be relevant for explaining industrial waste generation. At the same time, our model suggests a relative decoupling in the waste Kuznets curve (WKc).

The remainder of the paper is structured as follows. Next, we briefly review the literature. We then propose the model and the hypotheses to be evaluated. We present the results obtained. The paper concludes with a section of final considerations.

**REVIEW OF THE LITERATURE**

The comparative literature has hardly any papers analysing whether industrial waste taxes actually reduce industrial waste generation. The descriptive paper by Andersen (1998) shows that from 1987 to 1993 the Danish tax reduced the waste generated in households and construction, but increased industrial waste. Some US government studies simulate the possible impact of state taxes on hazardous waste generation and management techniques (Congressional Budget Office (CBO), 1985; Environmental Protection Agency (EPA), 1984), and similarly, the EU has analysed the impact of different waste management instruments (BIO Intelligence Service, 2012). Nonetheless, as far as we know, only three econometric papers analyse the relationship between taxing solid industrial waste and its generation, without any encouraging results: Deyle and Bretschneider (1990) find a decline in hazardous waste management in New York State following a 1985 increase in New York’s waste-end taxes, although several other significant policy shifts might also have contributed to the decline. Sigman (1996) finds that the generation of industrial waste in the United States over the period 1987–90 does not change in response to the state taxes on land disposal (although its does respond timidly to taxes on incineration). Sasao (2014b) finds that taxes on industrial waste in the prefectures of Japan have hardly reduced its generation.

Although none of these papers uses spatial econometrics models to take into account the spatial nexus between regions, the last two do consider the fact that a
region’s tax decisions can have effects in neighbouring regions. Specifically, Sigman (1996) considers the possibility that taxes on waste incineration in neighbouring states influence (as an additional variable) waste generation in a state. Sasao (2014b) does the same in his study of waste sent to landfill (which he estimates either including or excluding the waste of neighbouring prefectures), although not in his study of generated waste.

This spatial dimension is also considered in the literature on urban waste and industrial pollution, generally using a spatial econometrics technique (e.g., Cheng et al., 2016; Liu et al., 2017; Mazzanti et al., 2012; Xiong et al., 2018) because it seems to have been shown that otherwise the results are skewed and inconsistent (Anselin, 1988).

A parallel literature, although collateral to our study, has been developed which analyses interjurisdictional regulatory or fiscal competition on waste (Fredriksson, 2000; Kunce & Shogren, 2005; Levinson, 2003) and the impact that such competition may have on waste imports or flow (Levinson, 1999a, 1999b; Sasao, 2014c, 2014d; Sturm, 2003), on the pollution haven hypothesis (Dou & Han, 2019; Levinson, 2000), on illegal waste disposal (D’Amato et al., 2014; Sasao, 2014c) or on how environmental taxes can change the way companies manage waste (Bartelings et al., 2005; Mazzanti et al., 2012; Mazzanti & Zoboli, 2009; Sigman, 1996).

**AN ECONOMETRIC MODEL FOR INDUSTRIAL WASTE GENERATION: PROPOSED HYPOTHESES**

According to the Instituto Nacional de Estadística (INE – National Statistics Institute) survey of waste generation in the industrial sector (Encuesta sobre generación de residuos en el sector industrial), very different volumes of waste are generated by the industrial sector in Spain at the regional level. As shown in Figure 1, Madrid and Cantabria are the regions or ACs that generate the most waste on average over the period studied in relation to their gross value added (GVA), followed by the Balearic Islands and Aragon. At the opposite extreme are Castilla-La Mancha, Castilla-León, the Canary Islands, Galicia and La Rioja.

In order to explain these differences in the volume of waste generated and analyse the sensitivity that industries display in their waste generation in relation to the stringency of environmental policy, we have followed Sigman (1996) and Hettige et al. (2000) in considering that industrial waste can be treated as an input in the production process, along with the conventional inputs (labour, capital and energy), and that the companies generating waste will try to minimize their costs, subject to a production function. As a key factor explaining the generation of industrial waste, we have used the business costs associated with the environmental policy of the AC, including taxes on industrial waste. We have also taken into account other variables such as income, enabling us to test the hypothesis of the WKC.

Also, as indicated above in the introduction, our proposed model takes into account the spatial dimension underlying waste generation by industries, and the persistence of this generation over time, as well as the fact that the spatial dependency may continue or diffuse over time. Thus, the model we propose is dynamic because it considers that the waste generation of a year may depend on past experience, due to the adjustment cost associated with a given industrial and business structure. Also, the model is spatio-temporal because it considers that waste generation in an AC may depend on waste generation in the other ACs, in both the same year and previous years; on certain explanatory variables in neighbouring ACs, relating to the degree of stringency of the environmental policies adopted; and on a combination of omitted variables which may be spatially correlated.\(^3\) We also include fixed effects to capture possible sources of variation in specific costs or specific characteristics of the ACs, and to avoid the results being skewed by the omitted variables.

We carried out our analysis for a sample of all 17 Spanish ACs over the period 1999–2017 with the following specification:

\[
W_{it} = \rho \sum_{j=1}^{N} \omega_{ij} W_{jt} + \partial \sum_{j=1}^{N} \omega_{ij} W_{jt-1} + \gamma W_{it-1} + \sum_{k=1}^{K} \sum_{i=1}^{N} \omega_{ik} z_{it} \beta_{i} + \sum_{s=1}^{S} \sum_{j \neq i}^{N} \omega_{sj} z_{jt} \varphi_{i} + \delta_{i} + \epsilon_{it}
\]

where \(W_{jt}\) measures the volume of industrial waste generated in the AC \(i\) (\(i = 1, \ldots, 17\)) in year \(t\) (\(t = 1999, \ldots, 2017\)); \(\rho\) is the spatial lag coefficient that measures global contemporary spatial dependence; \(\partial\) captures the global spatial diffusion factor produced over time; \(\omega_{ij}\) is the spatial weights used to capture the effect of industrial waste generation of AC \(j\) on AC \(i\), where \(\omega_{ij} \neq 0\), if ACs \(i\) and \(j\) interact, and by definition \(w_{ii} = 0\) (to simplify, we suppose that the matrix of spatial weights is the same as the matrix of spatio-temporal weights, even though they are measured differently); \(\gamma\) is the persistence coefficient of waste generation or the dynamic component; \(z_{it}\) is the \(k\) socioeconomic characteristics of AC \(i\); \(z_{jt}\) is the \(s\) characteristics of the neighbouring ACs \(j\), so \(\beta_{i}\) is the \(k\) coefficients of the variables \(z\) of AC \(i\); and \(\varphi_{i}\) is the \(s\) spatial coefficients of local dependence which capture the spatial effect of the explanatory variables of neighbouring ACs. We suppose that \(\rho, \partial, \gamma, \varphi,\) and \(\beta_{i}\) are constant over space and time; \(\delta_{i}\) captures the specific effect of each AC; and \(\lambda\) is the spatial autocorrelation error coefficient, with \(u_{it} = \epsilon_{it}\) in the absence of spatial dependence in the error term.

The definitions and descriptive statistics of the variables used in the model are summarized in Table 1. The correlation matrix of the main variables and the
variance inflation factor appear in Tables A1 and A2 in Appendix A in the supplemental data online, and we can derive from them that there are no serious problems of multicollinearity between the variables. The variables are expressed in logarithmic form, and we have grouped them in four blocks.

**Stringency of environmental policies**

Over the last two decades, several ACs (Figure 2) have established industrial waste taxes in order to reduce their generation and, in many cases, to cover the costs of environmental protection. To see whether these taxes de-incentivize industrial waste generation (static efficiency), we have included a variable to capture the level of taxes on industrial waste \( WASTETAX \). Although Figure 2 does not seem to suggest that the ACs imposing these taxes generate less waste after their implementation, the expected sign for this variable would be negative.

It is possible that waste taxes reduce waste generation not only directly but also indirectly through the investment processes they induce in firms (dynamic efficiency). Also, governments can establish regulations and other waste control measures apart from taxes, which can also encourage such investments (Leiter et al., 2011; Sigman, 1996). For this reason, we have included the variable \( WASTEEXPEND \), which is intended to capture the effect on waste generation of all industrial waste-related government measures (tax or other), which we have approximated through industries’ waste-related investment costs. This variable would be a proxy for the dynamic efficiency of waste taxes, and is expected to have a negative sign.

Most of the measures, taxes and regulations adopted in an AC in order to reduce environmental damage might give an idea of how much the AC is concerned about the environment (e.g., Fan et al., 2019; Ministry of the Environment, 1996), and they could lead to lower levels of waste and pollution by different agents, including waste-generating industries, whether this is thanks to raising awareness, the need to adapt to regional regulations, minimizing the tax burden or a combination of all these reasons (static efficiency). In Spain, as well as an industrial waste tax, some ACs have established a wide range of environmental taxes in their territories, which we think can influence the volume of industrial waste generated, given the synergies and interactions which seem to emerge between policies with different goals. This is why we have considered them in our analysis through the variable \( GREENTAX \). And as it is possible that taxation may not be the only source of variance in costs of waste management and pollution reduction (Dou & Han, 2019 and Sigman, 1996), we have also included the current expenditure \( GREENCURRENTEXP \) and capital expenditure \( GREENINVEST \) induced in industries by any...
Table 1. Variables, source and descriptive statistics.

| Variable  | Definition                                                                 | Source                                                                 | Mean       | SD    |
|-----------|----------------------------------------------------------------------------|------------------------------------------------------------------------|------------|-------|
| WASTE     | Solid industrial waste (tonnes)                                            | *Encuesta sobre generación de residuos en el sector industrial* (INE); *Registro estatal de emisiones y fuentes contaminantes – PRTR* (State Pollutant Release and Transfer Register) | 4,174,331  | 8,010,124 |
| WASTETAX  | Regional tax revenue from the tax on industrial waste/regional volume of industrial waste | *Haciendas autonómicas en cifras* (1999–2016) (Ministry of Finance)       | 0.94       | 6.76  |
| WASTEEXPEND | Business investments at the regional level relating to waste management/regional volume of industrial waste | *Encuesta del gasto de la industria en protección ambiental* (Survey of Industry Spending on Environmental Protection) (INE) | 3.40       | 4.85  |
| GREENTAX  | Regional tax revenue from environmental taxes/regional volume of industrial waste | *Haciendas autonómicas en cifras* (1999–2016) (Ministry of Finance)       | 171.41     | 580.60 |
| GREENCURRENTEXP | Current spending on environmental protection by regional industries/regional volume of industrial waste | *Encuesta del gasto de la industria en protección ambiental* (Survey of Industry Spending on Environmental Protection) (INE) | 74.39  | 87.30  |
| GREENINVEST | Regional investment in environmental protection by industries/regional volume of industrial waste |                                                                       | 38.85       | 53.71  |
| OUTPUT    | Industrial gross domestic product (GDP) of the region                       | INE                                                                   | 10,100,000 | 9,596,001   |
| DENSITY   | Number of industrial firms in the region/km²                               |                                                                       | 0.79       | 0.77  |
| INDWEIGHT | Industrial GDP/GDP                                                         |                                                                       | 20.06      | 7.00  |
| RECYCLING | Percentage of industrial firms in the region dedicated to waste recycling |                                                                       | 0.12       | 0.03  |
| WAGE      | Industry labour costs/regional GDP                                         | INE                                                                   | 47.85      | 2.37  |
| ENERG     | Energy production/regional GDP                                             |                                                                       | 0.03       | 0.01  |
| R&D       | Regional expenditure on research and development (R&D)/regional GDP        |                                                                       | 0.97       | 0.46  |
| INCOME    | Regional GDP per capita                                                   | INE                                                                   | 22.60      | 4.49  |
| OLDPOP    | Percentage of the population over 65 years                                 |                                                                       | 0.18       | 0.03  |

Note: INE, Instituto Nacional de Estadística (National Institute of Statistics).
environmental restrictions, regulations and controls set by the governments (Somanathan et al., 2014). These expenditures will enable us to approximate the dynamic efficiency of taxes to some degree. The expected sign of these three variables, which we use as proxies for the level of environmental awareness of an AC, will therefore be negative.

To adjust to the idea of the deferred impact of taxes as suggested in Levinson (1999a), we have lagged all these variables relating to the stringency of environmental policies. This in turn lets us eliminate the possible endogeneity problems which these variables could present, although our test in the results section confirms they are non-endogenous.

Regional productive structure
In this group of variables we have considered, first, the volume of industrial production (OUTPUT), as industrial waste generation would be expected to increase parallel with industrial production (Hettige et al., 2000; Levinson, 1996b; Sigman, 1996). Second, we have considered the productive structure hypothesis, because the relative importance of industry and relatively high land prices for industrial sites may influence the industrial waste generated in the region (Hettige et al., 2000; Sigman, 1996). To capture this hypothesis, we considered two variables. On the one hand, industrial agglomeration, which we approximate with the density of industrial firms in the AC (DENSITY). The concentration or clustering of industries in order to leverage the external economies of agglomeration and specialization of products, suppliers and labour, and of sector-specific associated services, with the possibility of joint access in the search for group efficiency. Therefore, a greater density of industrial firms in an AC means larger industrial clusters, generating larger agglomeration economies, so it would be reasonable to expect a positive sign for the variable DENSITY. On the other hand, we have considered congestion or the intensity of industry, which we approximate by interacting the density of industrial firms in the AC (DENSITY) with the relative importance of the industrial sector (IND-WEIGHT). When industrial concentration is excessive and the weight of the industrial sector is high, this can lead to congestion costs or agglomeration diseconomies (high land prices, etc.), which would be identified by a negative sign for this interaction, and could lead to the expulsion of industrial activity or transfer of firms to other ACs (Brülhart & Mathys, 2008). However, a negative sign in this interaction could also reflect the fact that although large industries, which tend to cluster geographically, are responsible for much of the generated waste, they usually manage their own waste internally (McGlinn, 2000). We also included a variable to capture the presence of recycling companies (RECYCLING), whose expected sign would a priori be undetermined, as a greater weight of these companies may reduce waste generation, as they may raise awareness of the need to reduce their impact on the environment, but they may also have the opposite effect, by encouraging the belief that the waste generated will be reused. They may also be linked to several political, socio-demographic, historical and other factors, reinforcing the indeterminacy of their expected effect. Jensen (2012), Glover (2017) and Erhardt (2019), among others, highlight the importance of considering this type of variable in their studies on waste.

Factors of production
In line with Sigman (1996) and Hettige et al. (2000), we will also consider the relative intensity, in terms of production, of the following inputs: income from wages.
(WAGE), capital endowment\(^7\) (R&D) and energy consumption (ENERG) of industries, as explanatory factors to determine whether their relationship with industrial waste generation is complementary or substitutional. If the relationships of the KLEM models are the same,\(^8\) materials-intensive production processes will tend to generate a greater volume of waste (Hettige et al., 2000).\(^9\)

Thus, in the Spanish case we might think that activities that consume raw materials intensively or are intensive in labour are typical of mature production processes with considerable negative impacts on the environment, expecting to obtain a positive coefficient for the wage variable (WAGE). Capital-intensive sectors (R&D) appear associated with more innovative activities with a less negative environmental impact, with a negative effect expected for this variable (Mazzanti & Zoboli, 2009). And high-energy consumption (ENERG) would have an undetermined effect on the generated industrial waste, because it captures a greater use of new capital assets, more efficient and less polluting, while alternately it is a symptom of antiquated production processes, energy intensive and with a high environmental impact.

### Socioeconomic variables

The inclusion of income or wealth (INCOME) and its square enable us to test the WKC hypothesis, according to which economic growth favours industrial waste generation until a maximum is reached, after which this waste generation decreases. This hypothesis rests on the argument that higher levels of development imply a change in the structure of the economy towards industry and services, where the production processes are based on more efficient technologies which help to conserve natural resources, thus considerably reducing environmental degradation (Grossman & Krueger, 1995).\(^10\) A negative sign for this variable in levels would indicate that we are on the downward slope of the environmental curve (absolute decoupling), while a positive sign for the variable in levels and negative for its square would reveal that we are on the upward slope, but with relative decoupling.

At the same time, we believe that the age of the population (AGEDPOP) may condition industrial waste generation, as, on one hand, the lower level of environmental awareness of an older population, and the lower costs of waste generation (due to the abundance of available space) associated with ageing and less densely populated territories, may lead to greater industrial waste generation, while, on the other hand, the aspects relating to less dynamic economies and less industrial activity in ACs with older populations may be more important. The expected sign of this variable will therefore be undetermined.

### RESULTS

As the literature suggests, we have considered the possible endogeneity of the explanatory variables relating to the volume of industrial production (OUTPUT), taxes (WASTETAX and GREENTAX), the business costs of waste management and pollution reduction (WASTEEXPEND, GREENCURRENTEXP and GREENINVEST) and the presence of recycling companies (RECYCLING). To do so, we have applied the Hausman procedure in two stages, using the lagged variables themselves as instruments, and we have calculated the Durbin and Wu–Hausman statistics, which, as can be seen in Table A3 in Appendix A in the supplemental data online, show that we cannot reject the null hypothesis of exogeneity of the variables. Meanwhile, the Sargan and Basmann tests indicate that we cannot reject the null hypothesis that the instruments used are valid.

At the same time, we tested the hypothesis proposed above of spatial dependence in the industrial waste generation model, using the Pesaran and Moran tests.\(^11\) Both tests (see Table A4 in Appendix A in the supplemental data online) confirm the presence of spatial dependence, so to keep the estimators consistent, spatial dependence models should be used, such as those proposed in (1). These models require the use of a spatial matrix (\(o\)) which includes the criteria of neighbourhood or proximity (Anselin, 2002), and is not related to the explanatory variables of the model. We opted for a \(17 \times 17\) spatial matrix that considers as neighbours the five nearest ACs in terms of geographical distance, which fits with Tobler’s (1970) consideration that nearby elements are more related than distant ones, while enabling us to avoid the problem of isolated ACs (Balearic and Canary Islands), or ACs with an unusually large number of immediate neighbours (such as Castilla–León and Castilla–La Mancha).\(^12\)

Table 2 summarizes the results of estimating industrial waste generation with different spatial fixed-effect models. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) model selection criteria, which appear at the bottom of Table 2, and the likelihood ratio (LR) and Lagrange multiplier (LM) tests, in Table A6 in Appendix A in the supplemental data online, suggest that the right spatial model for our estimation is the dynamic Durbin (dynamic SDM), shown in the two last columns of Table 2 under the headings dynamic SDM (a) and (b). In these two models the spatial dependence arises from the endogenous and the explanatory variables, but in dynamic SDM (b) the variable GREENTAX is constructed taking into account all environmental taxes except WASTETAX, which is, however, considered in dynamic SDM (a).

We estimated this spatial and dynamic model with panel data using quasi-maximum likelihood (QML) techniques which implement Lee and Yu’s (2010) data transformation for fixed-effect models, and using Driscoll–Kraay standard errors, which produce heteroscedasticity-robust estimators. The results corroborate the existence of a dynamic component (\(y\)) in waste generation, which shows a growing trend in industrial waste generation, that is, that the industrial waste a region generates today depends positively on the waste it generated in the past. We also see a spatial interaction in waste generation. In fact, the coefficients \(\rho\) and \(\delta\), which capture global
Table 2. Results of the estimates of fixed-effect models for industrial waste generation.

| Spatial autocorrelation model (SAC) | Spatial autoregressive model (SAR) | Dynamic SAR | Spatial error model (SEM) | Spatial Durbin model (SDM) | Dynamic SDM (a) | Dynamic SDM (b) |
|------------------------------------|-----------------------------------|-------------|--------------------------|---------------------------|-----------------|-----------------|
| \( \gamma = 0, \partial = 0, \varphi = 0 \) | \( \gamma = 0, \partial = 0, \varphi = 0, \lambda = 0 \) | \( \gamma = 0, \partial = 0, \) | \( \gamma = 0, \partial = 0, \varphi = 0, \lambda = 0 \) | \( \gamma = 0, \partial = 0, \lambda = 0 \) | \( \lambda = 0 \) | \( \lambda = 0 \) |
| Dynamic component (\( \gamma \)) | 0.044*** | 0.049*** | 0.048*** | 0.049*** | 0.048*** | 0.047*** |
| WASTETAX | −0.006 | −0.005 | 0.010 | −0.006 | −0.010 | 0.002 | 0.002 |
| WASTEEXPEND | −0.002 | 0.000 | 0.002 | −0.001 | −0.004 | −0.001 | 0.000 |
| GREENTAX | −0.010** | −0.010** | −0.007*** | −0.010*** | −0.013*** | −0.006** | −0.005* |
| GREENCURRENTEXP | −0.844*** | −0.841*** | −0.942*** | −0.841*** | −0.831*** | −0.935*** | −0.935*** |
| GREENINVEST | −0.076* | −0.076* | −0.031*** | −0.078* | −0.077* | −0.039*** | −0.040*** |
| OUTPUT | 0.561*** | 0.573*** | 0.648*** | 0.515*** | 0.606*** | 0.625*** | 0.613*** |
| DENSITY | −0.228 | −0.127 | 0.956*** | −0.157 | 0.029 | 1.013*** | 1.004*** |
| DENSITY*INDWEIGHT | 0.152 | 0.122 | −0.217*** | 0.129 | 0.074 | −0.230*** | −0.228*** |
| RECYCLING | 0.014 | 0.002 | −0.017 | 0.018 | −0.035 | 0.005 | 0.011 |
| ENERG | −0.035* | −0.027 | −0.050*** | −0.035* | −0.027 | −0.054*** | −0.054*** |
| WAGE | 0.889 | 0.555 | −0.166 | 0.834 | 0.583 | −0.148 | −0.195 |
| R&D | 0.181** | 0.187** | 0.258*** | 0.188*** | 0.161** | 0.245*** | 0.245*** |
| INCOME | −0.618 | 0.471 | 7.137*** | −0.460 | −0.255 | 6.522** | 6.554** |
| INCOME² | 0.007 | −0.200 | −1.176*** | −0.022 | −0.108 | −1.070** | −1.073** |
| OLDPOP | −13.283*** | −13.137*** | −11.772*** | −13.115*** | −12.583*** | −11.581*** | −11.728*** |

Spatial dependence

| Spatial correlation coefficient (\( \rho \)) | 0.028 | 0.044 | −0.043** | −0.143** | 0.101** | 0.096* |
| Space-time lagged dependent variable (\( \partial \)) | 0.004 | 0.035*** | 0.035*** |
| Spatial autocorrelation error coefficient (\( \lambda \)) | −0.355*** | −0.324*** |
| Spatial coefficient of local dependence (\( \varphi \)) | \( \omega \) WASTETAX | −0.027 | −0.031 | −0.031 |
| \( \omega \) WASTEEXPEND | −0.048 | −0.036 | −0.031 |
| \( \omega \) GREENTAX | −0.017* | −0.021*** | −0.024*** |

(Continued)
Table 2. Continued.

| Model | \(\gamma = 0\), \(\partial = 0\), \(\varphi = 0\) | \(\gamma = 0\), \(\partial = 0\), \(\varphi = 0\) | Dynamic SAR | \(\gamma = 0\), \(\partial = 0\), \(\rho = 0\), \(\varphi = 0\) | Spatial Durbin model (SDM) | Dynamic SDM (a) | Dynamic SDM (b) |
|-------|---------------------------------|---------------------------------|--------------|---------------------------------|-----------------------------|-----------------------------|-----------------------------|
| \(\omega\) GREENINVEST | \(\omega\) RECYCLING | \(R^2_{\omega}\) | \(R^2_{\omega}\) | \(R^2\) | Akaike information criterion (AIC) | Bayesian information criterion (BIC) | Log-likelihood | Observations |
| \(-0.071\) | \(-0.004\) | \(-0.001\) | \(0.093\) | \(-0.117\) | \(-0.113\) | \(-393.307\) | \(-388.704\) | \(-616.567\) | \(-394.870\) | \(-394.927\) | \(-624.154\) | \(-623.567\) | \(-1363.4303\) | \(-326.283\) | \(-325.403\) | \(-553.266\) | \(-331.571\) | \(-327.902\) | \(-560.853\) | \(-560.266\) | \(-1363.4303\) | 306 | 306 | 306 | 306 | 306 | 306 | 306 | 306 |

Note: \(\gamma\), \(\partial\), \(\varphi\), \(\lambda\) and \(\rho\) are the coefficients of specification (1).

In the SDM (b) model, the variable GREENTAX does not include waste taxes.

***Significance at 1%, **significance at 5%, *significance at 10%.
spatial dependence (in the endogenous variable), indicate the existence of a positive relationship (or contagion effect) in industrial waste generation between ACs, that is, that more industrial pollution in neighbouring ACs (now and, although less so, in the past) is associated with more waste generation by the AC itself. These results are consistent with the Spanish industrialization process, which was already highly concentrated geographically (in the north-east of mainland Spain), and has become more so thanks to specialization strategies and territorial agglomeration.

Our model also suggests that the existence of waste-producing industries in the productive structure of the ACs is the result of the interaction of centrifugal and centripetal forces associated with the broader environmental protection regulations adopted at the regional level. More specifically, it shows how waste generation increases when per capita income (INCOME), investment effort (R&D), recycling firms (RECYCLING) and industrial production (OUTPUT) increase, and when business agglomeration processes (DENSI01TY) intensify.13 Although the negative sign of the DENSITY*IND-WEIGHT interaction also demonstrates the presence of agglomeration diseconomies and congestion costs, which can make an industry move to another location, as has been noted in the literature (Brülhart & Mathys, 2008). The results also show that, as the WKC suggests, ACs move forward on the path of economic growth, industrial waste generation decreases. The positive but decreasing relationship shown between industrial waste and regional income (negative sign of INCOME) places us on the upward slope of the Kuznets curve, but with relative decoupling (as in Mazzanti et al., 2012, for municipal waste); the turning point is between €21,070 and €21,180 per capita, depending on the dynamic SDM considered (a or b). This means that although the average income level for the set of ACs is €22,600 per capita, the southern and western ACs have not yet reached this turning point.

In contrast, specialization in energy-intensive activities and ageing population structures, together with the public environmental policies introduced in recent decades, are forces allowing waste generation to be limited. In other words, our model suggests, as Hettige et al. (2000) stated, that energy consumption (ENERG) and waste generation are substitutional. However, we did not find any connection between ACs with labour-intensive industries (WAGE) and waste generation.14 Our model also shows that older populations (AGEDPOP) generate less industrial waste, which would be in line with the lower industrial specialization in areas that are less demographically dynamic. And finally, that the current and capital expenditure induced in the industries by any environmental policy set by the governments (GREENCURRENTEXP and GREENINVEST), and environmental taxation (GREENTA), contribute to reducing industrial waste generation (especially GREENCURRENTEXP, which presents 93% elasticity). Nevertheless, the scope of these variables does not appear to extend beyond the AC where the environmental policy is implemented. This would be in line with Nicoll and Mazzanti’s (2013) paper on urban waste, which also finds that the technological capacity installed in nearby regions is not significant. Only the coefficient \( \varphi \) of the variable GREENTA, which captures the local spatial dependence, suggests that a region’s waste generation will decrease as the stringency of environmental taxes in neighbouring regions increases.

Therefore, all the groups of explanatory variables are found to be significant for explaining industrial waste generation. However, neither taxes on industrial waste (WASTE TAX) nor the business investment induced by the regulations governing its management (WASTE EXPEND) are able to reduce its generation, in the AC itself or in the neighbouring ACs (\( \varphi \)).15 Also, this result does not seem to depend on the estimation technique used, as when we estimate the model using differences-in-differences, waste taxes are still no effective in reducing industrial waste. This can be seen in Table A7 in Appendix A in the supplemental data online, where we have included a dummy variable (dTreated), which takes the value 1 in ACs applying waste tax, and 0 otherwise; another dummy (dAfter), which takes the value 1 in years when waste tax is applied, and 0 otherwise; and a third dummy (dtItEration), which would be the interaction of the previous two (dTreated*dAfter), and which if not significant ratifies the results of our dynamic SDM: that waste taxes implemented at the regional level did not reduce industrial waste generation in Spain.16 This result, as the literature notes (Sigman, 1996), may be due to the low tax rates and the generous exemptions set by the ACs,17 which make the bill for waste generation affordable based on the industries’ profits. Low tax rates may conceal strategic behaviour, so the ACs set tax regulations which, while guaranteeing some form of compliance with the ‘polluter pays’ principle, do not lead to reductions in industrial waste, but rather are designed to attract firms for the purposes of tax revenue and economic stimulus (Lagares, 2014). In fact, there is anecdotal evidence of a certain race to the bottom in the context of the Spanish ACs and waste tax; for example, Madrid, which tends to apply lower tax pressure to its residents, reduced its tax rate in 2003. It has also been observed that ACs which have introduced this tax later than others have usually done so with lower tax rates than their neighbours, for example, Murcia and Extremadura, which established the tax after their neighbour Andalusia, set lower tax rates.18 If WASTE TAX is not found to be significant this may also be because dumpsites do not do a good enough job of passing on taxes to the waste-generating industries, fearing that they would then choose different dumps (Sasao, 2014b).19 The truth is that the result obtained comes as no surprise, given that the effect attributed to these taxes in the literature is quantitatively scanty or null (e.g., Sigman, 1996, and Sasao, 2014b, for industrial waste; Martin & Scott, 2003; Mazzanti et al., 2012, and Nicoll & Mazzanti, 2013, for urban waste; or even Im & Whonhyuk, 2010, and Loganathan et al., 2014, for emissions).
So is taxation inefficient in combating waste generation? Our model seems to indicate that although waste taxes do not seem to be effective, the aggregate of environmental taxes (GREENTAX), in both a given AC and its neighbouring ACs (φ), do succeed in reducing waste generation, whether for economic reasons, since a large part of the taxes are borne by the polluting industries in question, or because the taxes help to raise awareness. As we explain above, given the synergies and interactions that appear to arise between policies with different goals, the aggregate of environmental taxes might let us measure a sort of regional environmental awareness, which does not seem to be captured by waste tax alone. This is probably because the preferences and circumstances of each AC mean that each one prioritizes some environmental taxes over others, so that not all ACs have a waste tax, and where it exists, it is not equally relevant, etc. In any case, their coefficient (0.6%, and 0.2% for neighbouring ACs) indicates that the effectiveness of these taxes is really very minor.

We tried including other variables, such as those relating to education or political differences, but they were not found to be significant and did not improve estimation, so we chose not to include them in the model and thus avoid reducing the degrees of freedom.

**CONCLUSIONS**

This paper helps to fill a large gap in the literature on the effectiveness of environmental taxes in reducing industrial waste, which is needed given the specific characteristics this type of waste presents, compared with urban waste and other forms of pollution. It is also the first paper to analyse this question while also taking into account spatial dependence between regions and the persistence of waste generation over time. It also suggests the existence of centrifugal and centripetal forces, associated with tax competition effects for environmental protection actions, which help to explain the existence of polluting industries in the productive structure. We conducted the study for Spanish ACs in the period 1999–2017, because the gradual introduction of environmental taxes by some Spanish ACs, the diversity of their design and the different characteristics of the ACs make this scenario a kind of natural experiment, ideal for this kind of analysis.

The results show that there are dynamic and spatial components in industrial waste generation in Spain, indicating that the waste generated in an AC depends on both the waste generated by its neighbouring ACs and the waste it generated in the past. The model also suggests that although the environmental tax policy adopted by the Spanish ACs enables them to comply with the ‘polluter pays’ principle, it is quantitatively not very effective in combating industrial waste generation. However, the induced effect of taxes and other environmental regulations on firms (i.e., investment costs, and especially current expenditure by industries due to such policies) do actually appear to discourage industries from generating solid waste. Therefore, Spanish governments should continue and even intensify their environmental regulation and control policies, as it appears that the actions taken so far are bearing fruit. Moreover, our model suggests that rather than just one environmental policy, it would be advisable to implement a range of policies to reduce the industrial waste generation.

Also, the results corroborate a relative decoupling situation for the WKC, which demonstrates the efforts Spanish ACs are making to grow while controlling the industrial waste generated. In any case, the quantitative importance of the variable INCOME suggests that we are still far from the turning point needed to achieve absolute decoupling between growth and waste generation.

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**DISCLOSURE STATEMENT**

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**NOTES**

1. There is abundant literature on urban waste (e.g., Bartelings et al., 2005; Mazzanti & Zoboli, 2009; Mazzanti et al., 2012; Nicoli & Mazzanti, 2013).
2. It has also analysed the effect of variables such as the productive specialization of the economy, the size of firms, trade, employment or productivity, capital structure and ownership type, the structure and intensity of energy use, the importance of research and development (R&D) or investment in environmental protection technology.
3. Time lags on explanatory variables or the error term could also be incorporated; however, as Anselin et al. (2008) and Elhorst (2012) show, the parameters of such models are not identifiable.
4. Since the emissions tax introduced in Galicia in 1996, many more environmental taxes have been implemented in different ACs, making up the current wide-ranging and varied map of regional environmental taxes. Examples of these environmental taxes include: the atmospheric pollution tax of Galicia, Murcia, Aragon, Catalonia and Andalusia; the tax on facilities impacting the environment.
in Castilla–La Mancha, Asturias, Valencian C. and Extremadura; the tax on environmental damage caused by certain uses of reservoir water in Aragon and Galicia; or the tax on large commercial establishments in Asturias and Aragon (for these, see the Ministry of Finance’s website – Portal Institucional del Ministerio de Hacienda).

5. Opposing the inclusion of tax variables, an alternative strand of the literature opts to define global indexes of policies and regulations on the environment or pollution (Çagatay & Mihçi, 2003; Brunel & Levinson, 2016).

6. The substitution relationship between economies of scale and transport cost is the main reason for industrial agglomeration (Krugman, 1998). Dou and Han (2019) measure the degree of economic agglomeration with non-agricultural production per km² and use the regional weight of industrial gross domestic product (GDP) to express the economies of scale of the industrial sector. The greater the weight of industry, the better the industrial base, and this positive external effect is useful for improving the efficiency of production and attracting industries.

7. Given the strong correlation between capital endowments and regional income, we have used regional expenditure on R&D as a proxy for capital endowment.

8. Hettige et al. (2000) indicate that the econometric estimates of KLEM models (capital, labour, energy, materials) suggest that K and E are complementary, as are L and M, while the pairs KE and LM are substitutional.

9. The use of materials is not included because we do not have territorialized information for the ACs.

10. Hettige et al. (2000) explain that the initial phases of industrialization generate heavy pollution loads as raw materials are converted to primary inputs (e.g., metals, paper, cement and sugar). However, during the economic development process, primary industries have a lower share of production as cleaner industries increase (e.g., vehicle assembly and electronics). Meanwhile, Nicollì and Mazzanti (2013) posit that as environmental quality is generally considered a normal good, it is plausible to suppose that wealthier ACs can demand stricter regulations, and therefore their pollution levels will be lower, with income showing a negative coefficient.

11. With Moran’s test, Mazzanti et al. (2012) do not find spatial dependence for landfill waste at the level of provinces in Italy, although their paper focuses on municipal solid waste for the period 2011–07. Also, they observe an initial situation with relevant spatial dependence for generated waste, prior to the effective introduction of economic-based management instruments, followed by a period without spatial dependence, probably related to a spatially progressive homogenization in urban waste generation, and no clustering at regional or interregional levels.

12. Matrices with other specifications produce worse results, as can be seen in Table A5 in Appendix A in the supplemental data online.

13. Mazzanti et al. (2012) also find a direct relationship between density and municipal waste generation.

14. This result is in line with Sigman (1996), although Hettige et al. (2000) find complementarity between labour and industrial water pollution.

15. However, Sigman (1996), while not using spatial econometrics, obtains high elasticity for state taxes on incineration, in both the state itself and neighbouring states.

16. We thank a reviewer for the suggestion to use differences-in-differences to test the robustness of our results.

17. Despite Spain being urged by various international organizations, on numerous occasions, to raise its environmental taxes (e.g., OECD, 2015; European Commission, 2019), in 2015 it ranked fourth from last in the EU-28 countries in terms of the weight of environmental taxes within national GDP (Hogg et al., 2016).

18. We also interacted the variables WASTETAX and WASTEEXPEND to see the effect of raising investment spending in response to changes in tax levels, although this interaction was not found to be significant or to improve the model.

19. Spain is one of the countries that the European Commission has referred to the European Court of Justice for breaching the requirements of the EU Landfill Directive (EEA, 2019).
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