UNDERSTANDING DISPARITIES IN PUNISHMENT: REGULATOR PREFERENCES AND EXPERTISE

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Abstract. This paper provides an empirical framework to evaluate regulatory discretion and apply it to California water quality regulation. We identify and estimate an adverse selection model of the regulator-discharger interaction to measure the extent to which the regulator's environmental preferences and administrative or political costs affect penalties and compliance. We find that, because of the heterogeneity in compliance costs, the disparities in penalties would decrease by at most 15 percent, even if the regulator were homogeneous across dischargers. We also find that introducing a one-size-fits-all policy would lead to an increase in violations by large facilities and those located in densely populated areas.

1. Introduction

Regulations are often written flexibly so that the authorities in charge of applying them can do so judiciously. For example, following a particular violation, enforcement authorities may choose one from a range of punishments, considering a host of aggravating and mitigating factors that are at times subjective. One reason to allow discretion in enforcement is that it might be impossible, in practice, for the written regulation to specify all possible contingencies—especially when the circumstances surrounding any given violation, such as the compliance costs borne by the regulated entity and the resource-constraints faced by the enforcement authority, can vary considerably from one case to another. However, without proper incentive, regulators may put forward their own interests instead of applying their expertise to make an appropriate judgment as a social planner (Stigler, 1971; Peltzman, 1976). In this paper we identify and estimate a principal-agent model to quantify the extent

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to which variation in the regulator's preferences drives disparities in the enforcement of regulation across different entities, and to evaluate how policy reforms limiting the regulator's discretion would affect enforcement and compliance.

To begin with, we document heterogeneity in the punishment of water quality violations across domestic wastewater treatment facilities in California, in the context of the enforcement of the Clean Water Act and the state's Porter-Cologne Water Quality Control Act. First, we find a large dispersion in penalties for observationally identical violations. Second, we show that facility attributes explain a large portion of the variations in penalties, even after controlling for a variety of violation characteristics.

Becker (1968) provides a theoretical justification for disparities in punishment, by considering the optimal amount of enforcement when it is costly to impose sanctions. In the absence of such costs, the optimal punishment induces an offense level that equates the marginal social harm from the offense and the marginal private gain by the offender. With costly punishment, the optimal offense level also depends on the extent to which offenders respond to changes in penalties. Under this framework, disparities in punishment may have several, non-exclusive sources: heterogeneity in the social harms of violations, the private violation gains, the costs of punishment, and the elasticity of violations to penalties.

An interesting, additional dimension to consider is that regulators are not a social planner. Even if regulators considered the same factors in determining enforcement policies as the latter would, they may assign different weights to each of these factors. For example, previous studies have empirically documented the incentives to relax law and regulation enforcement for political purposes in the context of deforestation in Indonesia (Burgess, Olken and Sieber, 2012); coal mining safety regulations in the U.S. (Gordon and Hafer, 2014) and China (Jia and Nie, 2017); and street vending and squatting in Latin American cities (Holland, 2016). The regulators may also consider their own personal reputation (Leaver, 2009), agency budget (Helland, 1998), and special interest groups (Cropper, Evans, Berardi, Ducla-Soares and Portney, 1992), as well as local preferences or economic conditions (Deily and Gray, 1991; Agarwal, Lucca, Seru and Trebbi, 2014). In California, the authorities in charge of water quality regulations are the State Water Resources Control Board and Regional Water Quality Control Boards, whose members are appointed by the governor. It is possible that these political appointees, at least to some extent, pander to the state administration or pursue their own agenda.

Our structural approach helps disentangling the aforementioned sources of disparities in regulation enforcement. We model the interaction between the regulator and each facility in a principal-agent setting, following Maskin and Riley (1984) and Mookherjee and Png (1994). For each facility, the regulator sets a penalty schedule, and, given that schedule, the facility exerts costly effort to affect the probability distribution of the violations. The regulator knows the distribution of compliance cost types of each facility, but observes neither the realized compliance cost type nor the facility's effort. In determining the penalty schedule, the regulator minimizes the sum of the facility's expected compliance costs, the environmental costs of violations, and the enforcement costs associated to assessing and imposing penalties. The latter two costs reflect the regulator's preferences, which may incorporate both public interests and her private concerns.

We use data on violations and penalties to identify and estimate the model, exploiting a set of institutional changes in the mid-2000s. These changes include: the launch of a new computerized system to track and manage information about violations and enforcement; and the establishment of a new statewide office to support enforcement activities. We document that, after these changes, the average amount of penalties increased and violations became less frequent. Moreover, we find little evidence that the compliance cost structure changed during the period. This institutional feature provides a unique opportunity to identify the dischargers' compliance cost function.

We provide conditions under which the model is non-parametrically identified. Our identification strategy is closely related to two recent papers, d´Haultfoeuille and Février (2016) and Luo, Perrigne and Vuong (forthcoming), both of which address the identification and estimation of screening models. The former study focuses on the informed party, and employs exogenous variation in the contracts to identify that party's distribution of types (which, in our application, would consist of the distribution of facilities' compliance costs). Conversely, the latter paper builds upon the optimality conditions of both the informed and non-informed parties to identify the model primitives without necessarily relying on any external variation. We show that, by combining both approaches, we can identify a more general model than the ones considered by these two papers. Closely following the identification strategy, we estimate the model semi-parametrically. In this regard, we contribute to the literature on the estimation of regulation models (Wolak, 1994; Thomas, 1995; Gagnepain and Ivaldi, 2002; Timmins, 2002; Broncas et al., 2006; Gagnepain et al., 2013; Bontemps and Martimort, 2014; Lim and Yurukoglu, forthcoming; Abito, 2017).

Our model estimates indicate that both the compliance costs and the regulator preferences vary considerably across the facilities. We also find evidence that the regulators tailor the enforcement policies according to local residents' preferences. If the average resident near a wastewater treatment facility places a high value on water quality, then the regulators tend to consider the violations by that facility as more environmentally damaging and less costly to punish than those by other facilities.

Given the estimated heterogeneity in both the compliance costs and the regulator preferences, we perform a decomposition exercise to understand the observed disparities in penalties. In doing so, we consider a counterfactual scenario in which the regulator's preferences are identical across all facilities. Not surprisingly, homogenizing the regulator's preferences reduces the cross-facility dispersion of penalties, but only to a moderate extent: relative to the baseline scenario, the standard deviation of the distribution of expected penalties across all dischargers would fall by five to 15 percent. Such small reductions indicate that differences in compliance costs drive most of the heterogeneity in penalty schedules across the facilities in our sample.

In an alternative scenario, we consider a one-size-fits-all policy, in which all facilities face the same penalty schedule, regardless of their compliance costs. Under this uniform schedule, we find that both the level and the dispersion of violation frequencies would increase by 6-19 percent, even though the average stringency of the penalty schedule would be comparable to that under the current policy. This finding illustrates the value of regulators' discretion in employing their knowledge on the compliance cost distributions of different facilities (Duflo, Greenstone, Pande and Ryan, 2016). Furthermore, we find that the violation increase due to this policy change would be pronounced for large facilities and those located in a densely populated area.

The rest of the paper is organized as follows: Section 2 describes how the water quality regulations in California are enforced and provides details of the institutional changes. In Section 3, we present the data and some descriptive statistics. Section 4 contains the theoretical model, and Section 5 describes the identification and estimation of the structural model. Section 6 presents the estimation and counterfactual results. We conclude in Section 7.

2. Institutional Background

2.1. **Water Quality Regulation.** Both the Clean Water Act and the state's Porter-Cologne Water Quality Control Act govern the water quality regulation in California. The former act created the National Pollutant Discharge Elimination System (NPDES) to regulate facilities that discharge pollutants from any point source, such as a pipe or a ditch, into surface waters in the US, including lakes, rivers and the ocean. Although the program is federal, many of its permitting, administrative, and enforcement aspects are implemented by the state government. An NPDES permit is typically a license for a facility to discharge a specified amount of a pollutant into a receiving water under certain conditions, where the limits on the concentration of the pollutants are based on both the availability of pollution control technologies and the water quality standards of the receiving water body.

Both laws require that permittees periodically submit discharge monitoring reports with information about the quantity and quality of their effluents. They are also required to sample receiving waters, to perform bioassays, and to characterize and report the toxicity potential of the discharges. Enforcement actions are mostly based on these reports. In the 2000-2014 period, 95% of all violation records were detected from permittees' self-reports, while the remaining 5% were detected during an inspection or triggered by a complaint, referral, or sewer overflow.

The NPDES self-monitoring reports are generally considered reliable by the regulatory community. Potential problems of the self-monitoring programs, such as poor sample collection procedures, analytical techniques, and report preparation and documentation, are acknowledged by the community, and various measures are in place to prevent or minimize these problems. First, the details of monitoring and reporting requirements are included in the permit, and facility and compliance inspections are routinely performed. Routine inspections are also occasionally complemented by unscheduled ones that are triggered by complaints or noncompliance.[1]

Second, intentional misreporting can be punished by criminal sanctions to the responsible employees.[2] If an employee has accurately reported operation conditions

[1]Based on the 10,840 inspection records of 2000-2013, about 2% of them (253 inspections) were triggered by complaints or noncompliance. We find that the frequency of inspections is not statistically correlated with the self-reported violations, and 90% (36%) of major (minor) dischargers received at least one inspection per year. See Section 3 for a detailed discussion on the designation of major/minor facilities.

[2]According to Section 122.22(d) of Title 40 of the Code of Federal Regulations, employees signing any report required by the permits must make a certification that they are aware of significant penalties for submitting false information, including the possibility of fines and imprisonment for misreporting

not in compliance with the NPDES permit, he/she cannot be held liable in a civil suit because meeting the permit requirements is the responsibility of the permitted facility, not that employee. Falsification of monitoring reports, however, is a criminal offense that can lead to the prosecution of both the responsible employees and the facility.

2.2. **Water Quality Regulation Enforcement.** The California Water Boards, consisting of the State Water Resources Control Board and nine Regional Water Quality Control Boards, are in charge of enforcing the water quality regulations in the state. The state board oversees the regional boards, which have primary jurisdiction in issuing permits, monitoring water quality, and taking enforcement actions against violating dischargers. Regional board boundaries follow mountain chains and ridges that define watersheds, and the board members are appointed to a four-year term by the governor and confirmed by the state senate.

For an initial determination of compliance, the regional board' staff screens the self-monitoring reports. When a violation is identified, the staff issues a formal notice of violation, which is critical in determining violations and clarifying errors, vague permit language, or other areas of disagreement between the discharger and the staff. If a violation is confirmed, the case is then evaluated for enhanced enforcement, such as an administrative civil liability (ACL), which might result in a monetary penalty. To impose an ACL, the staff must make an ACL complaint, followed by a 30-day public comment period. The notice for the comment period is posted on the water board's website and may also be mailed to interested parties or published in a local newspaper. The discharger may waive its right to a board hearing and pay the liability, negotiate a settlement, or appear at the hearing to dispute the ACL.

When determining the penalty amount, various factors are considered: the potential for harm to the beneficial water uses, the toxicity, and the susceptibility to cleanup or abatement of the discharge; the volume and degree of violations; the violator's conduct; the economic benefit derived from the violations to the discharger; and the violator's ability to pay. Furthermore, serious or multiple non-serious NPDES violations are subject to a mandatory minimum penalty (MMP) of $3,000 per violation. A *serious* violation is associated with a discharge above limits of a Group I (Group

violations. Self-reported data have been used in the existing literature to assess compliance with environmental regulation (Magat and Viscusi, 1990; Earnhart, 2004; Shimshack and Ward, 2005; Gray and Shimshack, 2011).

II) pollutant by 40 percent (20 percent) or more.[3] As for non-serious violations, the minimum penalty applies when such violations occur four or more times in any period of six consecutive months. There are several exceptions for these mandatory penalties, which we discuss in detail in Section 3.2.

The administrative process to investigate violations and to issue an ACL require a fair amount of staff time. Acknowledging this administrative burden, the regulations allow that the assessed amount of an ACL may include staff costs. Out of the 1,695 ACLs that were effective during 2000-2014, there are 62 occurrences that included nonzero staff costs ranging to $201,800 in 2010 dollars, with the average being $23,700 per ACL.

2.3. **Institutional Changes in Enforcement.** Two major changes in the water quality regulation in California were the launching of the California Integrated Water Quality System (CIWQS) in July 2005 and the establishment of the Office of Enforcement under the state water board in July 2006.[4]

First, the new computer system tracks and manages information about permittees, permits and other orders, inspections, violations, and enforcement activities. It also allows online submittal of self-monitoring data by permittees and makes data available to the public through reports. Previously, dischargers would submit hard copies of the self-monitoring reports, which would then need to be manually entered into the system by the boards' staff. This system dramatically increased efficiency and enabled more resources to be devoted to compliance.

Second, the Office of Enforcement, comprised of legal and investigative staff, was established to provide statewide enforcement and to support the regional water boards' enforcement programs. The staff of the office regularly meets with representatives from the regional water boards to discuss enforcement matters and gives feedback on enforcement approaches. Besides providing support to the regional water boards, the office has the authority to perform independent enforcement actions.

[3]The list of the pollutants of Groups I and II is in Appendix A to Section 123.45 of Title 40 of the Code of Federal Regulations.

[4]In November 2006, Governor Schwartzenegger was reelected. The timing of these two administrative actions by the state government may be potentially related to the incumbent governor's reelection motives (List and Sturm, 2006), but this is beyond the scope of our analysis. At the same time, based on the historical budget publications, available online by the state department of finance, the annual budget allocated for the support of the water boards regarding water quality issues (the item numbered as 3940-001-0001 until the 2008–9 budget or 3940-001-0439 after) has been steady at around $480 million in 2010 dollars.

2.4. **Wastewater Treatment Facilities.** We focus on the facilities that treat domestic wastewater and discharge the treated water. Based on our data, there are in total 288 such facilities that had an active NPDES permit during 2000–2014.[5] They are responsible for the vast majority (73%) of effluent and water quality violations statewide during the period of study. A clear assessment of the compliance behavior of these facilities is thus particularly important for the better understanding of water pollution regulation in general. It is notable that most (95%) of them are publicly owned and operated by cities, counties, or special districts.

Wastewater treatment facilities reduce oxygen-demanding substances, such as organic matter and ammonia, disinfect and chlorinate wastewater to decrease infectious micro-organisms, and remove phosphorus, nitrogen, and inorganic or synthetic organic chemicals. The process for treating wastewater includes a primary stage, in which solids are removed, and a secondary stage, which treats biological and dissolved organics. In addition, a tertiary stage may be used for disinfection and treatment of nitrogen, phosphorus, and other pollutants. The Clean Water Act requires municipal wastewater treatment plants to implement at least secondary stage treatment.

Even after all three stages, facilities often fail to comply with the water quality regulations. The causes of violations include improper maintenance and operation, as well as insufficient investment. Both the EPA and the California water boards stress the importance of the former factor for explaining violations.[6] We also find evidence corroborating this view by analyzing the description of corrective measures that were planned or taken following the detection of a violation in the data: out of 3,504 violations with such a description, only 30% of them were associated with a need for investment in the sense that the corrective measure description contained words related to capital investment, while the rest of the violations were associated with short-term measures.[7]

A number of factors make it harder for some facilities to comply with the permit conditions than others. Facilities differ substantially in age and size (see Table 1 in Section 3). They also differ in their finances. For example, although the state and the

[5]There are 12 treatment facilities that treat non-domestic wastewater, all of which are excluded from the analyses to maintain the homogeneity of our sample.

[6]For details, see US Environmental Protection Agency (2004) and California State Water Resources Control Board (2010a). For example, the latter document provides details of a case in which a facility administrator employed uncertified operators and failed to provide adequate supervision to trainees, leading to permit violations.

[7]The keywords used to classify corrective measure descriptions into capital investment are: *capital; construct; design; fund; grant; install; invest; new; project;* and *upgrade.*

federal governments provide subsidized financing to water treatment projects through the Clean Water State Revolving Fund (CWSRF), facilities located in small or disadvantaged communities often lack the resources and in-house expertise necessary to apply for grants and determine which types of project are the most appropriate for their needs (California State Water Resources Control Board, 2008). Moreover, weather conditions, which can substantially obstruct compliance efforts, vary both across facilities and over time.

3. Descriptive Statistics

We draw data from the California Integrated Water Quality System (CIWQS) database for the NPDES violations and enforcement actions during 2000–2014.[8] We also obtain county-level attributes from various sources: the California Secretary of State website for the vote shares for ballot propositions, the American Community Survey for average household income, the Census for population and water use, Congressional Quarterly Press for gubernatorial election results, and the California Irrigation Management Information System for precipitation. The precipitation data are provided at the 253 weather stations level, which we aggregate at the county level based on the stations' locations.

We focus on effluent or water quality violations subject to the mandatory minimum penalty (MMP) of $3,000. During the period of study, there are in total 48,155 violation records by domestic wastewater treatment facilities, and 19,740 (41%) of these records are subject to the MMP. Almost the entirety (99%) of the MMP records are associated with effluent and water quality violations.[9] As described in Section 2.2, MMP violations are either serious in the violation extent or chronic. Therefore, the violations that are not subject to the MMP are relatively insignificant violations that were not repeated more than three times within six months. These violations tend not to result in penalties: for example, 5.3% of the non-MMP violations that occurred in 2009 led to penalties within four years of their occurrence, while 96.4% of the MMP violations of the same period were monetarily penalized.

Table 1 provides summary statistics of variables related to violations, penalties and attributes of the domestic wastewater treatment facilities in our sample. The table presents the statistics by the facilities' location. Specifically, it distinguishes facilities

[8]Data from prior to July 2005, when the water boards launched the CIWQS, were imputed retroactively into the CIWQS.

[9]The remaining 142 MMP violation records are regarding the timing of self-reports (126), order conditions (12), deficient monitoring (2), and enforcement actions (2).

regulated by the inland regional water boards, i.e., Central Valley, Lahontan, and Colorado River Basin; from those regulated by the rest, or the coastal water boards. The two geographic categories represent the respective residents' demographic and political differences as well as the heterogeneity in the industry composition and the technological challenges that a wastewater treatment facility might face. The coastal counties tend to have a higher average household income, a larger population density, a lower rate of water use for irrigation, and higher turnout and vote share for the Democratic candidate in the 2010 gubernatorial elections. The voters in the coastal counties were more likely to support California Proposition 84 in 2006, a statewide ballot proposition authorizing the issuance of bonds to fund various water projects. Note also that although the age distribution is comparable between the two areas, the proportion of *major* facilities, which either discharge more than 1 million gallons per day on average or pose a high degree of threat to water quality, is larger in coastal than in inland regions.[10]

Both compliance and enforcement behaviors systematically vary across these two areas. First, the coastal facilities tend to have a smaller number of effluent or water quality MMP violations and are more likely to be in compliance than their counterparts in the inland area. On average, a domestic wastewater facility in the coastal area has 1.03 MMP violations per three months, while a counterpart in the inland area has 1.59 violations. Second, the average penalties per effluent or water quality MMP violation are larger for the coastal facilities ($3,068 within four years of the violation's occurrence) than for the inland ones ($2,653).[11] Note that the CIWQS database links each enforcement action with all associated violation records, which allows us to measure the enforcement stringency without having to make an assumption on the length of a lag before an enforcement action is taken.[12] Third, all of the aforementioned patterns persist before and after the 2006 institutional changes.

[10]The classification of major or minor facilities is relevant for enforcement priority. The federal regulations (Section 123.45 of Title 40 of the Code of Federal Regulations) require that states quarterly report noncompliance statistics of major facilities.

[11]Penalties may occur even after four years of the occurrence of a violation, but given the length of our panel data (fifteen years) and the usual length of a permit (five years), we focus on the four-year window. A large fraction of penalty actions occurs in four years: for example, based on 1,459 effluent or water quality MMP violations that occurred in 2005, the average lag before the first penalty record is 2.71 years, with a median of 2.95, a 95 percentile of 4.61, and a 99th percentile of 7.43 years.

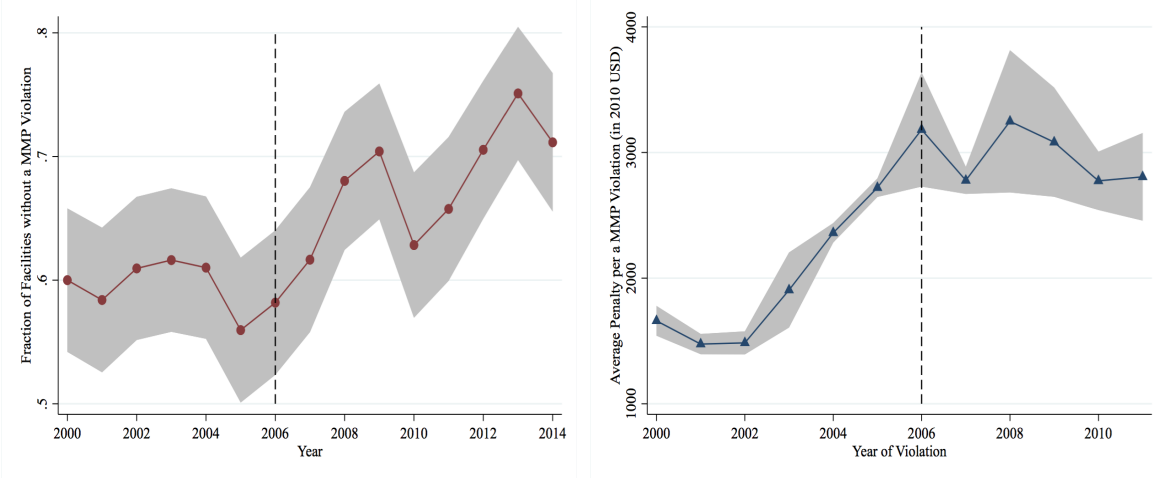
[12]When a penalty action is associated with multiple violation records, we divide the amount by the number of the linked violations to calculate the penalty amount for a given violation record.

TABLE 1. Summary Statistics

	Coastal		Inland	
	Mean	SD	Mean	SD
Quarterly compliance and enforcement per facility				
All periods (2000-2014)				
Any MMP violation	0.17	-	0.21	-
Number of MMP violations	1.03	6.61	1.59	8.30
Penalty per MMP violation[a] (in 2010 dollars)	3,068	18,293	2,653	8,825
Before the 2006 institutional changes (2000-2005)[b]				
Any MMP violation	0.20	-	0.23	-
Number of MMP violations	1.14	8.23	1.71	9.84
Penalty per MMP violation	2,483	5,368	1,761	2,101
After the 2006 institutional changes (2009-2014)[b]				
Any MMP violation	0.12	-	0.20	-
Number of MMP violations	0.63	3.11	1.42	6.89
Penalty per MMP violation	4,060	12,602	3,181	7,399
Facility characteristics				
Major[c]	0.79	-	0.55	-
Year of the first NPDES permit[d]	1983.5	6.84	1984.2	6.38
County characteristics				
Total precipitation during a quarter (in inches)	5.48	6.61	5.62	6.76
Average household income in 2010 (in dollars)	63,859	13,314	50,709	11,352
Population density in 2010 (per squared miles)	1,188	2,405	213	332
Fresh water withdrawal for irrigation in 2010 (%)	39.55	29.10	73.94	24.06
Vote share for Governor Brown in 2010 (%)	46.67	6.72	43.43	10.29
Turnout in the 2010 gubernatorial election (%)	54.36	7.38	43.42	7.42
Vote share for the 2006 CA proposition 84[e] (%)	57.20	10.46	44.95	9.75

Notes: This table is based on the CWIQS database regarding all domestic wastewater treatment facilities that have an active NPDES permit under the Clean Water Act during 2000–2014. The unit of observation is facility-quarter, and there are 9,263 observations for the coastal area and 6,350 for the inland area. a. This variable indicates the average amount of total penalty per effluent or water quality MMP violation that occurred during three months, accounting for the penalties assessed within four years of the occurrence of the violation. b. For the statistics on violations, we use the sample of 2002–2005 for the period before the 2006 institutional changes and 2009–2014 for the post-change period. As for the penalty statistics, we employ the effluent or water quality MMP violations of 2000–2001 and 2009–2010 and the follow-up penalty actions for four years. We do not use the observations of 2000–2001 for analyzing the extent of compliance because we suspect that not all violation records are in the database for this early period. We also do not employ the observations of 2006–2008, acknowledging that the 2005-2006 institutional changes may take time to be fully incorporated. The key patterns found in the table are robust to our choice of the periods. c. A *major* facility is defined as one with an average daily discharge greater than 1 million gallons per day or with a high degree of threat to water quality. d. The NPDES permits are typically renewed every five years. By looking at the first permit record, we measure the age of the facility. e. The 2006 California Proposition 84 is to authorize $5.4 billion in bonds to fund various water projects.

FIGURE 1. Compliance and Enforcement



(A) Fraction of Facilities in Compliance (B) Average Penalty per MMP Violation

Notes: Panel (A) shows the fraction of the domestic wastewater treatment facilities without an effluent or water quality MMP violation for a given year. In Panel (B), we provide the average penalty per effluent or water quality MMP violation assessed within 4 years of the occurrence of the violation. Note that the 2006 institutional changes affected the within-4-year penalty for the violations that occurred in 2002 and after. The shaded areas represent the 95 percent confidence intervals.

3.1. **Compliance and Enforcement Over Time.** We find that the institutional changes described in Section 2.3 are associated with an increase in both compliance and enforcement stringency. Table 1 shows such patterns at the aggregate level before and after the institutional changes, and Figure 1 shows how the average violation frequency and the average penalty per violation changed over time. Panel (A) in the figure provides the fraction of the facilities without an effluent or water quality MMP violation per year. The graph shows that the annual fraction of compliant facilities is relatively stable up until 2006 and substantially increases after that year.

In Panel (B) of Figure 1, we present the average penalty per effluent or water quality MMP violation within four years of the occurrence of the violation. Note that the 2006 institutional changes affected the within-4-year penalties for the violations of 2002 and after. Accordingly, the figure shows that the average penalty is stable at around $1,500 per violation of 2000–2002, starts increasing from 2002 to 2006, and then is stable at $3,000 per violation.

These changes in both compliance and enforcement do not seem to have been driven by a change in the concurrent compliance cost structure. Most facilities were operating well before and after 2006: more than 85% of the facilities in our sample

started their operation before 1988; and the permit records show that 15 wastewater treatment facilities (5%) in our data became inactive before 2006, and 8 facilities (3%) were newly registered after 2006. Based on the Census of Government Finance and Employment in 1997–2012, there has been a steady flow of capital investment for sewerage services by local governments, with an average of $1.87 billion (in 2010 dollars) per year in total.[13] Given that the investment size did not markedly increase after 2006 and the population size that the facilities serve has been increasing, the data do not provide evidence that the increase in compliance after 2006 was driven by changes in the compliance cost structure of the facilities.

3.2. **Discretion in Enforcement.** The water quality regulations in California allow identical violations to result in different punishments. First, the regulations often specify conditions under which a violation may be exempt from penalty. For example, the California Water Code stipulates that the mandatory minimum penalty (MMP) is not administered if the violator is in compliance with an interim order, such as Cease and Desist Order (CDO) or Time Schedule Order (TSO), aimed at eventually having the violator in compliance with the original permit conditions and limits. Additional reasons for exemption include: if the wastewater treatment facility is new or reconstructed; and if the violation is caused by a natural disaster or an intentional act by a third party.[14] In total, there are 32,378 effluent or water quality MMP violations by domestic wastewater facilities in 2000-2014, and 12,780 (40%) of them were exempt from the minimum penalty.[15]

Second, the regulations also allow regulators' judgments to affect the monetary assessment of penalties. For example, the 2010 Water Quality Enforcement Policy, established by the state water board, describes a ten-step penalty calculation method, where the first step is to assess actual or potential harm to beneficial uses of water and to assign a score out of an integer scale from 0 to 5.[16] Each score is associated with a brief description, which varies from "no actual or potential harm to beneficial uses" for 0 to "high threat to beneficial uses (i.e., significant impacts to aquatic life

[13]During the years when all governments were surveyed, the total capital expenditures for sewerage services by local governments in California are $2.24 billion (1997), $1.43 billion (2002), $2.27 billion (2007), and $1.16 billion (2012) in 2010 dollars.
[14]Sections 13385 (j) and (f) of the California Water Code provide the reasons for MMP exemption.
[15]Table 1 and Figure 1 are based on non-exempt MMP violations only, disregarding exempt MMP violations. All our analyses below are focused on non-exempt MMP violations to study regulators' discretion.
[16]See pages of 9–22 for the penalty calculation method in California State Water Resources Control Board (2010b).

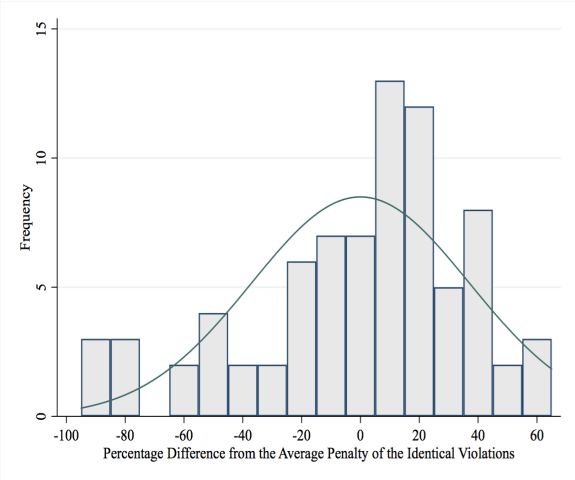
or human health), long term restrictions on beneficial uses (e.g. more than five days), high potential for chronic effects to human or ecological health" for 5. The policy recognizes, on page 10, that "with respect to liability determinations, each regional water board, and each specific case, is somewhat unique." It also acknowledges, on the same page, that, although a consistent penalty amount is expected for standard and routine violations, for more complex matters, "the need to assess all of the applicable factors in liability determinations may yield different outcomes in cases that may have many similar facts."

Even after taking the application of the exemption clauses in the regulation as given, we find empirical evidence that regulator discretion plays an important role in determining penalties. To start off, many violations are not penalized: about 30% of the non-exempt effluent or water quality MMP violations of 2000-2010 by the domestic wastewater treatment facilities led to no penalty within four years of their occurrence. Moreover, among those with nonzero penalty, the average penalty per violation is $2,706 (in nominal values) with the maximum amount over $100,000. To be sure, this large variation in penalty per violation observed in the data does not immediately imply a large degree of regulator discretion. This variation may also be driven by a large heterogeneity in the violation significance and severity, which are weighed in the determination of penalty amount.

To gauge the extent of regulator discretion, we look at observationally identical MMP violations in terms of the pollutant and its permitted and actual amounts of discharge for a given period (e.g. 30-day median, weekly average, etc.). Focusing on the domestic wastewater treatment facilities' violations of 2009–2014 that resulted in a nonzero penalty, we identify 21 unique groups of identical violations by at least three distinct facilities, with a total of 79 violation records. Figure 2 presents a histogram of the percentage difference of the assigned penalty for a violation from the average penalty for its identical violations in the group. There is a large dispersion, ranging from -86% to 61%; and 53% of the violations in the sample led to penalties that differ by more than 20% from the average penalty of their group.

This anecdotal finding suggests that seemingly identical violations may have been treated differently, but there are three caveats to consider. First, the sample size may not be large enough to generalize the finding. Second, because multiple violations are penalized at a time and the itemized penalty per violation is unavailable, we divide the assessed amount of an ACL action by the number of all violations that are affiliated with that action, and use this per-violation penalty when constructing the

FIGURE 2. Heterogeneous Penalties for Identical Violations



Notes: This figure shows a histogram of the percentage difference of the assigned penalty for a given violation from the average penalty for its identical violations in terms of the pollutant and the permitted and actual amounts of discharge, overlaid with a fitted Normal density function. The histogram and the density function are based on 79 violation records with nonzero penalties, grouped into 21 unique cases of identical violations by at least three distinct domestic wastewater treatment facilities during 2009–2014.

histogram in Figure 2. Therefore, the observed dispersion in the assigned penalties for a group of identical violations could have been driven by the heterogeneity in the nature of the other violations that were penalized along with each violation in the group. Third, the past violations that are not explicitly affiliated with an ACL action could have been factored into the penalty amount.

To address these caveats, we broaden the analysis by regressing whether there was a penalty action (Columns of (1)–(3) in Table 2) or the amount of penalty (Columns of (4)–(6) in the table) on the attributes of the associated violation, the facility, and the county where the facility is located, using all effluent or water quality MMP violations of 2000–2010 by the domestic wastewater treatment facilities. As expected, when a given violation occurs in the same quarter as other violations by the same facility, both the probability and the amount of penalty for that violation increase. However, the correlation between penalty for a violation and the violations in the preceding quarter is not statistically significant. One striking feature of the results in the table is that, even after controlling for violation attributes, the facility attributes further explain the penalty variations: major facilities and the facilities located in a county with a high average household income or a low turnout for the 2010 gubernatorial election tend to be penalized more often and more severely than other facilities.

TABLE 2. Determinants of Penalty for MMP Violations

	Penalized			Log (Penalty Amount + 1)		
	(1)	(2)	(3)	(4)	(5)	(6)
Group I pollutant	0.0670	0.0653	0.0534**	0.531	0.517	0.417**
	(0.0510)	(0.0507)	(0.0252)	(0.387)	(0.384)	(0.195)
Other MMP violations[a]		0.0886**	0.109***		0.777***	0.926***
		(0.0372)	(0.0376)		(0.278)	(0.284)
Past MMP violations[b]		-0.0181	0.0299		-0.134	0.253
		(0.0708)	(0.0498)		(0.557)	(0.387)
Major facility			0.143***			1.193***
			(0.045)			(0.350)
Log (Average income)[c]			0.759***			6.191***
			(0.206)			(1.635)
% Turnout[d]			-0.0174***			-0.140***
			(0.0056)			(0.0432)
Other violation controls	Yes	Yes	Yes	Yes	Yes	Yes
Other facility controls	No	No	Yes	No	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of obs.	16,314	16,314	16,314	16,314	16,314	16,314
Adjusted R^2	0.169	0.171	0.414	0.177	0.179	0.424

Notes: This table reports OLS estimates. The unit of observation is a violation. Standard errors are adjusted for two-way clustering at the county and facility levels, and are provided in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. All non-exempt effluent or water quality MMP violations of 2000–2010 by the domestic wastewater treatment facilities are included. The dependent variables are: whether the violation led to a nonzero penalty within four years of its occurrence for Columns (1)–(3); and the logarithm of the nominal dollar value of the associated penalties plus one dollar, based on the penalty actions within the four-year window, for Columns (4)–(6). a. *Other MMP violations* indicates whether other MMP violations also occurred along with the given violation during the same quarter. b. *Past MMP violations* is a dummy variable indicating whether there were MMP violations during the past quarter. c. *Log (Average income)* is the logarithm of the average household income in 2010 in the county. d. We consider the turnout rate in percentage for the 2010 gubernatorial election. Other violation controls include whether the violation is ranked as "priority" for enforcement purposes and the total precipitation amount during the quarter in which the violation occurred. Other facility controls are the age of the facility and the county attributes such as the 2010 population density, the ratio of fresh water withdrawal for irrigation in 2010, the vote share for the 2006 ballot proposition 84, and the water board region dummies.

These findings guide our modeling assumptions. First, the regulator may treat different facilities differently although their violations are identical, depending on the observed facility attributes. Second, our unit of analysis is a facility-period, and we allow the penalty schedule to be a (nonlinear) function of the violations that occurred during a period. In our main analysis, we consider periods of three months to account for four seasons with varying precipitation. In a sensitivity analysis, we employ six months as a unit of period, an find our results to be robust (see Appendix C). Third,

our study assumes a static environment, in the sense that MMP violations during the past period do not affect the enforcement on the MMP violations of the current period, as shown in Table 2.[17]

4. Theoretical model

4.1. **Setup.** We model regulation enforcement as an adverse selection problem, as analyzed by Maskin and Riley (1984) and Mookherjee and Png (1994).[18] Consider a wastewater treatment facility that chooses the extent to which it complies to regulations given a penalty schedule. The facility is better informed than the regulator about its compliance costs. Specifically, each facility is endowed with a type, θ, which is known to the facility only. The regulator knows that θ is the realization of a random variable Θ which follows a strictly increasing and continuously differentiable distribution function $F(\cdot)$ with support $[0, \bar{\theta}]$. Let $f(\cdot)$ be the associated density.

The facility sets a negligence level $a \in \mathbb{R}_+$, which is not observed by the regulator and affects the facility's compliance status in the following manner: let K be a random variable representing the number of emission violations incurred by the facility, and assume that K follows a Poisson distribution with mean a. By setting the negligence level a, the facility derives private benefit $\theta b(a)$, which reflects the operation cost savings associated with lower compliance. In the reminder of the paper, we refer to this private benefit as the facility's compliance costs.[19] Note that because the facilities in our data are often publicly owned, $\theta b(a)$ could be different from the actual operational cost savings from emitting more pollutants to the waters, reflecting the career concerns of the facility administrators and the scrutiny from the public. We assume that the facility benefits from avoiding both compliance costs and penalty.

[17]As Harrington (1988) first discussed, dynamic deterrence can be effective when penalties are restricted, and it is widely used in the context of environmental regulation. For example, in the Clean Air Act, penalties are larger for the priority noncompliance facilities (Blundell, 2017). The MMP regulations also incorporate a dynamic feature in that the minimum mandatory penalty applies if the facility violates effluent limitations four or more times in any period of six consecutive months.

[18]In Mookherjee and Png (1994), the regulators choose both a (random) monitoring frequency and a penalty schedule. Our model abstracts away from monitoring decisions and focuses on the penalty schedule. Implicitly, we assume that exogenously determined inspection activities provide incentives for firms to truthfully self-report any violation. The model is identical to the one in Mookherjee and Png (1994) with zero monitoring costs.

[19]Let us denote the benefit from maximum negligence or no compliance efforts as $\theta\bar{b}$. This means that no negligence or full compliance efforts would cost the facility $\theta\bar{b}$. By choosing some negligence level a, the facility avoids incurring some compliance costs, $\theta b(a)$, leading to the total compliance cost of $\theta[\bar{b} - b(a)]$.

Because the realization θ and the consequent negligence level a are not known by the regulator, a penalty schedule depends on the realized number of violations only. Given k violations, the facility has to pay the penalty according to a random function $\epsilon(k)$.[20] Assuming that the facility is risk-neutral, we can restrict our attention to the expected penalty, conditional on a, which we denote by

$$e(a) \equiv \sum_{k=0}^{\infty} \mathbb{E}[\epsilon(k)] \frac{a^k \exp(-a)}{k!}. \tag{1}$$

The payoff to a facility setting the negligence level a is

$$\theta b(a) - e(a). \tag{2}$$

We define that a negligence schedule, $a(\cdot)$, is *implemented* by a penalty schedule $e(\cdot)$ if $a(\theta)$ maximizes (2) for all $\theta \in \Theta$. Notice that, if $a(\cdot)$ is implemented by $e(\cdot)$, we have that

$$\theta b' \left[a(\theta)\right] = e' \left[a(\theta)\right], \tag{3}$$

whenever $a(\theta) > 0$.

Given a penalty schedule $e(\cdot)$, the regulator's expected costs are

$$\int_0^{\overline{\theta}} \left\{h \left[a(\theta)\right] + \psi e \left[a(\theta)\right] - \theta b \left[a(\theta)\right]\right\} f(\theta) d\theta, \tag{4}$$

where $\psi > 0$ denotes the marginal cost of imposing penalty, and $h(\cdot)$ represents the regulator's environmental costs related to the facility emission violations.[21] The regulator's enforcement costs, given by $\psi e[a(\theta)]$, comprise the administrative and political costs associated with taking formal actions against a facility.[22] Notice that $h(\cdot)$ and $\psi > 0$ may reflect both public concerns, as considered by Becker (1968), and private ones, which might steer the regulator's objective function away from that of a social planner. Our analysis cannot directly distinguish these two types of concerns.

[20]This is to reflect that facilities with the same non-exempt MMP violations do not always face the same amount of penalty, even after controlling for observed attributes, as discussed in Section 3.2.

[21]In our model, we assume that the regulator perceives the potential harm of each violation as identical. In Appendix C, we relax this assumption and re-estimate the model. Our key empirical findings persist.

[22]Money raised from penalties is generally deposited in the Cleanup and Abatement Account, a fund managed by the state board from which the regional boards may request money for a project. Alternatively, publicly owned wastewater treatment facilities in small communities may be allowed to recover part of the amount they pay in penalties for compliance or supplemental environmental projects. Our analysis does not distinguish between these potential destinations of the penalties, since all facilities are liable to pay the penalty amount regardless. However, the possibility that some facilities are able to partially recover the penalties provides another reason why the enforcement cost borne by the regulator may vary by facility attributes, such as its location.

When choosing a penalty schedule, the regulator faces a constraint that the expected penalty for any a must be nonnegative and not exceed ω:

$$e(0) = 0 \text{ and } 0 \leq e(a) \leq \omega, \tag{5}$$

for any a. Note that without the limit on punishments, any desired $a(\cdot)$ could be achieved by sufficiently steep penalties. The optimal penalty schedule minimizes (4), subject to constraints that the schedule satisfies (5) and that it implements the negligence schedule $a(\cdot)$.

4.2. **Characterization of equilibrium.** We make the following assumptions on the facility's compliance cost function, $b(\cdot)$, and the regulator's preference on water quality, $h(\cdot)$.

ASSUMPTION 1. *(i) $b(\cdot)$ is strictly increasing and is bounded by $0 < \overline{b} < \infty$. (ii) $h(\cdot)$ is strictly increasing.*

Note that since the regulator cannot impose infinitely large punishments, we assume that $b(\cdot)$ is bounded above. Under Assumption 1, it can be shown that a schedule of negligence choices, $a(\cdot)$, is implemented if and only if $a(\cdot)$ is nondecreasing and satisfies

$$\omega \geq \overline{\theta}\overline{b} - \int_0^{\overline{\theta}} b[a(\theta)]d\theta, \tag{6}$$

and the requisite expected penalty schedule is

$$e(a) = \theta(a)b(a) - \int_0^{\theta(a)} b[a(v)]dv, \tag{7}$$

where $\theta(a)$ denotes the highest type θ selecting an $a(\theta) \leq a$. For a proof, see the Lemma in Mookherjee and Png (1994). By this argument, the regulator chooses a schedule of negligence, $a(\cdot)$, to minimize

$$\int_0^{\overline{\theta}} \left\{ h[a(\theta)] + \psi \left(\theta b[a(\theta)] - \int_0^{\theta} b[a(v)]dv \right) - \theta b[a(\theta)] \right\} f(\theta)d\theta, \tag{8}$$

subject to $a(\cdot)$ being nondecreasing and (6). For simplicity we assume that (6) is not binding at the optimum. By using integration by parts, we rewrite (8) as

$$\int_0^{\overline{\theta}} \left\{ h[a(\theta)] - \left((1-\psi)\theta + \frac{\psi[1-F(\theta)]}{f(\theta)} \right) b[a(\theta)] \right\} f(\theta)d\theta.$$

We then consider point-wise optimization for each θ, and thus either $a(\theta) = 0$ or $a(\theta)$ satisfies the first order condition:

$$h'[a(\theta)] - b'[a(\theta)] \left((1-\psi)\theta + \frac{\psi[1-F(\theta)]}{f(\theta)} \right) = 0. \tag{9}$$

By totally differentiating (9), one can see that the following assumption, along with Assumption 1, is sufficient to guarantee that the neglience schedule characterized above, denoted by $a^*(\cdot)$, is optimal and strictly increasing in θ for any θ such that $a^*(\theta) > 0$.

ASSUMPTION 2. *(i)* $(1-\psi)\theta + \frac{\psi[1-F(\theta)]}{f(\theta)}$ *is strictly increasing in* θ. *(ii) The second order conditions for (3) and (9) are satisfied for all* $\theta \in [0, \overline{\theta}]$.

The following proposition summarizes the characterization of the optimal negligence schedule.

PROPOSITION 1. *Under Assumptions 1–2, the optimal negligence schedule,* $a^*(\cdot)$*, is continuous and nondecreasing in* θ. *For* θ *such that* $a^*(\theta) > 0$, $a(\cdot)$ *is characterized by (9) and strictly increasing in* θ.

5. STRUCTURAL MODEL

5.1. **Data generating process.** There are one regulator and many facilities, which we index by i. Periods are indexed by t. Assume that Θ is i.i.d. across facilities and periods.[23] To reflect the institutional changes discussed in Section 2.3, we allow the primitives characterizing the regulator to vary across periods. The regulator sets the optimal penalty schedule, as described in Section 4. Because of the potential changes in the primitives, the solution to the regulator's problem can also change over time. We denote by $\bar{\epsilon}_t(\cdot)$ the expected penalty function in period t. Given $\bar{\epsilon}_t(\cdot)$ and a realization of Θ, each facility i sets its optimal negligence level. As Θ is a random variable, the equilibrium negligence set by facility i in period t is also a random variable, which we denote by $A_{i,t}$. Let $G_t(\cdot)$ be the distribution of negligence levels across the population of facilities in period t.

The primitives of the model are: $F(\cdot)$, the distribution of facilities' types; $b(\cdot)$, the baseline compliance cost function; the regulator's perceived social cost of emissions,

[23]By this assumption, each facility independently draws its type every period. An alternative assumption is that the facilities' types are constant over time and the regulator commits not to exploit the information on the facility type obtained in the previous periods. Our identification argument holds under either of these two assumptions, which are both consistent with the static penalty schedules in the data (Table 2).

$h_t(\cdot)$; and the marginal enforcement cost, ψ_t. We allow all model primitives to vary with observable facility-period characteristics but, for ease of notation, we do not explicitly condition the model primitives on these characteristics in the discussion of identification below. The observables are: $K_{i,t}$, the number of violations in period t for each facility i; and the penalty assessed due to facility i's violations in period t.

5.2. **Identification.** For the identification of the model, we follow three steps. First we recover the distribution of negligence levels set by the facilities in each period, based on the observed violations. The second step, following the strategy proposed by d´Haultfoeuille and Février (2016), employs the exogenous change in the penalty schedule associated with the 2006 institutional changes to partially identify the facility type distribution and the marginal compliance cost function. Note that this step does not rely on any assumption about the regulator's behavior, other than testable assumptions on the observed penalty schedule $\bar{\epsilon}_t(\cdot)$.

The third step, which builds upon the approach by Luo, Perrigne and Vuong (forthcoming), explores the restrictions imposed by the first-order conditions of the regulator to recover the social cost of emissions and the marginal enforcement cost, as well as to achieve exact identification of the type distribution and the marginal compliance cost function. By exploiting the exogenous variations in the penalty schedule, we are able to identify a more general model than would be possible using their approach alone.[24]

We restrict our attention to the case where it is optimal for all facilities to choose a nonzero rate of violations, or $a_t(\theta) > 0$, for any period t and $\theta \in [0, \overline{\theta}]$. A sufficient condition to guarantee that $a(\theta) > 0$ for any θ is $b'(0)\psi - h'(0)f(0) > 0$. Our identification argument can be extended to accommodate a corner solution for the facility (or complete compliance, with $a_t = 0$). But, even without allowing corner solutions, our estimated model, reported in Section 6.1, fits the data very well.[25]

We begin by noticing that, given any period t, the distribution of the number of violations by any facility is a mixture Poisson. Indeed, a facility chosen at random sets a negligence level according to the distribution $G_t(\cdot)$, and, given the negligence level,

[24]In particular, our approach enables us to consider a more flexible form for the regulator's objective function. For example, Luo, Perrigne and Vuong (forthcoming) assume that $h(\cdot)$ (the monopolist's cost function in their setting) is linear, while we can accommodate a polynomial specification of arbitrary degree.

[25]In the data, 10 percent of the facilities that were active during all the 60 quarters in our sample period (2000–2014) never violated. Note that, if the number of violations follows a Poisson distribution with mean a, a facility that sets $a = 0.001$ will never violate during 60 periods with probability $exp(-0.001 \times 60) = 0.94$.

the number of violations for that facility follows a Poisson distribution. The following lemma establishes the identification of $G_t(\cdot)$ from the observed number of violations across facilities. To prove this lemma, we exploit the moment generating function of the Poisson distribution, which was also used in Aryal, Perrigne and Vuong (2017). See Appendix A for the proofs of the lemmas and the propositions in this section.

LEMMA 1. *For every t, $G_t(\cdot)$ is identified.*

Having identified the distribution of negligence levels in each period, our strategy to partially identify $b'(\cdot)$ and $F(\cdot)$ closely follows that proposed by d´Haultfoeuille and Février (2016). We consider two enforcement regimes, before and after the 2006 institutional changes, and assume that, within each regime, the penalty schedule does not change. Formally, we make the following assumption on $e_t(\cdot)$, the expected penalty in period t, as a function of the negligence level set by the facilities:

ASSUMPTION 3. *$e_t(\cdot) = e_{pre}(\cdot)$ for all $t < 2006$. Similarly $e_t(\cdot) = e_{post}(\cdot)$ for all $t > 2008$. Moreover, $e'_{post}(a) > e'_{pre}(a)$ for all $a > 0$.*

Because the functions $e_{pre}(\cdot)$ and $e_{post}(\cdot)$ are directly observed from the data, this assumption is testable. The latter part of the assumption implies that the enforcement regime becomes stricter after the institutional changes. We exclude the period of 2006-2008 as a transition period, although such an exclusion is not necessary and the length of the transition period can be adjusted. Notice that, in the definition of the model primitives, we assumed that $F(\cdot)$ and $b(\cdot)$ do not change over the entire time period covered by our sample, which is analogous to an exclusion restriction.

Under Assumption 3, any facility of a given type θ sets at most two different negligence levels—one for each of the two enforcement regimes. Accordingly, we denote by $G_j(\cdot)$ the distribution of negligence levels holding in period $j \in \{pre, post\}$, where, as above, *pre* refers to $t < 2006$ and *post* to $t > 2008$. Also, we denote by $\tilde{a}(\cdot, j)$ the equilibrium negligence function in period $j \in \{pre, post\}$. From equation (3), it is clear that $\tilde{a}(\theta, pre) > \tilde{a}(\theta, post)$ for all θ. Let the supports of the negligence level distributions before and after the regime change be given by $\mathcal{A}_{pre}$ and $\mathcal{A}_{post}$, respectively. We assume that $\mathcal{A}_{pre} \cap \mathcal{A}_{post} \neq \emptyset$.

The strategy described below, and formalized in Proposition 2, allows us to partially recover $b'(\cdot)$ and $F(\cdot)$ without making further assumptions about the behavior of the regulator. Define the function $\tilde{\theta}(a, j)$ as the inverse of $\tilde{a}(\cdot, j)$ for any $a \in \mathcal{A}_j$. Define also the following two functions:

$$T^H(a) \equiv G_{pre}^{-1}\left[G_{post}(a)\right], \tag{10}$$

$$T^V(\theta, a) \equiv \frac{e'_{post}(a)}{e'_{pre}(a)}\theta. \tag{11}$$

Notice that $T^H(\cdot)$ is defined for any $a \in \mathcal{A}_{pre} \cap \mathcal{A}_{post}$, while $T^V(\cdot,\cdot)$ is identified over the entire domain of a and θ. The following lemma plays a key role in the identification of $b'(\cdot)$ and $F(\cdot)$:

LEMMA 2. *Under Assumptions 1–3, we have that* $T^H(a) = \tilde{a}\left[\tilde{\theta}\left(a, post\right), pre\right]$ *for* $a \in \mathcal{A}_{pre} \cap \mathcal{A}_{post}$, *and* $T^V\left[\tilde{\theta}(a, pre), a\right] = \tilde{\theta}(a, post)$ *for any* $a \in \mathcal{A}_{pre}$.

This lemma establishes that $T^H(a)$ returns the negligence exerted in the *pre* regime by a facility type that, while in the *post* regime, exerted negligence level a; and $T^V\left[\tilde{\theta}(a, pre), a\right]$ returns the type that exerts negligence level a in the *post* regime.

To partially identify $F(\cdot)$ and $b'(\cdot)$, we normalize $\tilde{\theta}(a_0, post) = \theta_0 = 1$ for some $a_0 \in \mathcal{A}_{post}$, and then define recursively:

$$\begin{aligned} a_l &= T^H(a_{l-1}), \\ \text{and} \quad \theta_l &= T^V\left(\theta_{l-1}, a_l\right). \end{aligned}$$

The transform $T^H(\cdot)$ connects points in the negligence distribution supports in both regimes. Notice that for any $a \in \mathcal{A}_{post}$, $T^H(a) \in \mathcal{A}_{pre}$. However, under Assumption 3, we have that $T^V\left[\tilde{\theta}(a, pre), a\right] > \bar{\theta}$ for $a > \max(\mathcal{A}_{post})$; i.e., there are relatively high negligence levels that, in equilibrium, are only set in the *pre* regime. Let $\bar{L}$ be largest integer such that $T^H(a_{\bar{L}}) \in \mathcal{A}_{post}$. We are now ready to state the following result.

PROPOSITION 2. *Suppose Assumptions 1–3 hold. Then, for any* $l \in \{0, 1, \ldots, \bar{L}\}$ *and* $j \in \{pre, post\}$, *the following objects are identified up to the normalization* $\theta_0 = 1$*: (i) the equilibrium negligence level,* $\tilde{a}(\theta_l, j)$*; (ii) the distribution of cost types,* $F\left(\theta_l\right)$*; and (iii) the marginal baseline compliance cost function,* $b'\left(\tilde{a}(\theta_l, j)\right)$.

Notice that, under the assumptions of Proposition 2, $F(\cdot)$ and $b'(\cdot)$ are only identified over a finite set of values. The set is finite due to the boundedness of the type space, and the exact number of values at which the functions are identified depends on the shape of the functions $\tilde{a}(\cdot, pre)$ and $\tilde{a}(\cdot, post)$.

To complete the identification of the model, we must explicitly consider the regulator's problem. We begin by making the following simplifying assumption:

ASSUMPTION 4. *(i)* $h_t(\cdot) = h_{pre}(\cdot)$ *and* $\psi_t = \psi_{pre}$ *for all* $t < 2006$, *and* $h_t(\cdot) = h_{post}(\cdot)$, $\psi_t = \psi_{post}$ *for all* $t > 2008$. *(ii) For* $j \in \{pre, post\}$, *the function* $h_j(a)$ *is a polynomial function of a finite degree* R *with* $h_j(0) = 0$*; i.e.,* $h_j(a) = \sum_{r=1}^{R} \gamma_{j,r} a^r$ *for any* R.

Assumption 4 (i) implies that all the primitives of the model are constant within each of the two regimes. Assumption 4 (ii) imposes a flexible parametric structure to the regulator's costs of emissions. Notice that it implies $h_j(0) = 0$, for $j \in \{pre, post\}$. We also make the following technical assumption on the equilibrium penalty schedule, which guarantees that we can employ the fist-order conditions from the regulator's problem to recover ψ_j and $\gamma_{j,r}$, for $j \in \{pre, post\}$ and $r \in \{1, \ldots, R\}$:

ASSUMPTION 5. *There is an interval $U \in \mathbb{R}_+$ such that the functions $\tilde{E}_0(a) \equiv \frac{e'_{post}(a)}{e'_{pre}(a)}$ and $\tilde{E}_{j,r}(a) \equiv \frac{a^r}{e'_j(a)}$ for all $r \in \{1, \cdots, R\}$ are strictly monotone in $a \in U$.*

We can now state the following proposition.

PROPOSITION 3. *Suppose Assumptions 1–5 hold. Then, if $\bar{L} \geq 1$, the following objects are identified up to the normalization $\tilde{\theta}(a_0, post) = 1$ for some $a_0 \in \mathcal{A}_{post}$: (i) the distribution of facilities' types, $F(\cdot)$; (ii) the derivative of the baseline compliance cost function, $b'(a)$ for any $a \in \mathcal{A}_{pre} \cup \mathcal{A}_{post}$; and (iii) the parameters of the regulator's objective function, $\{\gamma_{j,r}\}_{r=1}^{R}$ and ψ_j, for $j \in \{pre, post\}$.*

In a nutshell, we first identify the parameters of $h_j(\cdot)$ and ψ_j based on (9), the first order condition of the regulator, evaluated at the vector $\{\theta_l\}_{l=0}^{\bar{L}}$ for which $\tilde{a}(\theta_l, pre)$ and $\tilde{a}(\theta_l, post)$ are known from Proposition 2. The main challenge in the process is that $f(\theta_l)$ is not yet identified. To address the challenge, we exploit the relationship between a density and its quantile function, a technique that has been employed by Luo, Perrigne and Vuong (forthcoming). Once the regulator's objective function parameters are identified, we recover $F(\cdot)$ and $b'(\cdot)$ from (9).

5.3. **Semiparametric Estimation.** As discussed in Section 5.1, we allow the primitives of the model to vary with observable attributes of the facilities. With this intent, let $\mathbf{x}_{i,t}$ denote the observed characteristics of facility i in quarter t. The vector $\mathbf{x}_{i,t}$ includes facility and county characteristics summarized in Table 1, as well as dummies for the regional water boards.

The procedure consists of four steps. First, we parametrically estimate the penalty schedules and the distribution of negligence levels before and after the 2006 institutional changes. Although these objects can be nonparametrically estimated in principle, our sample size and our intent to condition the estimates on $\mathbf{x}_{i,t}$ render such an approach infeasible. We assume that the expected penalties $\mathbb{E}[\epsilon_{pre}(k|\mathbf{x})]$ and

$\mathbb{E}\left[\epsilon_{post}(k|\mathbf{x})\right]$ take the following functional form:

$$\mathbb{E}\left[\epsilon_j(k|\mathbf{x}_{i,t})\right] = \begin{cases} \phi_0 + \phi_{1,j}k + \phi_2\mathbf{x}_{i,t}, \text{ if } k > 0 \\ 0, \text{ if } k = 0, \end{cases} \tag{12}$$

for $j \in \{pre, post\}$. Under Assumption 1, $\phi_{1,j} > 0$ and $\phi_0 + \phi_2\mathbf{x}_{i,t} > 0$ for all j and $\mathbf{x}_{i,t}$. We thus estimate (12) using a constrained OLS, ensuring that these conditions are satisfied.

To estimate the negligence level distributions, $G_{pre}(\cdot|\mathbf{x}_{i,t})$ and $G_{post}(\cdot|\mathbf{x}_{i,t})$, we assume that the number of emission violations follows a Poisson-Gamma mixture distribution. Formally, let $\nu_{i,t}$ follow a gamma distribution with density

$$\frac{\delta^\delta}{\Gamma(\delta)}\nu_{it}^{\delta-1}\exp(-\nu_{it}\delta),$$

where δ is a positive parameter. Assume that ν_{it} is i.i.d. across facilities and over periods. Assume also that the distribution of violations by facility i in period t, conditional on $\nu_{i,t}$ and $\mathbf{x}_{i,t}$, follows a Poisson distribution with mean

$$\nu_{i,t}\exp\left(\beta_{0,j} + \beta_1\mathbf{x}_{i,t}\right), \tag{13}$$

where $j \in \{pre, post\}$. This distribution of violations is equivalent to a negative binomial distribution with mean $\exp\left(\beta_{0,j} + \beta_1\mathbf{x}_{i,t}\right)$ and variance $\exp\left(\beta_{0,j} + \beta_1\mathbf{x}_{i,t}\right)\left(1 + \nu_{i,t}^{-1}\exp\left(\beta_{0,j} + \beta_1\mathbf{x}_{i,t}\right)\right)$. Then the estimation of the distribution of negligence levels amounts to estimating the parameters δ, β_{pre}, and β_{post}. We estimate these parameters by MLE. See Cameron and Trivedi (2013) for details about this estimator.

The remaining steps of the estimation procedure closely follow the identification strategy in Section 5.2. We employ the estimates in the first step and Proposition 2 to compute estimates of $\tilde{\theta}(a, pre)$ and $\tilde{\theta}(a, post)$ for a finite set of negligence levels a. Then, we estimate the parameters of the regulator's objective function, using the regulator's first order condition (9) evaluated at the estimates from steps one and two. In our empirical analysis, we constraint the regulator's costs of emissions to be linear on the negligence level set by the facility.[26] Finally, employing the estimates from all previous steps, we nonparametrically estimate the distribution of cost types and the baseline compliance cost function, following Proposition 3. Appendix B describes in detail each step of the estimation procedure.

[26]As explained above, we are able to consider a general polynomial specification for these costs. We experimented with polynomials of degrees two to four, but none of these more flexible specifications performed better than the linear one in terms of fitting the data.

In sum, for any vector of observable attributes $\mathbf{x}_{i,t}$, we obtain estimates of the following model primitives: the functions $F(\cdot|\mathbf{x}_{i,t})$ and $b'(a|\mathbf{x})$, which characterize the distribution of facility compliance costs; and the scalars $\gamma_{pre}(\mathbf{x}_{i,t})$, $\gamma_{post}(\mathbf{x}_{i,t})$, $\psi_{pre}(\mathbf{x}_{i,t})$ and $\psi_{post}(\mathbf{x}_{i,t})$, which characterize the regulator preferences before and after the 2006 institutional changes.

6. Results

6.1. **Estimates and Model Fit.** Table 3 presents the penalty schedule estimates, ϕ's in (12), and the estimates of the negligence distributions, δ and β's in (13). Consistent with the preliminary results discussed in Section 3, the estimated slope of the penalty schedule after the 2006 institutional changes ($\hat{\phi}_{1,post}$) is larger than its counterpart before 2006 ($\hat{\phi}_{1,pre}$). That is, given the same number of violations, a facility expects to pay a higher penalty in the period following the changes, relative to the prior periods. Furthermore, $\hat{\beta}_{0,pre} - \hat{\beta}_{0,post} < 0$; the facilities decrease negligence levels after the changes.

Given these first-stage estimates, we proceed with the remaining steps to estimate the model primitives. We do so separately for each of the 264 facilities that were active in the first quarter of 2005. The estimated model fits the data well. Table 4 compares the distributions of the number of quarterly violations and average quarterly penalty, as predicted by the estimated model, with the counterpart distributions observed in the data. The estimated model is able to reproduce both the high probability of no violations at the facility-quarter level and the shift in the distribution of violations and penalties that took place following the 2006 institutional changes. We also verify that the estimated model primitives satisfy Assumptions 1 and 2 from Section 4, which are sufficient for the equilibrium negligence levels set by the facilities to be increasing in the compliance cost type.

Table 5 presents the summary statistics of our estimates of the primitives of the model: the marginal compliance costs and regulator preferences (γ and ψ) for the periods before and after the 2006 institutional changes. Recall that we separately estimate the primitives for each facility. Accordingly, we calculate the summary statistics over the facilities. Noting that our model primitives include the marginal compliance cost function and the cost type distribution, we report the median marginal compliance costs evaluated at a negligence level equal to one, i.e., $Med(\Theta)b'(1)$.

There are two notable aspects in the results in Table 5. First, our estimates imply that the increase in enforcement stringency after the 2006 institutional changes, as

TABLE 3. Enforcement Schedule and Negligence Distribution Estimates

	Penalty Schedule†	Negligence Distribution
$\phi_{1,pre}$	475.99 (203.36)	
$\phi_{1,post}$	2,643.35 (136.06)	
$\beta_{0,post} - \beta_{0,pre}$		-0.62 (0.09)
δ		12.18 (0.49)
ϕ_2's and β_1's:		
Major	7,329.09 (1,912.03)	0.03 (0.10)
First permitted in 1982-1987	521.46 (966.83)	-0.19 (0.14)
First permitted after 1987	10,890.51 (5,946.32)	-0.48 (0.24)
Total precipitation	0.00 (15.88)	0.02 (0.01)
Average household income (log, in $)	370.80 (4,480.90)	3.93 (0.43)
Population density per sq. miles (log)	914.47 (1,034.07)	0.05 (0.10)
Irrigation water use (%)	68.97 (3,800.59)	2.37 (0.29)
Turnout (%)	98.95 (137.06)	-0.05 (0.01)
Proposition for water project bonds (%)	-48.40 (90.78)	-0.09 (0.01)
Regional water board fixed effects	Yes	Yes
Number of observations	837	8,195

Notes: Unit of analysis is at the facility-quarter level. Column (1) presents the parameters of the penalty schedules in (13), estimated by constrained OLS. The dependent variable is the total amount of penalties associated to effluent or water quality MMP violations occurring in the quarter. We employ facility-quarter observations in the periods of 2000-2001 and 2009-2010. In Appendix C, instead, we use the periods of 2000–2002 and 2009-2011, and consider a three-year penalty window, as opposed to a four-year window. This alternative specification provides results that are similar to the ones shown in the main text. Column (2) presents the estimated parameters of the negligence distributions, based on a Poisson-Gamma regression in which the dependent variable is the number of effluent or water quality MMP violations occurring in the quarter. In this estimation, we employ all facility-quarter observations in the periods 2002-2005 and 2011-2014. See Section 3 for a description of the regressors. Bootstrap standard errors are in parenthesis.
†: Measured in 2010 USD.

documented in Table 1 and Figure 1, is rationalized both by a decrease of the marginal enforcement costs and an increase of the marginal environmental costs. The computerized information system and the support from the Office of Enforcement may have reduced the administrative burden of imposing penalties borne by each regulator in the regional water boards. At the same time, the institutional changes may have increased the pressure by the state government and the public to improve compliance, leading to an increase in the perceived environmental cost of a violation.

TABLE 4. Model Fit

	Before		After	
	Data	Model	Data	Model
Number of violations				
0	0.79	0.80	0.86	0.83
1	0.07	0.06	0.04	0.06
2	0.04	0.03	0.02	0.03
3	0.03	0.02	0.02	0.02
4	0.02	0.01	0.01	0.01
5 and more	0.07	0.08	0.05	0.05
Average penalty (in $)	2,978	2,943	3,415	3,291

Notes: This table provides the estimated distributions of the number of violations and the average quarterly penalty across all facilities, unconditional on the occurrence of a violation, as observed in the data and predicted by the fitted model.

TABLE 5. Model Primitive Estimates: Summary Statistics

	Mean	Standard Deviation	Interquantile Range	Min	Max
Marginal compliance cost	2,041 (284)	1,729	2,595	224	8,774
Environmental cost per violation (γ)					
Before the 2006 changes	2,390 (1,314)	2,631	1,426	176	15,714
After the 2006 changes	5,956 (1,703)	3,360	2,456	526	19,078
Enforcement cost per penalty (ψ)					
Before the 2006 changes	1.11 (0.06)	0.10	0.12	0.92	1.35
After the 2006 changes	1.08 (0.05)	0.09	0.10	0.83	1.29

Notes: We estimate the compliance cost function, the distribution of cost types and the regulator preference parameters for each of the 264 facilities that were active in the first quarter of 2005. This table provides the summary statistics of the marginal compliance cost evaluated at a negligence level equal to one ($Med(\Theta)b'(1)$) and the regulator preference parameters (γ, ψ), before and after the 2006 institutional changes. Bootstrap standard errors for the mean values of the estimates are in parenthesis.

Second, the estimated marginal compliance costs and regulator preferences vary considerably across facilities. Assuming that the realized cost type θ is the median value, conditional on the observed facility attributes, the marginal compliance cost when a facility's negligence level leads to, on average, one violation per quarter varies from \$224 to \$8,774, with mean \$2,041 and standard deviation \$1,729. Based on the minimum and the maximum values of the estimated γ's after the 2006 changes, the regulators' perceived environmental costs per violation for a facility can be 36 times as high as those for another facility. Similarly, the range of values of the estimated

ψ's after the changes indicates that the regulators' costs associated with imposing an extra dollar of penalty to a facility can be 1.6 times as large as those for another facility in the data.

6.2. **Explaining Compliance Costs and Regulator Preferences.** To understand the sources of the heterogeneity in the estimated marginal compliance costs and regulator preferences, we run regressions of the model primitive estimates on the facility attributes and provide the results in Table 6. We find that large marginal compliance costs are associated with for major facilities and those located in a county with a high population density, a large agriculture industry presence, a high turnout for the 2010 gubernatorial general elections, and a low support for the 2006 California proposition 84 to fund water quality projects.

We also find that the estimated heterogeneity in compliance costs is correlated with the heterogeneity in capital investment needs. To investigate this relationship, we employ the federal EPA's Clean Watersheds Needs Survey, which reports the amount of the capital investment needed by wastewater treatment facilities to meet the water quality goals of the Clean Water Act. Based on the 2012 survey, we obtain information on the financial needs of 215 of the facilities used in the estimation, out of which 108 have nonzero needs. We find that our estimates of the marginal compliance costs for facilities with nonzero needs are, on average, 25 percent larger than those for the facilities with no needs.

We find evidence that the regulators' preference parameter estimates presented in Table 5 are related to the environmental preferences of local constituents, measured as the percentage of voters supporting California Proposition 84 in 2006 at the county level. Figure 2 shows the correlation between this measure and the estimated values of γ and ψ for each facility. Panel (A) in the figure indicates a positive correlation between the regulator's weight on violations in her objective function (γ) and the local preferences for water quality—both before and after the 2006 institutional changes. Panel (B) shows a negative correlation between the regulator's weight on the penalty (ψ) and the local preferences. Table 6 shows that the aforementioned patterns persist even after we control for other facility attributes.

These results suggest that the regulator's preferences reflect those of the population at the facility location. This may be driven by the state government's political considerations that partially determine enforcement resource allocation and the regional board members' ability and willingness to tailor the enforcement standards to local preferences and needs. Because regional board members are paid by hour at

TABLE 6. Explaining Compliance Costs and Regulators' Preferences

	Compliance Cost	γ		ψ	
		Before	After	Before	After
Major	2,046***	601**	1,043***	0.060***	0.098***
	(86.61)	(228)	(331)	(0.011)	(0.010)
	[534]	[2,092]	[2,402]	[0.042]	[0.044]
Average household income (log, in $)	277	2,647**	8,101***	0.091**	0.045
	(367)	(1,072)	(1,667)	(0.044)	(0.037)
	[1,210]	[6,673]	[7,598]	[0.158]	[0.166]
Population density per sq. miles (log)	677***	-1,069***	-1,556***	0.016*	0.013*
	(69.15)	(188)	(324)	(0.009)	(0.009)
	[342]	[2,242]	[2,464]	[0.021]	[0.021]
Irrigation water use (%)	2,173***	-3,989***	-4,030***	0.147***	0.095***
	(280)	(709.4)	(1,071)	(0.027)	(0.019)
	[1,081]	[6,166]	[6,988]	[0.095]	[0.074]
Turnout (%)	28.49***	-12.96	-95.09	-0.001	-0.0004
	(9.80)	(28.86)	(41.11)	(0.001)	(0.001)
	[38.03]	[206]	[231.49]	[0.004]	[0.004]
Proposition for water projects (%)	-81.65***	124.9***	62.18	-0.003***	0.0001
	(9.69)	(26.78)	(39.52)	(0.001)	(0.001)
	[37.88]	[279]	[317]	[0.004]	[0.002]
Regional water board fixed effects	Yes	Yes	Yes	Yes	Yes
All other attributes used in estimation	Yes	Yes	Yes	Yes	Yes
Number of observations	264	264	264	264	264
Adjusted R^2	0.881	0.612	0.469	0.478	0.549

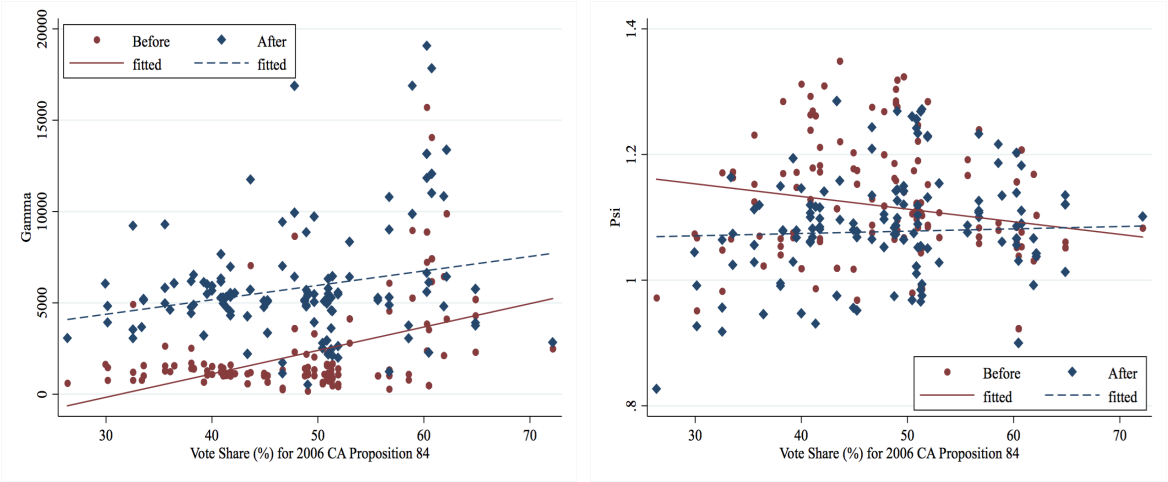
Notes: This table reports the OLS regression results of the estimated marginal compliance cost evaluated at a negligence level equal to one ($Med(\Theta)b'(1)$) and the estimated regulator parameters (γ and ψ) on all facility attributes used in the estimation (see Table 3), using the facility-level estimates for each of the 264 facilities active in the first quarter of 2005. Robust standard errors under the assumption that the estimated parameters are measured without error are in parenthesis, and the bootstrap standard errors without such an assumption are in brackets. Asterisk marks are based on the former standard errors; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

a relatively low rate while their job requires significant expertise, they are likely to serve the boards out of civic duty or personal political aspirations, which may help align their actions with the local constituents' preferences.

6.3. **Counterfactual Analyses.**

6.3.1. *Why Disparities in Penalties?* Our estimates of the model primitives indicate that the parameters characterizing the regulator preferences, γ and ψ, vary across facilities. We now assess the extent to which this heterogeneity in preferences explains the disparities in penalties documented in Section 3. With this intent, we consider a counterfactual scenario in which all facilities are subject to a regulator with the

FIGURE 2. Regulator versus Local Constituency Preferences



(A) Estimates of γ's (B) Estimates of ψ's

Notes: These figures show the correlation between the regulator parameter estimates for each facility (γ and ψ on panels (A) and (B), respectively) and the environmental preferences of local constituents, measured as the percentage of voters supporting California Proposition 84 in 2006 at the county level, both for the period prior to the 2006 institutional changes and for the period after the changes.

average values of γ and ψ across the 264 facilities active in the first quarter of 2005. We refer to this scenario as the *homogeneous regulator preference* (HRP) case. In our counterfactual analyses, we focus on the distribution of two outcomes across the facilities: (i) the expected violation frequencies; and (ii) $e\left(1|\mathbf{x}_{i,t}\right)$, the expected penalties schedule, evaluated at a negligence level equal to one. For each such outcome, we compute the mean and the standard deviation across the facilities.

In Table 7, the counterfactual outcomes under the homogeneous regulator preferences scenario before and after the 2006 changes are in Columns (3) and (4), respectively; Columns (1) and (2) present the baseline scenario outcomes. Relative to the baseline scenario, the dispersion in the expected penalties across the facilities fall to a relatively small extent in the scenario with the homogeneous preferences regulator. The standard deviation falls by 15 and five percent in the periods before and after the 2006 changes, respectively. Figure 3 provides further information on how the penalty schedule changes across the different scenarios. The figure compares the the point-wise average, 5th, and 95th percentiles of the penalty schedule across the facilities under the two scenarios, as well as those under another counterfactual scenario, which we address below. The changes in the 5th and 95th percentiles are relatively small between the baseline scenario and the HRP scenario, especially in the

TABLE 7. Effects of Enforcement Discretion

	Baseline scenario		Homogeneous regulator preferences		Uniform penalty schedule	
	Before (1)	After (2)	Before (3)	After (4)	Before (5)	After (6)
Violation frequency						
Mean	1.49	0.80	1.06	0.70	1.77	0.85
Standard deviation	1.35	0.72	0.95	0.69	1.60	0.77
Expected penalty at $a = 1$						
Mean	6,483	7,467	6,985	7,478	5,300	7,467
Standard deviation	3,437	3,859	3,285	3,350	-	-

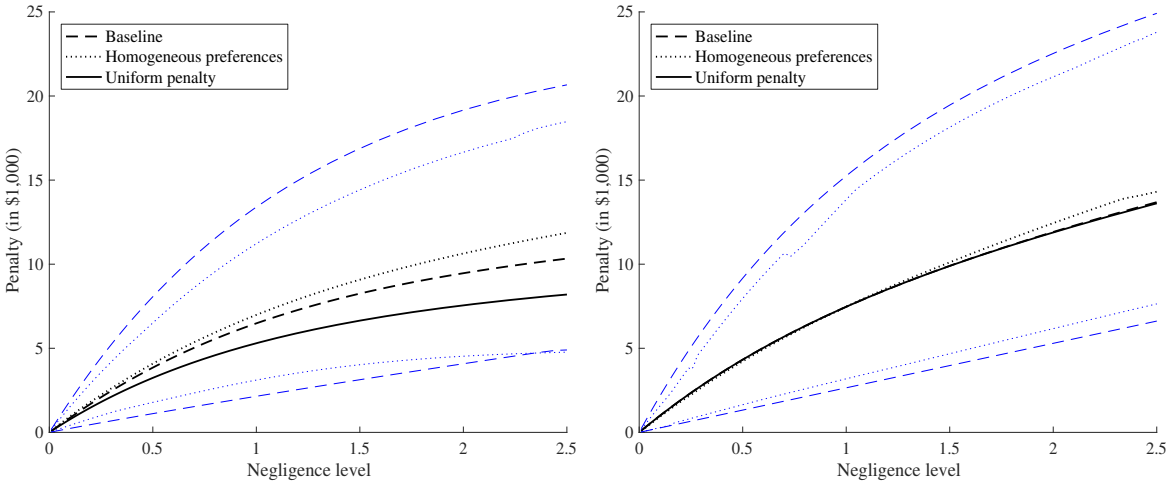
Notes: This table presents the results of two counterfactual scenarios that reduce the enforcers' discretion. In the first one (Columns (3) and (4)), every facility is under a regulator with the average preferences across all facilities active in the first quarter of 2005. In this scenario, the regulator accounts for the compliance cost distribution of each facility, so different facilities can still face different penalty schedules. In the second counterfactual scenario (Columns (5) and (6)), each facility is subject to the same penalty schedule, devised by a regulator with the same preferences of the first scenario for a facility with average observed characteristics. The outcomes obtained from the fitted model are presented in Columns (1) and (2). The table reports the results both for the period prior to and after the 2006 institutional changes.

post-2006 period. Taken together, these results suggest that the heterogeneity in the distributions of compliance costs are responsible for most of the observed disparities in penalties.

6.3.2. *The Value of Expertise on Compliance Costs.* Our empirical finding that the heterogeneity of compliance costs explain a large part of the heterogeneity in penalty disparities motivates us to consider a one-size-fits-all penalty schedule to all facilities. Suppose a regulator with preferences equal to the average across the facilities, as considered in the homogeneous regulator preference (HRP) scenario, designs an optimal penalty schedule for a facility with the average observable characteristics $\mathbf{x}_{i,t}$, and apply this schedule to all facilities. We refer to such a scenario as the *uniform penalty schedule* (UPS) case. Figure 3 provides the resulting penalty schedule in this scenario for the period before the 2006 institutional changes (Panel (A)) and the one following the changes (Panel (B)). Columns (5) and (6) of Table 7 present the mean and standard deviation across the facilities of the expected equilibrium violation frequencies under this scenario.

Comparing the HRP and the UPS cases provides a unique opportunity to assess how the flexibility to adjust the penalty schedule depending on compliance costs affects the facilities' equilibrium compliance behavior, holding constant the regulator preferences. We consider this flexibility as an avenue for the regulator to exercise

FIGURE 3. Average and Dispersion of Equilibrium Penalty Schedules



(A) Before the 2006 changes (B) After the 2006 changes

Notes: These figures show the point-wise average (in black), and the 5th and 95th percentiles (in blue) of the penalty schedules across the 264 facilities active in the first quarter of 2005 in the following three scenarios: (i) the baseline scenario; (ii) the scenario with homogeneous regulator preferences across all facilities; and (iii) the scenario with an uniform penalty schedule. Panels (A) and (B) display the penalty schedules before and after the 2006 institutional changes, respectively.

her expertise on the heterogeneous compliance costs of the different facilities. Table 7 shows that both the average and the standard deviation of violation frequencies increase under the UPS scenario, compared to the HRP case.

These results illustrate the importance of the regulators' expertise in the design of the penalty schedule. Figure 3 compares the point-wise averages across the facilities of the penalty schedules in the baseline, UPS, and HRP cases. The figure shows that the average schedules in the UPS and HRP scenarios are very similar to each other. Thus, the uniform penalty schedule is harsher for some facilities than a flexible schedule under the HRP case, while, for other facilities, the uniform schedule is relatively lenient. As facilities with higher compliance costs are the ones that tend to face stricter penalties under a flexible enforcement schedule, switching to an uniform penalty schedule would lead to more violations overall. Similarly, the dispersion of the violation frequencies across the facilities would increase substantially in the UPS scenario.

We also find that compared to the baseline scenario, both the average and the standard deviation of violation frequencies would increase under the UPS case. This

result is striking, since, as shown in Panel (B) of Figure 3, the average penalty schedules in these two scenarios are almost identical to each other, especially after the 2006 institutional changes. That is, the increase in the average violation frequencies does not follow from an overall decrease in the stringency of the penalty schedule under the UPS scenario. The comparison between the UPS and baseline scenarios corroborates our findings about the importance of regulator's expertise. One downside of giving discretion to regulators is that it allows them to put forward their private interests, rather than the objectives of the social planner. As previously discussed, our analysis cannot identify whether the heterogeneity in the estimated regulator preferences reflects differences in private or social concerns. But, even under the assumption that the private concerns prevail—which would, in principle, favor an uniform policy—our counterfactual results indicate that preventing the regulator from setting stricter penalties for high-cost facilities would lead to more violations and increases the dispersion in compliance across the facilities.

Relatedly, Duflo, Greenstone, Pande and Ryan (2016) find that increasing inspection frequencies for a random group of polluting industrial plants did not improve environmental outcomes. The authors show evidence that the treatment inspections, which were allocated evenly across all plants, were poorly targeted, relative to inspections allocated at the regulator's discretion in the status quo. Although their findings are focused on the detection of violations, whereas we study penalties, both analyses show that an even allocation of enforcement resources across the regulated entities does not necessarily improve the regulatory outcomes. We provide an extra dimension for understanding these results by separately assessing how regulator preferences and expertise affect the use of discretion.

6.3.3. *Distributional Effects of Regulator Discretion.* In the counterfactual experiments described above, we reduced regulatory discretion in two steps—first addressing the case in which the regulator preferences are homogeneous, and then considering the scenario with an uniform penalty schedule. The effects of each of these steps on violation frequencies potentially differ across the facilities in our sample. For example, in the transition from the HRP to the UPS cases, some facilities face a more stringent enforcement schedule, while others benefit from a more lenient one. We now analyze what facility attributes mostly explain the changes in violation frequencies between the different regimes. Specifically, using our estimation and counterfactual results, we create dummy variables indicating whether each facility in the data increases its expected negligence level in the following regime comparisons: a transition from the

baseline scenario to the HRP case; a transition from the HRP to the UPS scenarios; and a transition from the baseline to the UPS cases. We then separately regress each of these dummies on the facility attributes used in the estimation. Table 8 provides the results. For example, the dependent variable of Columns (1) and (4) takes value one if the facility increases its negligence level under the uniform penalty schedule scenario, relative to the baseline scenario.

We find that several facility attributes explain the heterogeneous effects of imposing a uniform penalty; in particular, major facilities and those located in high population density areas would increase violations. Notice that major facilities tend to have high compliance costs, as documented in Table 6. Therefore, compared to the HRP case, the uniform penalty schedule leads to an increase in violations for these facilities, as shown in Columns (2) and (5) of Table 8. Furthermore, the regulators tend to perceive the environmental costs of the violations by these facilities as being higher than those by minor ones (Table 6). Accordingly, applying average regulator preferences to these facilities would imply less stringent penalties and higher violation frequencies (Columns (3) and (6) in Table 8). That is, the effects of having a regulator with uniform preferences and preventing the regulator from using her expertise reinforce each other. On the other hand, we find that, although the regulators put less weight on violations by facilities located in relatively high population density areas (Table 6) the uniform penalty schedule is less stringent than the baseline for these facilities, as high population density also tends to be associated with high compliance costs.

7. Conclusion

We provide an empirical framework to evaluate regulatory discretion by identifying and estimating a model of strategic interactions between a regulator and privately-informed dischargers. Applying our framework to data on the regulation of wastewater treatment facilities in California, we estimate the environmental preferences and enforcement costs of regulators and the distribution of facilities' compliance costs. We find that the disparities in penalties in the data are mostly explained by compliance cost heterogeneity across facilities; even if the regulator's objective function were homogeneous across facilities, the existing penalty disparities would, to a large extent, remain.

Our study provides insights on the welfare implications of regulatory discretion. First, our results suggest that the regulator preferences reflect environmental preferences of local constituents. Second, mandating a one-size-fits-all policy that all

TABLE 8. Effects of Enforcement Discretion and Facility Attributes

Dependent variable: An increase in the negligence level due to a policy change?						
	Before			After		
	UPS−B	UPS−HRP	HRP−B	UPS−B	UPS−HRP	HRP−B
	(1)	(2)	(3)	(4)	(5)	(6)
Major	0.659***	0.206***	0.111***	0.606***	0.552***	0.068
	(0.039)	(0.050)	(0.047)	(0.041)	(0.058)	(0.059)
Income	0.082	0.252	0.231	0.077	-0.630***	1.166***
	(0.127)	(0.227)	(0.214)	(0.129)	(0.269)	(0.252)
Population density	0.066***	0.130***	-0.187***	0.055*	0.120***	-0.183***
	(0.029)	(0.041)	(0.041)	(0.029)	(0.042)	(0.043)
Irrigation water use	0.019	0.626***	-0.809***	-0.024	0.351***	-0.689***
	(0.080)	(0.134)	(0.133)	(0.082)	(0.155)	(0.156)
Turnout	0.007*	-0.008	-0.008	0.014***	0.008	-0.016**
	(0.004)	(0.007)	(0.005)	(0.005)	(0.007)	(0.006)
Water proposition	0.001	-0.022***	0.022***	0.007*	-0.007	0.002
	(0.005)	(0.005)	(0.004)	(0.005)	(0.006)	(0.006)
Regional board FE	Yes	Yes	Yes	Yes	Yes	Yes
All other attributes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	264	264	264	264	264	264
Adjusted R^2	0.765	0.549	0.591	0.742	0.388	0.437

Notes: This table reports the OLS regression results where the dependent variable indicates if the facility would increase its negligence level (and hence increase the frequency of violations) under a scenario on the left compared to a scenario on the right. We consider three policies: the baseline current scenario (B), the scenario with homogenous regulator preferences across all facilities (HRP), and the uniform penalty schedule scenario (UPS). The independent variables are identical to those of Table 6, and the unit of observation is each of the 264 facilities active in the first quarter of 2005. Robust standard errors under the assumption that the dependent variables are measured without error are in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

facilities face the same penalty schedule, regardless of their compliance costs, would lead to an increase in both the level and the dispersion of violation frequencies. Third, the increase in violations would be prominent for large facilities and those located in a densely populated area. These findings provide support for regulatory discretion without yet directly incorporating the local residents' demand for environmental quality.

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Appendix A. Proofs

Lemma 1. *For every t, $G_t(\cdot)$ is identified.*

Proof. Fix any time period t. The moment generating function of the number of violations K_t, $M_{K_t}(\cdot)$, is:

$$\begin{aligned} M_{K_t}(s) &= \mathbb{E}[\exp(ks)] = \mathbb{E}_{A_t}[\mathbb{E}_K[\exp(ks)|a]] \\ &= \mathbb{E}_{A_t}[\exp(a[\exp(s)-1])] = M_{A_t}[\exp(s)-1], \end{aligned}$$

where the third equality follows from the moment generating function of the Poisson distribution with parameter a. Note that because A_t has a bounded support, $[0, a_t(\overline{\theta})]$, $M_{K_t}(s)$ exists for any $s \in \mathbb{R}$. Letting $u = \exp(s) - 1$ shows that

$$M_{A_t}(u) = M_{K_t}[\log(1+u)],$$

for $u \in (-1, \infty)$. Therefore, $M_{A_t}(\cdot)$ is identified on a neighborhood of 0, thereby identifying $G_t(\cdot)$. □

Lemma 2. *Under Assumptions 1–3, we have that $T^H(a) = \tilde{a}\left[\tilde{\theta}\left(a, post\right), pre\right]$ for $a \in \mathcal{A}_{pre} \cap \mathcal{A}_{post}$, and $T^V\left[\tilde{\theta}(a, pre), a\right] = \tilde{\theta}(a, post)$ for any $a \in \mathcal{A}_{pre}$.*

Proof. The first equation follows from $F(\cdot)$ and $b(\cdot)$ not changing over time and from the strict monotonicity $\tilde{a}(\cdot, j)$ in its first argument. Concerning the second equation, from (3), we have that $\tilde{\theta}(a, j)b'(a) = e'_j(a)$ for $j \in \{pre, post\}$, which implies that $\tilde{\theta}(a, post) = \frac{e'_{post}(a)}{e'_{pre}(a)}\tilde{\theta}(a, pre)$. □

Proposition 2. *Suppose Assumptions 1–3 hold. Then, for any $l \in \{0, 1, \ldots, \bar{L}\}$ and $j \in \{pre, post\}$, the following objects are identified up to the normalization $\theta_0 = 1$: (i) the equilibrium negligence level, $\tilde{a}(\theta_l, j)$; (ii) the distribution of cost types, $F(\theta_l)$; and (iii) the marginal baseline compliance cost function, $b'(\tilde{a}(\theta_l, j))$.*

Proof. We first show by induction that $\theta_l = \tilde{\theta}(a_l, post) = \tilde{\theta}(a_{l+1}, pre)$. From the normalization, $\theta_0 = \tilde{\theta}(a_0, post)$. For any l, let $\theta_l = \tilde{\theta}(a_l, post)$. Then, $a_{l+1} = T^H(a_l) = \tilde{a}\left[\tilde{\theta}(a_l, post), pre\right] = \tilde{a}(\theta_l, pre)$, where the first and second equalities are due to the

definition of a_{t+1} and Lemma 2, respectively. Thus, $\theta_l = \tilde{\theta}(a_{l+1}, pre)$. Moreover, $\theta_{l+1} = T^V(\theta_l, a_{l+1}) = T^V\left[\tilde{\theta}(a_{l+1}, pre), a_{l+1}\right]$, where the second equality is due to the definition of θ_{l+1}. Therefore, from Lemma 2, we have that $\theta_{l+1} = \tilde{\theta}(a_{l+1}, post)$. We can then use (3) to write $b'(a_l) = \frac{e'_{pre}(a_l)}{\theta_{l-1}} = \frac{e'_{post}(a_l)}{\theta_l}$. Moreover, $F(\theta_l)$ is identified by

$$F(\theta_l) = G_{post}(a_l) = G_{pre}(a_{l+1}).$$

□

PROPOSITION 3. *Suppose Assumptions 1–5 hold. Then, if $\bar{L} \geq 1$, the following objects are identified up to the normalization $\tilde{\theta}(a_0, post) = 1$ for some $a_0 \in \mathcal{A}_{post}$: (i) the distribution of facilities' types, $F(\cdot)$; (ii) the derivative of the baseline compliance cost function, $b'(a)$ for any $a \in \mathcal{A}_{pre} \cup \mathcal{A}_{post}$; and (iii) the parameters of the regulator's objective function, $\{\gamma_{j,r}\}_{r=1}^R$ and ψ_j, for $j \in \{pre, post\}$.*

Proof. Let $Q(\alpha)$ denote α-quantile of $F(\cdot)$. We can rewrite equation (9) as

$$b'\left[G_j^{-1}(\alpha)\right]\left[(1-\psi_j)Q(\alpha) + \frac{\psi_j(1-\alpha)}{f\left[Q(\alpha)\right]}\right] = \sum_{r=1}^{R} \gamma_{j,r}\left[G_j^{-1}(\alpha)\right]^{r-1}. \tag{14}$$

We may also rewrite equation (3) as:

$$e'_j\left[G_j^{-1}(\alpha)\right] = Q(\alpha)b'\left[G_j^{-1}(\alpha)\right]. \tag{15}$$

Using equation (15) and the relationship between the density and its quantile function, i.e.,$f\left[Q(\alpha)\right] = 1/Q'(\alpha)$, we rewrite equation (14) as

$$\frac{e'_j\left[G_j^{-1}(\alpha)\right]}{Q(\alpha)}\left[(1-\psi_j)Q(\alpha) + Q'(\alpha)\psi_j(1-\alpha)\right] = \sum_{r=1}^{R} \gamma_{j,r}\left[G_j^{-1}(\alpha)\right]^{r-1},$$

which implies

$$\frac{Q'(\alpha)}{Q(\alpha)} = \frac{\sum_{r=1}^{R} \gamma_{j,r}\left[G_j^{-1}(\alpha)\right]^{r-1} - e'_j\left[G_j^{-1}(\alpha)\right](1-\psi_j)}{e'_j\left[G_j^{-1}(\alpha)\right]\psi_j(1-\alpha)}, \tag{16}$$

for $j \in \{pre, post\}$. Define $\Gamma_{j,r} \equiv \frac{\gamma_{j,r}}{\psi_j}$ and $\Psi_j = \frac{1-\psi_j}{\psi_j}$, and notice that there is a one-to-one relationship between $\left(\{\Gamma_{j,r}\}_{r=1}^R, \Psi_j\right)$ and $\left(\{\gamma_{j,r}\}_{r=1}^R, \psi_j\right)$. Integrating the above equation from some α_0 to α gives

$$\log\frac{Q(\alpha)}{Q(\alpha_0)} = \int_{\alpha_0}^{\alpha}\left(\sum_{r=1}^{R}\Gamma_{j,r}\frac{\left[G_j^{-1}(u)\right]^{r-1}}{e'_j\left[G_j^{-1}(u)\right]} - \Psi_j\right)\frac{1}{(1-u)}du. \tag{17}$$

Remember that $F(\theta_l) = G_j[\tilde{a}(\theta_l, j)]$. From Proposition 2, there is a vector $\{\theta_l\}_{l=0}^{\bar{L}}$ such that $\tilde{a}(\theta_l, j)$ is known for $j \in \{pre, post\}$. Since equation (17) holds for arbitrary α and α_0, the following holds for for any $l \in \{1, \ldots, \bar{L}\}$ and $j \in \{pre, post\}$:

$$\log \frac{\theta_l}{\theta_0} = \sum_{r=1}^{R} \Gamma_{j,r} \int_{G_j[\tilde{a}(\theta_0,j)]}^{G_j[\tilde{a}(\theta_l,j)]} \frac{\left[G_j^{-1}(u)\right]^{r-1}}{e_j'[G_j^{-1}(u)]\,(1-u)} du - \Psi_j \int_{G_j[\tilde{a}(\theta_0,j)]}^{G_j[\tilde{a}(\theta_l,j)]} \frac{1}{(1-u)} du. \quad (18)$$

Furthermore, we obtain the following equations for any α by observing that equation (16) holds for both regimes:

$$\frac{\sum_{r=1}^{R} \Gamma_{post,r} \left[G_{post}^{-1}(\alpha)\right]^{r-1}}{e_{post}'\left[G_{post}^{-1}(\alpha)\right]} - \frac{\sum_{r=1}^{R} \Gamma_{pre,r} \left[G_{pre}^{-1}(\alpha)\right]^{r-1}}{e_{pre}'\left[G_{pre}^{-1}(\alpha)\right]} + \Psi_{pre} - \Psi_{post} = 0. \quad (19)$$

Note that, for each regime, equation (18) specifies a system of $\bar{L}$ linear equations and $R+1$ unknowns $\left(\{\Gamma_{j,r}\}_{r=1}^{R} \text{and} \Psi_j\right)$, and equation (19) specifies an infinite number of equations. Assumption 5 suffices for a system consisting of equations (18) and (19) to have an unique solution for $\{\gamma_{pre,r}\}_{r=1}^{R}, \{\gamma_{post,r}\}_{r=1}^{R}, \psi_{pre}$ and ψ_{post}. Now, setting $\alpha_0 = G_j(a_0)$ in equation (17), we identify $Q(\cdot)$ and, accordingly, $F(\cdot)$ and $f(\cdot)$. Lastly, using equation (14), we identify $b'(a)$ for $a \in \mathcal{A}_{pre} \cup \mathcal{A}_{post}$.

Note that our model is over-identified because we can evaluate (19) at an arbitrarily large number of quantiles. Moreover, for each regime, there is at least one more equation that we could use for the identification of the model primitives evaluating equation (9) at the upper bounds of $\mathcal{A}_j$'s. □

Appendix B. Estimation Procedure

Step 1. We parametrically estimate the expected penalties as specified in (12) by a constrained OLS. Given the estimates, we estimate the marginal expected penalty, $\hat{e}_j'(a|\mathbf{x})$ using equation (1) for $j = \{pre, post\}$. To estimate $G_j(\cdot|\mathbf{x})$, we use the parametric specification of (13) and estimate δ and β_j's by MLE.

Step 2. We denote by $\hat{\theta}(a, j|\mathbf{x})$ an estimator of the facility type that sets negligence level a under regime j, given $\mathbf{x}$. We normalize $\hat{\theta}(1, post) = 1$, and employ the empirical counterparts of the transforms T^H and T^V, defined in (10) and (11), to obtain $\hat{\theta}(a, j|\mathbf{x})$ for a sequence of values of a. Normalizing $\hat{a}_0(\mathbf{x}) = 1$ and $\hat{\theta}_0(\mathbf{x}) = 1$, we define

recursively:

$$\hat{a}_l(\mathbf{x}) \equiv \hat{G}_{pre}^{-1}\left[\hat{G}_{post}\left[\hat{a}_{l-1}(\mathbf{x})|\mathbf{x}\right]|\mathbf{x}\right],$$

$$\text{and} \qquad \hat{\theta}_l(\mathbf{x}) \equiv \frac{\hat{e}'_{post}\left[\hat{a}_l(\mathbf{x})|\mathbf{x}\right]}{\hat{e}'_{pre}\left[\hat{a}_l(\mathbf{x})|\mathbf{x}\right]}\hat{\theta}_{l-1}(\mathbf{x}).$$

Let us define $\hat{\theta}_l^{post}(\mathbf{x}) \equiv \hat{\theta}_l(\mathbf{x})$, $\hat{\theta}_l^{pre}(\mathbf{x}) \equiv \hat{\theta}_{l-1}(\mathbf{x})$, $\hat{a}_l^{post}(\mathbf{x}) \equiv \hat{a}_l(\mathbf{x})$ and $\hat{a}_l^{pre}(\mathbf{x}) \equiv \hat{a}_l(\mathbf{x})$, for every l. We employ $\hat{\theta}_l^j(\mathbf{x})$ as an estimator of $\tilde{\theta}\left(\hat{a}_l^j(\mathbf{x}), j|\mathbf{x}\right)$, for $j \in \{pre, post\}$ and any l.

Step 3. Equation (18) implies that

$$\sum_l \left\{ \log\frac{\theta_l}{\theta_0} - \sum_{r=1}^{R}\Gamma_{j,r}\int_{\alpha_0}^{\alpha_l}\frac{\left[G_j^{-1}(u)\right]^{r-1}}{e'_j\left[G_j^{-1}(u)\right](1-u)}du + \Psi_j\int_{\alpha_0}^{\alpha_l}\frac{1}{(1-u)}du \right\}^2 = 0,$$

for $j \in \{pre, post\}$. Also, from (19), we have

$$\sum_{\alpha\in\mathbf{U}} \left\{ \frac{\sum_{r=1}^{R}\Gamma_{post,r}\left[G_{post}^{-1}(\alpha)\right]^{r-1}}{e'_{post}\left[G_{post}^{-1}(\alpha)\right]} + \Psi_{pre} - \frac{\sum_{r=1}^{R}\Gamma_{pre,r}\left[G_{pre}^{-1}(\alpha)\right]^{r-1}}{e'_{pre}\left[G_{pre}^{-1}(\alpha)\right]} - \Psi_{post} \right\}^2 = 0,$$

where $U = \{\alpha_1, \ldots, \alpha_{N_U}\}$ is a grid in the $(0,1)$ interval such that $G_{post}^{-1}(\alpha) > 0$ for all $\alpha \in U$. We estimate $\{\Gamma_{pre,r}(\mathbf{x})\}_{r=1}^R$, $\Psi_{pre}(\mathbf{x})$, $\{\Gamma_{post,r}(\mathbf{x})\}_{r=1}^R$ and $\Psi_{post}(\mathbf{x})$ using a sample analogue of the above two equations for any given $\mathbf{x}$. We then estimate $\{\gamma_{j,r}(\mathbf{x})\}_{r=1}^R$ and $\psi_j(\mathbf{x})$ as

$$\hat{\psi}_j(\mathbf{x}) \equiv \frac{1}{1-\hat{\Psi}_j(\mathbf{x})} \quad \text{and} \quad \hat{\gamma}_{j,r}(\mathbf{x}) \equiv \hat{\Gamma}_{j,r}(\mathbf{x})\hat{\psi}_j(\mathbf{x}),$$

for $j \in \{pre, post\}$ and $r = \{1, \ldots, R\}$.

Step 4. From the empirical analogue to (17) with $\alpha_0 = 0$, we estimate the quantile function associated with the distribution of types, conditional on $\mathbf{x}$, as

$$\hat{Q}_j\left(\alpha|\mathbf{x}\right) \equiv \hat{\theta}_0^j(\mathbf{x})\exp\left(\int_{\hat{G}_j\left[\hat{a}_0^j(\mathbf{x})|\mathbf{x}\right]}^{\alpha}\left[\sum_{r=1}^{R}\Gamma_{j,r}(\mathbf{x})\frac{\left[\hat{G}_j^{-1}(u|\mathbf{x})\right]^{r-1}}{e'_j\left[\hat{G}_j^{-1}(u|\mathbf{x})|\mathbf{x}\right]} - \Psi_j(\mathbf{x})\right]\frac{1}{(1-u)}du\right),$$

for $j \in \{pre, post\}$. Given our restriction that $Q_{pre}(\cdot) = Q_{post}(\cdot)$, an estimator of the quantile function of $F(\cdot|\mathbf{x})$, which we denote by $\hat{Q}\left(\cdot|\mathbf{x}\right)$, is:

$$\hat{Q}\left(\alpha|\mathbf{x}\right) = \hat{\pi}_{pre}(\mathbf{x})\hat{Q}_{pre}\left(\alpha|\mathbf{x}\right) + \left[1-\hat{\pi}_{pre}(\mathbf{x})\right]\hat{Q}_{post}\left(\alpha|\mathbf{x}\right),$$

where the scalar $\hat{\pi}_{pre}(\mathbf{x})$ is a weight that depends on the relative frequency of observations from the pre-2006 regime, conditional on the observable characteristics $\mathbf{x}$. An

estimator for $F(\cdot|\mathbf{x})$, or $\hat{F}(\cdot|\mathbf{x})$, is the inverse of $\hat{Q}(\cdot|\mathbf{x})$. Note that under Assumption 2, the inverse of $\hat{Q}(\cdot|\mathbf{x})$ is guaranteed to exist. Finally, we define

$$\hat{b}'(a|\mathbf{x}) \equiv \left\{\hat{\pi}_{pre}(\mathbf{x})\hat{e}'_{post}(a|\mathbf{x}) + [1-\hat{\pi}_{pre}(\mathbf{x})]\,\hat{e}'_{pre}(a|\mathbf{x})\right\}/\hat{Q}[\hat{F}(a|\mathbf{x})\,|\mathbf{x}].$$

Appendix C. Sensitivity Analyses

To assess the sensitivity of our findings to some of the assumptions made in our empirical analysis, we present results based on alternative assumptions in Table 9. First, we estimate the penalty schedule by considering all penalties within three years of the occurrence of each violation, as opposed to the four years used in the original results. This change allows us to use a longer period of data for the penalty schedule estimation in the first step. Specifically, we employ the penalties for the violations of 2000–2002 (2009-2011) to estimate the penalty schedule before (after) the 2006 institutional changes, instead of 2000–2001 (2009–2010), as in the original results.

Second, we incorporate the idea that some MMP violations are more severe or significant than others. With this intent, we use the water boards' ranking of violations into *priority* and the rest. The water quality enforcement policy (California State Water Resources Control Board, 2010b) defines priority violations as those "that pose an immediate and substantial threat to water quality and that have the potential to cause significant detrimental impacts to human health or the environment," and states that the water boards should rank violations and then prioritize cases for formal discretionary enforcement action. In our original estimation, we treat all MMP violations as identical to each other. In our sensitivity analysis, instead, we assume that one MMP violation ranked as a priority violation is equal to two non-priority MMP violations. This way, even if the number of MMP violations is the same for two facilities, if one facility has more priority violations than the other, the former is more likely to be associated with a larger negligence level than the latter.

Third, we change the unit of observation from a facility-quarter to a facility-semester. For a given period, a facility draws its cost type and determines the level of negligence; and a regulator sets a penalty schedule over the violations during the period. A quarter reflects the distinct precipitation patterns across four seasons in California. A semester, however, may also be a suitable period to consider, because, among all 1,605 penalty actions imposed on domestic wastewater treatment facilities in 2000-2014, the median period of violations comprised by an unique penalty action (either an ACL or a settlement in court) is 7 months

Table 9 shows that the estimates of the model primitives obtained from each of the three alternative specifications are similar to our original estimates. Specifically, the marginal compliance cost estimates are very similar to the original ones, and the our finding that regulators' environmental costs are higher for violations by major facilities than for those by minor ones persists. Moreover, the main results of our counterfactual analysis in Section 6.3 are robust to these three alternative specifications.

TABLE 9. Sensitivity Analyses

	Estimated Model Primitives				
	Marginal Compliance Cost ($Med(\Theta\|)b'(1)$)	Environmental Cost per Violation (γ)		Enforcement Cost per Penalty (ψ)	
		Before	After	Before	After
Original specification					
Mean	2,041	2,390	5,956	1.11	1.08
Standard deviation	1,729	2,631	3,360	0.10	0.09
Alternative specification 1: Penalty within 3 years					
Mean	1,808	2,232	5,616	1.11	1.08
Standard deviation	1,473	4,934	5,753	0.12	0.13
Alternative specification 2: Distinguishing priority vs non-priority violations					
Mean	2,182	1,583	5,023	1.12	1.08
Standard deviation	1,728	1,631	2,274	0.09	0.10
Alternative specification 3: Semester-long period					
Mean	2,726	8,641	13,491	1.18	1.11
Standard deviation	2,476	19,774	21,228	0.15	0.10

	Counterfactual Scenarios					
	Baseline scenario		Homogeneous regulator preferences		Uniform penalty schedule	
	Before	After	Before	After	Before	After
Original specification						
Violation frequency						
Mean	1.49	0.80	1.06	0.70	1.77	0.85
Standard deviation	1.35	0.72	0.95	0.69	1.60	0.77
Expected penalty at $a = 1$						
Mean	6,483	7,467	6,985	7,478	5,300	7,467
Standard deviation	3,437	3,859	3,285	3,350	-	-
Alternative specification 1: Penalty within 3 years						
Violation frequency						
Mean	1.48	0.79	0.99	0.7	1.75	0.83
Standard deviation	1.35	0.72	0.85	0.73	1.5	0.73
Expected penalty at $a = 1$						
Mean	5,990	6,942	6,609	6,903	4,720	6,943
Standard deviation	3,256	3,727	2,829	3,154	-	-
Alternative specification 2: Distinguishing priority vs non-priority violations						
Violation frequency						
Mean	2.21	0.88	1.70	0.82	2.62	0.95
Standard deviation	2.09	0.84	1.72	0.85	2.24	0.86
Expected penalty at $a = 1$						
Mean	6,105	7,055	6,189	6,848	4,995	7,055
Standard deviation	3,321	3,692	3,119	3,018	-	-
Alternative specification 3: Semester-long period						
Violation frequency						
Mean	2.3	1.21	0.82	0.74	2.63	1.28
Standard deviation	1.31	0.69	0.62	0.44	1.65	0.74
Expected penalty at $a = 1$						
Mean	8,074	9,735	12,593	11,725	7,452	9,732
Standard deviation	4,452	5,062	6,367	7,698	-	-