

Economic Analysis of Law Review

A Study on Environmental Violations for Brazilian Municipalities: a Limited Information Maximum Likelihood Approach to a Spatial Dynamic Panel Data

Um Estudo Sobre Infrações Ambientais em Municípios Brasileiros: uma Abordagem de Máxima Semelhança e Informações Limitadas para um Painel de Dados Dinâmicos Espaciais.

Júlia Gallego Ziero Uhr¹
Universidade Federal de Pelotas (UFPEL)

André Luis Squarize Chagas²
Universidade de São Paulo (USP)

Daniel de Abreu Pereira Uhr³
Universidade Federal de Pelotas (UFPEL)

Renan Porn Peres⁴
Universidade Federal de Pelotas (UFPEL)

RESUMO

Este artigo apresenta novas evidências para infrações ambientais no Brasil, abordando as seguintes questões: As sanções aplicadas pelo IBAMA, especialmente as multas, detêm os infratores reais e potenciais? Existem padrões espaciais ou temporais que afetam as violações? Este artigo contribui para a literatura existente ao fornecer novas evidências para o Brasil e ao incorporar controles espaciais em uma abordagem de painel dinâmico para estudar infrações contra o meio ambiente. Os dados são provenientes de um extenso conjunto de dados de infrações contra a flora e multas aplicadas nos municípios brasileiros entre 1998-2015. Nós empregamos um novo estimador de máxima verossimilhança de informação limitada dinâmico-espacial (SDLIML). Os resultados mostram que existe um efeito dissuasivo pedagógico associado aos valores das multas. As multas impostas no município da infração e nos municípios vizinhos são importantes para desestimular novas infrações.

Palavras-chave: Violações; Ofensas Ambientais; Dissuasão; Efeito pedagógico; Multas; Brasil, LIML Espacial.

JEL: K32; K23

ABSTRACT

This paper presents new evidence for environmental offenses in Brazil by addressing the following questions: Do sanctions applied by IBAMA, especially sanction charges, deter actual and potential offenders? Are there any spatial or temporal patterns affecting violations? This paper contributes to the existing literature by providing new evidence for Brazil and by incorporating spatial controls in a dynamic panel approach to study infractions against the environment. The data comes from an extensive dataset of offenses against flora and applied fines in the Brazilian municipalities between 1998-2015. We employ a new Spatial Dynamic Limited Information Maximum Likelihood (SDLIML) estimator. Results show that there is a pedagogic deterrent effect associated with fine values. Sanction charges imposed in the municipality of the infraction and the neighborhood are important to discourage new offenses.

Keywords: Violations; Environmental Offenses; Deterrence; Pedagogic effect; Fines; Brazil, Spatial LIML.

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¹ E-mail: zierouhr@gmail.com

² E-mail: achagas@usp.br

³ E-mail: daniel.uhr@gmail.com

⁴ E-mail: renanpperes@gmail.com

1. Introduction

The continental size of Brazilian territory makes monitoring and enforcing the laws an enormous challenge, mainly when it comes to environmental crimes. The Environmental Crimes Law (ECL), published in 1998, is a milestone in defense of the environment. It introduced the punishment system with specific sanctions for the offenders. Along with Federal Decree 6,514, published in 2008, they define environmental violations and possible penalties to criminals. The Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) is responsible for monitoring infractions and has the power to apply administrative sanctions. Since its creation, the institute's line of action has been guided by a national and worldwide concern: deforestation and other aggressions against Brazilian flora. IBAMA's annual management reports show not only the significance of technological advances in monitoring deforestation and other offenses but also the proper role of sanctioning for deterring environmental crimes. For example, the reports mention the importance of on-site enforcement actions to the continuous deterrence of illegal practices and that IBAMA acts more effectively in emblematic perpetrators to deter other potential offenders (IBAMA 2008, 2009, 2010). The institute reported that "the strategy of [its] operations focuses on large actions with a pedagogic deterrent effect, based on the decapitalization of offenders, with the seizure of goods and products of environmental crime."⁵

Is there data support for the claim that sanctioning transgressors change the future behavior of actual and potential offenders that are observing IBAMA's actions? Are there spatial and temporal patterns in the distribution of violations? If so, how do these patterns affect violations? To answer those questions, this paper use data on violations against environmental⁶ and applied fines (values), recorded by IBAMA, for all Brazilian municipalities⁷ between 1998 and 2015⁸. Sanction charges have a significant role in Brazilian legislation since fines are applied individually or cumulatively to other sanctions, therefore being applied to all environmental violations⁹. It is important to note that the assembled dataset provides the resources for an extensive study of environmental infractions and applied penalties at the municipal level, nationwide, and for future papers evaluating other relating aspects. No such study has been undertaken so far. We also contribute to the existing literature by applying a new Spatial Dynamic Limited Information Maximum Likelihood (SDLIML) approach to address the endogeneity between fines and values of penalties.

The research on regulation enforcement is well established. The theoretical foundation proposed by Becker (1968), and later generalized by Posner (1974), was applied by Russell et al. (1986) to pollution control. The first empirical studies focused on the available mechanisms of monitoring and enforcement to regulatory agencies (Magat and Viscusi, 1990; Laplante and Rilstone, 1996; Gray and Deily, 1996; Nadeau, 1997; Helland, 1998; Sigman, 1998; Viladrich-Grau and Groves, 1997). The literature advances in the study of the deterrent effects of sanctions and monitoring on formal and informal perspectives (Afsah et al., 1996, Dasgupta et al., 2000; Stafford,

⁵ Available at <<https://uc.socioambiental.org/noticia/acoes-de-fiscalizacao-do-IBAMA-e-de-parceiros-levam-a-queda-historica-de-desmatamento>>.

⁶ Brazilian legislation defines various categories of environmental infractions (flora, fauna, pollution, etc.). They are not limited to cases of deforestation, but also deal with situations such as trading or transporting chainsaws, coal, and other minerals without a license, make use of fire or cause fire in rural or forested area, manufacture, sell or release balloons that may cause fire in urban or rural areas, commercialize or maintain ornamental plants without a license.

⁷ There are currently 5,564 municipalities in Brazil.

⁸ Our data set initiated in 1998, the same year of the publication of the Brazilian Environmental Crimes Law.

⁹ In Brazil, as for other countries, administrative penalties such as fines are far more common than civil or criminal prosecutions (Alm and Shimschak, 2014). However, we are working on separating the administrative offenses that are also prosecuted as environmental crimes to see the impact of the possibility of incarceration and other heavier penalties for violations.

2002; Stafford, 2003; Anton et al., 2004; Shimshack and Ward, 2005; Shimshack and Ward, 2008; Rousseau, 2008). Gray and Shadbegian (2007) use spatial analysis to study regulatory compliance. The authors find that compliance is positively spatially correlated, showing that regulatory activity has effects over inspected and neighboring plants in the same state. Almer and Goeschl (2010) studied the deterrent effect of criminal prosecution over environmental crimes in Germany. They find that public trials have a more significant effect on the offense rate than the likelihood of conviction and the magnitude of fines. Gray and Shimshack (2011) review the empirical literature showing that there is sufficient evidence demonstrating how monitoring and enforcement generate not only specific deterrence at the targeted plant, but also substantial spillover effects (general deterrence) by reducing future violations at other firms. More recently, Earnhart and Friesen (2013), Aklin et al. (2014) and Sjöberg (2016) add other important aspects to the analysis: experiential deterrence, corruption as a cause of poor law, the role of local governments in the application of environmental laws.

This paper applies a Spatial Dynamic Limited Information Maximum Likelihood (SDLIML) Estimator that accounts for the potential endogeneity of sanction charges. Fine magnitudes are instrumented using variables suggested by the ECL as extenuating conditions for the penalty gradation: low income and low levels of education of the punished. We are interested in finding the direct (or specific) and indirect (spillover) effects of accessing IBAMA's claim that there is a pedagogic deterrent effect in monitoring and enforcement actions affecting actual and potential offenders. Our main finding is that there is a pedagogic deterrent effect associated with fine values. Sanction charges imposed in the municipality of the infraction and the neighborhood, are important to discourage new offenses. For the long run, fines above 33.7 thousand applied in one municipality are already sufficient to deter violations in the same municipality. When it considered the indirect effects (spillovers), the necessary fine values applied in the municipality, and the neighboring localities are of 22.6 thousand (general deterrence).

The remainder of this paper is organized as follows. The Brazilian environmental legislation, the monitoring procedure, and the enforcement process are presented in the next section. Data and descriptive statistics are discussed in section three. Section four describes the applied methodology (Spatial Dynamic LIML estimator) and the regression equation. The empirical results are discussed in section five. Final thoughts are presented under the conclusions.

2. A review of the literature on compliance and enforcement

The research on regulation enforcement is a well-established research agenda. The theoretical foundation was firstly proposed by Becker (1968). According to him, fines have several advantages over other punishments to enforce a specific action. Fines conserve resources, compensate society as well as punish offenders, and simplify the determination of the optimal probability of punishment and the size of the punishment for those convicted. Offenders who cannot pay fines have to be punished in other ways, but the optimality analysis implies that the monetary value to them of these punishments should generally be less than the fines. Later, Posner (1974) disseminated this idea to the legal community arguing that criminal acts are a source of enormous social costs that no society can ignore, and the modern criminal law is the product of a painstaking evolution powerfully influenced by the explicitly economic approach.

In terms of quantitative empirical studies on compliance and enforcement, Russell et al. (1986) are one of the first work. They considered the command and control practices extensively to pollution control. Other empirical studies focused on the available mechanisms of monitoring and enforcement to regulatory agencies. Magat and Viscusi (1990) examined the impact of

inspections on the level of biochemical oxygen demand discharges by pulp and paper plants in the US and on whether or not a firm complied in any given period. A key finding is that inspections substantially reduced discharges with a permanent effect on reducing a firm's future pollution levels. Laplante and Rilstone (1996) observed plants in the pulp and paper industry in Quebec. They found a negative relationship between the probability of inspection and water emissions relative to the cap. Gray and Deily (1996) investigated compliance and enforcement of environmental regulations in the U.S. steel industry and observed a positive relationship between expected inspections and compliance. Nadeu (1997) looked at the effectiveness of the enforcement in reducing the time that manufacturing plants spend in a state of noncompliance. Plants that are found in violation remained so for several periods. His results indicated that the enforcement was effective at reducing the time plants spend violating standards, and the increase in enforcement activity results in a reduction in violation time.

Helland (1998) showed that a violation is punished one-quarter period after it occurs. Surrounding community situation influences the inspections, which suggest a potential interference of interest-group influence. Inspections that detect violations encourage self-reporting, showing that firms demonstrate their desire to cooperate with regulators by disclosing violations. Sigman (1998) studied the determinants of illegal disposal analyzing the frequency of used oil dumping. His results suggested that dumping is sensitive to the cost of legal waste management options, including disposal and reuse, and the threat of enforcement. In particular, state policies that restrict legal disposal cause substantial substitution of illegal dumping. Finally, Viladrich-Grau and Groves (1997) evaluated the effectiveness of Coast Guard enforcement efforts in reducing oil spills. They concluded that: (i) Coast Guard enforcement effort works to decrease both the frequency of oil spills and the spill size, even though in this latter case the effect is smaller; (ii) the expected fine has no effect on either the frequency or size of oil spills; (iii) few spills from non-monitored transfers are detected; and (iv) the implementation of the new performance standards increases the effectiveness of the Coast Guard monitoring efforts.

The literature advanced in the study of the deterrent effects of sanctions and monitoring on formal and informal perspectives. Afsah et al. (1996), for instance, presents a multi-agent model in which the role of government as the regulator would be complemented by the community and the market as monitoring of environmental violations. Thus, the environmental performance of pollutants would be influenced, for example, by groups close to a firm or by its consumers. Well-educated, richer, and organized communities have many ways to ensure compliance with environmental standards. Dasgupta et al. (2000), on the other hand, study the impact of firm characteristics, markets, formal and informal regulation (community pressure) on pollution control for Mexican factories. The authors find little evidence for the effectiveness of market incentives and no evidence of formal regulation for the reduction of emissions in the Mexican industrial sector.

Stafford (2002, 2003) examines the impacts of increased penalties and government spending on the environment for the illegal disposal of hazardous wastes. The results indicate that increased penalties and government spending led to a decrease in violations, i.e., the revised policy had the desired effect by raising the number of companies in compliance with hazardous waste legislation. Anton et al. (2004) study the influence of market incentives on the voluntary adoption of environmental management systems, such as the ISO 14000 standard, and their effect on the environmental performance of companies. The results show that consumer and investor pressures, together with the possibility of punishment and the past scale of emissions, are the most critical determinants for the adoption of environmental management strategies.

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Concerning the interaction among firms, Shimshack and Ward (2005) have observed that the effect of a fine imposed on other firms is equal to the firm itself being fined, that is, the specific effect and the spillover effect have the same influence on the firm's decision to commit infringements.

Gray and Shadbegian (2007) use spatial analysis to study regulatory compliance. The authors find that compliance is positively spatially correlated, showing that regulatory activity has effects over inspected and neighboring plants in the same state. Almer and Goeschl (2010) studied the deterrent effect of criminal prosecution over environmental crimes in Germany. They find that public trials have a more significant effect on the offense rate than the likelihood of conviction and the magnitude of fines. Gray and Shimshack (2011) review the empirical literature showing that there is sufficient evidence demonstrating how monitoring and enforcement generate not only specific deterrence at the targeted plant, but also substantial spillover effects (general deterrence) by reducing future violations at other firms. More recently, Earnhart and Friesen (2013), Aklin et al. (2014) and Sjöberg (2016) add other important aspects to the analysis: experiential deterrence, corruption as a cause of poor law, the role of local governments in the application of environmental laws.

Brazil has recent and growing literature on the subject. De Oliveira (2002) discusses the importance of decentralization to implement environmental policies (mainly the creation of protected areas) presenting a case study for the state of Bahia. Assunção et al. (2013) evaluate the impact of monitoring and enforcement actions by IBAMA on Amazon deforestation. The authors use the number of fines as a proxy for command and control. They conclude that IBAMA had a significant role in deterring deforestation: observed deforestation between 2007 and 2011 would have been 73% bigger in the absence of fines. Uhr and Uhr (2014) use data on environmental infractions against flora, but their dataset is for Brazilian states. Using fines as a proxy for regulators willingness to enforce the law, they find that sanction charges have a substantial deterrent effect over environmental violations: a value increase produces a specific effect, reducing infractions on the state in which it was applied, and a spillover effect, reducing offenses in neighboring states. Da Silva and Bernard (2016) argued that the Brazilian system for enforcing environmental law is inefficient. Using data for wildlife infractions and payment of fines in the state of Pernambuco, they show that over twelve years, only 1% of fines were paid.

3. The Brazilian Environmental Regulation¹⁰

3.1 Brazilian environmental legislation

The Law 9,605/98, known as the "Environmental Crimes Law" (ECL), is considered the most significant political and legal advance in defense of Brazilian environmental resources, adding to other relevant legislation on environmental liability (Federal Constitution, Laws 4,771/65, 6,938/81, 7,735/89, 9,433/97, among others). Despite the name, the law is not restricted to establishing sanctions against environmental crimes but also addresses administrative offenses against the environment. The norm inaugurates the punishment system with specific penalties for the offenders and guides monitoring actions through different categories of environmental crimes.

The ECL defines the concept of "administrative environmental infraction" as "any act or omission that violates the legal rules of use, enjoyment, promotion, protection, and recovery of the

¹⁰ This section is based on Federal Legislation, so the same laws apply to all municipalities. For a historical overview of the Brazilian environmental legislation, we recommend reading Drummond and Barros-Plataiu (2006).

environment,” this being a rather broad concept. Also, the law establishes, in general terms, the administrative procedure for investigating offenses and the applicable sanctions. The Federal Decrees 6,514/08 and 6,686/08 regulate the types of environmental infractions and administrative penalties applicable to each particular case. The Decree 6.514/08 also deals with the federal regulatory process for investigating these violations in a more accurate way than the ECL.

The Federal Decree 6,514/08 has replaced the previous one (Decree 3,179/99). The difference lies in the aggravation of the penalties imposed; the inclusion of aggravating circumstances such as repeated infringement by the offender in a shorter period than five years; the exclusion of a conduct adjustment term that could replace the payment of a fine; and the addition of new potentially harmful acts to the environment. Also, the Decree reduced the number of possible appeals, from four to two judging instances. The Decree 6,686/08 does not revoke the previous one, but changes and adds new legal devices, making the regulation more comprehensive and rigid.

The following categories of administrative violations against the environment are defined by the law: offenses against flora; fauna; relating to pollution; and other environmental infractions. The Federal Decree 6,514/08 defines administrative offenses against flora, such as: Destroying or damaging forests or other forms of natural vegetation in area considered as “permanent preservation site” without permission of the competent agency; Cut trees in permanent conservation area or whose species are specially protected without authorization; Cause direct or indirect damage to protected areas; Cause fire in woods or forest; Cut or turn hardwood into charcoal; Prevent or hinder the natural regeneration of forests or other forms of native vegetation in protected areas; Clearing forests or other native formations, outside the legal reserve, without authorization of the competent authority; Commercialize chainsaws without a license.

The legislation describes ten different administrative sanctions, such as warning; fine imposition; apprehension of products and by-products or any equipment; activities embargo and the restriction of civil rights. The inspection agent, when communicating the infraction, also indicates the appropriate sanctions to the transgressor. It is important to stress that fines can be issued with (cumulative penalties) or without other sanctions, therefore being applied to all infractions in every case. The values range from fifty to fifty million Reais (local currency)¹¹, respecting the relevant unit of measurement for different types of infractions, maximum and minimum values as defined by the law for each violation, the severity of the offense, potential impacts on the health of neighboring populations, and the identification of the offender’s economic capacity and level of education. At the time of the final judgment, after the legal process, the fine can be increased or lessened by 50% depending on aggravating or mitigating circumstances predicted by Decrees 6,514/08 and 6,686/08 and IBAMA normative instructions IN 08/03, 14/09 and 10/12.

¹¹ Something between US\$15.00 and 15.3 million dollars.

3.2 The administrative process for monitoring and enforcement of environmental violations

IBAMA was created in 1989 by Federal Law 7,735. It is linked to the Ministry of Environment (MMA), integrating the National Environmental System (SISNAMA). The institute is responsible for exercising the power of environmental police, performing actions related to surveillance, environmental monitoring, and control, exercising the role of judging the authority and the application of administrative sanctions (Law 11,516/07 and IN 10/12). Also, the agency can propose and edit environmental quality norms and standards and establish criteria for managing the use of natural resources through the country. To achieve its objectives, the Institute works in conjunction with other agencies and entities of public administration that are members of SISNAMA, in federal, state and municipal levels. IBAMA has units in all 26 Brazilian states and the Federal District also. Until the 1990s investigation activities were carried out according to complaints and were focused on emergencies such as fires and deforestation, mainly in the Amazon and Pantanal regions. Nowadays, inspections are planned and directed by the use of new technologies such as remote sensing, satellite images, and geo-referenced location, acting throughout the country. After the publication of Decree 6,514/08, Annual Management Reports (IBAMA 2008, 2009, 2010) show that the Institute changed its deterrence methodology. Instead of pulverized actions, monitoring operations became more abundant and focused on "major violators" and critical locations, resulting in fewer inspections, but with higher penalties to decapitalize criminals and deter other potential offenders through a "pedagogic effect."

The agency carries out efforts to investigate actions that might cause pollution or environmental degradation, attacks on fauna and flora, biopiracy and illegal acts in fishing activities. The Institute also performs inspections requested by the Brazilian Public Ministry or through anonymous complaints, with the participation of the civil society.

The procedure for investigating infractions and imposing penalties are both defined by IBAMA IN 10/12. Verified the violation, a notice of infraction is issued, and administrative sanctions are applied following the legislation. In this investigation phase, the assessed is given the possibility of defense within 20 days, counted from the date he became aware of the notification. IBAMA must inform the Public Ministry if the violator's conduct also configures environmental crime. In that case, alongside the administrative investigation, it will take place the criminal prosecution of the environmental crime, carried out by the Public Ministry. After the defense, IBAMA will proceed with the trial, and the offender may appeal within 20 days. Once the notice of infraction is approved, then the enforcement stage begins. At this point, the offender is intimated to pay the fine assigned to him at the time of assessment. The value is increased or reduced by mitigating or aggravating circumstances if any. Recent technological advances are making possible for IBAMA to track all current and past notifications, so the efficiency of the Institute in enforcing the law is increasing, as can be seen by the higher rates of collected fines (IBAMA, 2010). In addition to exercising the power of police and judging authority, IBAMA must disseminate environmental legislation and promote educational activities to reduce violations.

4. Data

All data used in this study came from open sources. Brazilian Access to Information Law guarantees easy access to public interest information produced by government agencies, ensuring mandatory disclosure of data relating to infractions and their penalties imposed by environmental agencies. Data for violations are related to administrative offenses against Flora, between 1998 and

2015. For penalties imposed, we use fine values applied to each infraction¹². This data is available at IBAMA's website¹³.

The database contains violations with fines varying between BRL 50 (US\$12.5) and BRL 50 million (US\$12.5 million), which are the minimum and maximum values as defined by the ECL. The offenses were classified into three categories (warnings, infractions, and outliers) in order to separate the milder cases from those of more significant harm to the environment. The Decree 6.514/08 defines as a warning those administrative infractions that are less harmful to the environment, with a maximum fine not exceeding BRL 1,000 (about US\$ 250). It is considered as infractions those cases with fines varying between more than BRL 1,000 and less than or equal to BRL 2.5 million (US\$ 625 thousand). Outliers are the remaining violations (fines up to BRL 50 million, or US\$ 12.5 million)¹⁴. All this information was grouped at the municipal level for the full set of Brazilian cities¹⁵. We chose to work all number of violations in every year of the dataset.

Figures 1 to 6 show the distribution of offenses in percentiles for the Brazilian territory (municipalities) and the values of sanction charges for the whole period (aggregated data for 1998 to 2015) separated by violation category (warnings, infractions, and outliers). IBAMA records show that the municipalities with the largest number of annual infractions are in the central-west and northern regions of Brazil, mainly in the states that border or are part of the region called Deforestation Arc¹⁶. Regarding the values of imposed fines, municipalities in the states of Pará (PA), Amazonas (AM), Maranhão (MA) and Mato Grosso (MT) lead the highest positions. It is important to note that there is a significant number of cities, 818 in total, that did not record any assessment or fine from IBAMA over the 18 years studied. The average number of municipalities per year that registered notifications is 1,658, for a total of 5,482. Therefore, there is a significant number of zeros in the dataset for every year¹⁷. Another 1,556 cities were assessed only once or twice during the period.

¹² It's important to stress that fines can be issued with (cumulative penalties) or without other sanctions, therefore being applied to all infractions in every case. The inspection agent, when communicating the infraction, also indicates the appropriate sanctions to the transgressor. The fine gradation must respect the relevant unit of measurement for different types of infractions, maximum and minimum values as defined by the law and decrees for each type of violation, the severity of the offense, potential impacts on the health of neighboring populations, and the identification of the offender's economic capacity and level of education, among other minor factors.

¹³ Crude data contains information about the violator (if physical or legal persons, if public or private firms), the year and municipality of the infraction, the magnitude of the applied fine, the status of the payment, and the legal basis of assessment. We are working on separating public and private companies from individual violators, analyzing recidivism, and on categorizing the offenses that also gave rise to criminal proceedings.

¹⁴ We apply these definitions for the entire period. We deflate fine values for the year 2015 and then apply the listed criteria to classify offenses in warnings, infractions, or outliers for each year of the dataset. Warnings represent 27% of the cases, infractions 72,2%, and outliers 0,8%.

¹⁵ The information provided by IBAMA contained some issues that had to be addressed by the authors, such as duplication of records, fines with lower values than allowed by law, and errors in the description of the municipalities where the violations took place. During the studied period, some municipalities were divided, creating new localities. To avoid potential caveats, we had to adapt the database to only consider the existing municipalities in 1997. Working with Brazilian minimum comparable areas (MCA) is a standard procedure for the spatial econometrics literature. An MCA is a municipality or aggregation of municipalities necessary to enable consistent spatial analyses over time (Da Silva *et al.*, 2016).

¹⁶ This area is composed of 248 municipalities and extends from Rondônia (RO) to Maranhão (MA).

¹⁷ Because of that we include a quadratic term for fines in the regressions.

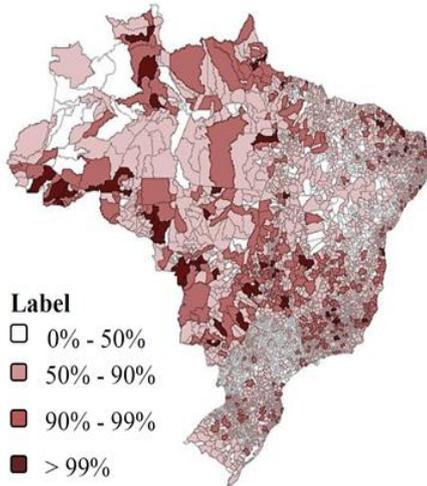


Figure 1 – Percentile map for Warnings

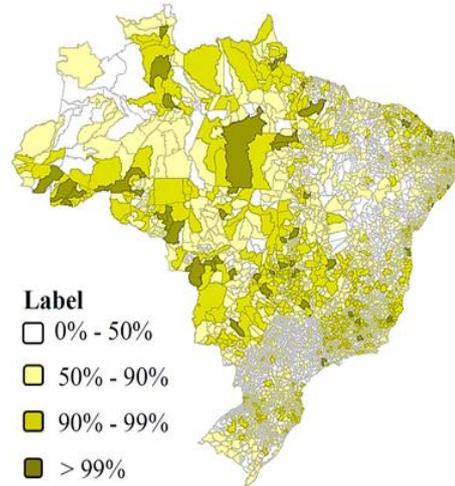


Figure 2 – Percentile map for Values Warn.

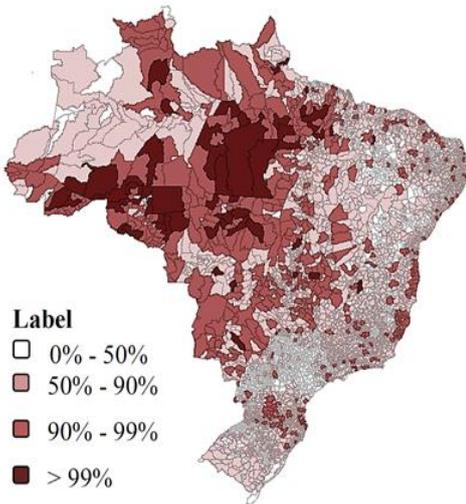


Figure 3 – Percentile map for Infractions

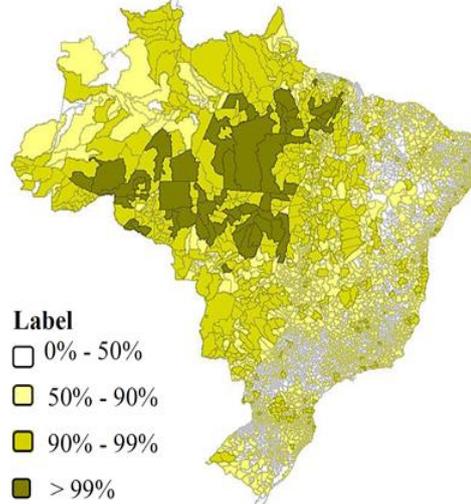


Figure 4 – Percentile map for Values Infr.

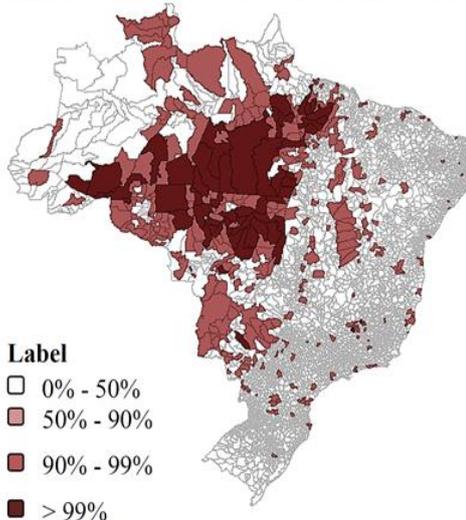


Figure 5 – Percentile map for Outliers

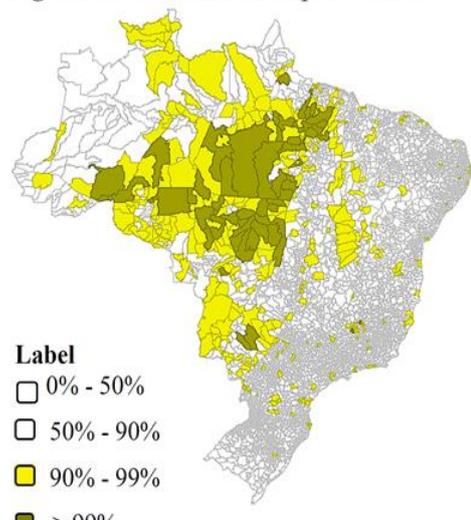


Figure 6 – Percentile map for Values Outl.

The other variables in the dataset are related to municipal, agricultural production (rice, sugar cane, cattle, coal extraction), available for the entire period, GDP in added value for the agricultural, industrial, and service sectors, available up to 2014, and local population, available for

the 1998-2015 period (including projections for the latter years). Data for these socioeconomic variables can be downloaded at the Brazilian Institute of Geography and Statistics (IBGE)¹⁸.

Table I - Descriptive Statistics

Variable	Description	mean	sd	max	Min
Warnings ^a	Num. of Asst. with fine ≤ R\$1,000	0.288	2.449	252	0
Infractions ^a	Num. Assessments with R\$1,000 < fine ≤ R\$2.5mi	1.813	9.892	763	0
Outliers ^a	Num. Assessments with R\$ 2.5mi < fine ≤ R\$50 mi	0.025	0.402	38	0
Total offenses ^a	Total number of assessments	2.127	11.107	945	0
Value Warn. ^a	Imposed fines for warnings	162.99	1,267	147,696	0
Value Infrac. ^a	Imposed fines for infractions	151,234	1.6mi	125mi	0
Value Outl. ^a	Imposed fines for outliers	237,855	5.2mi	560mi	0
Value Total ^a	Total value of imposed fines	389,251	6mi	567mi	0
Population	Resident population	33,732	200,164	12mi	724
Rice	Ha. of rice production	554.20	2,885	91,229	0
Sugar Cane	Ha. of sugar cane production	1,336	4,965	114,000	0
Cattle	Cattle livestock	35,996	83,119	2.3mi	0
Coal Extract.	Coal extraction in metric tons.	312.13	3,924	506,888	0
Agro. GDP ^{ab}	Gross value added of agriculture	24,787	47,492	1.7mi	0
Ind. GDP ^{ab}	Gross value added of industry	120,0001mi	67mi	-2.9mi	
Serv. GDP ^{ab}	Gross value added of services	268,290	3.8mi	411mi	1,194
Low Income ^c	Workers earning up to 2 MW	69,854	17,975	100,000	0
Low Educ. ^c	Workers with 4th grade or lower	21,834	15,351	100,000	0

Notes: ^acalculated using 2015 prices/deflated to 2015. ^bValues per BRL 1,000. ^cRates per 100,000 workers. Statistics calculated at the municipal level in panel structure.

Fine magnitudes are instrumented using variables suggested by the Environmental Crimes Law (Law 9,605/98) as extenuating conditions for the penalty gradation: low income and low levels of education. These variables were obtained at RAIS (Annual Report of Social Information), an administrative register of the Ministry of Labor. They refer to the number of workers in the municipality who did not reach the fifth grade of basic education, including illiterates and lower levels of education, and the number of workers in the municipality receiving up to two minimum wages (MW) as monthly income.

Table I presents the variables description and descriptive statistics for the dataset in a panel structure.

¹⁸ <<http://seriesestatisticas.ibge.gov.br/>>

5. Method

The standard dynamic spatial panel methodology does not cope with spatial dependence. However, models can be extended to incorporate these effects. One advantage of the panel approach is that it deals with many aspects of spatial heterogeneity as well (Anselin et al., 2008). Our empirical strategy is to use a Spatial Dynamic Panel Data model (SDPD) (Lee and Yu, 2010a) including both spatial, dynamic, and spatial-time effects to investigate the patterns of dependence on environmental violations at the municipal level. The model captures the direct and indirect effects of accessing IBAMA's claim that there is pedagogic deterrent effect in monitoring and enforcement actions affecting actual and potential offenders.

5.1 The Spatial Limited Information Maximum Likelihood (LIML) Estimator¹⁹:

Consider the model

$$y_{nt} = \rho W_n y_{nt} + \tau y_{nt-1} + \eta W_n y_{nt-1} + Y_{1nt} \gamma + X_{2nt} \beta + \epsilon_{nt} \quad (1)$$

With

$$Y_{1nt} = X_{1nt} \Pi + U_{nt} \quad (2)$$

Where y_{nt} is a $nt \times 1$ vector of the dependent variable. W_n is a $n \times n$ spatial weights matrix of known constants with a zero diagonal and rows or columns sum less than 1. Consider that Y_{1nt} is a $n \times k$ matrix of variables potentially correlated with ϵ_{nt} . X_{1nt} is a $n \times k_1$ set of instrumental variables that directly affect Y_{1nt} and X_{2nt} is a $n \times k_2$ set of regressors that impact the endogenous variables y_{nt} . ρ, τ and η are autoregressive parameter associated with the spatial, time lag and spatial-time lag dependencies, respectively. γ is the parameter of the endogenous variable and β and Π are parameters of independent variables in the first and second equations. It is assumed that the errors $E(U_{nt}) = 0$ and $E(U_{nt}' U_{nt}) = \Sigma_u$. The correlation between Y_{1nt} and ϵ_{nt} is captured by $E(U_{nt}' \epsilon_{nt}) = \sigma_{u\epsilon}$. Let's define $S(\rho) = I_{nt} - \rho W_{nt} - \tau I_{-1,nt} - \eta W_{-1n}$, $Y_{nt}(\rho) = [S(\rho)y_{nt}, Y_{1nt}]$ and $\Gamma = \begin{bmatrix} 1 & 0 \\ -\gamma & I_g \end{bmatrix}$, where

$$W_{nt} = \begin{bmatrix} W_n & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & W_n & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & W_n \end{bmatrix},$$

¹⁹ Liu (2012) derives the LIML estimator for a spatial autoregressive model with endogenous regressors. We extend that to the panel case.

$$I_{nt} = \begin{bmatrix} I_n & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & I_n & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & I_n \end{bmatrix},$$

$$I_{-1,nt} = \begin{bmatrix} \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ I_n & \mathbf{0} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & I_n & \mathbf{0} \end{bmatrix},$$

$$W_{-1,n} = \begin{bmatrix} \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ W_n & \mathbf{0} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & W_n & \mathbf{0} \end{bmatrix}, \text{ and}$$

I_g is the identity matrix $g \times g$. So, the model can be written in its short form as $Y_{nt}(\rho)\Gamma = Z_{nt}B + \mathcal{H}_{n0} + V_{nt}$, where $Z_{nt} = [X_{1nt}, X_{2nt}]$, $B = \begin{bmatrix} 0 & \Pi \\ \beta & 0 \end{bmatrix}$, $\mathcal{H}_{n0} = \begin{bmatrix} \tau y_{n0} & \eta W_n y_{n0} \\ \mathbf{0} & \mathbf{0} \\ \vdots & \vdots \\ \mathbf{0} & \mathbf{0} \end{bmatrix}$, and $V_{nt} = [\epsilon_{nt}, U_{nt}]$.

Assuming that the joint distribution of errors is normal, then the density of $V_{nt,i}$ is given by $(2\pi)^{-(g+1)/2} |\Sigma|^{-1/2} \exp(-\frac{1}{2} V_{nt,i} \Sigma^{-1} V_{nt,i})$, where $\Sigma = \begin{bmatrix} \sigma_\epsilon^2 & * \\ \sigma_{u\epsilon} & \Sigma_u \end{bmatrix}$. The Jacobian of the transformation of V_{nt} into $[y_{nt}, Y_{1nt}]$ is $\begin{vmatrix} S'_{nt}(\rho) & \gamma' \otimes I_{nt} \\ 0_{ntg \times nt} & I_{ntg} \end{vmatrix} = |S_{nt}(\rho)|$.

Therefore, the log-likelihood function of this model is given by

$$\begin{aligned} \mathcal{L}(\theta, \Pi, \Sigma) &= -\frac{nt(g+1)}{2} \ln(2\pi) + t \ln |S_{nt}(\rho)| - \frac{nt}{2} \ln |\Sigma| \\ &\quad - \frac{1}{2} \sum_i [Y_{nt,i} \Gamma - Z_{nt,i} B - \mathcal{H}_{n0}] \Sigma^{-1} [Y_{nt,i} \Gamma - Z_{nt,i} B - \mathcal{H}_{n0}]' \end{aligned} \tag{3}$$

where $\theta = [\rho, \tau, \eta, \beta]$.

It is convenient to concentrate the log-likelihood function with respect to Σ^{-1} , as suggested by Davidson and MacKinnon (1993). As $\frac{\partial \mathcal{L}}{\partial \Sigma^{-1}} = \frac{nt}{2} \Sigma - \frac{1}{2} [Y_{nt} \Gamma - Z_{nt} B]' [Y_{nt} \Gamma - Z_{nt} B]$, then we have that $\Sigma = \frac{1}{nt} [Y_{nt} \Gamma - Z_{nt} B]' [Y_{nt} \Gamma - Z_{nt} B]$. The concentrate log-likelihood function becomes

$$\begin{aligned} \mathcal{L}(\theta, \Pi) &= c + t \ln |S_{nt}(\rho)| \\ &\quad - \frac{nt}{2} \ln \left| \frac{1}{nt} [Y_{nt}\Gamma - Z_{nt}B - \mathcal{H}_{n0}]' [Y_{nt}\Gamma - Z_{nt}B - \mathcal{H}_{n0}] \right| \\ &= c + \ln |S_{nt}(\rho)| - \frac{nt}{2} \ln |V_{nt}' V_{nt}| \end{aligned} \tag{4}$$

where c is a constant. Consider now an alternative representation of equation (1)

$$\begin{aligned} y_{nt} - \rho W_n y_{nt} &= \tau y_{nt-1} + \eta W_n y_{nt-1} + Y_{1nt}\gamma + X_{2nt}\beta + \epsilon_{nt} \\ &= z_{nt} b' + \epsilon_{nt} \end{aligned}$$

where $z_{nt} = [y_{nt-1}, W_n y_{nt-1}, X_{2nt}, Y_{1nt}]$ and $b = [\tau, \eta, \beta, \gamma]'$. Applying a Cochrane-Orcut transformation to this equation we obtain

$$y_{nt} - \rho W_n y_{nt} = z_{nt} (z_{nt}' z_{nt})^{-1} z_{nt}' (y_{nt} - \rho W_n y_{nt}) + \epsilon_{nt} \tag{5}$$

Equation (5) shows that the spatial transformation in the dependent variable could be represented as a projection of this transformed variable on the regression plus the error term. Due to the endogeneity in Y_{1nt} , the projection of y_{nt} and $W_n y_{nt}$ in z_{nt} is potentially biased. Then, we suggest applying an IV correction using all the exogenous variables as instruments. Consider h_{nt} formed by all exogenous variable, then $h_{nt} = [y_{nt-1}, W_n y_{nt-1}, X_{1nt}, X_{2nt}]_{LI}$, where LI stressed that only the linear independent columns of b are considered. Then, we can consider a correction in (5), as

$$y_{nt} - \rho W_n y_{nt} = \hat{z}_{nt} (\hat{z}_{nt}' \hat{z}_{nt})^{-1} \hat{z}_{nt}' (y_{nt} - \rho W_n y_{nt}) + \epsilon_{nt} \tag{5'}$$

Where $\hat{z}_{nt} = h_{nt} (h_{nt}' h_{nt})^{-1} h_{nt}' z_{nt}$. Then, we can express ϵ_{nt} as the sum of the two terms,

$$\epsilon_{nt} = \epsilon_{nt}^0 - \rho \epsilon_{nt}^L \tag{6}$$

Where $\epsilon_{nt}^0 = y_{nt} - \hat{z}_{nt} (\hat{z}_{nt}' \hat{z}_{nt})^{-1} \hat{z}_{nt}' y_{nt}$ and $\epsilon_{nt}^L = W_n y_{nt} - \hat{z}_{nt} (\hat{z}_{nt}' \hat{z}_{nt})^{-1} \hat{z}_{nt}' W_n y_{nt}$.

Substituting (6) in V_{nt} we have

$$E|V'_{nt}V_{nt}| = \left(\frac{1}{n}\right)^{k+1} \begin{vmatrix} \epsilon_{nt}^{0'}\epsilon_{nt}^0 - \rho\epsilon_{nt}^{0'}\epsilon_{nt}^L - \rho\epsilon_{nt}^0\epsilon_{nt}^{L'} + \rho^2\epsilon_{nt}^{L'}\epsilon_{nt}^L & (\epsilon_{nt}^0 - \rho\epsilon_{nt}^0)'U_{nt} \\ U_{nt}'(\epsilon_{nt}^0 - \rho\epsilon_{nt}^0) & U_{nt}'U_{nt} \end{vmatrix}$$

Finally, we can rewrite the log-likelihood (4) as

$$\mathcal{L}(\rho) = c + t \ln|S_{nt}(\rho)| - \frac{nt}{2} \ln |e(\rho, b)| - \frac{nt}{2} \ln |\mathcal{U}(\rho, b)| \tag{7}$$

Where $\ln|S_{nt}(\rho)| = \ln |I_n - \rho W_n|$, due to the properties of the determinant of diagonal block matrices, $e(\rho, b) = \frac{1}{n}(\epsilon_{nt}^{0'}\epsilon_{nt}^0 - 2\rho\epsilon_{nt}^{0'}\epsilon_{nt}^L + \rho^2\epsilon_{nt}^{L'}\epsilon_{nt}^L)$, and $\mathcal{U}(\rho, b) = \frac{1}{n}[U_{nt}'U_{nt} - U_{nt}'(\epsilon_{nt}^0 - \rho\epsilon_{nt}^0)e(\rho, b)^{-1}(\epsilon_{nt}^0 - \rho\epsilon_{nt}^0)'U_{nt}]$. To avoid efficiency questions, sensitive in LIML context, we employed the bias correction suggested by Yu et al. (2012).

5.2 Monte Carlo Simulation

We run a Monte Carlo evaluation of the Spatial Dynamic LIML (SD-LIML) estimator performance compared to the results with a GMM-IV estimator, similar to the Kelejian and Prucha (1999) and Kapoor et al. (2007) approach, in which the endogeneity of $W_n y_{nt}$ is treated considering the spatial lag of the exogenous variable as an instrumental variable. Specifically, we consider $W_n X_{2nt}$, $W_n X_{1nt}$ and $X_{1nt} X_{2nt}$ as instrumental variables. In each simulation we change the panel sample size considering $n = (20,100)$ and $t = (10,25,50)$. We also change the correlation between U_{nt} and ϵ_{nt} , considering three situations: a small correlation (0.1), a median (0.5), and a strong correlation (0.9). For each simulation we change the spatial parameters (ρ , τ , and η) in a set of values (-0.9, -0.5, -0.2, 0, 0.2, 0.5, 0.9). The spatial matrix was defined as a circular world in the following sense: for the first and last one third of the regions, we consider one neighbor at right and one and left; for the remained one third of the regions, we consider five neighbors at right and five neighbors at left. To avoid non-stationarity, we limit the simulation to that combination of parameters in that $\left|\frac{\tau+\eta}{1-\rho}\right| < 1$, and $\left|\frac{1}{1-\rho-\tau-\eta}\right| < 1$. These inequalities assure the short and the long run stationarity, respectively. Then, we consider 1,032 different combinations of parameters and, for each of them, 500 simulations were run. The graphics with the bias and the root mean square error (RMSE), resuming the results by level of the spatial and temporal parameters are presented in figure 7. For the spatial parameter (ρ), both estimators (SD-LIML and GMM-IV) have good results in terms of bias, but the Spatial Dynamic LIML has RMSE lower than the GMM-IV estimator. For the two other parameters, the temporal lag and the spatial-temporal lag the Spatial Dynamic LIML overcome the GMM estimator both in terms of bias and RMSE statistic. These results give us certainty about the use of SD-LIML in the empirical work.

Therefore, we estimate the following regression for each category of offenses:

$$y_{nt} = \alpha + \rho W_n y_{nt} + \tau y_{nt-1} + \eta W_n y_{nt-1} + \gamma_1 F_{nt} + \gamma_2 W_n F_{nt} + \gamma_3 F_{nt}^2 + \gamma_4 W_n F_{nt}^2 + X_{2nt}\beta_1 + W_n X_{2nt}\beta_2 + \epsilon_{nt} \tag{7}$$

for $n = 5,482$ (Brazilian municipalities); $t = 1998, \dots, 2015$ (years); y_{nt} is the logarithm of the offense rate per 100 thousand inhabitants for a given location and year; F_{nt} is the natural logarithm of total value of imposed fines for a given location; X_{2nt} represents control variables (all in natural logarithm); W_n is the spatial weights matrix²⁰, α is the constant, and ε_{nt} is the error term. The set of parameters to be estimated is given by $(\alpha, \rho, \tau, \eta, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \beta_1, \beta_2)$. Fines are instrumented using the Low-income and Low-education variables (and their spatial lags) discussed earlier. We included quadratic terms for fines due to the expressive number of municipalities without registered violations in each period.

In equation (7) the value of the dependent variable (violations) for one location is jointly determined with that of the neighboring municipalities. Therefore, $W_n y_{nt}$ is the weighted average of the neighboring observations, with weights defined by W_n ; $W_n y_{nt-1}$ is the weighted average of the neighboring observations one year prior; and y_{nt-1} is the number of violations in the same location is the previous year. The coefficients ρ , τ , η , represent the pure spatial effect, the spatial-time effect, and the pure dynamic effect, respectively.

²⁰ The size of the spatial weights matrix was chosen using the Akaike criterion for data adjustment (Stakhovych and Bijmolt, 2009). The best fit was obtained with a matrix $q = 5$ nearest neighbors. We tested changing the matrix to $q = 15, 20$ and 25 and the estimated coefficients did not alter significantly.

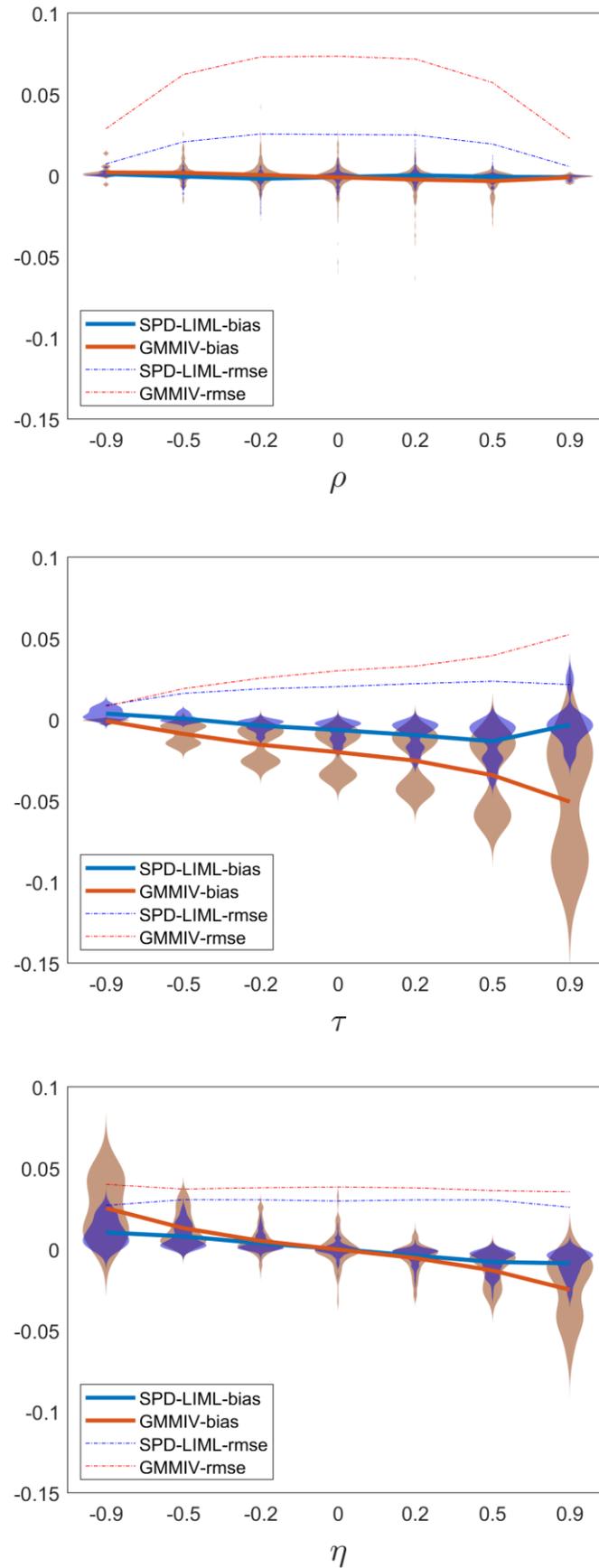


Figure 7 - Bias and RMSE

6. Results and Discussion

Results for the spatial dynamic model, not considering the endogeneity of fines, are shown in Table II and are separated by violation category (warnings, infractions, and all offenses).

Table II – Results for the Spatial Dynamic Model

	Warnings	Infractions	All Violations
Time lag (y_{nt-1})	0.029243***	0.034970***	0.042539***
Spatial time lag ($W_n y_{nt-1}$)	0.005912**	0.018367***	0.005921**
Fines (F_{nt})	0.771677***	0.450404***	0.524978***
Square fines (F_{nt}^2)	-0.060910***	-0.018553***	-0.024494***
Neighbors' fines ($W_n F_{nt}$)	-0.096080***	-0.088208***	-0.10057 ***
Neighbors' square fines ($W_n F_{nt}^2$)	0.002365	0.003921***	0.003600***
Spatial lag ($W_n y_{nt}$)	0.357835***	0.299750***	0.363772***
R ² (overall)	0.7392	0.7998	0.7800
Log Likelihood	-291794.43	-229706.81	-369746
Akaike	100.9233	80.0351	128.2811
LM test no spatial lag	274.12***	24993.14***	45270.94***
Robust LM no spatial lag	2743474.5***	2285565.71***	5309068.54***
LM test no spatial error	107053.87***	89479.93***	140433.47***
Robust LM no spatial error	2850254.3***	2350052.50***	5404231.07***

Notes: Control variables are Pop., Rice, Sugar Cane, Cattle, Coal Extraction, Agro. GDP, Ind. GDP, Serv. GDP, and their spatial lags. Regressions include a constant, time and space FE. Levels of significance: ***1%, **5%, *10%. Num. of Obs.: 87,712.

The coefficients in Table II are estimated using dynamic spatial panel techniques, controlling for spatial and time-specific effects (Yu et al., 2008; Yu et al., 2012; Lee and Yu, 2010b²¹). Results for the Spatial LIML Estimator are presented in Table III also separated by violation category (warnings, infractions, and all offenses). The classic LM tests and the robust LM tests for choosing between lagged or error specifications in all estimations in Tables II and III point that the hypotheses of no spatially lagged dependent variable and no spatially autocorrelated error term are both rejected. However, the Robust LM tests indicate for all estimations in Tables II and III that the spatial lag specification is preferred to the spatial error model since the calculated values are slightly smaller for the no spatial lag hypothesis.

²¹ Lee and Yu (2010b) develop a bias-corrected maximum likelihood estimator for the dynamic spatial panel specification with time-period fixed effects.

Table III – Results for the Spatial Dynamic Model with Endogeneity (SLIML Estimator)

	Warnings	Infractions	All Violations
Time lag (y_{nt-1})	0.027987***	0.034461***	0.041713***
Spatial time lag ($W_n y_{nt-1}$)	0.004653*	0.016672***	0.004643*
Fines (F_{nt})	0.795785***	0.464668***	0.548639***
Square fines (F_{nt}^2)	-0.062872***	-0.019403***	-0.026240***
Neighbors' fines ($W_n F_{nt}$)	-0.103943***	-0.092236***	-0.105661***
Neighbors' square fines ($W_n F_{nt}^2$)	0.003220*	0.004229***	0.004149***
Spatial lag ($W_n y_{nt}$)	0.349831***	0.294758 ***	0.353774***
R ² (overall)	0.7371	0.8002	0.7808
Log Likelihood	2083745.8	1695662.9	1595747.3
Akaike	-759.2350	-617.6506	-581.1983
LM test no spatial lag	109.3325***	20897.43***	40666.20***
Robust LM no spatial lag	2618040.5***	2147774.83***	4910717.01***
LM test no spatial error	103430.38***	85855.17***	134076.47***
Robust LM no spatial error	2721361.5***	2212732.58***	5004127.28***
Anderson-Rubin test ^a	0.2655(0.876)	0.0031(0.998)	0.1993(0.905)

Notes: Control variables are the same as Table II. Regressions include a const., time and space FE. Instruments: Low Income, Low Educ., and their spatial lags. ^ap-value is shown in parenthesis. Levels of significance: ***1%, **5%, *10%. Num. of Obs.: 87,712.

Ignoring spatial dependence in the disturbances might lead to a loss of efficiency, but the cost of ignoring spatial dependence in the dependent variable is high since the estimator of the coefficients for the remaining variables will be biased and inconsistent (LeSage and Pace, 2009; Greene, 2005). We also performed the Anderson and Rubin (1949) overidentification test (Davidson and MacKinnon, 1993) rejecting the hypothesis of weak instruments for all models in Table III.

The estimated coefficients for the pure spatial effect ($W_n y_{nt}$), the spatial-time effect ($W_n y_{nt-1}$), and the pure dynamic effect (y_{nt-1}) in Tables II and III are all positive and significant across specifications, with combined values less than one (not explosive). They indicate the existence of time and space dependence for violations in all categories. Municipalities with more offenses in the past or that are surrounded by other municipalities with a high number of violations tend to present a higher number of assessments. That might indicate that some regions are more propitious for environmental offenses than others and that, because of it, IBAMA focuses continuously on the same locations in a process called *Regulator Targeting*. As pointed by Alm and Shimshack (2014), *Regulator Targeting* might build in a potentially misleading positive correlation between environmental violations and IBAMA actions, suggesting that assessments might be less effective than they really are. That is possibly why we observe positive signs instead of negative signs for these variables.

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The coefficient for Fines (F_{nt}) is also positive and significant for all models in both estimation procedures, but the quadratic term (F_{nt}^2) is negative indicating the existence of an inflection point. As pointed before, we included a quadratic term due to the expressive number of municipalities without registered violations in each period. In a linear regression, this large number of zeros can pull the regression line down towards it, mixing up the interpretation of the effectiveness of sanction charges. With the quadratic term, we still consider those cases with zero offenses, but we can capture fine impacts more clearly. On the other way, fines applied in neighboring municipalities ($W_n F_{nt}$) have a negative signal, with a positive quadratic effect ($W_n F_{nt}^2$). However, these coefficients cannot be interpreted directly, because they do not represent the partial derivatives (LeSage and Pace, 2009). To do that we must calculate the direct (own-economy) and indirect effects (spillovers) as suggested by LeSage and Pace (2009). Direct, indirect, and total effects are presented in Table IV for the short-run and long-run (Elhorst, 2012) and were calculated for the Spatial Dynamic Model with Endogeneity only.

The calculated direct, indirect, and total effects have different magnitudes depending on the category of offense. For Fines, all three effects are positive and significative for all categories of violation in the short and long-run. For the quadratic term, all three effects are negative and significative. So, specific deterrence (direct effect), spillovers (indirect effect), and general deterrence (total effect) all obey an inverted U pattern, indicating the existence of an inflection point after which increases in sanction charges have a negative impact on violations at the same municipality and on neighboring locations. In Table V we present the maximum values for fines, also calculated for the Spatial Dynamic Model with Endogeneity for the short and long-run.

For warnings, amounts totaling more than 540 Reais are sufficient to discourage new violations in the same municipality where the fines were imposed (direct effect). Regarding neighbors (indirect effect), even fines totaling low values (around 110 Reais) are enough to discourage further offenses. Perhaps because these are less harmful violations with lower financial returns, only the observation that IBAMA is monitoring offenders (even with low penalties) is enough to deter potential offenders. When is considered both effects, inflection values calculated for specific deterrence are overestimated for the short and long terms in comparison to general deterrence values. When we consider spillover effects, the necessary value in applied fines to restrain warnings at the municipal level is reduced by 39%, to 330 Reais (total effect).

Table IV – Short-term and Long-term Direct and Indirect Effects

	Short-term Effects			Long-term Effects		
	Direct	Indirect	Total	Direct	Indirect	Total
Warnings						
Fines	0.807837	0.25626	1.0641	0.83266	0.28768	1.12034
Square Fines	-0.06417	-0.0276	-0.0918	-0.06616	-0.03044	-0.0965
Infractions						
Fines	0.467169	0.06092	0.52809	0.48498	0.08439	0.56937
Square Fines	-0.01949	-0.0020	-0.0215	-0.02023	-0.00297	-0.02311
All Violations						
Fines	0.554836	0.13065	0.68549	0.580341	0.15812	0.73846
Square Fines	-0.02660	-0.0076	-0.0342	-0.02783	-0.0081	-0.03683

Notes: All significant at 1% level. The presented effects are the respective elasticities for the Spatial Dynamic Model with Endogeneity (SLIML Estimator) displayed in Table III.

For infractions, inflection values suggest that offenders observe (or consider) only high magnitudes of sanctions charges being applied in neighboring municipalities. For the short-run, IBAMA must apply fines totaling more than 3.2 million in neighboring localities to discourage new infractions. Considering the long-run, when the environmental authority’s reputation in applying big fines is considered, the inflection value is reduced to around 1.4 million in fines. If sanction charges are too small, they are either not observed (IBAMA’s actions aren’t known) or aren’t big enough to discourage offenders (they are known, but not intense enough). If we only consider specific deterrence, inflection values for infractions are underestimated. The necessary value in applied fines to restrain infractions at the municipal level is around 213 thousand Reais, 33% higher than the calculated value for the direct effect.

We have found evidence that there is a *pedagogic deterrent effect* associated with fine values. Sanction charges imposed in the municipality of the infraction and in the neighborhood, are important to discourage new offenses. Low fine values encourage further violations, but the quadratic effect of sanction charges shows that after certain values, offenses fall. However, IBAMA's reputation for imposing heavy fines on neighboring municipalities appears to be important only in the case of Infractions. In the case of Warnings, even low values applied in neighboring municipalities are sufficient to discourage further violations, suggesting that, for this category of offense, monitoring may be more important than the imposed penalty. Considering all violations, for the long run, fines above 33.7 thousand applied in one municipality are already sufficient to deter offenses in the same municipality. When we consider the indirect effects (spillovers), the necessary fine values applied in the municipality and in the neighboring localities is of 22.6 thousand (general deterrence).

Table V – Short-term and Long-term Inflection Values for Fines (R\$)

	Short-term			Long-term		
	Direct	Indirect	Total	Direct	Indirect	Total
Warnings	542	104	330	540	113	330
Infractions	160,638	3,276,057	213,510	160,875	1,465,662	213,510
All Violations	33,835	5,500	22,610	33,774	6,536	22,610

Notes: Maximum values calculated for the Spatial Dynamic Model with Endogeneity (SDLIML Estimator), displayed in Table III.

7. Conclusions

We found evidence for the existence of time and space dependence for environmental violations in all categories studied. Municipalities with more offenses in the past or that are surrounded by other municipalities with a high number of violations tend to present a higher number of assessments. Regulator Targeting is the possible explanation for that result. We also found evidence that there is a *pedagogic deterrent effect* associated with fine values. Sanction charges imposed in the municipality and in the neighborhood are important to discourage new offenses. Low fine values encourage further violations, but the quadratic effect of sanction charges shows that after certain values, offenses fall. This result can open the discussion and base future public policies about changes in the minimum values of fines.

On the other way, increased sanction charges won't be effective if fines aren't collected at all. As pointed by Da Silva and Bernard (2016), only a small number of fines are paid. For future research, we are working on separating assessments by payment status to consider prescriptions, cancellations and other issues associated with non-payment.

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