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When Neighbours Matter: Asymmetries in Environmental Tax Responses Driven by Regional Context

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Abstract This paper explores the asymmetric nature of spatial interactions in environmental taxation. The analysis focuses on the intermediate level of government in Spain—namely, the regions—and is based on an extended dynamic spatial Durbin model. While the initial results confirm the existence of spatial dependence—where regions tend to imitate their neighbours' revenue-based measure of environmental tax stringency—the extended model, which interacts the spatial lag of the dependent variable with an index capturing the characteristics of neighbouring regions, reveals that this imitation is far from uniform. Specifically, regions tend to emulate the environmental tax behaviour of the neighbouring regions when these are prosperous but choose to behave differently when the neighbouring economies are poorly developed, with sluggish or stagnant markets. In this scenario, they opt for tax competition to attract firms. Moreover, tax interaction is minimal when neighbouring regions have very low environmental tax revenues or have a minority government. These findings challenge uniform approaches to environmental tax coordination and highlight the need for strategies that account for regional heterogeneity.

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1 Introduction

Environmental taxation is a key instrument in the fight against environmental degradation, and its use has intensified globally in recent decades. However, implementing such policies in decentralised economies introduces complex dynamics due to tax interactions between jurisdictions, which can greatly influence the effectiveness of environmental policy.

Research has shown strong spatial interdependence in environmental regulation, explained by three main theoretical frameworks that often operate simultaneously: spillovers or pollution externalities (Sigman 2002; Helland and Whitford 2003); tax competition theory, where jurisdictions compete to attract large industries, based on the seminal work of Zodrow and Mieszkowski (1986), Wilson (1986), Wildasin (1988); and/or the yardstick competition theory, which is based on the desire of governments to be re-elected and was developed by Besley and Case (1995), based on contributions by Salmon (1987). However, this interdependence does not operate uniformly. Recent studies suggest that jurisdictions behave in diverse ways, influenced by differences in economic size, structure, and institutional context. As a result, even geographically close regions may respond differently to similar pressures, leading to variations in the intensity and direction of strategic interactions.

Despite the theoretical and practical relevance of these findings, there is a notable gap in the literature: spatial interactions between subnational jurisdictions have been largely overlooked in the context of environmental taxation. Even more critically, little attention has been paid to the potential asymmetry of these interactions—a crucial aspect, since if these asymmetries exist, the design of environmental tax policies would necessarily need to adapt to territorial heterogeneity in order to maximise their effectiveness.

This research addresses this gap, with a dual objective. First, it analyses the factors influencing a revenue-based measure of regional environmental tax stringency, while also testing for the presence of spatial dependence. Second, it examines whether the strength and direction of this spatial dependence vary according to the various socioeconomic, institutional, and political characteristics of neighbouring regions, as well as their relative environmental tax revenues per firm.

We will analyse these questions for the intermediate level of government in Spain (regions, also known as Autonomous Communities) and the period 2005–2019. This case is particularly relevant, as regional governments have taken a leading role in environmental taxation, while the central government has remained relatively passive. We use an extended dynamic spatial Durbin model with interaction terms (asymmetry indices) to rigorously capture the different behavioural patterns.

This paper makes a significant contribution to the limited literature on spatial dependence in environmental taxation. It is the first to apply advanced spatial econometric techniques to this topic while explicitly accounting for regional heterogeneity. It is also the first study of its kind focused on Spain.

Our results indicate that there are substantial spatial dependence relationships between the Spanish regions, which influence their revenue-based measure of environmental tax stringency. Moreover, our model suggests that explanatory variables of a region's environmental taxation have effects beyond the region itself and it reveals that the economic, political and institutional characteristics of neighbouring jurisdictions condition the spatial dependence relationships arising in regional environmental tax outcomes.

The paper is structured as follows: Section 2 reviews the literature and outlines the theoretical framework. Section 3 describes the Spanish regional government system and its environmental tax landscape. Section 4 presents the spatial model and hypotheses. Section 5 discusses the empirical results. Section 6 explores the asymmetric patterns in spatial dependence. The final section offers concluding remarks.

2 Literature Review: Theoretical Foundations for a Model of Asymmetric Spatial Dependence in Environmental Taxation

Environmental taxation is theoretically grounded in the concept of negative externalities, as developed by Pigou (1920). This framework posits that economic activities generating pollution impose costs on third parties that are not adequately reflected in market prices, creating a divergence between private and social costs and leading to socially suboptimal levels of pollution. Pigouvian taxes aim to internalise these external costs into production and consumption decisions, encouraging economic agents to consider the environmental impact of their actions. The practical implementation of environmental taxation finds its modern expression in the 'polluter pays' principle, formalized by the OECD in 1972, which has since become one of the fundamental pillars of environmental policy. Over time, an additional dimension has been incorporated into the design of these instruments: beyond their corrective function, environmental taxes are also intended to generate public revenue that can be used to reduce more distortionary forms of taxation. This dual objective yields both environmental and economic benefits (OECD 2021a), a phenomenon known as the "double dividend" (Ekins 1999).

In decentralised contexts, tax design is often shaped by strategic interactions between jurisdictions through two main mechanisms (Brueckner 2003). The first is traditional tax competition, where jurisdictions compete to attract or retain mobile productive resources, particularly capital and firms (Zodrow and Mieszkowski 1986; Wilson 1999). In the environmental domain, this competition can lead to downward pressure on environmental taxes to prevent the relocation of economic activities to areas with lower environmental tax burdens—a dynamic known as the "race to the bottom." The second mechanism is yardstick competition, where citizens evaluate the performance of their governments by comparing them with neighbouring jurisdictions (Besley and Case 1995). This benchmarking process creates political incentives for tax convergence or mimicry, as governments seek to avoid significant deviations that might be perceived negatively by voters. The combination of these mechanisms generates spatial patterns of tax dependence that justify the empirical use of spatial econometric models, as demonstrated by Allers and Elhorst (2005) and Devereux et al. (2008).

However, traditional literature on spatial interaction has operated under an implicit assumption that recent empirical evidence has begun to challenge: the idea that all jurisdictions respond to their neighbours in a uniform and identical manner. This assumption of uniformity fails to account for the possibility that the intensity of interaction may depend on key factors such as economic size, productive structure, agglomeration economies, or the institutional characteristics of neighbouring jurisdictions.

This limitation is particularly problematic given the significant disparities among jurisdictions in areas that, theoretically, should lead to differentiated strategic behaviour. Recent studies show that environmental regulation interactions do not follow uniform patterns. In some contexts, they manifest as a "race to the top" (Millimet 2003; Bernauer and Caduff 2004; Zhang et al. 2021), while in others, they resemble a "race to the bottom" (Woods 2006; Zhang et al. 2022). As Revelli (2005) notes, identifying the underlying drivers of these interaction patterns is complex and requires models that allow for variation in both the intensity and direction of spatial effects. This perspective is reinforced by Koninsky (2007) and Jin and Shen (2018), who argue that the heterogeneity of jurisdictions could mean that races to the top can exist side-by-side with races to the bottom in their environmental regulations.

This asymmetry in interaction patterns can be explained by several theoretical frameworks. The concept of selective political learning (Meseguer 2005) suggests that governments tend to observe and emulate only those jurisdictions with which they share relevant characteristics, such as structural similarities, economic success, or political alignment. Similarly, the theory of asymmetric strategic interaction (Brueckner 2003) posits that regions adjust their policies based on perceived incentives, which vary depending on the "type" of neighbour. These asymmetric dynamics are particularly evident when considering relative economic development. Koninsky (2007) argues that wealthier, denser, or more dynamic regions may exert a leadership or attraction effect due to their greater normative influence or standard-setting capacity. This view aligns with the literature on new economic geography (Krugman 1991), which highlights how agglomeration economies create hierarchical territorial structures, with centrifugal spatial dependence patterns where economic centres lead and peripheral regions adopt reactive or compensatory strategies.

The literature on asymmetric federalism—where some regions enjoy greater tax autonomy than others—and on spatial transaction costs also suggests that institutional factors can shape jurisdictions' exposure to competitive pressures and economic flows, influencing their capacity to generate meaningful spatial dependencies (Rodden 2006; Atella et al. 2014). Moreover, the political dimension adds another layer of complexity to these asymmetric interactions. Studies have shown that factors such as government composition, stability, and ideology influence the likelihood of tax imitation (Allers and Elhorst 2005; Volden 2006). In this framework, regional governments with parliamentary majorities or ideological alignment with neighbouring administrations are more likely to observe and harmonise decisions—sometimes even receiving direct guidance if they belong to the same national party. In contrast, politically fragmented or ideologically divergent contexts tend to weaken coordination mechanisms, leading to more defensive, autonomous, or idiosyncratic strategies. As a result, distinct territorial clusters emerge on the tax map, reflecting the underlying political dynamics.

In the specific context of environmental taxation, these asymmetries acquire particular relevance. Governments may imitate the lax tax behaviour of neighbours with low environmental tax pressure or even respond strategically to avoid industrial relocation (Fredriksson and Millimet 2002). Richer jurisdictions might not respond to the actions of poorer regions, while poorer jurisdictions could react to the policies of both rich and poor neighbours. Similarly, regions whose economies rely heavily on polluting industries may pay closer attention to the practices of similarly pollution-intensive jurisdictions than to those whose economies are based on cleaner sectors. In this way, geographic proximity does not guarantee uniformity in strategic behaviour; rather, each jurisdiction's tax response is shaped by the characteristics of its surrounding regions, resulting in a complex mosaic of territorially differentiated interactions.

Despite the theoretical importance of these ideas, empirical evidence on spatial dependence in environmental taxation remains surprisingly limited. Very few papers analyse spatial dependence relationships specifically in the field of environmental tax policy. As far as we know, only Levinson (2003), Ashworth et al. (2006), and Renard and Xiong (2012) have analysed this topic, obtaining a positive association between some form of environmental tax among US states, Flemish municipalities, and Chinese provinces, respectively. However, the econometric techniques available for these papers were still in the very early stages, and none of them accounted for the territorial differences which could condition that spatial dependence, possibly skewing their estimates.

Nevertheless, in recent years a literature has emerged which focuses on a series of aspects, such as those relating to institutions, which can influence the spatial dependence relationships seen among jurisdictions. In the field of environmental policy, Perkins and Neumayer (2012) studied the so-called "California Effect," finding evidence of the diffusion of stricter environmental standards, especially where strong trade ties exist. The work of Wu et al. (2021) is particularly interesting, as it finds evidence that spatial interaction in the field of environmental regulation is more marked in jurisdictions with younger leaders and takes place only between towns in the same province. More recently, Chen et al. (2023) have shown that environmental taxes exhibit significant spatial autocorrelation and generate spillover effects on neighbouring provinces' carbon emissions, while Rao et al. (2023) document spatial dependence between environmental taxes and green economic efficiency across Chinese regions. Li et al. (2024) and Shangguan et al. (2022) provide evidence that fiscal interactions, although unrelated to environmental taxes, are themselves conditioned by regional characteristics. Likewise, Yang et al. (2023) disentangle the mechanisms of tax competition by incorporating regional heterogeneity into spatial models, while Deng et al. (2022) reveal that the effects of tax competition are nonlinear and vary with regional characteristics, such as economic development and pollution levels. Parent and Lesage (2008), Gérard et al. (2010), Cassette et al. (2012), Atella et al. (2014), and Yu et al. (2016), among others, also take institutional and/or socioeconomic aspects into account when measuring spatial spillovers, although in areas not related to ecological regulation, such as direct taxation, healthcare costs, knowledge, or investment.

In sum, the literature lacks studies that systematically analyse the asymmetric patterns of spatial dependence in regional environmental taxation. This gap is particularly relevant given that, as we have seen, existing theoretical frameworks not only support the plausibility of such asymmetries but also suggest that they may play a crucial role in understanding the effectiveness of environmental tax policies in decentralised contexts.

This study therefore aims to address this gap by analysing whether spatial dependence in revenue-based measure of environmental tax stringency follows asymmetric patterns depending on a set of socioeconomic, institutional, and political characteristics of neighbouring regions, as well as their relative levels of environmental tax stringency. The setting for our analysis is the Spanish regions, where the combination of high fiscal decentralisation and pronounced regional heterogeneity offers an especially suitable context for this type of investigation.

3 The Spanish Context

Spain is not strictly speaking federal, although it is as heavily politically and economically decentralised as any federal country (İrepoğlu 2016). The 1978 Constitution (Constitución Española, CE) establishes three levels of government: central, regional, and local. Part VIII of the Constitution sets out the core areas of the decentralisation process, assigning the central level exclusive powers (Article 149) to ensure the unity and identity of the Spanish economic system and national economic policy and regulate the sectors with significant externalities. All other matters correspond to the regions (art. 149.3) if they are included in their Statutes of Autonomy or in Article 148 of the CE. At the local level—which includes municipalities and provinces—responsibilities are designed to meet the needs of local populations and to complement the functions of other levels of government, as established by the Ley de Bases del Régimen Local (LBRL). This distribution of responsibilities has resulted in regional governments becoming the primary actors in public spending and investment (Catalina 2009). The regional level is territorially organised into 17 Autonomous Communities (and 2 Autonomous Cities).

Spain's regional financing system is characterised by a notable institutional duality, with two clearly distinct funding systems operating in parallel. On the one hand, the "common system," which applies to 15 Autonomous Communities and is regulated by the Organic Law on the Financing of Autonomous Communities (LOFCA). This model grants limited tax autonomy and prevents these regions from levying taxes on matters already taxed by the central or local governments. On the other hand, the "foral system," in place in the Basque Country and Navarre, is rooted in historical rights and provides significantly greater tax autonomy. Under this system, these regions collect nearly all taxes within their territories and subsequently make a contribution to the central government (the "cupo" in the Basque case and the "aportación" in Navarre) to fund non-devolved state responsibilities.

This institutional framework has enabled the Spanish regions to establish their own taxes, particularly in the field of environmental taxation, where they have taken a leading role in response to the limited initiative shown by the central government[1]. Since the 1980s, the regions have developed an increasing number of environmentally motivated taxes, resulting in a markedly asymmetric and fragmented tax landscape (Labandeira et al. 2009). According to the Ministry of Finance—Ministerio de Hacienda (2023), there are currently more than 80 region-specific taxes across the Autonomous Communities, 56 of which are environmental in nature. These taxes can be grouped into four broad categories (Gago and Labandeira 2014): taxes on pollutant emissions, water discharges, waste, and facilities with environmental impact. Their development has varied widely across regions. For example, in 2019, Catalonia had eleven environmental taxes, Andalusia and Aragon each had five, Cantabria had two, Madrid had one, among other regions. Furthermore, each region has full legislative authority over its environmental taxes, independently determining aspects such as the taxable base, tax rates, and tax benefits.

In 2019, revenues from all environmental taxes represented just over 5% of Spain's total tax revenue (both central and regional), a figure that is very close to the average for both the OECD and the European Union, according to Eurostat. Data from the Spanish Ministry of Finance for that same year indicate that regional governments obtained 9.6% of their total tax revenue from environmental taxes, thereby highlighting the proactive role of regional authorities compared with the relative inaction of the central administration in this area.

In comparative terms, Spain's model of tax decentralisation also occupies an intermediate position among decentralised systems (OECD 2021b; Dougherty and Montes-Nebreda 2023). For example, in Germany, the management of environmental taxes falls exclusively under the federal government, leaving the Länder with very limited room for action (OECD 2023). In Italy, although regions have regulatory authority to establish their own taxes, their application in the environmental field has been more limited and scattered (OECD 2013). By contrast, Belgium, with a more consolidated federal structure, grants regional governments broad control over environmental taxation—particularly in areas such as waste and water—and benefits from more developed coordination mechanisms (OECD 2022). Viewed within this broader context, Spain's model combines a relatively high degree of regional tax autonomy with limited interregional coordination. The lack of coordination has led to a patchwork of disparate tax instruments, which may distort business location decisions and lead to "tax exportation" effects between neighbouring regions (Gago et al. 2016). These dynamics are further intensified by geographic proximity and economic interdependencies (López-Laborda 2011), especially along development or industrial concentration corridors such as the Ebro Valley (Aragón-Navarra-La Rioja), the Mediterranean Arc (Catalonia-Valencian Community), or the Cantabrian coast (Basque Country-Asturias), where significant cross-border environmental externalities emerge.

In addition, significant socioeconomic disparities among regions shape both the feasibility and the strategic approaches to implementing environmental taxes. The

[1] The lower lier of government does not utilise these taxes either.

political-institutional dimension also plays a crucial role. Political turnover and the ideological orientation of regional governments can modulate the ambition of environmental policies, which tend to be more progressive under left-leaning governments, such as those in Catalonia, Andalusia, or Aragon (Costa-Font and Rico 2006). Similarly, institutional factors—such as the foral system (García-Milá and McGuire 2007) or insular isolation—can have a differentiated impact on spatial dependency patterns.

In sum, the Spanish institutional and fiscal framework—combining a high degree of regional autonomy with limited interterritorial coordination—constitutes a particularly suitable setting for analysing the dynamics of tax competition and interaction in environmental matters within decentralised contexts.

4 Model and Hypothesis

The theoretical foundation of our empirical strategy is rooted in the classical framework of tax competition, which posits that subnational governments compete to attract mobile capital and economic activity by adjusting their tax policies. Within this competitive environment, regional authorities must strike a balance between maintaining fiscal revenues and preserving their economic attractiveness. This logic is further enriched by complementary theories, such as the double dividend hypothesis, and the yardstick competition model. In this context, each region is assumed to determine its level of environmental taxation based not only on internal factors—such as environmental pressure, regulatory stringency, economic development, tax capacity, and political characteristics—but also in response to the tax behaviour of neighbouring jurisdictions. This interdependence provides a strong empirical justification for the use of spatial econometric models, as demonstrated by studies such as Allers and Elhorst (2005) and Devereux et al. (2008), although their application in the field of environmental taxation remains relatively uncommon, which is precisely the focus of this paper.

Our analysis is based on panel data covering the 17 Spanish autonomous communities over the period 2005–2019. As illustrated by the line series in Fig. 1, environmental taxation per industrial firm followed distinct trajectories across regions. However, the bar chart in the same figure reveals that, on average, environmental tax revenue per industrial firm exhibited a steady upward trend across the Spanish autonomous communities throughout the study period. Figure 2 further shows that this trend is driven by an increase in environmental tax revenue (black line), rather than by a reduction in the number of industrial firms (orange line).

We use a dynamic spatial model which enables us to consider both the spatial dependence relationships which may arise, and the persistence over time or stability usually found in environmental tax policy. This model has the following general specification:

$$ET_{it} = \xi ET_{it-1} + \rho \sum_{j\neq i}^{N} \omega_{ij} ET_{jt} + \mu \sum_{j\neq i}^{N} \omega_{(ij)t-1} ET_{jt-1} + \sum_{m=1}^{M} x_{itm}\gamma_m + \sum_{v=1}^{V}\sum_{j\neq i}^{N} \omega_{ij} x_{jtv}\alpha_v + \delta_i + \tau_t + u_{it} \quad (1)$$

$$u_{it} = \lambda \sum_{j\neq i}^{N} \omega_{ij} u_{it} + \varepsilon_{it},$$

With $i = 1,...17$ and $t = 2005,...2019$.

Where ET_{it} is the effective tax rate or average revenue per industrial firm obtained in the year t from the environmental taxes of region i. To construct this variable, we aggregate the total revenue from all environmental taxes levied by each region. This approach reflects the fact that interregional tax interaction does not necessarily occur for a specific environmental tax, but rather across the broader category of environmental taxation (Berry and Berry 1992). This revenue is then normalised by the number of industrial firms in the region[2], which allows us capture both theoretical and empirical considerations relevant to the analysis of environmental tax competition. From a microeconomic perspective, environmental taxes are designed as Pigouvian instruments to internalise negative externalities, and their effectiveness depends more on the tax burden per polluting unit than on the economic size, productivity or tax capacity of the firm. Therefore, this measure aligns with the "polluter pays" principle, as each industrial firm represents a potential source of environmental impact. It also captures key dynamics of subnational tax competition, such as the potential relocation of industrial activity in response to tax pressure. Moreover, by focusing on the number of productive units rather than their economic scale, our dependent variable reduces structural bias across regions and enhances comparability. It also offers methodological advantages over alternatives like revenue-to-GDP ratios: it is more stable across economic cycles, less sensitive to the informal economy, and based on standardised administrative records. This measure reflects policy outcomes rather than policy design in the strict sense, as it may be influenced by economic activity, compliance behaviour, and administrative efficiency. However, in contexts of strategic tax interaction between regions, effective revenues constitute a relevant observable indicator of the actual tax burden, given that statutory rates may differ substantially from effective rates due to exemptions, enforcement gaps, or evasion. Accordingly, we use this average revenue per industrial firm as a proxy for the stringency of environmental taxation in each region.

The coefficient ρ measures the level of interaction between the revenue-based measure of environmental tax stringency of the regions, or contemporaneous global spatial dependence; in other words, how much the environmental tax stringency of

[2] The concept of 'industrial firm' is based on the official CNAE classification included in the Spanish Central Business Register (DIRCE) and encompasses sectors with a high environmental impact (such as extractive industries, manufacturing, energy supply, waste and water management) which account for over 80% of regional environmental tax revenue.

region i depends on the current stringency of the neighbouring regions, j, a phenomenon which has been labelled tax imitation or tax competition between governments. The coefficient μ measures non-contemporaneous global spatial dependence, that is, how much the environmental tax stringency of a region today depends on that of its neighbouring regions in previous years. The coefficient ξ captures the dynamic component, i.e., the degree to which a region's environmental taxes depend on those it had in the previous year, given that taxes are usually intended to continue from year to year.

The parameters γ_m capture the effect of the m observable characteristics of region i, x_{im}, on its revenue-based measure of environmental tax stringency Their inclusion follows directly from Section 2. Accordingly, and in line with tax-competition models where governments balance environmental ambition against the risk of firm relocation (Zodrow and Mieszkowski 1986; Wilson 1986; Brueckner 2003), we include variables that proxy both exposure to mobile, pollution-intensive activity and the capacity to sustain higher environmental taxes: *industrial_weight* and *agglo* reflect the economic importance and spatial concentration of industry, linked to lobbying pressure and relocation risk (Levinson 2003; Potoski and Woods 2002)[3]; *income* captures the level of economic development, allowing for potential nonlinearities consistent with environmental Kuznets curve arguments; and *unemployment* represents cyclical constraints that may heighten sensitivity to competitive pressures. Moreover, the Pigouvian rationale (Pigou 1920) and the double-dividend hypothesis (Ekins 1999; OECD, 2021a) motivate the inclusion of variables related to environmental pressure and revenue needs. In this regard, *pollution* proxies demand for corrective instruments, *regulation* captures the availability of regulatory substitutes or complements, *public_expenditure* reflects revenue requirements, and *direct_tax_revenue* identifies the scope for substitution between environmental and other taxes. *Pollution* and *regulation* have been lagged by one year. In addition, yardstick-competition arguments (Salmon 1987; Besley and Case 1995) support the inclusion of political variables affecting incentives to imitate neighbours. Thus, *ideology, electoral_support, coalition*, and *time_nex_election* capture how ideological orientation, parliamentary stability, political fragmentation, and electoral cycles condition governments' responsiveness to voter benchmarking. Finally, complementing the political mechanisms associated with yardstick competition, political economy research (Revelli 2005; Koninsky 2007; Perkins and Neumayer 2012) highlights that social preferences for environmental quality also shape the intensity of environmental taxation. These preferences are proxied by *educ* and *young_pop*, which capture

[3] Our specification does not incorporate sector-specific measures of pollution intensity or "industrial brownness". This choice stems from the nature of our dependent variable, which aggregates the revenue from all regional environmental taxes, each targeting different types of externalities (e.g., air emissions, waste, water discharges, or the impacts of specific facilities). Because economic sectors differ not only in how much they pollute but also in the type of externality they generate, a single sector-level indicator of "brownness" is not fully compatible with such an aggregated construct. Moreover, regional industrial structures in Spain exhibit strong temporal persistence, meaning that region fixed effects absorb most of this essentially time-invariant heterogeneity, thereby reducing the risk of omitted-variable bias arising from long-run structural differences across regions. Nonetheless, potential dynamic changes in industrial structure may still play a role that is not captured by our model, constituting a promising avenue for future research.

environmental awareness and intergenerational considerations, respectively, and by *pob_smalltowns*, which reflects rural-urban differences in the perceived costs and benefits of environmental taxation. Table 1 shows the definition and source of all the variables used in the estimation, and the expected sign of the explanatory variables according to the comparative literature we have examined. The descriptive statistics can be consulted in Table 8 of the Appendix.

The parameters α_v capture local spatial dependence, that is, the direct effect that the v observable characteristics of the neighbouring regions j, x_{jv} may have on revenue-based measure of environmental tax stringency in region i. These characteristics would be the population with environmental problems (*ωpollution*), their level of non-financial public expenditure (*ωnonfin_public_expenditure*), the weight of their industrial sector (*ωindustrial_weight*), and the stringency of their environmental regulations (*ωregulation*), which we have lagged by one year to account for a possible lag in its impact.

Let us suppose that ρ, μ, α_v and γ_m are constant in space and time. λ is the coefficient of the spatial autocorrelation of the error. δ_i and τ_t represent regional and time fixed effects.

To account for the spatial dimension, it is necessary to define which regions can influence region "*i*". Accordingly, we constructed a 17×17 spatial matrix that identifies the 5 geographically nearest neighbours of "*i*", based on the Euclidean distance between the geographic centroids of the autonomous communities[4]. This approach assumes that spatial interaction would occur between the closest regions, and not between the most distant ones (Tobler 1970), and follows a well-established practice in spatial econometrics (e.g., Kubara and Kopczewska 2024; Gerkman and Ahlgren 2014). This choice is particularly suitable in Spain for two reasons. First, environmental tax interactions are not driven solely by strict land contiguity: they may emerge along broader economic and industrial corridors (such as the Ebro Valley or the Mediterranean Arc), and through policy diffusion dynamics, with some regions acting as reference points in environmental taxation (such as Cataluña). Second, the distance-based specification provides a non-arbitrary and internally consistent way to incorporate the two island regions—Balearic Islands and Canary Islands—into the spatial structure. Although these territories do not share physical borders with the mainland, they are embedded in the same institutional, regulatory and political framework, and thus participate in the same processes of strategic alignment and policy diffusion within Spain's decentralised tax system[5]. Moreover, an inverse-distance matrix would assign extremely small weights to the islands due to their considerable geographical separation from the mainland, thereby artificially limiting their participation in the spatial structure of the model. Additionally, to ensure that the results do not depend on a particular neighbourhood definition, we estimated alter-

[4] To ensure the exogeneity of the spatial matrix, we did not weight its elements using any socioeconomic indicator. Instead, each element takes the value 1 if region j is one of the five nearest to region i (with $w_{ii} = 0$). These regions are hereafter referred to as neighbours or neighbouring regions.

[5] Although cross-border influences from French or Portuguese regions may affect some border areas, incorporating foreign jurisdictions into the spatial weights matrix lies beyond the scope of this study, given the lack of harmonised data and the absence of institutional comparability required for an unified spatial structure.

Table 1 Definition of variables, expected effect and source

	Definition	Expected effect	Source
DEPENDENT VARIABLE			
ET	Environmental tax revenue per industrial firm = Environmental tax revenue/number of industrial firms		Liquidación de presupuestos de las CCAA (Ministry of Finance and Civil Service) and National Statistics Institute (INE)
EXPLANATORY VARIABLES			
Pollution	Environmental problem, measured as the percentage of the population stating they have pollution problems	+	Living Conditions Survey (INE)
Regulation	Environmental regulatory stringency, measured as the average environmental expenditure per industrial firm to prevent and control pollution	Undetermined	Survey of industry spending on environmental protection (INE)
Income	GDP per capita	Undetermined	INE
Unemployment	Moment of the cycle, measured via the unemployment rate	–	
Public-expenditure	Public expenditure per capita	+	*Liquidación de presupuestos de las CCAA*. Ministry of Finance and Civil Service
Direct_tax_revenue	Direct tax revenue in terms of GDP	–	
Industrial_weight	Stakeholders, measured as the percentage of GDP that comes from the industrial sector	Undetermined	INE
Agglo	Industrial agglomeration, measured with the interaction industrial_weight*(no. of industrial firms/area)	Undetermined	
Pob_small-towns	Percentage of population living in towns under 1000 inhabitants	–	
Educ	Percentage of population aged 25–65 with secondary education	+	
Young_pop	Percentage of population under 15	+	
Ideology	= 1 if the governing party is left-wing = 0 otherwise	+	https://www.historiaelectoral.com
Electoral_support	% electoral support obtained in the last regional elections	+	
Coalition	= 1 if the government is a coalition = 0 otherwise	–	
Time_nex_election	Years remaining until the next regional elections	+	

Source: by the authors

native specifications using matrices with different numbers of nearest neighbours (from 2 to 6). The core findings—namely, the existence, magnitude and statistical significance of spatial dependence—remain stable across all these alternatives, as shown in Table 9. The choice of five neighbours reflects the best performance as indicated by the AIC and BIC information criteria (Kubara and Kopczewska 2024).

5 Estimation and Results

We began our empirical exercise by ruling out the existence of endogeneity problems in some of the model's explanatory variables, as suggested by the Durbin-Wu-Hausman statistics, shown in Table 2, Panel A. To conduct these tests we used a series of instrumental variables proven to be valid for this purpose, as suggested by the Sargan and Basmann tests, shown in Panel B of the same table.

For the spatial dependence analysis, we first examined what Pesaran's and Moran's tests indicate regarding our revenue-based measure of environmental tax stringency (environmental tax revenues per industrial firm). As Table 3 Panel A indicates, these tests suggest that environmental taxation across regions is not independent, but instead shows a substantial spatial autocorrelation. Thus, for the estimators obtained to be consistent, we must use models that include the spatial structure in the modelling. In addition, the LM tests, shown in Table 3 Panel B, indicate the need to include a spatial lag of the dependent variable, but not of the error term, as the LM-Error test was not significant (p-value = 0.13). Therefore, we excluded spatial autocorrelation in the error term from our final model. Furthermore, as explained in LeSage and Pace (2009) and Elhorst (2010), the best model is that which takes into account the spatial dimension in the endogenous variable (global spatial dependence) and in the explanatory variables (local spatial dependence). Since both dimensions are potentially relevant to our study, we used a dynamic spatial Durbin model incorporating both spatial dependence elements. Accordingly, our estimation has the following specification:

$$ET_{it} = \xi ET_{it-1} + \rho \sum_{j \neq i}^{N} \omega_{ij} ET_{jt} + \mu \sum_{j \neq i}^{N} \omega_{(ij)t-1} ET_{jt-1} + \sum_{m=1}^{M} x_{itm} \gamma_m + \sum_{v=1}^{V} \sum_{j \neq i}^{N} \omega_{ij} x_{jtv} \alpha_v + \delta_i + \tau_t + u_{it} \quad (2)$$

With i = 1,...17 and t = 2005, ...,2019.

We estimated this model using quasi-maximum likelihood (QML) techniques which implement the data transformation of Lee and Yu (2010) for fixed effect

[6] When panel data are short, estimating fixed effects produces biased estimations which are corrected if using the method of Lee and Yu (2010).

Table 2 Endogeneity analysis

	Panel A: Endogeneity tests		Panel B: Validity tests of the instruments used	
Variable	*Durbin*	*Wu-Hausman*	*Sargan*	*Basmann*
Industrial_ weight	0.303	0.282	1.801	1.686
	(0.58)	(0.59)	(0.17)	(0.19)
Public_ expenditure	0.438	0.408	2.391	2.244
	(0.50)	(0.52)	(0.12)	(0.13)
Direct_tax_ revenue	2.013	1.886	1.230	1.152
	(0.15)	(0.17)	(0.53)	(0.56)
Regulation	0.314	0.292	5.135	4.829
	(0.57)	(0.58)	(0.16)	(0.18)
Pollution	2.340	2.178	1.506	1.379
	(0.12)	(0.14)	(0.68)	(0.71)
Joint endogeneity	9.423	1.277	0.219	0.229
	(0.09)	(0.12)	(0.61)	(0.63)

The instrumental variables used for the endogeneity analysis were the percentage of adults with higher education, average industrial electricity consumption, number of industrial firms per capita, the importance of the services sector, atmospheric pollution, and capital public expenditure. The *p*-values are shown in brackets

Source: by the authors

Table 3 Spatial dependence

Panel A: Cross test for independence	
Pesaran test	2.472**
	(0.00)
Absolute average value of the off-diagonal elements	0.386**
	(0.00)
Moran MI Error test	2.090**
	(0.03)
Panel B: Model selection test	
LM-Error: Error has No Spatial AutoCorrelation	2.257
	(0.13)
LM-Lag: (Spatial Lagged Dependent Variable has No Spatial AutoCorrelation)	4.905**
	(0.02)

The *p*-values are shown in brackets

Source: by the authors

models (regional and temporal) and using Driscoll-Kraay standard errors[6] which produce heteroscedasticity-robust estimators.[7]

The first point that emerges from the estimation results, as shown in Table 4, is the existence of continuity or persistence in our revenue-based measure of environmental tax stringency. This is evidenced by the statistical significance and positive sign of the coefficient , which is consistent with contexts in which policy stability is essential to build trust among economic agents or to achieve long-term goals such as pollution reduction. This stability reinforces the credibility of tax instruments and enables economic agents to anticipate their evolution.

The second point is that there are substantial spatial dependence relationships among Spanish regions, confirming the information provided by the spatial dependence tests presented in Table 3. On the one hand, we see a considerable and positive spatial dependence relationship across regions' environmental tax stringency, both contemporaneously and non-contemporaneously. This indicates that environmental taxation in the regions follows a pattern of territorial cooperation, imitation, or dissemination, with some Autonomous Communities acting as leaders in environmental taxation (for example, wealthy or high-polluting regions) and the rest following their lead. Levinson (2003), Ashworth et al. (2006), and Renard and Xiong (2012) also obtain a substantial, positive spatial dependence relationship. On the other hand, there is evidence of clear local spatial interaction. Mainly, our model suggests that the more environmental problems the neighbouring regions have (*ωpollution*), the heavier the analysed region will make its "environmental taxes", probably to avoid pollutant industries relocating to their territory, as the NIMBY theory suggests.

And the third point is that many of the explanatory variables included in the estimation explain the environmental tax stringency. However, the effect of each variable cannot be interpreted solely through its regression coefficient. As noted by LeSage and Pace (2009), it is necessary to estimate both the direct and indirect effects, as well as their sum (the total effects). As shown in Table 5, these effects are more pronounced in the long term, which is consistent with expectations for environmental taxation, and they retain the same sign as the short-term effects. For the sake of clarity and conciseness, we focus here on the main observed indirect effects, which shed light on the interdependence (whether cooperative or competitive) between spatial units or regions, and on the short-term effects to avoid unnecessary complexity. To facilitate this analysis, we have grouped the explanatory variables in Table 6 according to the signs of their direct and indirect effects on the endogenous variable.

Table 6 shows that increased pollution in region i not only induces that region to tighten its environmental tax stringency[8], but also triggers a response with the same sign in neighbouring jurisdictions (positive direct and indirect effects). This indirect positive effect may result from imitative behaviour, political or strategic reasons

[7] This technique has been used in papers such as Case et al. (1993), Besley and Case (1995), and Brueckner and Saavedra (2001). An alternative could be to use IV/GMM, or Bayesian estimations. The pros and cons of these methods can be seen in Herrera (2017).

[8] Potoski and Woods (2002) and Renard and Xiong (2012) also obtain a positive effect for a similar variable in their studies of the stringency of environmental regulations and environmental taxes, respectively.

Table 4 Results of the Dynamic SDM estimation

	Coefficient [Robust standard error]
Dynamic component (ξ)	0.689*** [0.12]
Income	130.504*** [40.62]
income^2	–6.667*** [2.16]
Unemployment	0.019 [0.03]
Direct_tax_revenue	–0.409** [0.19]
Public-expenditure	3.225** [1.55]
Industrial_weight	–0.144** [0.06]
Agglo	–0.175** [0.07]
Pollution	0.038** [0.01]
Regulation	–1.051** [0.45]
Educ	0.030 [0.04]
Pob_smalltowns	–0.341** [0.14]
Young_pop	–0.836** [0.35]
Ideology	–0.091 [0.25]
Electoral_support	–0.018*** [0.00]
Coalition	–0.054 [0.16]
Time_nex_election	–0.008 [0.08]
Global spatial dependence	
Contemporaneous (ϱ)	0.568*** [0.06]
Non-contemporaneous (μ)	0.447*** [0.08]

Table 4 (Continued)

	Coefficient [Robust standard error]
Local spatial dependence (ω)	
ωPollution	0.142**
	[0.05]
ωNonfin_public_expenditure	0.002*
	[0.00]
ωRegulation	–1.663
	[1.56]
ωIndustrial_weight	–0.558
	[0.35]
Variance sigma2_e	1.119**
	[2.54]
R-sq: within	0.516
R-sq: between	0.709
R-sq: overall	0.599

***Significance at 1%, **Significance at 5%, *Significance at 10%
Standard errors are shown between square brackets

(NIMBYism), or the transboundary nature of environmental problems, which spread spatially and may generate similar tax responses in neighbouring areas.

In contrast, variables such as the weight of the industrial sector (*industrial_weight* and *agglo*) or direct taxes (*direct_tax_revenue)* have a localised negative impact, but with benefits spread across the territory (negative direct effects and the positive indirect effect). Thus, for example, the inverse relationship shown between the weight of the industrial sector (*industrial_weight* and *agglo*) and the revenue-based measure of environmental tax stringency suggests that the industrial sector is an effective lobbyist, as indicated in Levinson (2003) and as found in Potoski and Woods (2002) and Koninsky (2007) on the stringency of environmental regulation. However, it is causing environmental taxes to rise in other regions which do not fear competition from polluting industries already located in region *i*. These neighbouring regions could be looking to distance themselves from the behaviour of region *i* and position themselves as environmentally responsible territories, in order to attract cleaner companies, such as tech firms, who want to operate in areas committed to the environment. In this way, by increasing their tax stringency in response to the lower stringency of region *i*, the neighbouring regions are creating an environmental compensation effect in the regional system. A similar pattern is observed with direct taxes. The inverse relationship observed between direct taxes (*direct_tax_revenue)*, and a region's environmental tax stringency aligns with the double dividend theory. Moreover, this dynamic has the opposite effect on the environmental taxes of other regions, which try to "compensate" for the lower stringency of region *i*. From a global perspective, this compensatory behaviour may be beneficial, as the actions of the neighbouring regions help prevent stagnation in collective environmental taxation. However, an asymmetrical or uneven distribution of tax effort could lead to

Table 5 Direct, indirect and total effects of the Dynamic SDM estimation

	Direct effects	Indirect effects	Total effects	Direct effects	Indirect effects	Total effects
	Short-term			Long-term		
Income	138.085***	–53.367***	84.715***	438.684***	–128.028	310.656***
	[41.71]	[18.15]	[24.23]	[134.42]	[77.48]	[85.67]
income^2	–7.053***	2.728***	–4.325***	–22.408***	6.563	–15.845***
	[2.21]	[0.96]	[1.29]	[7.15]	[4.03]	[4.54]
Unemployment	0.020	–0.008	0.013	0.065	–0.014	0.050
	[0.04]	[0.01]	[0.02]	[0.15]	[0.04]	[0.11]
Direct_tax_revenue	–0.420**	0.161**	–0.259**	–1.332**	0.369	–0.963**
	[0.20]	[0.07]	[0.12]	[0.63]	[0.25]	[0.48]
Public-expenditure	3.337**	–1.308*	2.028**	10.622**	–3.352	7.270**
	[1.64]	[0.69]	[0.95]	[5.30]	[2.53]	[3.19]
Industrial_weight	–0.149**	0.058**	–0.091**	–0.473**	0.139	–0.334**
	[0.06]	[0.028]	[0.04]	[0.22]	[0.09]	[0.15]
Agglo	–0.173**	0.067*	–0.106**	–0.549**	0.165	–0.384**
	[0.08]	[0.03]	[0.05]	[0.27]	[0.12]	[0.17]
Pollution	0.030*	0.086**	0.115**	0.102*	0.314***	0.416**
	[0.02]	[0.03]	[0.04]	[0.09]	[0.13]	[0.16]
Regulation	–0.961**	–0.681	–1.642	–3.101**	–2.771	–5.814
	[0.46]	[0.96]	[1.14]	[1.48]	[3.34]	[4.03]
Educ	0.029	–0.011	0.018	0.094	–0.028	0.066
	[0.04]	[0.01]	[0.02]	[0.14]	[0.04]	[0.10]
Pop_small-towns	–0.346**	0.134**	–0.212**	–1.101**	0.324	–0.777**
	[0.14]	[0.05]	[0.08]	[0.45]	[0.22]	[0.29]
Young_pop	–0.856**	0.332**	–0.524**	–2.722**	0.812	–1.909**
	[0.36]	[0.15]	[0.21]	[1.17]	[0.56]	[0.77]
Ideology	–0.099	0.038	–0.060	–0.313	0.094	–0.218
	[0.24]	[0.09]	[0.15]	[0.78]	[0.23]	[0.58]
Electoral_support	–0.019**	0.007**	–0.012**	–0.060**	0.017	–0.044**
	[0.02]	[0.01]	[0.01]	[0.91]	[0.02]	[0.06]
Coalition	–0.046	0.019	–0.028	–0.148	0.052	–0.096
	[0.17]	[0.06]	[0.10]	[0.55]	[0.17]	[0.40]
Time_nex_election	0.005	0.001	0.003	–0.017	–0.000	–0.015
	[0.07]	[0.03]	[0.04]	[0.25]	[0.07]	[0.18]

***Significance at 1%, **Significance at 5%, *Significance at 10%
Standard errors are shown between square brackets

inter-regional tensions or a lower overall impact if the compensating regions are unable to sustain their greater effort over the long term. Thus, in this context we observe a form of complementarity in regional tax stringency.

However, variables such as *income* and *public expenditure*[9], tend to strengthen a region's environmental taxes, while simultaneously leading to lower taxes in neigh-

[9] Berry and Berry (1992) also conclude that budget pressure is relevant in their study of fiscal innovation.

Table 6 Explanatory variables grouped according to their direct and indirect effects (Dynamic SDM)

		INDIRECT EFFECT (IE)	
		+	–
DIRECT EFFECT (DE)	+	Pollution (DE* IE**) time_nex_election (DE IE)	Income (DE*** IE***) public-expenditure (DE** IE*) unemployment (DE IE) educ (DE IE)
	–	Direct_tax_revenue (DE** IE**) industrial_weight (DE** IE**) agglo (DE** IE*) pop_smalltowns (DE** IE**) young_pop (DE** IE**) ideology (DE IE) electoral_support (DE** IE**) coalition (DE IE)	Regulation (DE** IE)

Notes: DE is the direct effect, IE is the indirect effect.
***Significance at 1%, **Significance at 5%, *Significance at 10%.
Source: by the authors.

bouring regions (positive direct effects and negative indirect effects). This may occur either due to the perception of positive externalities which mean neighbouring regions can allow themselves to relax their own environmental taxes, as they are benefiting indirectly from the environmental policies of regions with high incomes and public spending (such as improved air or water quality), or because they seek to compete and attract investment and firms, even polluting ones, to their territory. In such cases, regional dynamics generate adverse effects on the collective environmental tax stringency.

Ultimately, the identified mechanisms reveal that regional environmental tax policy operates through three main logics: reactive coordination in response to shared environmental problems (such as pollution), competitive differentiation based on factors like economic specialisation (e.g., industrial weight), and exploitation of externalities according to tax capacity (free-riding). These findings suggest that spatial dependence in environmental taxation is not merely a diffusion phenomenon, but rather the result of deliberate territorial strategies, where regions adjust their tax stance by taking into account the decisions and characteristics of their neighbours. These spatial dynamics highlight the need to design environmental policies that consider positive and negative externalities across regions. Inter-regional cooperation and coordinated planning are crucial to avoid mutual weakening dynamics and inequalities in environmental tax effort, as well as to promote a more coherent, balanced, and effective design of tax policy in a decentralised context.

Although the degrees of freedom are constrained by the limited sample size, our safeguards—a parsimonious and theoretically grounded specification (avoiding excessive parameterisation and ad hoc model proliferation), QML estimation with robust standard errors, and extensive robustness checks—help mitigate overfitting concerns and support the qualitative stability of the main results.

6 Asymmetries in Spatial Dependence

While the previous analysis establishes the existence of spatial interdependence in environmental taxation (our revenue-based measure of environmental tax stringency), it assumes uniform responses across all regional contexts. However, regions may react differently to neighbouring policies, depending on their specific economic, institutional, and political circumstances (Atella et al. 2014).

This section examines how contextual factors modify the intensity and nature of spatial tax interactions, following a similar strategy used in Charlot and Paty (2010) and Fréret and Maguain (2017) to analyse the influence of agglomeration forces in spatial interaction of local French business taxation, and in Elhorst and Fréret (2009) to test yardstick competition through analysis of welfare spending. To this end, we interacted the spatially lagged dependent variable from our previous model with an index, *asymmetry*, which alternatively captures different characteristics of the neighbouring regions. Thus, the extended model is specified as follows:

$$\begin{aligned} ET_{it} = {} & \xi ET_{it-1} + \rho \sum_{j\neq i}^{N} \omega_{ij} ET_{jt} + \rho_a \sum_{j\neq i}^{N} \omega_{ij} ET_{jt} \times asymmetry_j \\ & + \mu \sum_{j\neq i}^{N} \omega_{(ij)t-1} ET_{jt-1} + \sum_{m=1}^{M} x_{itm}\gamma_m + \sum_{v=1}^{V}\sum_{j\neq i}^{N} \omega_{ij} x_{jtv}\alpha_v \\ & + \delta_i + \tau_t + u_{it} \end{aligned} \tag{3}$$

With $i = 1,...17$ and $t = 2005,...2019$.

Therefore, if the specific characteristic captured by *asymmetry* influences the spatial dependence relationship, the parameter ϱ_a will be significant and will measure the magnitude of that influence, such that the effect on region i of the environmental tax stringency of neighbouring regions j, ϱ, will be strengthened or weakened by ϱ_a when the neighbouring regions present that characteristic. In other words, the effect of neighbouring regions' environmental tax stringency on region i will be measured by $\rho + \rho_a$, when the neighbours have the characteristic captured in *asymmetry*; and by ϱ, when the neighbours do not present that characteristic[10].

The index *asymmetry* is intended to specifically measure four characteristics of neighbouring regions, alternatively. For the first characteristic, we adapted the approach of Fredriksson and Millimet (2002) to the scenario of environmental taxation, and we used the revenue that neighbouring regions obtain from environmental taxes as the limiting criterion of the index *asymmetry*. We would expect the intensity of spatial interactions between jurisdictions to be different, depending, on the one hand, on the relative position of the neighbouring regions in terms of environmental tax revenue per firm, and on the other, on whether the neighbouring regions have relaxed these taxes in the current year. Thus, as shown in Table 7 panel A, to analyse the first case, the index $asymmetry_{LOW\text{-}ET}$ identifies the neighbouring regions whose environmental tax revenue per firm is below the average, or, alternatively, below 90% of the

[10] As usual, we will suppose that ϱ_a is constant in space and time.

average. To analyse the second case, $asymmetry_{DECREASE\text{-}ET}$ identifies the jurisdictions that have reduced their environmental taxation, i.e., when the environmental tax per firm in year *t* is lower than in year *t–1*.

For the second characteristic, we captured economic aspects relating to the level of development or growth, as well as the agglomeration income that can be obtained in these regions, since, as shown in Koninsky (2007), jurisdictions may respond more to the policy changes of wealthier regions with dynamic markets than to those of poorer regions. Therefore, we used this index to identify, first, poor neighbouring regions ($asymmetry_{POOR}$), whose per capita income is below the national average, or alternatively below 1.2 times the national average. Second, the neighbours with a high unemployment rate ($asymmetry_{\text{UNEMP}}$), specifically, above the national average rate, or above 1.3 times the national average rate. And third, neighbours whose population density or business (firm) density is below the national average, or below 80% of the national average ($asymmetry_{LOW\_\text{POPDENSITY}}$ or $asymmetry_{LOW\_\text{FIRMDENSITY}}$), given that agglomeration income tends to be lower in such regions. We also used the density of large firms (with more than 100 employees) as a reference factor ($asymmetry_{LOW\_\text{LARGEFIRMDENSITY}}$).

For the third characteristic, we paid attention to institutional aspects (Rodden 2006 and Atella et al. 2014), identifying, on the one hand, the 'foral' regions ($asymmetry_{SING}$), given that they have a particular funding system that gives them a clear tax advantage, as they possess significantly greater regulatory power in the tax sphere than the other regions; and, on the other hand, the island regions ($asymmetry_{ISLAND}$), as their unique geographical situation may shape their spatial dependence patterns.

Finally, we analysed whether political aspects (Allers and Elhorst 2005 and Volden 2006), such as electoral support, the ability to reach agreements, and the ideology of the regional government, play a role in spatial dependence patterns. For this, the index $asymmetry_{MINORITY}$ captures neighbouring regions with a minority government, i.e., with less than 50% of the votes; $asymmetry_{COALITION,}$ those with coalition governments; and $asymmetry_{LEFT}$, those with left-wing governments.

The results of these estimations, shown in Table 7 Panel B, indicate that in all cases the coefficients capturing the temporal persistence or inertia of environmental taxes () and spatial interactions (ρ and μ) remain significant. However, as we expected, the degree of spatial dependence or the reaction function differs according to the characteristics of regions' surroundings or neighbourhood, as the asymmetry coefficient, ϱ_a, takes a non-zero and statistically significant value.

More specifically, our model indicates that if neighbouring regions collect less than 90% of average environmental tax revenue per firm ($\text{Asymmetry}_{\text{LOW-ET}}$), regions exhibit only minimal spatial interaction. This is reflected in the total spatial coefficient, which equals $0.067 = (\rho + \rho_a = 0.362–0.295)$ and suggests that low environmental tax levels in neighbouring regions fail to trigger competitive responses in environmental taxation, because the tax burden is insufficient to influence firm location decisions. However, when neighbouring regions maintain substantial environmental tax levels, strong spatial dependence emerges ($\rho = 0.362$), supporting cooperative or imitative behaviour. This threshold effect indicates that effective en-

Table 7 Sensitivity of the spatial dependence relationship to various characteristics of the neighbouring regions

Panel A: Characteristics captured with the asymmetry index		Panel B: Results Spatial dependence ρ	ρ_a	Total ($\rho + \rho$) Interpretation	μ	Temporal persistence ξ	R^2 Within Between
REVENUE WITH ENVIRONMENTAL TAXES							
Asymmetry$_{LOW-ET}$	= 1 if environmental tax (j) < average environmental tax	0.511*** [0.10]	–0.077 [0.07]	0.434 Cooperation	0.480*** [0.09]	0.695*** [0.12]	0.536 0.695
	= 1 if environmental tax (j) < 0.9* average environmental tax	0.362*** [0.07]	–0.295*** [0.05]	0.067 Minimal interaction	0.584*** [0.01]	0.722*** [0.12]	0.567 0.638
Asymmetry$_{DECREASE-ET}$	= 1 if environmental tax (j) in t < environmental tax (j) in t-1	0.565*** [0.06]	0.026 [0.04]	0.591 Cooperation	0.435*** [0.07]	0.690*** [0.12]	0.503 0.708
ECONOMIC ASPECTS							
Asymmetry$_{POOR}$	= 1 if income (j) < 1.2 * average income	0.319*** [0.11]	–0.679* [0.40]	–0.360 Weak competition	0.511*** [0.11]	0.670*** [0.13]	0.352 0.764
	= 1 if income (j) < average income	0.251* [0.13]	–0.966*** [0.42]	–0.715 Strong competition	0.479*** [0.13]	0.644*** [0.13]	0.276 0.612
Asymmetry$_{UNEMP}$	= 1 if unemployment (j) > 1.3* average unemployment	0.652*** [0.05]	–0.750*** [0.16]	–0.098 Minimal interaction	0.455*** [0.08]	0.677*** [0.10]	0.405 0.718
	= 1 if unemployment (j) > average unemployment	0.490*** [0.08]	–0.238 [0.24]	0.252 Weak cooperation	0.424*** [0.10]	0.670*** [0.13]	0.503 0.737
Asymmetry$_{LOW-POPDENSITY}$	= 1 if population density (j) < average population density	0.366*** [0.48]	–0.457*** [0.14]	–0.091 Minimal interaction	0.572*** [0.10]	0.690*** [0.12]	0.560 0.571
	= 1 if population density (j) < 0.8* average population density	0.366*** [0.48]	–0.457*** [0.14]	–0.091 Minimal interaction	0.572*** [0.10]	0.690*** [0.12]	0.560 0.571

Table 7 (Continued)

Panel A: Characteristics captured with the asymmetry index		Panel B: Results Spatial dependence ρ	ρ_a	Total ($\rho + \rho$) Interpretation	μ	Temporal persistence ξ	R^2 Within Between
Asymmetry$_{\text{LOW-FIRMDENSITY}}$	= 1 if firm density (j) < average firm density	0.366*** [0.04]	–0.457*** [0.14]	–0.091 Minimal interaction	0.572*** [0.10]	0.690*** [0.12]	0.560 0.571
	= 1 if firm density (j) < 0.8* average firm density	0.430*** [0.04]	–0.313*** [0.10]	0.117 Weak cooperation	0.520*** [0.09]	0.688*** [0.12]	0.547 0.611
Asymmetry$_{\text{LOW-LARGEFIRMDENSITY}}$	= 1 if large firm density (j) < average large firm density	0.492*** [0.04]	–0.222* [0.11]	0.270 Weak cooperation	0.451*** [0.09]	0.683*** [0.12]	0.529 0.672
	= 1 if large firm density (j) < 0.8* average large firm density	0.513*** [0.05]	–0.199*** [0.07]	0.314 Weak cooperation	0.482*** [0.08]	0.687*** [0.12]	0.513 0.653
INSTITUTIONAL ASPECTS							
Asymmetry$_{\text{SING}}$	= 1 if the neighbouring region, *j*, is Navarre or Basque Country	0.524*** [0.09]	–0.203 [0.30]	0.321 Weak cooperation	0.494*** [0.10]	0.698*** [0.12]	0.542 0.681
Asymmetry$_{\text{ISLAND}}$	= 1 if the neighbouring region, *j*, is Canary Islands or Balearic Islands	0.565*** [0.06]	5.597* [2.95]	6.162 Strong imitation	0.414*** [0.08]	0.632*** [0.12]	0.520 0.105
POLITICAL ASPECTS							
Asymmetry$_{\text{MINORITY}}$	= 1 if electoral support (j) < 50%, that is, if there is a minority government	0.408*** [0.07]	–0.332*** [0.13]	0.076 Minimal interaction	0.411*** [0.11]	0.656*** [0.12]	0.292 0.759
Asymmetry$_{\text{COALITION}}$	= 1 if the neighbouring region, *j*, has a coalition government	0.538*** [0.05]	–0.157 [0.11]	0.381 Weak cooperation	0.493*** [0.10]	0.693*** [0.12]	0.522 0.736
Asymmetry$_{\text{LEFT}}$	= 1 if the governing party of the neighbouring region, j, is left-wing	0.560*** [0.06]	–0.059 [0.06]	0.501 Cooperation	0.477*** [0.09]	0.697*** [0.13]	0.517 0.718

***Significance at 1%, **Significance at 5%, *Significance at 10%
Robust Standard errors are shown between square brackets

vironmental tax coordination requires minimum tax levels in neighbouring regions in order to generate meaningful strategic interactions.

Secondly, when neighbouring regions are economically weak—either because their per capita income is low, their unemployment rate is high, or their population or business density is low—and therefore do not benefit from agglomeration income, jurisdictions tend to behave differently from their neighbours and engage in tax competition to attract firms from those neighbouring jurisdictions, provided that the total spatial dependence relationship between regions ($\rho+\rho_a$) is negative. For example, when neighbouring regions have below-average per capita income, region *i* increases its environmental tax revenue per firm by €0.71 for every euro decrease in its neighbours' revenue, as indicated by the total spatial dependence coefficient of –0.715. This result points to clear tax competition: regions exploit their neighbours' economic weakness by raising their own environmental standards while attracting firms fleeing less environmentally demanding jurisdictions, consistent with predictions of the NIMBY theory. This competitive response reflects rational strategic behaviour: regions recognize that economically distressed neighbours cannot sustain high environmental taxes without losing additional economic activity, creating opportunities for neighbouring regions to raise their environmental standards while attracting displaced economic activity, in line with the industrial lobbyist theory found in Levinson (2003) and Potoski and Woods (2002). This finding has significant implications for environmental policy coordination. Economic asymmetries between regions create structural barriers to cooperation, suggesting that effective coordination of environmental taxation requires addressing underlying economic disparities first.

By contrast, if the nearby territories experience economic prosperity—low unemployment rates, or deep and dynamic markets that generate significant agglomeration economies—the analysed region *i* tends to imitate the behaviour of these prosperous neighbours, thereby reinforcing the upward trend in environmental taxation. This is likely because such regions can sustain higher environmental taxes without losing competitiveness, creating more favourable conditions for stable and coordinated environment taxation.

For institutional aspects, spatial cooperation intensifies when neighbouring regions are islands (total spatial coefficient = 6.162), reflecting how geographical isolation reduces competitive pressures and reinforces tax coordination. This pattern is consistent with the characteristics of these offshore territories, where competitive strategies are largely unnecessary, thereby fostering stronger tax-imitation behaviour. However, spatial dependence relationships are not conditioned by whether neighbouring regions benefit from a special funding system, such as the 'foral' regime. This result may stem from the fact that very few regions enjoy this advantageous tax regime, or because these regions' environmental taxes are very low, likely due to their greater fiscal flexibility in other taxes.

Finally, our results suggest that political stability significantly affects spatial coordination. When neighbouring regions have minority (and thus weak) governments, there is hardly any cooperation among regional environmental tax strategies (total spatial coefficient is 0.0763). Conversely, regions with majority governments demonstrate strong cooperative behaviour (spatial coefficient = 0.408), facilitating policy imitation and environmental tax convergence across jurisdictions. This result is consistent with fiscal federalism theory, which states that parliamentary minorities are more sensitive to yardstick competition than governments with solid parliamentary majorities, as they continually need to justify their performance to voters and the opposition, and adjust their tax policies to minimise political and electoral risk (Allers and Elhorst 2005; Elhorst and Fréret 2009; Wasserfallen 2014). For a minority government, tax competition is a key tool for demonstrating efficiency and maintaining legitimacy. In contrast, as the political stability of solid governments does not depend as much on the direct evaluation of voters, they have a wider margin for cooperation and can align with others in environmental tax policy. Our results show that, in fact, the central region will hardly ever follow the lead of its neighbouring regions if those neighbours have minority governments. At the same time, our model suggests that spatial dependence relationships do not depend on whether neighbouring regions are governed by coalitions or single parties, or on the ideology of those governments, as obtained in Allers and Elhorst (2005) for property taxes.

7 Discussion and Conclusions

This study contributes to closing the gap in the literature on spatial interactions between subnational jurisdictions, with a particular focus on the potential asymmetries in these interactions. To this end, we draw on the natural setting provided by the Spanish regions, which have increasingly made use of environmental taxation.

Our estimates show, first, a pronounced persistence and positive average spatial dependence in environmental tax revenues per firm: current outcomes are influenced by past levels and, on average, co-move with the outcomes observed in geographically proximate neighbours, confirming the existence of an imitation, bandwagon or diffusion effect of environmental tax stringency of Spanish regions.

Second, the characteristics of a jurisdiction affect not only its own revenue-based measure of environmental tax stringency (direct effects) but also generate spatial multiplier effects that influence neighbouring jurisdictions (indirect effects). These indirect effects suggest that environmental tax stringency is being driven by regions with a high percentage of the population affected by environmental problems. They also reveal that regional differences in economic structure, such as industrial weight, fragment environmental efforts and lead to an uneven distribution of environmental taxation, prompting some jurisdictions to adjust their environmental taxes in response to others. To avoid this "*compensatory*" pattern from emerging solely through unilateral regional initiative, and to prevent an uneven distribution of environmental tax stringency from leading to inter-regional tensions and a lower overall level of environmental taxation, national or supra-regional coordination mechanisms may be beneficial. Common minimum environmental standards could help align environmental goals of the territories and generate fairer dynamics, while enabling regions to exploit positive externalities and potential economies of scale in environmental investments, and helping to prevent mutual weakening of tax effort. In addition, interregional compensation mechanisms—whereby regions with lower environmental tax stringency contribute and pay compensation to those with higher levels—could help stabilise incentives and encourage sustained collective commitment.

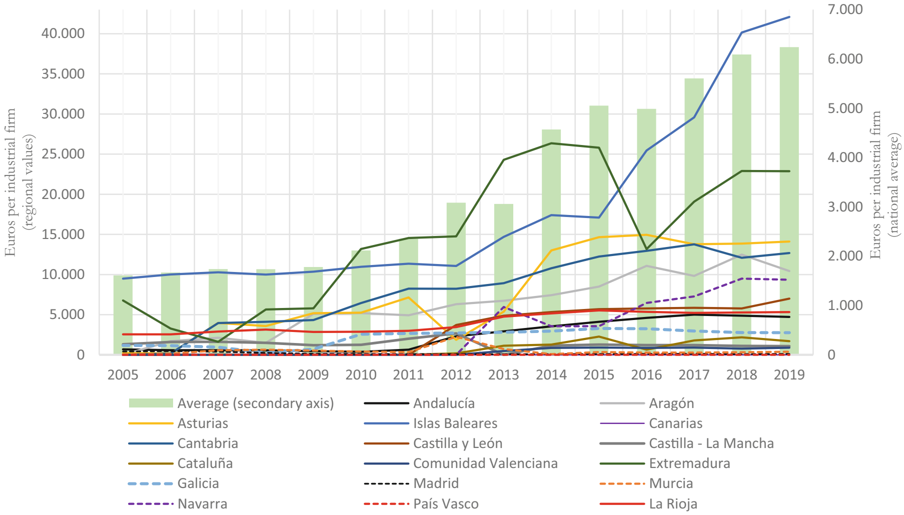
Third, not all jurisdictions react uniformly to their neighbours' behaviour, but that the spatial dependence relationship is conditioned by the economic, institutional and political circumstances surrounding each region. We observe asymmetric responses because the sign or magnitude of spatial dependence changes across neighbour types: regions tend to align more closely with prosperous neighbours, but respond differently when neighbours face weaker economic conditions (low income, high unemployment, or low agglomeration proxies), a pattern consistent with competitive differentiation in order to attract mobile activity. Likewise, spatial co-movement is muted when neighbouring regions display very low environmental tax revenues per firm or are governed by minority administrations. These findings support the broader view that "races to the top" and "races to the bottom" may co-exist within the same institutional setting, depending on context (e.g. Feng et al. 2023; Yang et al. 2023).

In any case, as noted by Revelli (2005) and Baskaran (2013), the spatial dependence and asymmetric patterns we observe do not, on their own, constitute evidence of intentional strategic behaviour. Co-movements in regional environmental taxation may arise because regional governments primarily respond to internal constraints (tax capacity, budget needs), administrative capability, and citizen preferences, while paying only limited attention to neighbouring choices. Our empirical design does not allow us to causally distinguish whether the observed spatial co-movements arise from deliberate strategic imitation or from underlying structural similarities across regions. Accordingly, the interpretation of these results should be approached with appropriate caution.

From a policy perspective, the results suggest that coordination efforts should be gradual and sensitive to regional heterogeneity. Where imitation or convergence dominates, minimum standards and structured information-sharing may help internalise cross-border externalities and strengthen collective environmental performance. Where competitive differentiation dominates, reinforcing administrative and tax capacity and addressing underlying economic disparities may be a prerequisite for effective harmonisation. In all cases, systematic monitoring of interregional interdependence and periodic evaluation of environmental tax packages would support adaptive coordination. More broadly, the evolution of environmental taxation as part of the green transition is likely to be most effective when embedded in coherent policy packages that connect tax instruments with regulatory enforcement, industrial strategy, and longer-term development goals. As environmental pressures intensify and societal demand for sustainable production increases, governments will face stronger incentives to expand and redesign environmental taxes; ensuring that this evolution supports both environmental performance and competitiveness will require sustained intergovernmental cooperation, transparent evaluation, and the engagement of firms and citizens.

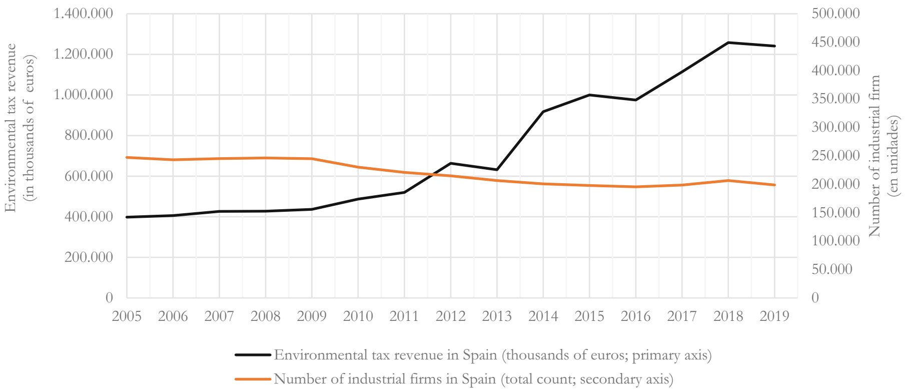
Finally, although Spain exhibits certain idiosyncratic features—particularly the coexistence of the common and foral regimes—the broader combination of meaningful subnational autonomy, territorial heterogeneity and incomplete coordination, is shared by many decentralised systems. In Australia, the states hold broad regulatory powers in environmental policy and operate with considerable autonomy within a framework that includes formal mechanisms for federal-state coordination. Canada and the United States grant provinces and states substantial regulatory and fiscal authority, including environmental instruments, fostering strategic interactions across jurisdictions. Germany, by contrast, operates under a strongly cooperative federal model, characterised by intensive intergovernmental coordination and a more limited fiscal margin for the Länder. Italy occupies an intermediate position: its regions exercise regulatory authority in certain domains and hold some spending capacity, although their direct tax autonomy remains comparatively constrained. To the extent that these features hold elsewhere, asymmetric spatial dependence in environmental taxation may also be relevant beyond Spain, even if the magnitude and channels of interaction depend on each country's fiscal architecture and coordination arrangements.

8 Appendix



Note: The regional trends correspond to the primary axis, and the national average to the secondary axis.
Source: By the authors, based on data from the National Statistics Institute (INE and the Ministry of Finance and Civil Service (*Liquidación de los presupuestos de las Comunidades Autónomas*).

Fig. 1 Environmental tax revenue per industrial firm: Regional trends and national average.



Note: Total revenue from environmental taxes (in thousands of euros) correspond to the primary axis and total number of industrial firms to the secondary axis.
Source: By the authors, based on data from the National Statistics Institute (INE and the Ministry of Finance and Civil Service (*Liquidación de los presupuestos de las Comunidades Autónomas*).

Fig. 2 Environmental tax revenue and industrial firms in Spain.

Table 8 Descriptive statistics

Variable	Obs	Mean	Std. dev.	Std. dev. between	Std. dev. within	Min	Max
ET	255	7.009	12.330	11.416	4.659	0	60.921
Pollution	255	9.996	5.022	3.138	3.921	0.4	23.8
Regulation	255	11.016	0.6364	0.707	0.14261	9.150	32.850
Income	255	23.538	0.479	0.455	0.150	15.081	34.906
Unemployment	255	16.251	7.173	4,071	5,90658	4.72	36.22
Public-expenditure	255	4.132	0.799	0.724	0.337	2.729	7.481
Direct_tax_revenue	255	3.630	1.872	1.728	0.720	0	12.445
Industrial_weight	255	16.754	5.802	5.734	0.881	5.278	28.145
Densempind	255	0.755	0.743	1.084	0.219	0.114	3.434
Pob_smalltowns	255	4.657	5.278	5,272	0,252	0.032	20.049
Educ	255	32.703	7.140	7.538	4.249	20.5	50.8
Young_pop	255	15.169	1.833	1.779	0.440	10.610	18.844
Ideology	255	0.368	0.483	0,320	0,361	0	1
Electoral_support	255	38.321	10.929	7.186	8.233	15.832	58.789
Coalition	255	0.388	0.488	0.316	0.372	0	1
Time_nex_election	255	0.142	0.110	0.064	0.458	0	3

Table 9 Sensitivity of the results of the estimation for the different specifications of the spatial neighbourhood matrix

	W_2: 2 nearest neighbours	W_3: 3 nearest neighbours	W_4: 4 nearest neighbours	W_5: 5 nearest neighbours	W_6: 6 nearest neighbours
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Dynamic component (ξ)	0.642***	0.687***	0.688**	0.689***	0.774***
Non-contemporaneous global spatial dependence (μ)	0.103	0.248***	0.304**	0.446***	1.049***
Income	61.920*	67.194*	104.765**	130.504***	188.000***
income^2	–2.842	–3.376*	–5.187**	–6.667***	–9.728***
Unemployment	0.003	–0.003	0.002	0.019	0.063*
Direct_tax_revenue	–0.404**	–0.400*	–0.366*	–0.409**	–0.239
Public-expenditure	3.049**	2.098	2.638*	3.225**	3.869***
Industrial_weight	–0.152*	–0.128**	–0.175*	–0.144**	–0.002
Agglo	–0.137*	–0.137**	–0.200**	–0.175**	–0.013
Pollution	0.008	0.016	0.024*	0.038**	0.049***
Regulation	–0.525	–0.662	–0.831*	–1.051**	–1.194***
Educ	0.024	0.081**	0.046	0.030	0.068*
Pob_smalltowns	–0.690***	–0.877***	–0.486**	–0.341**	–0.549***
Young_pop	–0.469	–0.862**	–0.751*	–0.836**	–1.832***
Ideology	0.010	0.142	–0.031	–0.091	–0.032
Electoral_support	–0.018***	–0.014**	–0.016*	–0.018***	–0.013**
Coalition	0.018	0.002	0.026	0.054	–0.087
Time_nex_election	0.002	0.013	0.032	–0.008	–0.046
Local spatial dependence (ω)					
ωPollution	0.011	0.033	0.088	0.142**	0.187**
ωNonfin_public_expenditure	0.000	–0.001*	–0.000	0.002*	0.001
ωRegulation	–0.695	0.564	–0.565	–1.663	1.072
ωIndustrial_weight	–0.160	–0.509***	–0.583*	–0.558	–1.242**
Contemporaneous global spatial dependence (ϱ)	0.317***	0.378***	0.526**	0.568***	0.325***
Variance sigma2_e	1.159**	1.158*	1.147*	1.119**	1.178**
R-sq: within	0.559	0.654	0.614	0.516	0.586
R-sq: between	0.509	0.468	0.757	0.709	0.394
R-sq: overall	0.490	0.463	0.669	0.599	0.397
AIC	729.807	729.096	728.167	722.539	726.788
BIC	778.419	777.708	776.779	771.151	775.399

W denotes a k-nearest neighbours spatial weights matrix

***Significance at 1%, **Significance at 5%, *Significance at 10%

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