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Beggar-thy-Neighbor or Free-riding? Transboundary Behaviors in Decentralized Water Pollution Policies

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Abstract

Public policies with different degrees of centralization face optimization problems at different administrative levels, which motivates beggar-thy-neighbor and free-riding behaviors that lead to insufficient regulations at jurisdictional boundaries. This paper investigates whether states exhibit these behaviors when implementing nonpoint-source (NPS) water pollution policies. I compile a unique and comprehensive dataset of three NPS policies and hydrological information using ArcGIS. Depending on the policies' characteristics, I use a Probit model, a duration model with selection, and a Heckman selection model, respectively. I find that rivers within 30 km of state borders are less likely to be treated by the two more decentralized policies, i.e. Water Quality Assessment Program, especially the Total Maximum Daily Load (TMDL) Program, but receive larger amounts of grants under the relatively centralized NPS Pollution Management Program. States exhibit beggar-thy-neighbor behavior within 5 km upstream of state borders, with a 10.28% to 18.9% lower probability of TMDL development than intrastate rivers, and exhibit free-riding behavior within 10 km downstream of state borders, with a 25.71% to 55.81% lower probability of TMDL development. The free-riding behavior is affected by the upstream state's environmental and political-economic characteristics. Each behavior leads to a large deadweight loss.

1 Introduction

Many public policies are implemented jointly by the central and local governments. When local governments dominate, they optimize policy implementation within their jurisdictions to maximize local welfare, thereby exhibiting different policy behaviors at jurisdictional boundaries. Examples include insufficient regulations near boundaries and transboundary policy spillovers. Since waterways connect jurisdictions, the transboundary analysis of water pollution policies is particularly important (Keiser et al. (2022)). However, the economic literature on water pollution policies is sparse relative to air pollution policies due to limitations in data and difficulties in hydro-spatial computation and causal identification (Keiser and Shapiro (2019)). Some studies of point-source pollution have found potential jurisdiction and enforcement issues for water policies in the U.S., China, India, Brazil, and other countries around the world (Sigman (2005), Chen et al. (2018), Greenstone and Hanna (2014), Lipscomb and Mobarak (2016), Sigman (2002)). However, the literature has been ambiguous in classifying and identifying the policy behaviors. In addition, because nonpoint sources are diffuse, they provide more opportunities for local governments to prioritize treatment geographically.

This paper studies whether state governments have different behaviors when implementing decentralized nonpoint-source (NPS) water pollution policies on near-boundary and transboundary rivers compared with intrastate rivers. I compile a unique and comprehensive dataset of NPS pollution policies and hydrological information to estimate the policy implementation priority and intensity across rivers' distances to state borders. I find states treat near-boundary and transboundary rivers less if the policy is highly decentralized. These policy behaviors are inefficient and lead to large deadweight losses.

The state governments have two types of transboundary policy behaviors. The first is beggar-thy-neighbor behavior, where states that possess the upstream portions of interstate rivers conduct insufficient treatment and let pollution flow into the downstream states. The second is free-riding behavior, where downstream states conduct insufficient treatment because they expect the upstream states to control the source of pollution. I identify every near-boundary and transboundary river in the contiguous United States based on its hydrographic and spatial features. I match every flow segment with its NPS policy treatment status using ArcGIS to study the transboundary policy behaviors.

The major NPS pollution policies in the Clean Water Act (CWA) are Section 305(b) Water Quality Assessment, Section 303(d) Total Maximum Daily Load (TMDL) Program, and Section 319(h) Nonpoint Source Management Program Grants. S305(b) is the first step of NPS pollution policies. S303(d) can only be conducted based on S305(b) assessment outcomes. S319(h) funding is not a follow-up to the other two policies, because many watersheds were approved for S319(h) grants without a TMDL. I differentiate the degree of decentralization of the three NPS policies by their levels of state authority and state-borne costs. S303(d) is the most decentralized policy because states have higher authority and costs in implementing S303(d) than in S305(b) and S319(h). States bear low costs and have low authority in S319(h) since grants are subject to final approval by the federal government. Therefore, S319(h) is the least decentralized among the three policies.

I adopt different empirical strategies to study states' behaviors based on the decision-making process of each NPS policy. S305(b) water quality assessment has binary outcomes, a catchment is either assessed or not depending on various factors that affect decision-making. Therefore, I use a discrete choice model (Probit) to study the effect of these factors on the probability of assessment. The development of TMDLs under S303(d) is based on the water quality assessment results. Only impaired water bodies need treatment. Based on the priority ranking, different water bodies receive TMDLs at different times. Thus, I use a duration model with selection: the first step is a discrete choice model (Probit) that selects the impaired water bodies, and the second step is a proportional hazard model that estimates the probability a catchment receives a TMDL. The amount of S319(h) NPS pollution management grants is based on the watershed restoration plan submitted by states and the Environmental Protection Agency (EPA)'s approval. Different watersheds receive different grant amounts. I conduct a Heckman two-step analysis to select the watersheds treated by S319(h) programs using a Probit model then estimate the effect of boundary factors on grant amount using an OLS model.

The policy's degree of decentralization affects the states' policy behavior at the near-boundary and transboundary rivers. My results show that the border catchments are 45.81% less likely to be assessed under S305(b) and 8.03% less likely to receive a TMDL under S303(d). Catchments within 1-30 km of state borders are between 6.26% to 12.68% less likely to be assessed and between 6.83% to 21.87% less likely to receive a TMDL compared to intrastate catchments. The S319(h) grant amounts fluctuate substantially across distances and portions of rivers. Border subwatersheds receive $20,185.5 more grants, and a subwatershed within 1-30 km of the state borders receives $9,714.2 to $23,957.7 more grants than intrastate subwatersheds. The more decentralized a policy is, the stronger the boundary behaviors. The relatively less decentralized S319(h) funding is granted more for near-boundary and transboundary rivers, indicating these rivers need more pollution management. However, the two more decentralized policies, S305(b) and S303(d), are less likely to be implemented for these rivers, which implies that the state-level policy decisions do not maximize the national welfare.

I construct a theoretical model for the federal and state government's policy decisions. Some interstate watersheds will be treated by the federal government to maximize the national welfare but will not be treated by the state government due to the beggar-thy-neighbor and free-riding behaviors. Therefore, a policy decided by the state government will result in deadweight losses. The empirical estimation results show that S319(h) does not reflect these behaviors. S305(b) reflects the beggar-thy-neighbor behavior but the results fluctuate. The upstream portions of interstate rivers are 9.66-11.15% less likely to be assessed within 2.5-10 km of state borders and are 6.3% less likely to be assessed within 20-25 km of state borders than intrastate rivers. States exhibit both behaviors in S303(d), and the behaviors diminish with the distance to state borders. The upstream portions of interstate rivers within 5 km of the state borders have a 10.28% to 18.9% lower probability of TMDL development, which is consistent with the beggar-thy-neighbor behavior. The downstream portions of interstate rivers within 10 km of the state borders have a 25.71% to 55.81% lower probability of TMDL development, which is consistent with the free-riding behavior.

Using the willingness to pay for clean water estimated in the literature (Hite, Hudson, and Intarapapong (2002), Jordan and Elnagheeb (1993), Chatterjee et al. (2017)), I conduct a back-of-the-envelope calculation and infer that each behavior incurs a large deadweight loss. The downstream free-riding behavior is stronger than the upstream beggar-thy-neighbor behavior in TMDL development but does not necessarily incur a larger deadweight loss, because the interstate rivers have more upstream tributaries than downstream tributaries. The free-riding behavior is affected by the upstream states' environmental and political-economic background. An upstream state that is environmentally friendly or smaller in population or GDP would intensify the free-riding behavior of the downstream state.

The two transboundary policy behaviors have not been studied directly and separately in the literature. Transboundary analyses of other environmental problems like air pollution (Fowlie, Petersen, and Reguant (2021)), endangered species (List, Bulte, and Shogren (2002)), etc. are not able to differentiate between the two policy behaviors because, unlike water flows, these other settings do not have a determined direction when crossing borders. While the literature on transboundary water pollution has been ambiguous regarding the two types of behaviors. One reason is that the literature uses pollution levels to indicate policy implementation, instead of studying the policy implementation directly. This makes it more difficult to differentiate the two types of policy behaviors and separate the results of policy behaviors from polluting activities. Helland and Whitford (2003)) finds high emissions in air and water from facilities in counties near state borders. Sigman (2014) finds higher interjurisdictional variation in water pollution levels. Sigman (2002) and Lipscomb and Mobarak (2016) find high pollution upstream near the jurisdictional borders.

These results can be attributed to both less pollution control and more polluting activities near the boundaries. Sigman (2005) finds high pollution downstream, which can result from both the beggar-thy-neighbor behavior and free-riding behavior in policy implementation. This paper studies the transboundary policy behaviors directly and separates the two behaviors using the policies' implementation status across different portions of interstate rivers.

This paper is also the first transboundary analysis of NPS water pollution policies. Since being established in 1972, the CWA has invested more than $1 trillion in pollution treatment. However, despite these investments, 50% of assessed rivers remain impaired (Kelderman et al. (2022)). The major threat is NPS pollution, which has become the most widespread contributor to water pollution in past decades (Birkeland (2001), Keiser and Shapiro (2019)). However, NPS pollution and regulations have received less attention in the literature. This is because NPS diffuses, which makes it difficult to monitor pollution levels and establish a causal relationship between NPS pollution and NPS policies. I avoid these difficulties by studying the NPS policy implementation status directly. The diffuse nature of NPS leads to more jurisdictional issues and creates more flexibility for the jurisdictional authorities to prioritize policy implementation than point sources, leading to a higher risk of transboundary policy behaviors.

The two transboundary policy behaviors studied in this paper are also applicable to other environmental policies. Because these behaviors result from local authorities' goal of maximizing local welfare, which is a common feature of many public policies. In addition, this paper decomposes the decision-making process of the three NPS policies and models each policy into its characteristics to better understand the policy incentives. Thus, the results in this paper improve our understanding of decentralized environmental policies and specify more flexibility in decision-making that is easier to generalize to other contexts. For example, S305(b) water quality assessment can be compared with other low local cost policies for providing information, such as air pollution monitoring and traffic monitoring. S303(d) TMDL development can be compared with other second-step policies with high-level local government authority, such as driving restrictions, construction of infrastructure and welfare facilities, protection of locally endangered species, etc. Results for S319(h) NPS pollution management granting program can be generalized to other decentralized grants, subsidies, and rebate programs subject to central approval. The heterogeneous near-boundary and transboundary effects across these policies provide valuable insights into the implementation of other environmental policies at jurisdictional boundaries.

This paper also provides an argument for the ongoing debate about environmental federalism. I study the policy behaviors on different portions of rivers and discuss the outcomes of environmental federalism using three different policies. Prior literature has found that the impact of decentralized environmental policies on environmental quality may be insignificant (List and Gerking (2000)), or positive (Millimet (2003), Sigman (2003)), or both, depending on jurisdiction homogeneity (Oates and Schwab (1988)) or decision-making process (Silva and Caplan (1997)). The debate over environmental federalism for water pollution control has intensified in recent years. This is because the Clean Water Act has been unclear in the jurisdiction definition of "waters of the United States" (WOTUS). The 2020 Navigable Waters Protection Rule (NWPR) adopts a narrow federal jurisdiction that excludes the "interstate waters". However, some studies point out that unclear jurisdictional responsibility and treating waters as locally public goods would increase interstate water pollution (Greenstone and Hanna (2014), Keiser et al. (2021), Keiser et al. (2022)). Keiser et al. (2022) proposes future research to connect studies of economic behavior with the nation's hydrological network to improve ex-ante projections of the impacts of future water rules and regulations. This paper fills an important gap in this literature.

The remainder of the paper proceeds as follows. Section 2 explains the mechanisms of each NPS pollution policy; Section 3 constructs the theoretical model for the transboundary policy behaviors; Section 4 presents the empirical approaches for each policy; Section 5 describes data; Section 6 presents the main estimation results; Section 7 discusses some extensions of the results; Section 8 concludes.

2 Policy Background

The series of nonpoint-source (NPS) pollution policies in the CWA are Section 305(b) Water Quality Assessment, Section 303(d) the Total Maximum Daily Load (TMDL) Program, and Section 319(h) Nonpoint-source Management Program Grants. These NPS pollution policies are water-quality based instead of effluent-based as are most point-source pollution policies. This is because nonpoint-source (NPS) water pollution cannot be regulated at the end of the pipe like point sources. Table 1 briefly summarizes the degrees of decentralization of the three NPS policies evaluated by their levels of state authority and state-borne costs.

2.1 Section 305(b): Water Quality Assessment

Section 305(b) Water Quality Assessment is the prerequisite of Section 303(d). S305(b) requires states to assess the quality of the state's surface and ground waters and submit an integrated report to the U.S. Environmental Protection Agency (EPA) every two years. Not all water bodies are assessed at once. From the establishment of the Clean Water Act in 1972 until the first integrated reporting cycle in 2002, many bodies of water in the nation were still listed as unassessed. As shown in Table 2, states categorize the assessment units (indexed catchments) into five integrated reporting categories (IRC). States set water quality standards for each pollutant by the water's designated uses and decide the water's attainment status. IRC 4A is also referred to as the "S303(d) list," which is the list of impaired water bodies that enter S303(d) for TMDL development. The cost of S305(b) mainly consists of monitoring and administrative costs, while monitoring is conducted jointly by federal, state, and local agencies. The costs borne by the state government are about $1 million per reporting cycle before 2002, $1.3 million in 2002, and $200,000 for subsequent listings (EPA (2001)).[1]

2.2 Section 303(d): Total Maximum Daily Load Program

Section 303(d) is the major federal policy to control NPS water pollution. After states have developed a list of impaired water bodies under S305(b), S303(d) requires states to develop TMDLs for the impaired water bodies by priority ranking. "A TMDL is the calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant."[2] Thus, a TMDL is a tool to set the pollutant reduction target. To meet the TMDL, the state allocates load reductions among the sources of the pollutant. According to an EPA report in 2011, about 76% of TMDLs were driven by nonpoint sources (EPA (2011)).

S303(d) was established in the Clean Water Act in 1972, but it was given limited attention at the time. Early water quality programs focused on point sources like industrial dischargers and sewage treatment facilities, primarily the National Pollutant Discharge Elimination System (NPDES) program (Craig and Roberts (2015), Keiser and Shapiro (2019)). However, nonpoint sources have become a widespread contributor to water pollution in the U.S. in past decades. As a result, the point source control programs are not able to achieve the desired level of environmental quality in the whole watershed. S303(d) was brought to the table again in the 1990s when citizen organizations began legal actions to facilitate the development of TMDLs (Craig and Roberts (2015)), the Clean Water Action Plan in 1998 highlighted nonpoint-source pollution, funding for

[1] S305(b) costs each state government about $1 million per reporting cycle before the July 2000 TMDL Program Regulation Revisions. "The July 2000 TMDL rule requires states to improve their methodologies for setting priorities, establish schedules for developing TMDLs, increase public participation, provide their lists in a consistent format, and convey the essential information supporting the listing." The states pay about $1.3million one-time transition costs for the first listing in 2002, and $200,000 for subsequent listings (EPA (2001)).

[2] EPA, https://www.epa.gov/tmdl/overview-identifying-and-restoring-impaired-waters-under-section-303d-cwa, https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls.

states to deal with nonpoint-source pollution almost doubled from $105 million in 1998 to $200 million in 1999 (GAO (2000)). To maintain the past progress in point-source pollution regulation, identify nonattainment water bodies polluted by multiple sources, and implement cost-effective restoration activities, EPA published final revisions to the TMDL regulations, effective after October 30, 2001 (EPA (2001)). These events represent a shift in the focus of water quality management from effluent-based point-source regulation to ambient-based water quality standards for designated uses (NRC (2001)). S303(d) assesses the integrated health of the watersheds and allows states to allocate abatement efforts among point sources and nonpoint sources, meeting the water quality standards at the lowest cost.

States have high authority in TMDL development. EPA reviews, modifies, and approves the TMDLs. EPA may promulgate a state S303(d) list if the state fails to do so, but overall, EPA's role in S303(d) is minimal.[3] The average annual cost for each state to develop TMDLs is estimated to be $63-69 million per year after 2001 (EPA (2001)).

The decentralized implementation of S303(d) leads to welfare maximization at the state level instead of the national level. Different water quality standards across states also increase the difficulty of developing TMDLs at state borders. Therefore, states may have different behaviors when developing TMDLs for near-boundary and transboundary waters.

2.3 Section 319(h): Nonpoint Source Management Program Grants

Section 319(h) provides funding for nonpoint source management programs.[4] States submit work plans and grant applications to the EPA regional offices. Each EPA regional office reviews the state's work plans and provides comments. The EPA region office will work with the state to ensure that the work plan is consistent with the EPA guidelines.[5] Only the EPA has the final authority to award the grants (EPA (2011)). S319(h) funding is not randomly granted, but it does not have the procedural order as do S305(b) and S303(d). S319 is an important mechanism for implementing TMDLs, but some S319(h) funding was granted in the absence of TMDLs.

Several features of S319(h) make it more centralized than S305(b) and S303(d). First, though the grant application is proposed by the state government, the EPA holds the final authority for

[3]For example, the EPA had prompted the states around the Chesapeake Bay to cooperate in the abatement of nutrient pollution for twenty-five years without sufficient progress, so the EPA had to promulgate the Chesapeake Bay TMDL in 2010 (Craig and Roberts (2015)).

[4]S319(h) grants supports a wide range of nonpoint-source pollution management activities including technical, financial, or incentive programs. Some projects also use the grants to assess water quality or develop TMDLs.

[5]An effective state program should contain nine key elements.

grant approval. States prioritize the restoration of impaired waters, but they must account for national welfare in the work plans to get funding approved by the EPA. One of the nine key elements of an effective state program required by the EPA is that "The State strengthens its working partnerships and linkages to appropriate state, interstate, tribal, regional, and local entities (including conservation districts), private sector groups, citizens groups, and Federal agencies."(EPA (2011)). This also provides an incentive for the policy to disproportionately target near-boundary and transboundary waters more. In addition, states can include S319(h) grants in Performance Partnership Grants (PPGs). The PPGs is designed to strengthen the partnerships between the EPA and states and interstate agencies through joint planning and priority setting. Thus, S319(h) work plans in PPGs address the national welfare more.[6] Given these settings, we expect that states exhibit less near-boundary and transboundary behaviors when implementing S319(h) than S305(b) and S303(d).

3 Theoretical Model

The federal government makes policy decisions to maximize the national welfare. The state-level decisions may conflict with the federal decisions on watersheds shared with other states. There are two potential transboundary policy behaviors for states: (1) Beggar-thy-neighbor. The upstream states do not get the full benefits of cleaning the interstate rivers so they conduct insufficient controls and allow pollution to flow down into the downstream states. (2) Free-riding. The downstream states conduct insufficient control of interstate rivers because they expect upstream states to control pollution and they can enjoy the benefits without spending on pollution control.

Assume there are $N = \{1, 2, ..., n, ..., N\}$ impaired watersheds within a state, and $T = \{1, 2, ..., t, ..., T\}$ of the N impaired watersheds are interstate watersheds. The benefits and costs of treating the N watersheds within the state's territory are $\mathbb{B} = \{B_1, B_2, ..., B_n, ..., B_N\}$ and $\mathbb{C} = \{C_1, C_2, ..., C_n, ..., C_N\}$.[7]

[6] "Performance Partnership Grants enable States and interstate agencies to combine funds from more than one environmental program grant into a single grant with a single budget." "The Performance Partnership Grant program is designed to: (1) Strengthen partnerships between EPA and State and interstate agencies through joint planning and priority setting and better deployment of resources; (2) Provide State and interstate agencies with flexibility to direct resources where they are most needed to address environmental and public health priorities; (3) Link program activities more effectively with environmental and public health goals and program outcomes; (4) Foster development and implementation of innovative approaches such as pollution prevention, ecosystem management, and community-based environmental protection strategies; and (5) Provide savings by streamlining administrative requirements.", Title 40 - Protection of Environment Chapter I - ENVIRONMENTAL PROTECTION AGENCY Subchapter B - GRANTS AND OTHER FEDERAL ASSISTANCE Part 35 - STATE AND LOCAL ASSISTANCE.

[7] B_n and C_n are continuously distributed nonnegative-valued random variables. $B_n \sim Rayleigh(\sigma)$ and $C_n \sim Rayleigh(\sigma)$.

The federal government ranks the net benefits of treating each watershed from high to low and prioritizes the treatment:

$$\max_{F} \quad \sum_{n=1}^{F}(B_n - C_n) \tag{1}$$

The federal government will treat the F watersheds that have positive net benefits, among which F_a are intrastate watersheds and F_t are interstate watersheds.

3.1 The Beggar-thy-Neighbor Behavior

Assume the T interstate watersheds lie in the upstream portions of interstate rivers. The upstream state u faces the same problem as the federal government in Equation 1 when deciding whether or not to treat the intrastate watersheds. However, the state bears the full costs of treating the T upstream watersheds but only enjoys a percentage α_t ($\alpha_t \in (0, 1)$) of the benefits. This is because when the upstream portion of an interstate watershed is cleaned, the downstream portion also has less pollution, but the environmental benefits in the downstream are acquired by the downstream states. Thus, some interstate watersheds with positive federal-level net benefits may have negative state-level net benefits. The state government ranks the state-level net benefits of treating each watershed from high to low and prioritizes the treatment. Compared with the federal-level rankings, the state government ranks higher the intrastate watersheds but lower the interstate watersheds. The problem faced by the upstream state u when deciding whether or not to treat the F_t upstream watersheds with positive national-level net benefits is:

$$\begin{aligned} \max_{x} \quad & \sum_{t=1}^{F_t - x}(\alpha_t B_t - C_t) \\ \text{s.t.} \quad & \alpha_t B_t - C_t \geq 0 \end{aligned} \tag{2}$$

An interstate watershed t would be chosen to be treated by the federal government but not treated by the state government if $B_t - C_t > 0$ but $\alpha_t B_t - C_t < 0$, which means $\alpha_t < \frac{C_t}{B_t} < 1$. Assume there are x such watersheds, then the upstream state would only choose to treat $F_t - x$ upstream watersheds. In total, the upstream state will treat $F - x = S_u$ watersheds with positive state-level net benefits.[8] Figure 1 shows the federal and state governments' decisions. FNB denotes the federal-level net benefits, SNB denotes the state-level net benefits. The grey shaded area is the deadweight loss due to the state's inefficient policy decision.

[8] The subscript u denotes the policy is implemented in the upstream state u.

3.2 The Free-riding Behavior

Assume the T interstate watersheds lie in the downstream portions of interstate rivers. Unlike the situation with the upstream watersheds in Section 3.1, the benefit of treating a downstream watershed, B_t, is the same at the national and state level. This is because the treated downstream portions of interstate rivers do not flow into other states, so the federal and the downstream state d enjoy the same environmental benefits when treating an interstate river from its downstream portions. The state's problem with the intrastate watersheds is the same as the federal government. However, the downstream state d has an incentive to free ride if they expect the upstream state to treat the interstate watersheds and they can enjoy the benefits without spending any costs. The policy implementation status of the upstream state on the upstream portion of the interstate rivers is binary:

$$y = \begin{cases} 1, & \text{if treat} \\ 0, & \text{if do not treat} \end{cases} \tag{3}$$

The downstream state d's expectation for the upstream state u's decision is $Pr(y = 1) = \gamma_{du}$, $\gamma_{du} \in (0, 1)$. γ is built on the downstream and upstream states' environmental and political-economic backgrounds. Theoretically, the federal government should treat interstate watersheds from their upstream portions to acquire larger environmental benefits. However, in reality, due to different administrative costs and the actual situation of the watersheds, the federal government may choose to treat the downstream portion of an interstate watershed instead of its upstream portion. In the case where the federal government can only treat interstate watersheds at their downstream portions, or if the downstream state government does not have any free-riding policy behaviors, the F_t interstate watersheds with positive federal-level net benefits should be treated. However, if the downstream state has an incentive to free ride, the downstream state government's problem for the F_t interstate watersheds is:

$$\begin{aligned} \max_{z} \quad & \textstyle\sum_{t=z+1}^{F_t}(B_t - C_t) + \sum_{t=1}^{z}(\gamma_{du} B_t) \\ \text{s.t.} \quad & B_t - C_t \geq 0 \\ & \gamma_{du} B_t \geq 0 \end{aligned} \tag{4}$$

A downstream watershed t will not be treated by the state government due to the free-riding behavior if $B_t - C_t > 0$ and $\gamma_{du} B_t > B_t - C_t$, i.e. $1 - \gamma_{du} < \frac{C_t}{B_t} < 1$. Assuming there are z such watersheds, then the downstream state would only choose to treat $F - z = S_d$ watersheds in total.[9] Figure 2 shows the federal and state government's decisions.[10] The grey shaded area is the deadweight loss incurred if the socially optimal solution is to treat these downstream watersheds. In reality, the deadweight loss could be smaller if it is sub-optimal to treat some interstate rivers from their upstream portions or if the downstream state's expectation for the upstream state's pollution control activity is accurate.

There are two parameters in the transboundary behavior models, α_t and γ_{du}. α_t is the upstream state's share of benefits in treating an interstate watershed, while γ_{du} is the downstream state's expectation for the upstream state's pollution management of interstate watersheds. All else equal, if $z > x$, we will have:

$$\begin{aligned} 1 - (1 - \gamma_{du}) &> 1 - \alpha_t \\ \alpha_t + \gamma_{du} &> 1 \end{aligned} \tag{5}$$

When α_t or γ_{du} is large enough to meet the above inequality, that is to say, when the upstream state could recover the majority of the benefits in treating the interstate watersheds, or when the downstream state has a high expectation that the upstream state will treat the interstate watersheds, the free-riding behavior leads to a larger percentage of under-managed interstate watersheds than the beggar-thy-neighbor behavior. If one or both of α_t and γ_{du} are small such that $\alpha_t + \gamma_{du} < 1$, the beggar-thy-neighbor behavior would be stronger than the free-riding behavior.

4 Empirical Strategies

To examine if states' have different behaviors when implementing the three NPS pollution policies on near-boundary and transboundary rivers, I study the probability of S305(b) water quality assessment, the priority of S303(d) TMDL development, and the funding level of S319(h) nonpoint-source pollution management programs for different water bodies.

4.1 Probit Model for S305(b) Water Quality Assessment

The assessment status of a catchment is binary with:

[9] The subscript d denotes the policy is implemented in a downstream state d.

[10] The state-level net benefit of not treating one of the z watersheds is $\gamma_{du} B_t$, which is non-negative. However, since the state does not treat these watersheds, the net benefits of these z watersheds do not appear in the state's treating decision. Thus, the net benefits of the z watersheds in Figure 2 are plotted as zeros.

$$Assess = \begin{cases} 1, & \text{if assessed} \\ 0, & \text{if not assessed} \end{cases} \tag{6}$$

I use a Probit model to estimate the probability that a state assesses a catchment when controlling for the hydrologic and social-economic factors of the catchment:

$$p_{cs} = Pr[\ Assess_{cs} = 1 | \mathbb{X}_{cs}] = \Phi(\alpha_0 + Distbin_c \beta_1 + \beta_2 CoastCat_c + Str_c \alpha_1 + X_c \alpha_2 + D_s) \tag{7}$$

The dependent variable is the probability that a catchment c in state s is assessed, i.e., it is not in IRC 3 in Table 2. I model the policy behaviors near state borders by dividing the distance of all the catchments to state borders into 9 bins from less than 1 km to more than 30 km and denote them as $Distbin$. This flexible modeling of the distance allows me to observe the changes in the probability of assessment with the catchments' distances to the state borders. β_1 for each distance bin represents the effect of being a near-boundary catchment within that distance bin on the probability that the catchment is assessed. The state government may treat the catchments in the coastal areas differently, so I control for a coastal catchment dummy variable $CoastCat$. I also control for several other stream characteristics Str in the catchment: First, since the main stream may be more likely to be assessed than its tributaries, I control for an index of stream size based on a hierarchy of tributaries. Second, I construct a variable $DistArea = \frac{4Distance}{\sqrt{Area}}$ to represent the percentage of the catchment's distance to state borders to the state's area. This is because if a large state conducts less pollution control within a certain distance of its borders, it can still properly manage pollution over the broad intrastate area. However, if a small state has fewer pollution controls within the same distance of its borders, a large part of the state would be under-managed. Therefore, the distance from the state borders at which the policy behavior occurs is related to the state area. I also control for the average social-economic factors X in each catchment, including county population and annual personal income, because when the states make an assessment decision, they may consider health benefits for nearby residents. In addition, I control for state-fixed effects D_s to account for the state-level factors that affect the assessment decisions. The standard errors are robust.

Equation 7 estimates the policy behaviors on near-boundary catchments. Next, I explore if the states have different policy behaviors on transboundary catchments near state borders in Equation 8. I interact the distance bins with a dummy variable $InterCat$ that equals 1 if the catchment contains segments of interstate rivers and 0 if the catchment only contains intrastate rivers. I also interact the coastal catchments with their distance to the shorelines to check the change in the probability of assessment for coastal catchments across distance bins.

$$\begin{aligned} p_{cs} = Pr[\ Assess_{cs} = 1|\mathbb{X}_{cs}] \ &= \Phi(\alpha_0 + Distbin_c\beta_1 + Distbin_c \times InterCat_c\beta_2 \\ &+ Distbin_c \times CoastCat_c\beta_3 + Str_c\alpha_1 + X_c\alpha_2 + D_s) \end{aligned} \tag{8}$$

To explore the beggar-thy-neighbor behavior and free-riding behavior separately, in Equation 9, I separate the interstate river into its upstream, downstream, and up\downstream portions and interact them with the distance bins.

$$\begin{aligned} p_{cs} = Pr[\ Assess_{cs} = 1|\mathbb{X}_{cs}] \ &= \Phi(\alpha_0 + Distbin_c\beta_1 + Distbin_c \times UpCat_c\beta_2 \\ &+ Distbin_c \times DnCat_c\beta_3 + Distbin_c \times UpDnCat_c\beta_4 \\ &+ Distbin_c \times CoastCat_c\beta_5 + Str_c\alpha_1 + X_c\alpha_2 + D_s) \end{aligned} \tag{9}$$

In Equation 9, β_1 for the 0-1 km distance bin is the coefficient for catchments of border flowlines. β_1 for the distance bins between 1 to 30 km are coefficients for catchments that are near-boundary but not transboundary. β_2, β_3, and β_4 are coefficients for different portions of interstate catchments across distance bins within 30 km of state borders. β_5 is the coefficient for coastal catchments across distance bins within 30 km of the shorelines. The omitted category includes catchments further than 30 km from state borders and shorelines, which are the intrastate catchments defined in Table 3.

4.2 Duration Model with Selection for S303(d) TMDL Development

The state government decides the priority to develop TMDLs for S303(d) listed impaired waters. Therefore, it takes different lengths of time for different catchments to receive TMDLs. I conduct a survival analysis to estimate the hazard rate that the state develops TMDLs for catchments across different locations. A simple duration model will estimate the hazard rate that an impaired catchment receives TMDLs. However, the catchments may not be impaired randomly. For example, catchments close to industrial areas, cultivated areas, livestock areas, or catchments prone to soil erosion may be more likely to be impaired. In this case, the estimation results from a simple duration model would be subject to selection bias. Therefore, I use a duration model with selection proposed by Boehmke, Morey, and Shannon (2006) to eliminate the selection bias. I select the sample of impaired catchments using a Probit model and estimate the hazard rate that state develops TMDLs for a catchment using a proportional hazard model. The Boehmke, Morey, and Shannon (2006) method uses a bivariate exponential distribution to bind together the selection and duration equations.[11]

A catchment's impairment status is binary:

$$Impair = \begin{cases} 1, & \text{if impaired} \\ 0, & \text{if not impaired} \end{cases} \tag{10}$$

The TMDL development status is only observed if $Impair = 1$. The selection equation is:

$$p_{cs} = Pr[\ Impair_{cs} = 1|\mathbb{X}_{cs}] = \Phi(\gamma_0 + Distbin_c\gamma_1 + Str_c\gamma_2 + Str1_c\gamma_3 + X_c\gamma_4) \tag{11}$$

In Equation 11, the dependent variable is the probability that a catchment c in state s is listed as impaired. Since past studies find higher pollution near jurisdictional boundaries (Sigman (2005), Sigman (2005), Lipscomb and Mobarak (2016)), I include $Distbin$ to control for the effect of a catchment's distance to state borders on its impairment status. I control for the stream characteristics Str in each catchment as in Equation 7, including the stream size index and the distance\area percentage, because pollution concentration may differ with stream size, and the intensity of polluting activities may differ with the distance from borders relative to the state area. Since the attainment status depends on the state's water quality standards by designated uses and is evaluated at the waterbody/pollutant level, I include another set of stream characteristics $Str1$, including the natural flows[12] and flow speed that affect pollution loads, and the water's designated uses that affect the attainment standards. Variables in $Str1$ affect the catchment's impairment status but are less relevant to the priority of TMDL development. Human activities affect pollution levels and types, so I also include social-economic factors X at the catchment level, including county population and annual personal income.

The duration equation is:

$$h(t)_{cs} = h_0(t)_{cs}exp(\alpha_0 + Distbin_c\beta_1 + \beta_2 CoastCat_c + Str_c\alpha_1 + X_c\alpha_2 + D_s) \tag{12}$$

[11] I also run an independent duration model without sample selection in Section A in the Appendix.

[12] Flow from runoff.

Equation 12 is a proportional hazards model. $h(t)$ is the hazard rate that a catchment receives a TMDL after t years of impairment. The larger the hazard, the sooner the catchment receives a TMDL. The baseline hazard $h_0(t) = pt^{p-1}$ follows a Weibull distribution. I use $Distbin$ to explore the state's policy behavior on near-boundary catchments. I control for the coastal catchments $CostCat$ because the states may have different behaviors when developing TMDLs for coastal catchments. I control for the same variables that affect policy decisions as in Equation 7, which include stream characteristics Str, social-economic variables X, and state-fixed effects D_s. The standard errors are robust.

To see whether states develop TMDLs for transboundary rivers with different hazard rates from intrastate rivers, I interact the distance bins with the interstate river dummy and coastal river dummy in Equation 13:

$$\begin{aligned} h(t)_{cs} = h_0(t)_{cs} exp(&\alpha_0 + Distbin_c\beta_1 + Distbin_c \times InterCat_c\beta_2 + Distbin_c \times CoastCat_c\beta_3 \\ &+ Str_c\alpha_1 + X_c\alpha_2 + D_s) \end{aligned} \tag{13}$$

I then divide the interstate river into different portions in Equation 14 to explore the hazard rate of TMDL development for the upstream and downstream portions of interstate rivers:

$$\begin{aligned} h(t)_{cs} = h_0(t)_{cs} exp(&\alpha_0 + Distbin_c\beta_1 + Distbin_c \times UpCat_c\beta_2 + Distbin_c \times DnCat_c\beta_3 \\ &+ Distbin_c \times UpDnCat_c\beta_4 + Distbin_c \times CoastCat_c\beta_5 + Str_c\alpha_1 + X_c\alpha_2 + D_s) \end{aligned} \tag{14}$$

4.3 Heckman Selection Model for S319(h) Nonpoint Source Pollution Management Grants

S319(h) funding is granted at the subwatershed (HUC12) level.[13] Different subwatersheds receive different amounts of grants. Subwatersheds in S319(h) programs are subject to the state government's planning and the federal government's approval, so they are not randomly selected. Therefore, I adopt a Heckman two-step analysis to estimate if the approved grant amounts are different for near-boundary and transboundary subwatersheds.

A subwatershed is either managed by the S319(h) program or not:

[13] Watersheds at the 12-digit hydrologic unit level.

$$Manage = \begin{cases} 1, & \text{if managed by S319(h)} \\ 0, & \text{if not managed by S319(h)} \end{cases} \tag{15}$$

The grant amount is only observed if $Manage = 1$. So I use a discrete choice model (Probit) for the first-step sample selection:

$$p_{ws} = Pr[\ Manage_{cs} = 1|\mathbb{X}_{ws}] = \Phi(\gamma_0 + Distbin_w\gamma_1 + Str_w\gamma_2 + Str1_w\gamma_3 + X_w\gamma_4 + D_s + D_h) \tag{16}$$

In Equation 16, the dependent variable is the probability that a subwatershed is managed by S319(h) program. Since we expect states to exhibit near-boundary and transboudnary behaviors in pollution management, I control for the subwatershed's distance to state borders, $Distbin$. I include the stream characteristics Str, including the stream size index, because larger streams are more likely to be selected into restoration programs, and the distance\area percentage, because the state's application for watershed restoration grants may be different across the watershed's distance to state borders and the state area. I also include the second set of stream characteristics $Str1$, including the natural flows and flow speed that affect pollution load thus the treatment needs, and the water's designated uses that affect the political authority's incentive to treat. Variables in $Str1$ affect the state's incentive to apply for S319(h) restoration grants but have little impact on the specific amount of grants received by each subwatershed. The political authority's pollution management incentive is also affected by social-economic factors X of the subwatershed. More populous and richer places may receive more government attention for pollution management. So I control for county population and annual personal income. Since the S319(h) programs are proposed by state governments, I include state-fixed effects D_s to control for state-level factors that affect the decision to apply S319(h) grants for a subwatershed. I also control for the watershed-fixed effects D_h at the HUC4 level,[14] because the S319(h) work plans are usually proposed at the watershed level, so HUC12 subwatersheds within the same HUC4 watershed have correlated probabilities to be managed by S319(h) programs. However, since the actual work plans may cover a larger or smaller scale of watersheds than HUC4, and the management practices vary across subwatersheds, the yearly grant amount for each subwatershed in a HUC4 watershed can be very different.[15]

[14] A larger scale of watersheds than the HUC12 subwatersheds.

[15] For subwatersheds that have entered the S319(h) programs, the mean and standard deviation of the grant amount for the whole sample is \$230,402 and \$294,522.6, respectively. The average standard deviation of the grant amount for subwatersheds in each HUC4 watershed is \$200,762.1, which is large relative to the whole sample statistics.

The second-step OLS regression estimates the near-boundary factors' effect on grant amount:

$$Grant_{wsy} = \alpha_0 + Distbin_w\beta_1 + \beta_2 CoastWs_w + Str_w\alpha_1 + X_w\alpha_2 + D_s + D_y + \theta\hat{\lambda_{ws}} + \epsilon_{wsy} \quad (17)$$

In Equation 17, $Grant_{wsy}$ is the total S319(h) grants awarded to subwatershed w in state s in year y. I use *Distbin* to examine the near-boundary granting trend. I control for coastal subwatersheds *CoastWs* because the coastal subwatersheds may be subject to different S319(h) granting behaviors and other sources of grants like the EPA's Coastal Zone Act Reauthorization Amendments (CZARA). I control for stream features *Str*, including the stream size index since larger streams may receive larger amounts of grants, and the distance\area percentage that may affect treatment incentives. I control for the average social-economic factor X at the subwatershed, including county population and annual personal income, because the political authority may consider benefits for nearby residents when deciding the grant amount. I include the state-fixed effects D_s to account for state-level factors that affect the grant amount. I also include the year-fixed effects D_y to control for the yearly granting trend common for all subwatersheds. $\hat{\lambda_{ws}}$ is an estimate of the inverse Mills ratio derived from the estimation of the selection equation 16. The standard errors are robust.

I then interact the distance bins with interstate and coastal subwatershed dummies and split the interstate dummy into different portions to explore the granting behaviors on transboundary rivers in detail:

$$\begin{aligned} Grant_{wsy} = \alpha_0 &+ Distbin_w\beta_1 + Distbin_w \times InterWs_w\beta_2 + Distbin_w \times CoastWs_w\beta_3 + Str_w\alpha_1 \\ &+ X_w\alpha_2 + D_s + D_y + \theta\hat{\lambda_{ws}} + \epsilon_{wsy} \end{aligned} \quad (18)$$

$$\begin{aligned} Grant_{wsy} = \alpha_0 &+ Distbin_w\beta_1 + Distbin_w \times UpWs_w\beta_2 + Distbin_w \times DnWs_w\beta_3 \\ &+ Distbin_w \times UpDnWs_w\beta_4 + Distbin_w \times CoastWs_w\beta_5 + Str_w\alpha_1 + X_w\alpha_2 \\ &+ D_s + D_y + \theta\hat{\lambda_{ws}} + \epsilon_{wsy} \end{aligned} \quad (19)$$

5 Data

5.1 Hydrology and Spatial Data

I acquire the features of all the stream flowlines in the U.S. from the National Hydrography Dataset Plus, Version 2 (NHDPlus V2). The NHDPlus V2 is a comprehensive geospatial dataset that draws stream networks and records stream characteristics by segments. The line features are applicable to upstream and downstream navigation and also contain stream attributes such as natural flows, speed, and index of stream size based on a hierarchy of tributaries. NHDPlus allows interactive modeling with other geospatial data layers. Thus, I match the hydrographic feature with other spatial, temporal, and political data using ArcGIS to construct a unique and comprehensive dataset for modeling the water pollution policy decisions on hydrological variables.

Since the further away a flow segment is from the state borders, the less likely that it is subject to the near-boundary and transboundary policy behaviors, this paper takes the catchments\subwatersheds within 30 km of state borders as near-boundary catchments\subwatersheds. Table 3 describes the different portions of rivers and the number of catchments in the sample for each portion. There are four types of interstate catchments: A border catchment contains river segments that are within 1 km of the state borders; An upstream catchment contains only the upstream portion of interstate rivers; A downstream catchment contains only the downstream portion of interstate rivers; An up\downstream catchment contains interstate river segments that are the upstream of one state border but the downstream of another state border. A coastal catchment contains river segments that are within 30 km of a shoreline and will flow into the ocean or the Great Lakes. Catchments that are within 30 km of state borders but do not contain river segments that flow to other states, the ocean, or the Great Lakes are near-boundary but non-transboundary. The catchments that are further than 30 km away from the state borders are intrastate catchments.

Figure 3 and Figure 4 show river flowlines in two representative watersheds.[16] The blue flowlines are intrastate rivers. Watershed 07 in Figure 3 mainly covers areas of Minnesota, Wisconsin, Iowa, and Illinois. The border flow segments (within 1 km of state borders) are marked in yellow, the upstream portions of interstate rivers are green, the downstream portions of interstate rivers are red, and the up\downstream portions are pink. In watershed 07, a segment of the Mississippi river forms the state borders, and most of its tributaries are the upstream portions. This may explain why the number of upstream catchments in the sample is much larger than the number of downstream catchments. Watershed 18 in Figure 4 mainly covers California. This watershed has

[16] The watersheds are at the 2-digit hydraulic unit level.

many coastal flowlines.

5.2 Policy Data

I obtain the catchment-level S305(b) and S303(d) information from the Assessment, Total Maximum Daily Load Tracking and Implementation System (ATTAINS). The ATTAINS records all the catchments' Integrated Reporting Categories (IRC) from 2002 to 2020, and TMDL development information from 1987 to 2020. Figure 5 presents a map of catchments listed in three categories in the contiguous United States in 2020. I obtain the Section 319(h) projects and grants information at the HUC12 subwatershed level from the Grants Reporting and Tracking System (GRTS).[17]

The ATTAINS and GRTS data record the change in policy status in time and across locations, which allows me to match them with the hydrology and spatial data. I also match these data with state boundary, watershed boundary,[18] and shoreline data from the United States Geological Survey (USGS), and the annual county population and annual personal income data from the Census Bureau.[19]

Figure 6 shows the total approved S319(h) grants across subwatersheds in the contiguous United States. The darker area means a larger amount of grants. A comparison of Figure 6 and Figure 19 river borders in the Appendix shows that the subwatersheds of rivers that form the state borders seem to receive larger amounts of S319(h) grants. There are 10 states with river borders. Section 7.2 compares the S319(h) funding behavior for river-border states and the other states.

6 Results

This section presents the estimation results of near-boundary behavior and transboundary behavior for the three NPS pollution policies. By cutting the effects of boundary factors on policy implementation into upstream and downstream portions and distance bins, I can observe the changing pattern of the policy behaviors. However, this modeling also reduces the power of results in specific distance bins. Therefore, when interpreting the estimation results, it is more valuable and reliable

[17]Figure 18 in the Appendix shows an example of a subwatershed, the assessment units (catchments), and the flowlines in the subwatershed. The green boundary denotes the area of a huc12-level subwatershed; The purple and red areas are two assessment units; The blue lines are stream flowlines. The huc12-level subwatershed is a larger area than the catchments. A catchment is an area of land from which the stream drains the water.

[18]See Figure 20 in the Appendix for watershed boundaries at HUC4 level.

[19]Data are aggregated to catchment\subwatershed level. County population and annual personal income are averaged; The stream size index is aggregated to its maximum; The maximum, minimum, and average natural flow and speed are all used; Water uses are accumulated.

to focus on the overall changing pattern of the policy behaviors rather than the specific estimation results in each distance bin.

6.1 Policy Behaviors on Near-Boundary Rivers

The estimation results for policy behaviors on near-boundary rivers are presented in Table 4. The omitted category contains rivers further than 30 km from state borders (intrastate rivers). The coefficients of interest with 95% confidence intervals are plotted in Figure 7. States are less likely to implement both S305(b) water quality assessment and S303(d) TMDL development on near-boundary catchments. However, more S319(h) grants are approved for near-boundary subwatersheds.

Column (1) in Table 4 shows the effects of the catchment's distance to state borders on the probability of S305(b) water quality assessment. The border catchments are 45.81% less likely to be assessed than intrastate catchments. Catchments within 1-30 km of the state borders are 6.26-12.68% less likely to be assessed. Panel (a) of Figure 7 presents these coefficients.

Column (2) of Table 4 presents the estimation results for S303(d) TMDL development. The border catchments have an 8.03% lower hazard to receive TMDLs than intrastate catchments. Being a catchment within 1-30 km of the state borders lowers the hazards of TMDL development by 6.83% to 21.87%, which is greater than the decreased probability of S305(b) water quality assessment. Panel (b) in Figure 7 plots the coefficient estimates.

The estimation results for the approved S319(h) grants are presented in column (3) of Table 4. The border subwatersheds receive $20,185.5 more grants per year than intrastate subwatersheds. A subwatershed within 1-30 km of the state borders receives $9,714.2 to $23,957.7 more grants per year. Panel (c) in Figure 7 shows that the coefficients fluctuate across the distance bins, but coefficients closer to state borders are more positive and statistically significant, indicating higher funding approved for subwatersheds near state borders. Since S319(h) is relatively more centralized, the heterogeneous results from the three policies indicate that the two decentralized policies, S305(b) and S303(d), are not implemented sufficiently near the state borders.

6.2 Policy Behaviors on Transboundary Rivers

States' behaviors on interstate rivers are presented in Table 5 and Figure 8. Column (1) of Table 5 for S305(b) water quality assessment shows that most estimation results for interstate catchments near the state borders are negative, but the standard errors are large. Panel (a) in Figure 8 shows that the coefficients fluctuate substantially.

Column (2) in Table 5 shows the states' behaviors in S303(d) TMDL development. Interstate catchments within 1-5 km of the state borders have a lower hazard to receive TMDLs than the intrastate catchments, with -12.73% between 1-2.5 km and -10.65% between 2.5-5 km. Panel (b) in Figure 8 shows that the hazards of TMDL development increase as the distance bins become further away from the state borders.

Column (3) in Table 5 shows the results for S319(h) grants. Most estimation results for interstate subwatersheds are positive, indicating more funding granted than intrastate subwatersheds. Panel (c) in Figure 8 shows that the estimation results are insignificant in the 1-2.5 km distance bin, then become larger and statistically significant in bins further from state borders.

The above results show that the states have a significantly lower hazard to develop TMDLs on interstate rivers near state borders. On the contrary, more S319(h) grants are approved for interstate rivers. These results are consistent with our expectation of different behaviors across the policies by their different levels of decentralization.

Table 5 and Figure 9 present the estimation results for coastal rivers. The coastal catchments in most of the distance bins within 30 km of the state borders have a lower probability of assessment than intrastate catchments. The states have significantly lower hazards to develop TMDLs for the coastal catchments within 1-2.5 km of the shoreline. The hazard increases as the coastal catchment's distance from the shoreline becomes further. S319(h) grants approved for coastal subwatersheds fluctuate across the distance bins, with insignificant estimates near the shoreline and more positive estimates as the subwatersheds become further away from the shoreline.

6.3 The Beggar-thy-Neighbor and Free-riding Behaviors

I divide interstate rivers into upstream and downstream portions to study the states' beggar-thy-neighbor and free-riding behaviors. The estimation results are presented in Table 6, Figure 10, and Figure 11. The estimation results for the downstream portions of interstate rivers have larger standard errors than the upstream portions. This is because there are much fewer downstream portions of interstate rivers in the sample than the upstream portions, as is shown in Table 3 and Figure 3. The three policies exhibit different degrees of policy behaviors.

Column (1) of Table 6 shows the estimation results for the probability of S305(b) water quality assessment. The coefficients for the upstream catchments fluctuate, but all the coefficients are negative, indicating a lower probability of assessment. The statistically significant results indicate that the upstream catchments are 9.66-11.15% less likely to be assessed than intrastate catchments within 2.5-10 km of state borders and are 6.3% less likely to be assessed within 20-25 km of state borders. The coefficients for downstream catchments also fluctuate but are mostly insignificant, indicating a similar probability of assessment with intrastate catchments, except for catchments within 2.5 km downstream of state borders, which are 40.69% significantly less likely to be assessed. Catchments that are both upstream and downstream mostly have insignificant estimation results. The coefficients are plotted in Panel (a) of Figure 10 and Figure 11.

When implementing S305(b), the state governments exhibit beggar-thy-neighbor behaviors across a long distance from state borders, but the free-riding behavior is not clear. The lower probability of water quality assessment in the 1-2.5 km bin downstream could be a spurious estimate. This is because the estimation result in the nearby 2.5-5 km bin is close to zero and insignificant, as are all the other estimates in the downstream portions. Possible explanations for the single-side policy behavior are that the upstream state governments are less motivated to assess the quality of water bodies that are going to flow away from their territory, so they exhibit beggar-thy-neighbor behavior in some distance bins. But since the assessment cost is low, the behavior is also statistically insignificant in many distance bins. For the downstream portions of interstate rivers, because they continue to flow in the downstream states and the assessment costs are low, the downstream states assess the downstream portions of interstate rivers with a similar probability to their intrastate rivers. Most importantly, even if the upstream state assesses the upstream water quality, it will not provide much free-rider benefit to the downstream state. The downstream state is not able to make accurate inferences about the downstream water quality based on the upstream assessment results, especially when the catchment is far away from state borders. Therefore, the downstream states have a low incentive to free ride in S305(b) water quality assessment.

Column (2) of Table 6 presents the estimation results for S303(d) TMDL development. Panel (b) in Figure 10 shows that in most distance bins, the closer the upstream catchment to state borders the lower the hazards of TMDL development. States have an 18.9% lower hazard to develop TMDLs for the upstream catchments within 1-2.5 km of the state borders and a 10.28% lower hazard for catchments within 2.5-5 km of the state borders. This is the beggar-thy-neighbor behavior. Compared with the upstream catchments, the estimation results for the downstream catchments are larger and mostly negative, indicating lower hazards of TMDL development than intrastate catchments. Though the standard errors are larger due to the small sample size of the downstream portions of interstate rivers, the few statistically significant estimation results are more negative as the catchment becomes closer to state borders, indicating stronger free-riding behavior. Specifically, the downstream catchments have a 55.81% significantly lower hazard of TMDL development in the 1-2.5 km distance bin and a 25.71% significantly lower hazard in the 5-10 km distance bin. Catchments that are both upstream and downstream also have a lower hazard of TMDL development within 5 km of the state borders, with -45.05% in the 1-2.5 km bin and -33.18% in the 2.5-5 km bin, as shown in panel (b) of Figure 11. This is the mixed result of beggar-thy-neighbor and free-riding behaviors. The hazard of TMDL development has increasing trends in the upstream, downstream, and up\downstream portions of interstate rivers as the catchments' distance becomes further away from state borders. This implies that the transboundary behaviors diminish with the rivers' distance from state borders.

The state governments exhibit both the beggar-thy-neighbor behavior and free-riding behavior in S303(d). The magnitudes of the coefficients indicate that the downstream free-riding behavior is stronger than the upstream beggar-thy-neighbor behavior in the U.S. This is one of the situations discussed in Section 3, indicating that states could recover the majority of the benefits of developing TMDLs for interstate watersheds, or the downstream state has a high expectation that the upstream state will develop TMDLs for the interstate watersheds. However, the back-of-the-envelope calculation in Section 6.4 shows that the downstream free-riding behavior does not incur larger losses than the upstream beggar-thy-neighbor behavior. This is because the number of upstream tributaries of interstate rivers substantially exceeds the downstream tributaries.

Column (3) of Table 6 and panel (c) of Figure 10 and Figure 11 present the estimation results for S319(h) grants. The estimated coefficients for the upstream, downstream, and up\downstream portions of interstate rivers fluctuate substantially, and most estimation results are statistically insignificant. Thus, different portions of interstate rivers in most distance bins do not receive significantly different amounts of grants than intrastate rivers. Interstate subwatersheds in some distance bins receive a larger amount of grants than intrastate subwatersheds.

The S319(h) grant amounts do not reflect the state governments' beggar-thy-neighbor or free-riding behaviors. This is because the federal government has high authority in S319(h). Section 6.1 and Section 6.2 show that larger amounts of grants are approved for near-boundary rivers and some portions of interstate rivers and coastal rivers. These results imply that the near-boundary rivers and some portions of interstate rivers need more NPS pollution controls to maximize the national welfare. However, the probabilities of S305(b) assessment, especially the hazards of S303(d) TMDL development, are the opposite, which indicates that the state-level policy decision conflicts with the federal-level decision, leading to insufficient pollution controls for near-boundary and transboundary rivers.

6.4 The Costs of Beggar-thy-Neighbor and Free-riding Behaviors

Section 6.3 shows that states exhibit beggar-thy-neighbor behavior and free-riding behavior in TMDL development. Using the parameter estimates in Section 6.3, I conduct back-of-the-envelope calculations for the deadweight losses incurred in S303(d) TMDL development by each behavior. I use people's willingness to pay (WTP) for clean water in the literature to infer the unrecovered net benefits of pollution control. For example, Hite, Hudson, and Intarapapong (2002) conducted a survey in Mississippi, 1999, and estimates that people's WTP for agricultural NPS pollution abatement is $46.97 for 10% abatement and $49.94 for 20% abatement. Jordan and Elnagheeb (1993)'s 1991 survey in Georgia estimates that people are willing to pay $5.49 more in their monthly water bill for treat water. Chatterjee et al. (2017)'s 2016 survey in Florida estimates a WTP of $6.22 in the monthly water bill. Using these WTPs and the total population of counties that have interstate rivers within each distance bin that are undertreated, I infer the magnitude of the deadweight loss caused by each behavior as is indicated in Figure 1 and Figure 2.

Table 7 presents the estimated deadweight loss. The states' beggar-thy-neighbor (BTN) behavior in TMDL development has resulted in a $786 million loss if the TMDL development could have led to 10% agricultural NPS pollution abatement, or a $836 million loss with a 20% abatement, or a $73 to $113 million loss in the drinking water quality improvement each month. The free-riding (FR) behavior has led to a $766 or $814 million loss if the TMDL development could have led to a 10% or 20% agricultural NPS pollution abatement, or a $71 to $110 million loss in the monthly drinking water quality improvement. Catchments in both the upstream and downstream of interstate rivers are affected by both behaviors. The deadweight loss incurred in these catchments is $965 or $1026 million for 10% or 20% agricultural NPS pollution abatement or $89 to $138 million in the monthly water bill. This is a raw calculation because the true benefits of unconducted pollution management vary across time and locations. In addition, Keiser, Kling, and Shapiro (2019) and Keiser and Shapiro (2019) state that many studies on the benefit of water pollution abatement have ignored the nouse values and health benefits, so the unrecovered benefits could be even larger.

6.5 Policy Behaviors on Near-boundary but Non-transboundary Rivers

Table 5 and Table 6 also present the coefficients for catchments and subwatersheds that are near-boundary but not transboundary. Though the estimation results fluctuate and are not the same in the two regressions, they share similar trends. Figure 12 plots the coefficients in Table 6. The probabilities of S305(b) water quality assessment and S303(d) TMDL development are mostly lower for the non-transboundary catchments than intrastate catchments. The S319(h) for non-transboundary subwatersheds has positive and significant results at least within 2.5 km of state borders. The estimation results for non-transboundary rivers have similar variation patterns to the results for all near-boundary rivers in Figure 7, which are different from the variation patterns of interstate rivers. These results imply that the state governments exhibit different policy behaviors on interstate rivers than near-boundary rivers that do not cross borders.

6.6 Other Parameters of Interest

The estimation results for county population and personal income in Table 4, Table 5, and Table 6 are all statistically significant, positive, and small for S305(b) water quality assessment and S303(d) TMDL development, but insignificant for grants approval. This implies that states take the socio-economic background of the catchment into consideration when making decisions on S305(b) and S303(d). More populated and richer catchments have slightly higher probabilities of assessment and TMDL development. But S319(h) grant approval is not significantly affected by these factors.

Since states have the highest level of authority in S303(d) among the three policies, I plot the coefficients of the state-fixed effect for TMDL development in Table 5. Figure 13 shows that the northern and southeastern states have higher hazards to develop TMDLs.

The shape parameter p of the duration model for S303(d) TMDL development is higher than 8.97 in all three regressions (Equation 12, Equation 13, and Equation 14), which implies that the hazard that state develops a TMDL increases dramatically with time. For example, after 48 years of the establishment of the CWA, in 2020, a catchment is 42.34833 times more likely to receive TMDLs per year than in 2002, i.e. $(\frac{48}{30})^{8.97-1}$.

The error correlation ρ between the first and second-step regressions in the duration model with selection for S303(d) TMDL development is -0.25 in all three regressions. This has reached the limit restriction set by Boehmke, Morey, and Shannon (2006), which indicates strong correlations between the first and second-step regressions and that ignoring sample selection leads to biased estimates.[20] The negative error correlation suggests that if the probability that a catchment is listed as impaired is greater than average, the state's expected probability to develop TMDLs for the catchment is less than average. One possible explanation is: A watershed can be listed as impaired due to many factors, and the lack of proper pollution management is one of them. Since S303(d) TMDL development is also an NPS pollution management policy, the state may not develop TMDL timely

[20] Section A in the Appendix investigates the selection bias by running an independent duration model.

for the watershed either. The error correlation ρ in the Heckman selection model for S319(h) grants is around -0.24 in all three regressions. The negative error correlation suggests that subwatersheds that are more likely to enter S319(h) programs do not necessarily receive a larger amount of grants.

7 Extensions

7.1 Political Influence on Policy Behavior

The above analysis shows that states exhibit near-boundary and transboundary behaviors in S303(d) TMDL development. A state's policy behaviors are affected by the state's political ideology. Therefore, in this section, I explore the potential effects of political ideology on states' behavior in TMDL development. The first variable I use is the state governor's party. I add two control variables for the political party of the state governor in the year that the TMDL is developed and the year before in Equation 14. The political party dummy is 0 if the governor is a Democrat, and 1 if the governor is a Republican.[21] The coefficients of the political party dummy are presented in Table 8. A state with a Republican governor in the current year has a 46.54% lower hazard to develop TMDLs for a catchment than a state with a Democratic governor. A state with a Republican governor in the previous year has a 94.02% lower hazard.

The second factor I check is the League of Conservation Voters (LCV) score. The LCV score records the members of Congress' voting on environmental issues. The average lifetime LCV score is 70.8 and 76.1 for the Democratic senate and house, respectively, and 22.5 and 22 for the Republican senate and house. This is consistent with the results above that the Democratic are more environmentally friendly than the Republicans, so a state with a democratic governor has a higher probability to develop TMDLs. I check if a more environmentally-friendly state would have milder policy behavior, including insufficient policy implementation at near-boundary rivers, and the beggar-thy-neighbor and free-riding behaviors at interstate rivers. I run Equation 14 for each state to get state-specific coefficient estimates. Then I regress the coefficient estimates on the state Congress's average LCV score in the year of TMDL development. Based on the results from previous sections, the beggar-thy-neighbor and free-riding behaviors mostly occur within 10 km of the state borders, so I only present the influence of LCV scores on the policy behaviors within 10 km of the state borders. The results are plotted in Figure 14. The magnitudes of the estimated LCV influences are very small and most results are statistically insignificant at a 95% confidence

[21] The situation that the current governor is independent in the year of or the year before the TMDL development is rare so the independent party is dropped.

level, indicating that a state's LCV score has little effect on its near-boundary and transboundary policy behaviors.

The interstate rivers connect the state with its neighboring states. Therefore, in addition to the state's own influence, the neighboring state's political-economic features may also affect the state's behavior in the pollution management of interstate rivers. First, I run Equation 14 for each state separately. Then I regress each state's estimated coefficients on the features of its neighboring states. The results are presented in Table 9 and Figure 15. Panel (a) in Figure 15 shows that the downstream state's LCV score does not affect the upstream state's beggar-thy-neighbor behavior. However, the higher the upstream state's LCV score, the stronger the downstream state's free-riding behavior. 1 unit increase in the upstream state's LCV score will lower the proportional change of the downstream state's TMDL development hazard in the downstream catchments by 1.32% in the 1-2.5 km bin and by 2.57% in the 2.5-5 km bin. This is consistent with the theoretical model in Section 3.2: The degree of free-riding behavior in the downstream state depends on their expectation γ_{du} of the upstream state's pollution management. The higher the LCV score in the upstream state, the larger the expectation γ_{du} that the downstream state has for the upstream state's pollution management on interstate rivers, thus the stronger the free-riding behavior in the downstream state.

Panel (b) and panel (c) show the effect of a neighboring state's GDP and population on the state's policy behavior. The downstream state's effect on the upstream state's behavior is only negative and statistically significant within the 5-10 km distance bin to state borders, but the other two distance bins that are closer to state borders both have positive and insignificant results. Therefore, it is hard to infer a causal relationship between the downstream state's characteristics and the upstream state's behavior. For the downstream state, a 1 billion increase in the upstream state GDP or a 1 million increase in the upstream state population will increase the proportional change of the downstream state's TMDL development hazard for downstream catchments within the 2.5-5 km bin by 0.22% and 10.88%, respectively. The estimation results in the other two distance bins are insignificant but also positive, indicating that the upstream state's GDP and population slightly affect the downstream state's policy behavior. These results imply that the upstream state's beggar-thy-neighbor behavior is not affected by the downstream state's political-economic scale. A political-economically "large" downstream state does not have higher bargaining power over the water pollution management of the upstream state. While a "large" upstream state with high GDP and a huge population slightly incentivizes the downstream state to manage pollution more and free-riding less. This could result from higher bargaining power of the upstream state at the transboundary rivers. Or, a larger upstream state signals more pollution flows from the upstream, so the downstream state needs to take more actions to treat the downstream watersheds.

The above results show that the upstream state's beggar-thy-neighbor behavior is relatively independent. The downstream state's free-riding behavior depends on the downstream state's expectation for the upstream state's pollution management, which is built on the upstream state's political-economic features. A more environmentally friendly or political-economically "smaller" upstream state will intensify the downstream state's free-riding behavior.

7.2 Grants Approval in States with River Borders

Table 4 shows that near-boundary subwatersheds receive a larger amount of grants than intrastate subwatersheds. Figure 6 and Figure 19 suggest that more grants may have been approved for rivers that form the state borders. Figure 3 also shows that the distribution of the upstream and the downstream portions of interstate rivers are very different for rivers that form the state borders and rivers that only cross the state borders. Most of the tributaries of the border rivers are upstream of the river. Therefore, I run the Heckman selection model of approved grants for the 10 states that have river borders and the rest states separately to compare their coefficients. The results are presented in Figure 16.

Panel (a) of Figure 16 shows that in the states with river borders, the near-boundary rivers receive fewer grants than intrastate rivers. While in the states that do not have river borders, the near-boundary rivers receive more grants. Panel (b) for different portions of interstate rivers show that in the river-border states, the upstream portions of interstate rivers mostly receive larger amounts of grants than intrastate rivers. The downstream portions of interstate rivers mostly receive fewer grants than intrastate rivers. The upstream and downstream portions of interstate rivers in the non-river-border states do not receive significantly different grants from the intrastate rivers in most distance bins, with the few distance bins in the downstream portions receiving larger amounts of grants. Panel (c) presents the coefficients for non-transboundary rivers. Non-transboundary rivers receive fewer amounts of grants than intrastate rivers in river-border states but receive larger amounts of grants in non-river-border states. The variation patterns of the coefficients for non-transboundary rivers are similar to those in Panel (a) for all near-boundary rivers.

In conclusion, in states that do not have river borders, rivers that lie close to the state borders but do not cross the state borders receive relatively more grants; In states with river borders, the upstream portions of interstate rivers receive relatively more grants. These are the two driving factors of the larger amounts of grants for near-boundary and transboundary rivers estimated in Section 6.

7.3 The Probability of Impairment

I conduct a Heckman two-step analysis to estimate the probability that a catchment is listed as impaired. The impairment is one outcome of water quality assessment, it is not a decision made by the government like the three policies discussed above. However, being listed as impaired requires that the catchment is assessed. So I run a first-step selection of the assessed catchment then run the second-step Probit model for the probability of impairment.[22]

The estimated coefficients for near-boundary, interstate, and non-transboundary catchments are plotted in Figure 17. The near-boundary catchments are more likely to be listed as impaired. The interstate catchments, however, have a lower probability to be impaired when they are close to the state borders. The high probability of impairment for near-boundary catchments is mainly driven by the near-boundary but non-transboundary catchments. These results are consistent with the results in Section 6, which show that the near-boundary catchments receive a larger amount of S319(h) pollution management grants, while different portions of interstate rivers in most distance bins do not receive significantly different amount of grants than intrastate rivers.

8 Conclusions

This paper studies states' behaviors in the implementation of three nonpoint-source water pollution policies on near-boundary and transboundary rivers. Among S305(b) water quality assessment, S303(d) TMDL development, and S319(h) nonpoint source pollution management grant. S303(d) is the most decentralized policy among the three policies, and S319(h) is the list decentralized. Using different models depending on each policy's characteristics, this paper finds that states have a lower probability to assess the water quality and develop TMDLs for near-boundary rivers. However, more S319(h) grants are approved for near-boundary rivers.

[22] First step:

$$p_{cs} = Pr[\ Assess_{cs} = 1|\mathbb{X}_{cs}] = \Phi(\alpha_0 + Distbin_c\beta_1 + Str_c\alpha_1 + X_c\alpha_2 + D_s) \tag{20}$$

Second step:

$$p_{cs} = Pr[\ Impair_{cs} = 1|\mathbb{X}_{cs}] = \Phi(\alpha_0 + Distbin_c\beta_1 + \beta_2 CoastCat_c + Str_c\alpha_1 + Str1_c\alpha_2 + X_c\alpha_3) \tag{21}$$

The state governments have two transboundary policy behaviors: the beggar-thy-neighbor behavior that the upstream states conduct less pollution control to let pollution flow to the downstream states, and the free-riding behavior that the downstream state conduct insufficient pollution control. The beggar-thy-neighbor behavior is not affected by the downstream states' characteristics while the free-riding behavior depends on the upstream state's environmental and political-economic background. States exhibit both behaviors in S303(d) TMDL development, which results in large deadweight losses.

References

Birkeland, Sarah. 2001. "EPA's TMDL program." *Ecology Law Quarterly* :297–325.

Boehmke, Frederick J, Daniel S Morey, and Megan Shannon. 2006. "Selection bias and continuous-time duration models: consequences and a proposed solution." *American Journal of Political Science* 50 (1):192–207.

Chatterjee, Chiradip, Russell Triplett, Christopher K Johnson, and Parvez Ahmed. 2017. "Willingness to pay for safe drinking water: A contingent valuation study in Jacksonville, FL." *Journal of environmental management* 203:413–421.

Chen, Zhao, Matthew E Kahn, Yu Liu, and Zhi Wang. 2018. "The consequences of spatially differentiated water pollution regulation in China." *Journal of Environmental Economics and Management* 88:468–485.

Craig, Robin Kundis and Anna M Roberts. 2015. "When will governments regulate nonpoint source pollution: a comparative perspective." *BC Envtl. Aff. L. Rev.* 42:1.

EPA. 2001. "The National Costs of the Total Maximum Daily Load Program."

———. 2011. "A National Evaluation of the Clean Water Act Section 319 Program." .

Fowlie, Meredith, Claire Petersen, and Mar Reguant. 2021. "Border carbon adjustments when carbon intensity varies across producers: Evidence from california." In *AEA Papers and Proceedings*, vol. 111. 401–05.

GAO, US Government Accountability Office. 2000. "Key EPA and State Decisions Limited by Inconsistent and Incomplete Data."

Greenstone, Michael and Rema Hanna. 2014. "Environmental regulations, air and water pollution, and infant mortality in India." *American Economic Review* 104 (10):3038–72.

Helland, Eric and Andrew B Whitford. 2003. "Pollution incidence and political jurisdiction: evidence from the TRI." *Journal of Environmental Economics and management* 46 (3):403–424.

Hite, Diane, Darren Hudson, and Walaiporn Intarapapong. 2002. "Willingness to pay for water quality improvements: The case of precision application technology." *Journal of Agricultural and resource Economics* :433–449.

Jordan, Jeffrey L and Abdelmoneim H Elnagheeb. 1993. "Willingness to pay for improvements in drinking water quality." *Water resources research* 29 (2):237–245.

Keiser, David A, Catherine L Kling, and Joseph S Shapiro. 2019. "The low but uncertain measured benefits of US water quality policy." *Proceedings of the National Academy of Sciences* 116 (12):5262–5269.

Keiser, David A, Sheila M Olmstead, Kevin J Boyle, Victor B Flatt, Bonnie L Keeler, Catherine L Kling, Daniel J Phaneuf, Joseph S Shapiro, and Jay P Shimshack. 2021. "A water rule that turns a blind eye to transboundary pollution." *Science* 372 (6539):241–243.

Keiser, David A, Sheila M Olmstead, Kevin J Boyle, Victor B Flatt, Bonnie L Keeler, Daniel J Phaneuf, Joseph S Shapiro, and Jay P Shimshack. 2022. "The Evolution of the ¡°Waters of the United States¡± and the Role of Economics." *Review of Environmental Economics and Policy* 16 (1):146–152.

Keiser, David A and Joseph S Shapiro. 2019. "US water pollution regulation over the past half century: burning waters to crystal springs?" *Journal of Economic Perspectives* 33 (4):51–75.

Kelderman, Keene, Ari Phillips, Tom Pelton, Eric Schaeffer, Paul MacGillis-Falcon, and Courtney Bernhardt. 2022. "The Clean Water Act at 50: Promises Half Kept at the Half-Century Mark." *The Environmental Integrity Project* .

Lipscomb, Molly and Ahmed Mushfiq Mobarak. 2016. "Decentralization and pollution spillovers: evidence from the re-drawing of county borders in Brazil." *The Review of Economic Studies* 84 (1):464–502.

List, John A, Erwin H Bulte, and Jason F Shogren. 2002. "¡°Beggar thy neighbor:¡± Testing for free riding in state-level endangered species expenditures." *Public Choice* 111 (3):303–315.

List, John A and Shelby Gerking. 2000. "Regulatory federalism and environmental protection in the United States." *Journal of Regional Science* 40 (3):453–471.

Millimet, Daniel L. 2003. "Assessing the empirical impact of environmental federalism." *Journal of Regional Science* 43 (4):711–733.

NRC, National Research Council. 2001. *Assessing the TMDL approach to water quality management*. National Academies Press.

Oates, Wallace E and Robert M Schwab. 1988. "Economic competition among jurisdictions: efficiency enhancing or distortion inducing?" *Journal of public economics* 35 (3):333–354.

Sigman, Hilary. 2002. "International spillovers and water quality in rivers: do countries free ride?" *American Economic Review* 92 (4):1152–1159.

———. 2003. "Letting states do the dirty work: State responsibility for federal environmental regulation." *National Tax Journal* 56 (1):107–122.

———. 2005. "Transboundary spillovers and decentralization of environmental policies." *Journal of environmental economics and management* 50 (1):82–101.

———. 2014. "Decentralization and environmental quality: an international analysis of water pollution levels and variation." *Land Economics* 90 (1):114–130.

Silva, Emilson CD and Arthur J Caplan. 1997. "Transboundary pollution control in federal systems." *Journal of environmental economics and management* 34 (2):173–186.

9 Figures

Figure 1: Beggar-thy-Neighbor

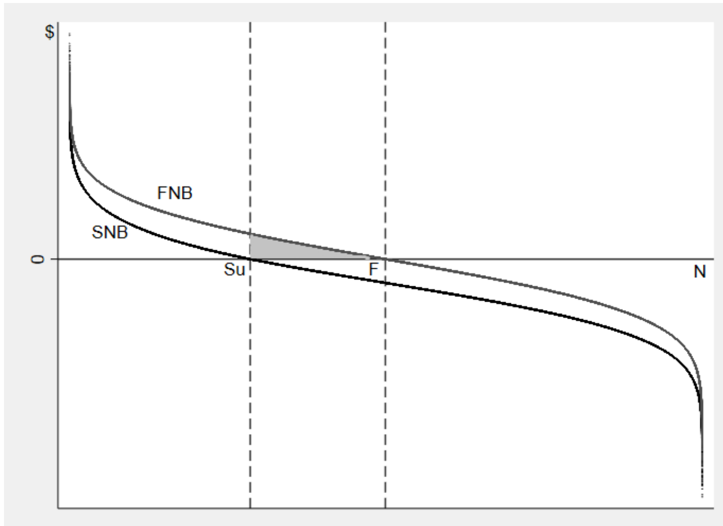


Figure 2: Free Riding

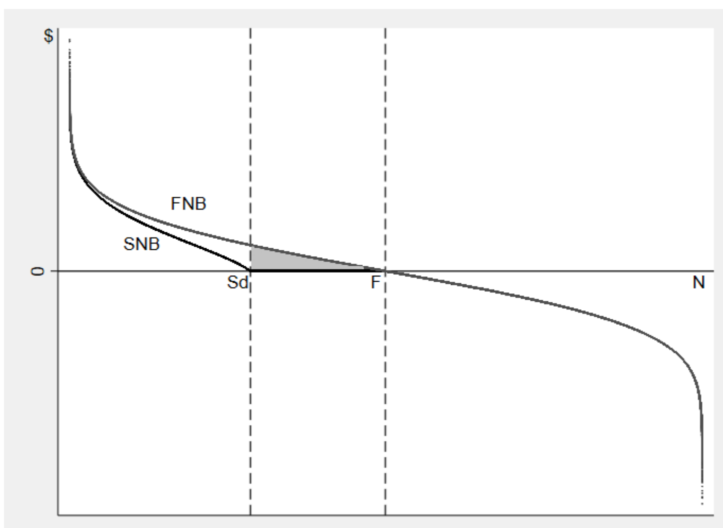


Figure 3: Watershed 07 Upper Mississippi Region

Figure 4: Watershed 18 California Region

Figure 5: Distribution of Catchments in Different IRC Categories in 2020

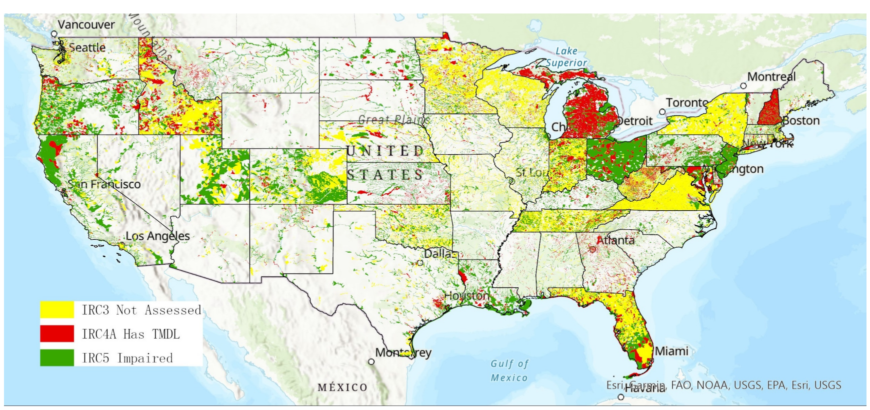


Figure 6: Total S319(h) Grants Across Subwatersheds by 2020

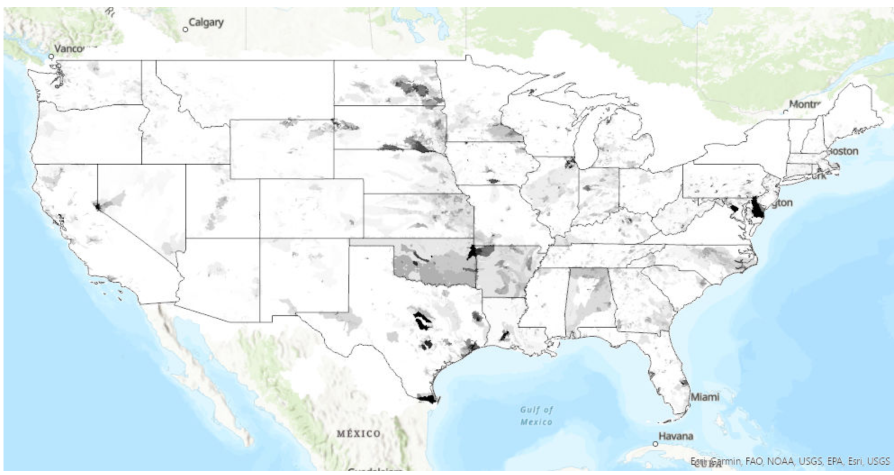
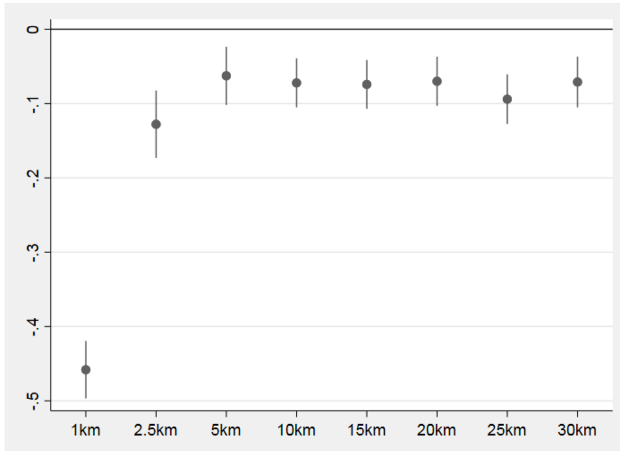
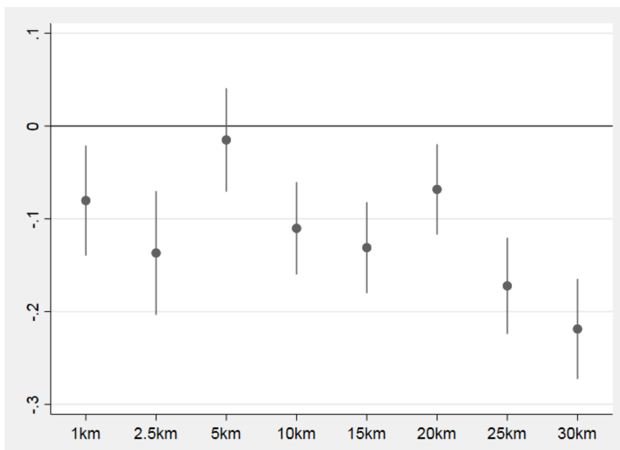


Figure 7: Policy Behaviors on Near-boundary Rivers

(a) Prob. of Assessment



(b) Hazard of TMDL Development



(c) Grants

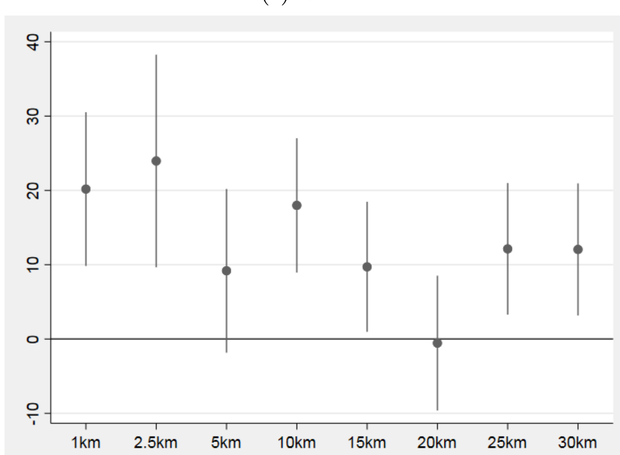
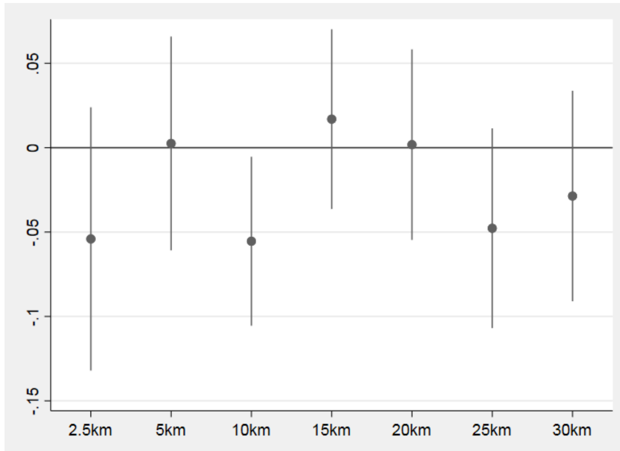
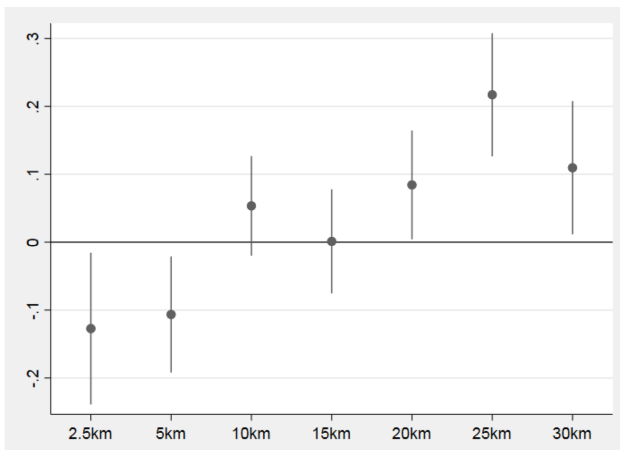


Figure 8: Policy Behaviors on Interstate Rivers

(a) Prob. of Assessment



(b) Hazard of TMDL Development



(c) Grants

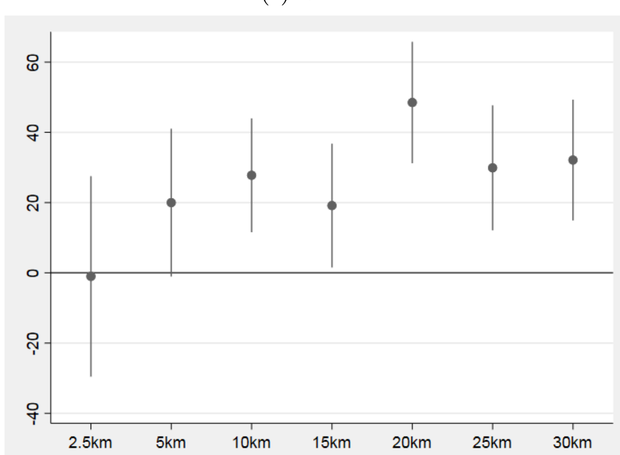
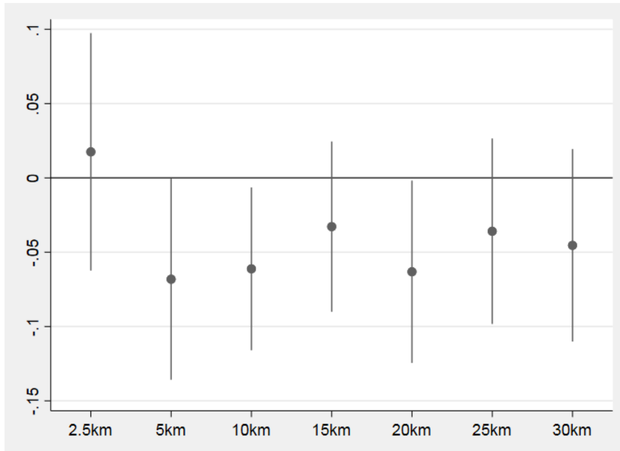
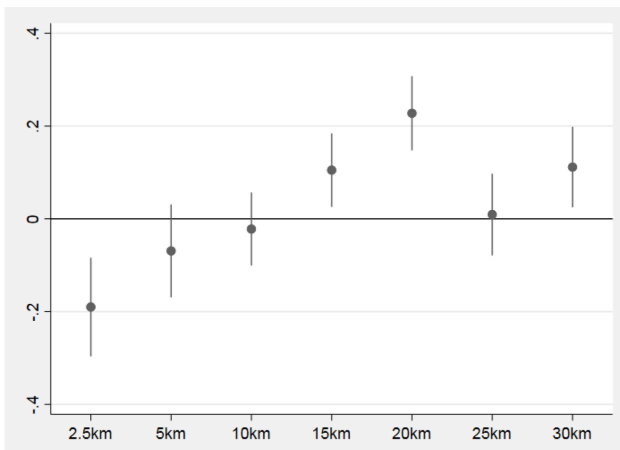


Figure 9: Policy Behaviors on Coastal Rivers

(a) Prob. of Assessment



(b) Hazard of TMDL Development



(c) Grants

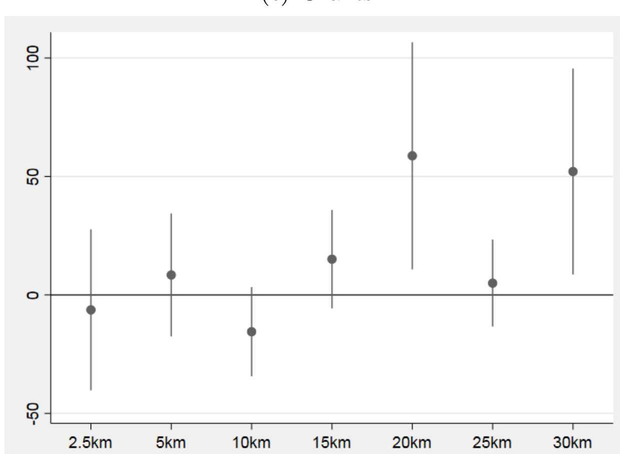
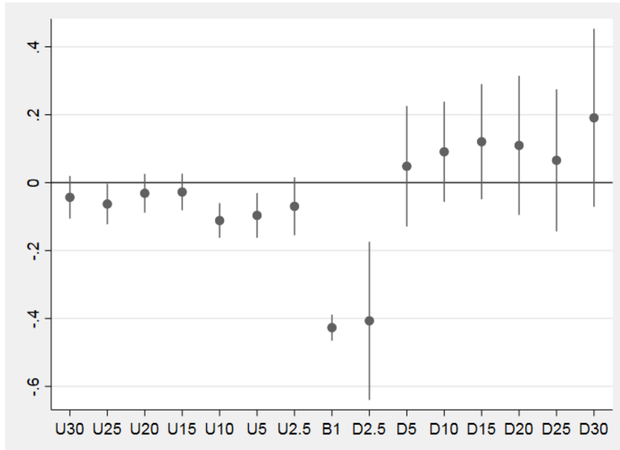
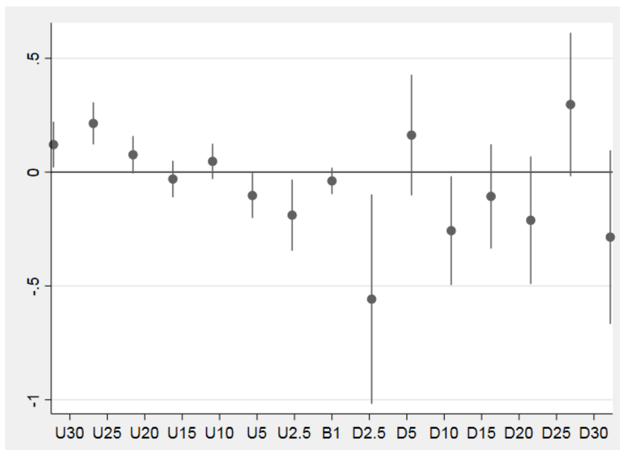


Figure 10: The Beggar-thy-neighbor Behavior Upstream and Free-riding Behavior Downstream of Interstate Rivers

(a) Prob. of Assessment



(b) Hazard of TMDL Development



(c) Grants

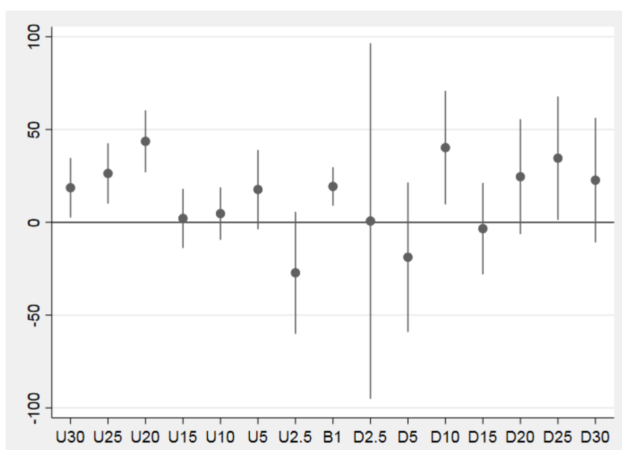
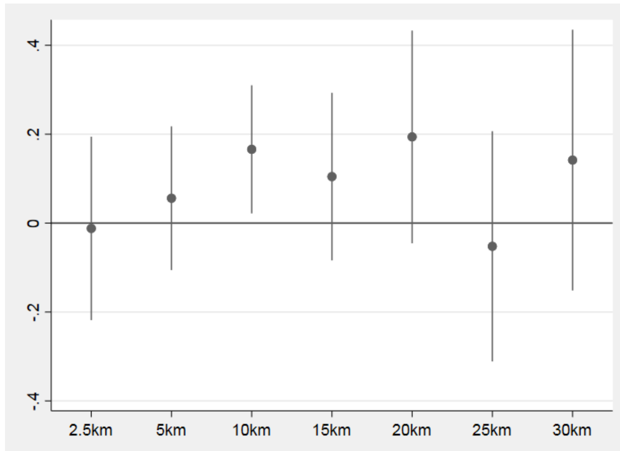
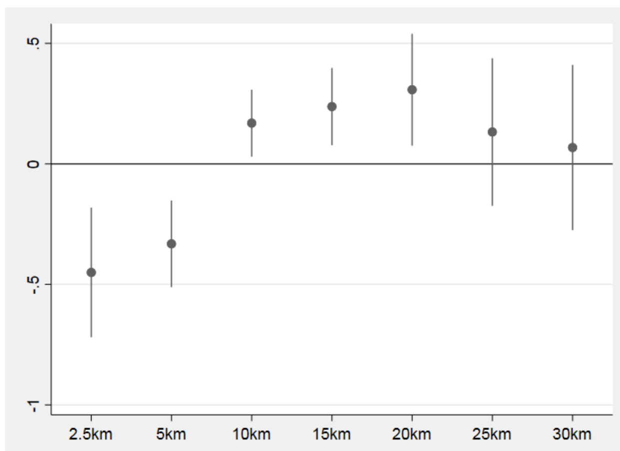


Figure 11: The Beggar-thy-neighbor Behavior and Free-riding Behavior in the Up\Downstream of Interstate Rivers

(a) Prob. of Assessment



(b) Hazard of TMDL Development



(c) Grants

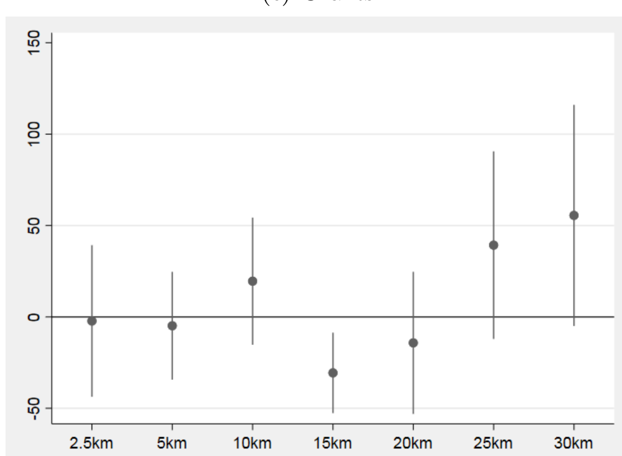
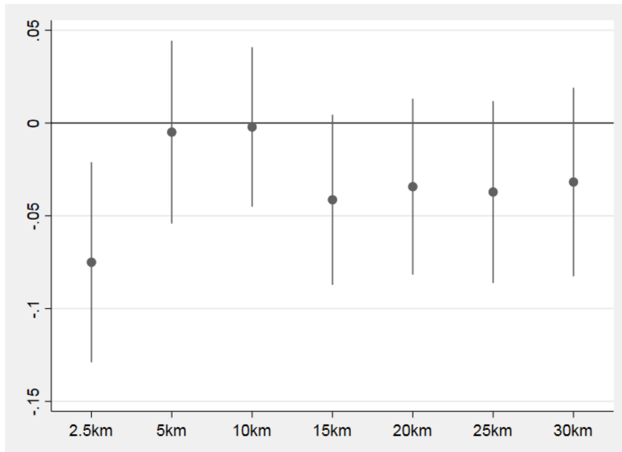
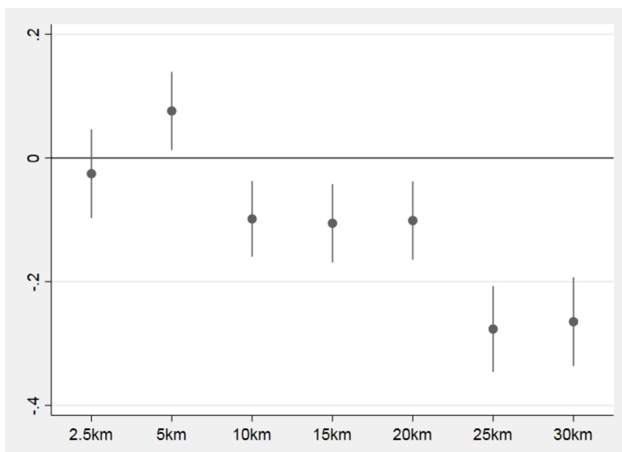


Figure 12: Policy Behaviors on Near-boundary but Non-transboundary Rivers

(a) Prob. of Assessment



(b) Hazard of TMDL Development



(c) Grants

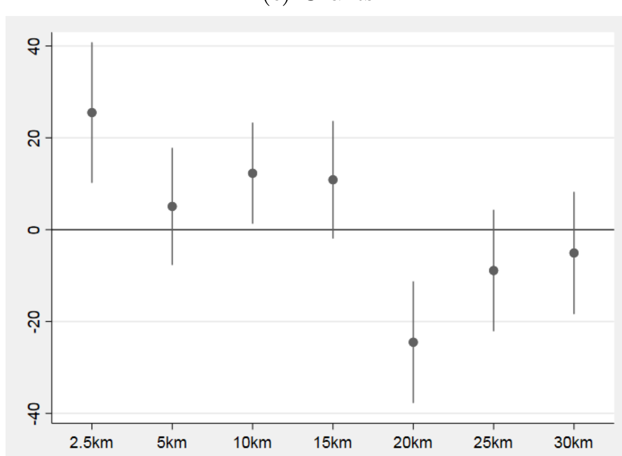


Figure 13: State-fixed Effects on Hazards of TMDL Development

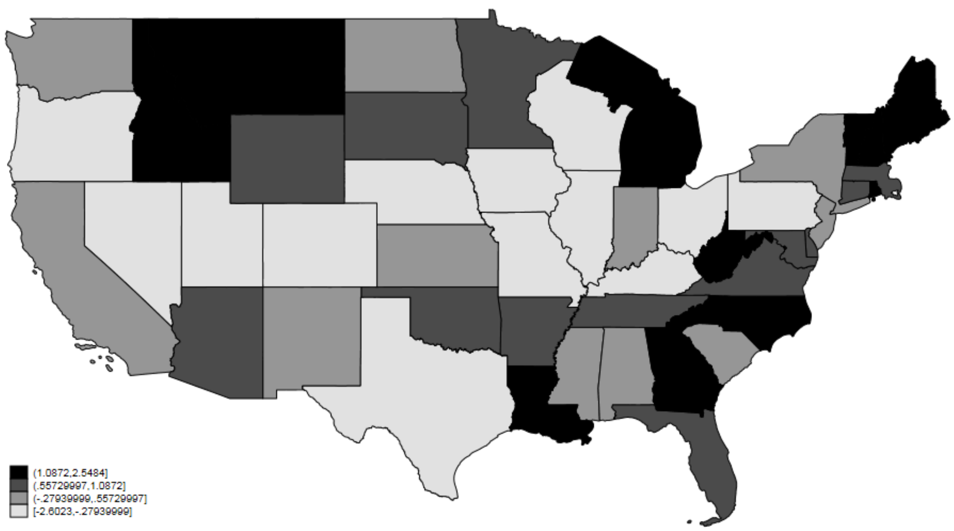
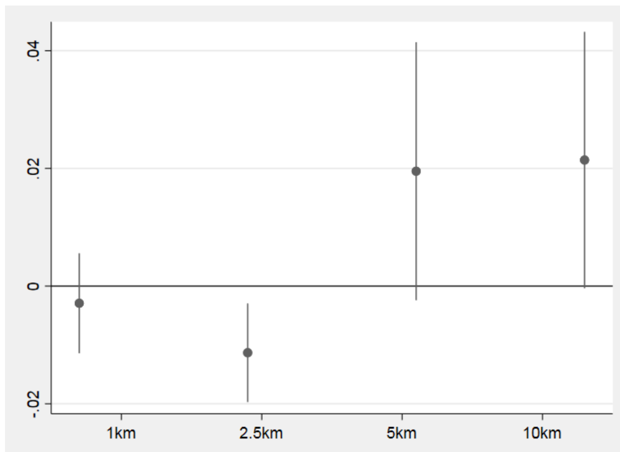


Figure 14: Influence of State LCV Score on Policy Behaviors

(a) Distance Bins



(b) Different Portions of the Interstate Rivers

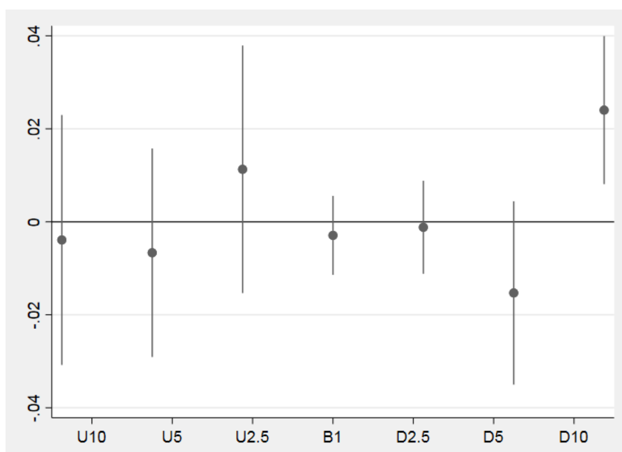
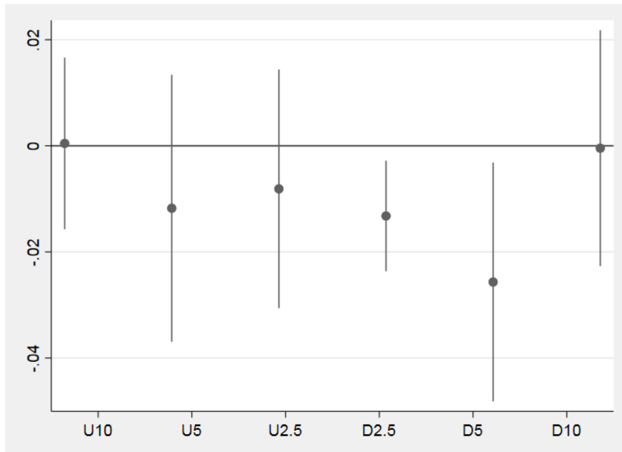
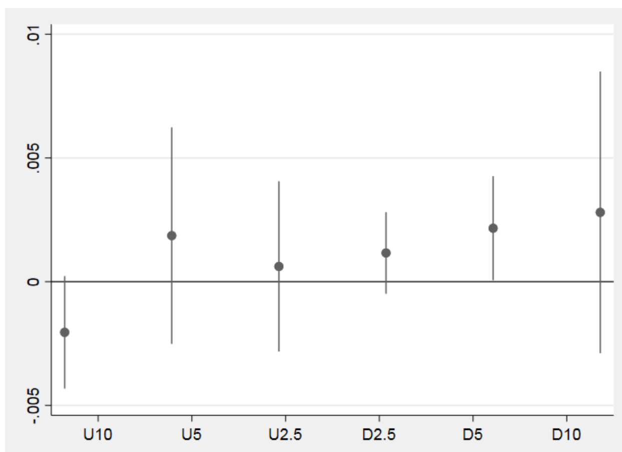


Figure 15: Influence on Policy Behaviors from the Neighboring State

(a) LCV



(b) GDP



(c) Population

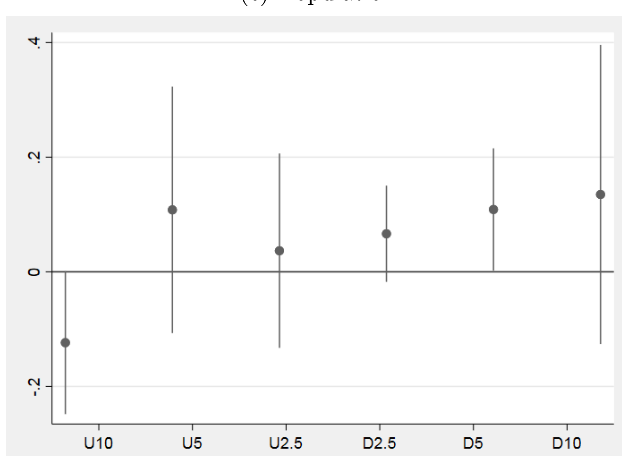
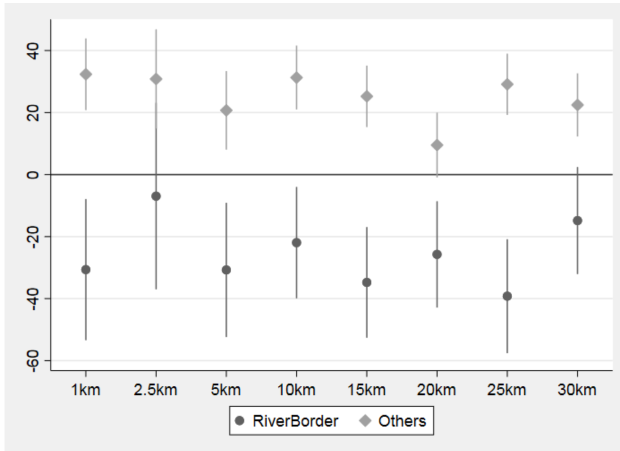
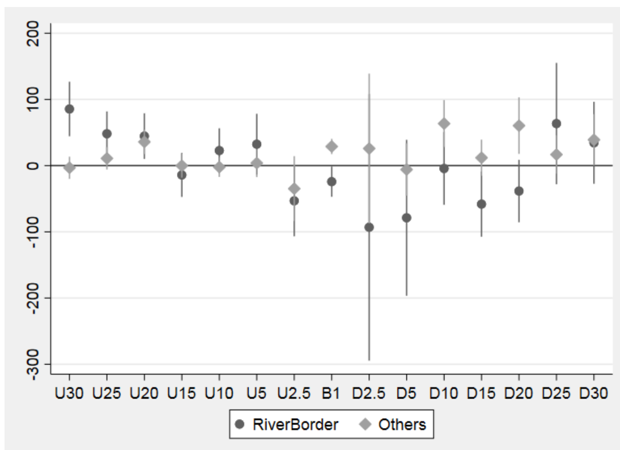


Figure 16: Comparison of Grants Approval for States with River Borders and the Other States

(a) Distance Bins



(b) Different Portions of Interstate Rivers



(c) Near-boundary but Non-transboundary Rivers

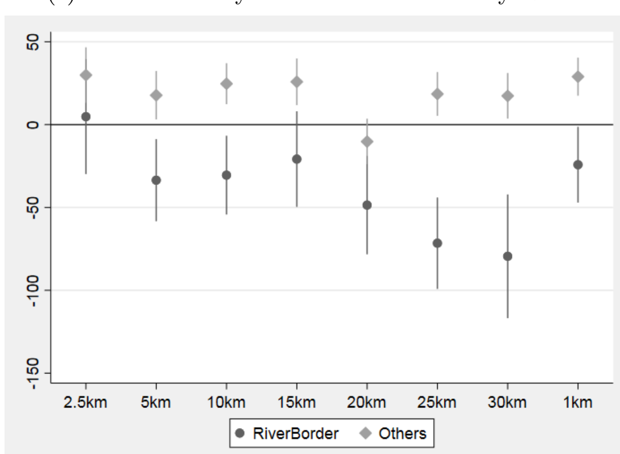
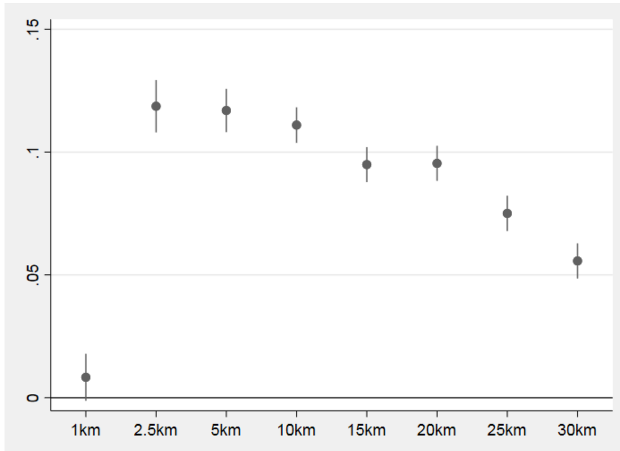
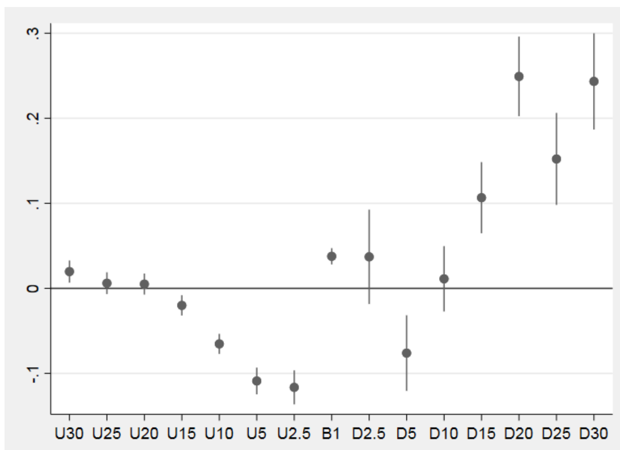


Figure 17: The Probability of Being Listed as Impaired

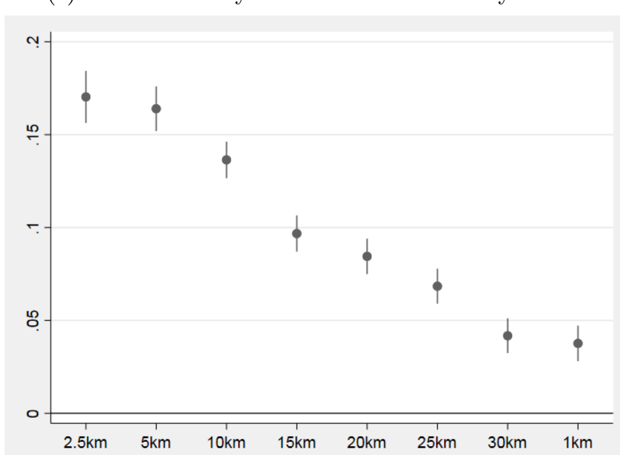
(a) Distance Bins



(b) Different Portions of the Interstate Rivers



(c) Near-boundary but Non-transboundary Rivers



10 Tables

Table 1: Degrees of Decentralization

NPS Policy	State Authority	State Costs (per year)	Decentralization
S305(b)	Medium	Low ($1.3 m. first, $0.2 m. subsq.)	Medium
S303(d)	High	High ($63-69 m.)	High
S319(h)	Low	Low	Low

Table 2: EPA Integrated Reporting Category

1	All Uses have been assessed and all are supporting Water Quality Standards
2	All assessed Uses are supporting Water Quality Standards but may have one or more Uses that were Not Assessed
3	Insufficient Information to make an assessment decision, or Not Assessed
4A	Impaired by a pollutant but already has a TMDL
4B	Impaired by a pollutant but doesn't need a TMDL since other pollution control measures are in place
4C	Impaired by something that is not a pollutant
5	Impaired by a pollutant and still needs a TMDL

Table 3: Portions of Rivers

Name	Description	Cat. No.
Interstate river		132,215
Border river	River segments within 1 km of the state borders	14,804
Upstream	The upstream portion of an interstate river within 30 km of the state borders	107,026
Downstream	The downstream portion of an interstate river within 30 km of the state borders	4,534
Up\Downstream	The upstream and downstream portion of an interstate river within 30 km of the state borders	5,851
Coastal river	River segments that flow into the ocean or the Great Lakes and within 30 km of the shoreline	53,844
Non-trans. river	River segments that are near-boundary but not transboundary	45,136
Intrastate river	River segments further than 30 km from the state borders	191,110

Table 4: Estimation Results: Distance to state borders

	(1) Assessment	(2) TMDL	(3) Grants
	Distance to state borders		
0-1km (Border)	-0.4581***	-0.0803***	20.1855***
	(0.0197)	(0.0302)	(5.2784)
1-2.5km	-0.1278***	-0.1368***	23.9577***
	(0.0231)	(0.0340)	(7.2959)
2.5-5km	-0.0626***	-0.0150	9.1819
	(0.0200)	(0.0285)	(5.6209)
5-10km	-0.0721***	-0.1103***	17.9849***
	(0.0168)	(0.0254)	(4.6124)
10-15km	-0.0741***	-0.1311***	9.7142**
	(0.0168)	(0.0250)	(4.4656)
15-20km	-0.0700***	-0.0683***	-0.5492
	(0.0169)	(0.0248)	(4.6281)
20-25km	-0.0940***	-0.1722***	12.1329***
	(0.0171)	(0.0264)	(4.5124)
25-30km	-0.0710***	-0.2187***	12.0541***
	(0.0174)	(0.0275)	(4.5337)
CoastCat.	0.1408***	0.1075***	-12.6375***
	(0.0126)	(0.0171)	(4.6956)
Pop. (k)	0.0001**	0.0001***	-0.0064
	(0.0000)	(0.0000)	(0.0070)
Inc. (m)	0.0000**	0.0000***	-0.0000
	(0.0000)	(0.0000)	(0.0001)
Constant	0.8310***	-36.3063***	-157.1660***
	-0.0365	(0.1521)	(57.5881)
p		8.9747***	
		(0.0000)	
rho		-0.2500***	-0.2383**
		(0.0000)	(0.0267)
Str	Yes	Yes	Yes
Year FE	No	No	Yes
State FE	Yes	Yes	Yes
Obs.	194,470	359,045	89,502

Note: Numbers in parentheses are robust standard errors.

Table 5: Estimation Results: Transboundary Rivers

	(1) Assessment	(2) TMDL	(3) Grants
0-1km (Border)	-0.4339***	-0.0381	18.4630***
	(0.0196)	(0.0297)	(5.3217)
	Near\Non-trans ×Distance		
1-2.5km	-0.0760**	-0.0329	23.8154*
	(0.0327)	(0.0409)	(12.9397)
2.5-5km	-0.0422	0.0792**	-7.6150
	(0.0270)	(0.0337)	(9.7492)
5-10km	-0.0161	-0.1037***	-2.6812
	(0.0225)	(0.0321)	(7.7115)
10-15km	-0.0624***	-0.1117***	-5.5869
	(0.0236)	(0.0326)	(8.5320)
15-20km	-0.0488**	-0.1062***	-37.3951***
	(0.0243)	(0.0325)	(7.8563)
20-25km	-0.0442*	-0.2784***	-12.2012
	(0.0251)	(0.0356)	(7.9115)
25-30km	-0.0356	-0.2679***	-12.8288*
	(0.0260)	(0.0367)	(6.9954)
	Interstate ×Distance		
1-2.5km	-0.0541	-0.1273**	-1.0035
	(0.0398)	(0.0570)	(14.5626)
2.5-5km	0.0025	-0.1065**	19.9959*
	(0.0323)	(0.0437)	(10.7347)
5-10km	-0.0554**	0.0535	27.7800***
	(0.0256)	(0.0374)	(8.2708)
10-15km	0.0169	0.0012	19.1527**
	(0.0272)	(0.0391)	(8.9924)
15-20km	0.0018	0.0844**	48.4971***
	(0.0288)	(0.0409)	(8.8228)
20-25km	-0.0477	0.2171***	29.8973***

	(0.0302)	(0.0463)	(9.0739)
25-30km	-0.0287	0.1097**	32.1216***
	(0.0318)	(0.0501)	(8.7727)
	Coastal ×Distance		
1-2.5km	0.0175	-0.1901***	-6.3073
	(0.0408)	(0.0542)	(17.3371)
2.5-5km	-0.0682**	-0.0692	8.4239
	(0.0345)	(0.0511)	(13.2414)
5-10km	-0.0612**	-0.0221	-15.5261
	(0.0279)	(0.0402)	(9.5890)
10-15km	-0.0328	0.1049***	15.0894
	(0.0292)	(0.0405)	(10.6083)
15-20km	-0.0631**	0.2275***	58.7162**
	(0.0313)	(0.0408)	(24.4602)
20-25km	-0.0359	0.0093	4.9850
	(0.0318)	(0.0449)	(9.3596)
25-30km	-0.0454	0.1115**	52.1040**
	(0.0330)	(0.0443)	(22.1852)
Pop. (k)	0.0001***	0.0001***	-0.0063
	(0.0000)	(0.0000)	(0.0071)
Inc. (m)	0.0000*	0.0000***	-0.0000
	(0.0000)	(0.0000)	(0.0001)
Constant	0.8351***	-36.3235***	-157.6376***
	(0.0365)	(0.1523)	(57.8772)
p		8.9777***	
		(0.0000)	
rho		-0.2500***	-0.2376**
		(0.0000)	(0.0261)
Str	Yes	Yes	Yes
Year FE	No	No	Yes
State FE	Yes	Yes	Yes
Obs.	194,470	359,045	89,502

Note: Numbers in parentheses are robust standard errors.

Table 6: Estimation Results: Different Portions of Interstate Rivers

	(1) Assessment	(2) TMDL	(3) Grants
0-1km (Border)	-0.4270***	-0.0386	19.3400***
	(0.0196)	(0.0297)	(5.2929)
	Near\Non-trans ×Distance		
1-2.5km	-0.0750***	-0.0254	25.4982***
	(0.0275)	(0.0366)	(7.8155)
2.5-5km	-0.0049	0.0759**	5.0651
	(0.0251)	(0.0322)	(6.5122)
5-10km	-0.0021	-0.0985***	12.2901**
	(0.0219)	(0.0312)	(5.6181)
10-15km	-0.0413*	-0.1056***	10.8650*
	(0.0234)	(0.0323)	(6.5345)
15-20km	-0.0343	-0.1012***	-24.5083***
	(0.0242)	(0.0323)	(6.7593)
20-25km	-0.0372	-0.2765***	-8.8900
	(0.0250)	(0.0355)	(6.7492)
25-30km	-0.0318	-0.2647***	-5.0710
	(0.0259)	(0.0366)	(6.7966)
	Upstream ×Distance		
1-2.5km	-0.0698	-0.1890**	-27.2125
	(0.0435)	(0.0798)	(16.7792)
2.5-5km	-0.0966***	-0.1028**	17.6531
	(0.0337)	(0.0505)	(10.9128)
5-10km	-0.1115***	0.0472	4.6954
	(0.0261)	(0.0396)	(7.2291)
10-15km	-0.0276	-0.0303	2.0996
	(0.0275)	(0.0409)	(8.1460)
15-20km	-0.0314	0.0765*	43.6373***
	(0.0291)	(0.0420)	(8.5279)

20-25km	-0.0630**	0.2141***	26.3316***
	(0.0305)	(0.0472)	(8.3015)
25-30km	-0.0432	0.1209**	18.6261**
	(0.0321)	(0.0512)	(8.1982)
	Downstream ×Distance		
1-2.5km	-0.4069***	-0.5581**	0.6925
	(0.1188)	(0.2348)	(48.8711)
2.5-5km	0.0482	0.1628	-18.8042
	(0.0905)	(0.1353)	(20.5534)
5-10km	0.0909	-0.2571**	40.2383***
	(0.0753)	(0.1220)	(15.6058)
10-15km	0.1206	-0.1066	-3.4005
	(0.0865)	(0.1168)	(12.5784)
15-20km	0.1097	-0.2114	24.5957
	(0.1045)	(0.1431)	(15.8137)
20-25km	0.0657	0.2971*	34.5460**
	(0.1067)	(0.1609)	(16.9658)
25-30km	0.1910	-0.2853	22.7175
	(0.1338)	(0.1946)	(17.1189)
	Up\Downstream ×Distance		
1-2.5km	-0.0120	-0.4505***	-2.2313
	(0.1053)	(0.1372)	(21.1495)
2.5-5km	0.0559	-0.3318***	-4.8435
	(0.0825)	(0.0917)	(15.0475)
5-10km	0.1659**	0.1690**	19.5644
	(0.0735)	(0.0708)	(17.7545)
10-15km	0.1046	0.2376***	-30.6352***
	(0.0962)	(0.0818)	(11.2364)
15-20km	0.1939	0.3076***	-14.2043
	(0.1221)	(0.1185)	(19.8327)
20-25km	-0.0523	0.1321	39.2648
	(0.1322)	(0.1561)	(26.1891)
25-30km	0.1417	0.0678	55.5285*
	(0.1496)	(0.1747)	(30.8769)

	Coastal ×Distance		
1-2.5km	0.0056	-0.1921***	-12.6686
	(0.0405)	(0.0539)	(17.2225)
2.5-5km	-0.0875**	-0.0708	0.2333
	(0.0344)	(0.0509)	(12.8879)
5-10km	-0.0756***	-0.0257	-21.6251**
	(0.0278)	(0.0402)	(9.3146)
10-15km	-0.0476	0.1015**	7.3941
	(0.0292)	(0.0404)	(10.3165)
15-20km	-0.0740**	0.2248***	53.2533**
	(0.0313)	(0.0408)	(24.1073)
20-25km	-0.0439	0.0076	1.0212
	(0.0318)	(0.0449)	(9.2705)
25-30km	-0.0510	0.1104**	48.9589**
	(0.0330)	(0.0442)	(22.0969)
Pop. (k)	0.0001***	0.0001***	-0.0046
	(0.0000)	(0.0000)	(0.0071)
Inc. (m)	0.0000**	0.0000***	-0.0000
	(0.0000)	(0.0000)	(0.0001)
Constant	0.8356***	-36.3287***	-156.9401***
	(0.0365)	(0.1523)	(57.6267)
p		8.9797***	
		(0.0000)	
rho		-0.2500***	-0.2374**
		(0.0000)	(0.0261)
Str	Yes	Yes	Yes
Year FE	No	No	Yes
State FE	Yes	Yes	Yes
Obs.	194,470	359,045	89,502

Note: Numbers in parentheses are robust standard errors.

Table 7: deadweight Loss due to Insufficient TMDL Development

	Dist.	Hazard	Pop. (m)	deadweight Loss (mil. $ in 2020) H. (2002) 10%	H. (2002) 20%	C. (2017)	J. (1993)
BTN	1-2.5km	0.1890	34.5557	475.4811	505.5466	43.8728	68.1251
	2.5-5km	0.1028	41.5063	310.6417	330.2841	28.6630	44.5075
	Total			786.1228	835.8308	72.5358	112.6326
FR	1-2.5km	0.5581	11.5362	468.7330	498.3719	43.2501	67.1582
	5-10km	0.2571	15.8833	297.3009	316.0997	27.4320	42.5961
	Total			766.0339	814.4716	70.6822	109.7543
Both	1-2.5km	0.4505	12.6005	413.2709	439.4028	38.1326	59.2118
	2.5-5km	0.3318	22.8543	552.0731	586.9817	50.9399	79.0989
	Total			965.3440	1026.3840	89.0726	138.3107

Table 8: The Effect of the State Governor's Political Party on the Hazard of TMDL Development

	Proportional Hazard
Republican Governer in Current Year	-0.4654***
	(0.1019)
Republican Governer in Previous Year	-0.9402***
	(0.1062)

Table 9: Influence on Policy Behaviors from the Upstream\Downstream State

	Distance to State Borders		
	1-2.5km	2.5-5km	5-10km
Dn. State	BTN Upstream		
LCV	-0.0081	-0.0118	0.0005
	(0.0114)	(0.0127)	(0.0082)
GDP (b.)	0.0006	0.0019	-0.0020*
	(0.0017)	(0.0022)	(0.0012)
Pop. (m.)	0.0368	0.1081	-0.1236*
	(0.0859)	(0.1089)	(0.0631)
Up. State	FR Downstream		
LCV	-0.0132**	-0.0257**	-0.0005
	(0.0053)	(0.0114)	(0.0113)
GDP (b.)	0.0012	0.0022**	0.0028
	(0.0008)	(0.0011)	(0.0029)
Pop. (m.)	0.0664	0.1088**	0.1349
	(0.0426)	(0.0540)	(0.1322)

Appendix

A Potential Selection Bias in the Survival Analysis of TMDL Development

I run the Weibull duration model without the first-step sample selection to explore the selection bias. Table 10 compares the constant terms in the two models for each regression. The independent duration model uses a sample of impaired catchments, the constant term increases from about -36 in the selected model to about -34, which indicates a larger hazard rate of TMDL development.

The coefficients of the near-boundary and interstate catchment dummies in the two models are plotted in Figure 21. Panel (a) shows that in the independent duration model, the states have much lower hazards to develop TMDLs for the near-boundary catchments. The difference between the coefficients of the two models is the smallest for the border catchments (within 1 km to state borders), the largest for catchments next to the border catchments, then the difference shrinks as the catchments become further away from the state borders. These differences indicate that states have a lower hazard to develop TMDLs for the impaired near-boundary catchments than for the near-boundary catchments in general, especially the catchments that are closer to state borders but do not lie on the borders. Panel (b) shows that the coefficients for different portions of interstate rivers are similar in the two models. The independent duration model has slightly more positive estimates in the downstream, indicating that states develop TMDLs for the impaired downstream catchments a bit sooner than the downstream catchments in general. Apart from the magnitude of the coefficients, the changing pattern of the proportional hazards in the two models are very similar.

B Figures

Figure 18: Subwatershed (huc12), Assessment Unit, and Flowlines

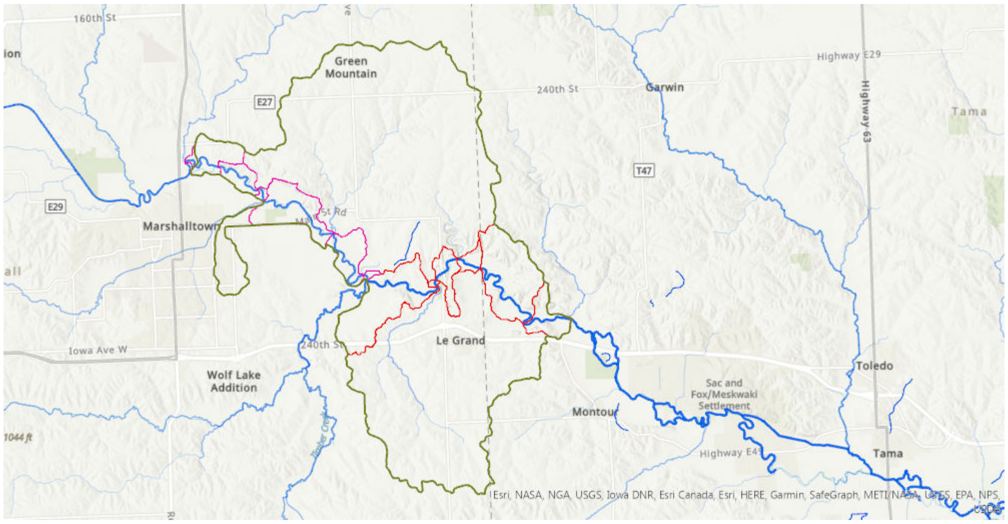
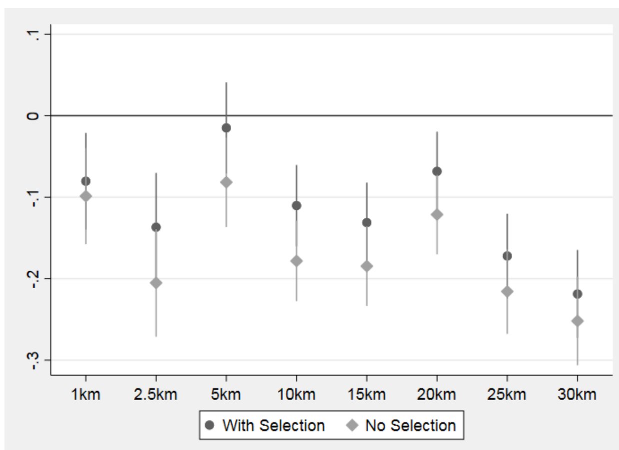


Figure 19: River Borders (NASA)

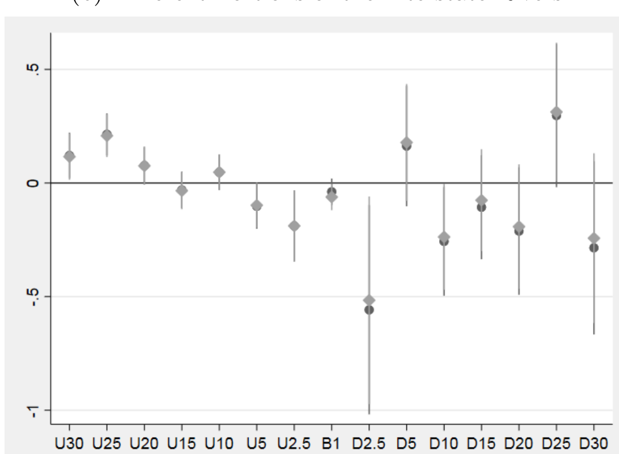
Figure 20: HUC4 Watershed Boundaries

Figure 21: Estimation Results of the Duration Model without Selection

(a) Distance Bins



(b) Different Portions of the Interstate Rivers



C Tables

Table 10: Comparison of the Constant Terms

Constant	Equation 12	Equation 13	Equation 14
With Selection	-36.3063***	-36.3287***	-36.3235***
	(0.1521)	(0.1523)	(0.1523)
No Selection	-34.3832***	-34.4041***	-34.3992***
	(0.1427)	(0.1429)	(0.1429)