

1           **Do River Chiefs Deliver? Political, Environmental, and Fiscal**  
2                           **Dimensions of Water Governance Effectiveness**

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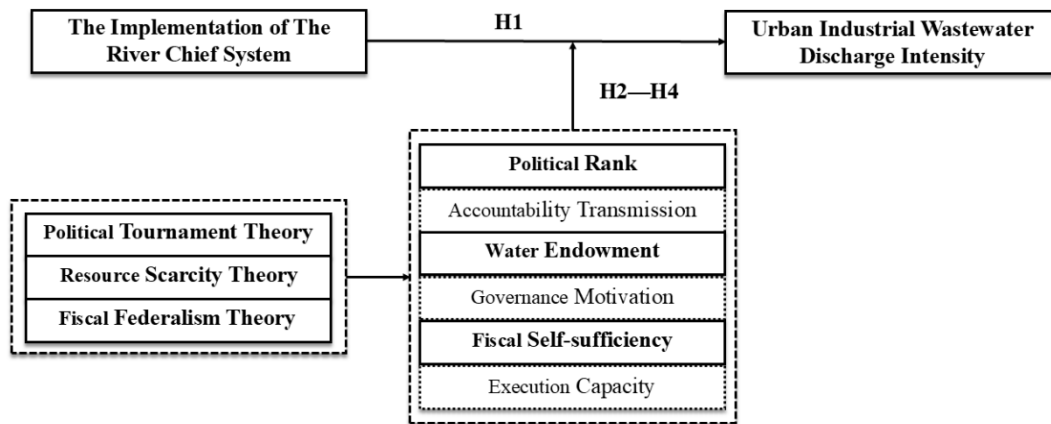
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12   **Graphical Abstract**



13

14 **Abstract**

15 Industrial wastewater discharge remains a critical threat to sustainable water resource  
16 management, yet how institutional accountability arrangements constrain urban  
17 pollution behavior under decentralized governance systems is insufficiently understood.  
18 This paper exploits the staggered provincial rollout of China's River Chief System to  
19 construct a staggered difference-in-differences model using panel data covering 285  
20 prefecture-level cities from 2013 to 2020. The results show that River Chief System  
21 implementation reduces urban industrial wastewater discharge intensity by  
22 approximately 7%, a finding that holds across parallel trends tests, placebo tests, and  
23 alternative estimators including the Callaway–Sant'Anna and Sun–Abraham approaches.  
24 The reduction is also visible in the discharge of chemical oxygen demand and ammonia  
25 nitrogen, the two pollutants targeted by China's water quality assessment. Policy effects,  
26 however, vary systematically across cities: a higher political rank of the provincial chief  
27 river official strengthens downward accountability transmission; greater water resource  
28 scarcity raises local officials' implementation initiative; and higher fiscal self-sufficiency  
29 enables more effective translation of institutional mandates into enforcement actions.  
30 The policy works in part by raising local environmental enforcement effort and  
31 encouraging a shift toward cleaner industrial activity. These findings suggest that  
32 embedding water quality targets within political career structures, combined with  
33 differentiated fiscal support matched to city-level resource endowments and capacities,  
34 offers a more robust pathway toward sustainable water governance than relying on short-  
35 term policy shocks alone, with implications for decentralized water management in other  
36 developing economies.

37 **Keywords:** River Chief System; Industrial wastewater discharge; Decentralized  
38 governance; Water resource endowment; Fiscal self-sufficiency; Political accountability

39

## 40 **1 Introduction**

41 Industrial wastewater discharge has been identified as a key threat to global  
42 freshwater systems. As industrialization deepens, rivers and lakes have absorbed growing  
43 volumes of pollutants, including organic compounds, heavy metals, and excess nitrogen  
44 and phosphorus, while their natural self-purification capacity has continued to decline  
45 under increasing environmental pressure and more frequent extreme weather events. The  
46 threats posed by industrial pollution to sustainable water use have therefore intensified  
47 along both quantitative and qualitative dimensions (Liang et al., 2025). As a major  
48 manufacturing economy, China has long recognized that severe contamination at many  
49 river headwaters originates primarily from poor industrial pollution control. Where  
50 industrial pollutants and domestic wastewater accumulate together, their combined  
51 impact poses a substantial risk to water resource security. At the city level, the intensity of  
52 industrial wastewater discharge reflects both the trade-offs that local governments  
53 confront between economic growth and environmental protection and the practical  
54 effectiveness of water pollution control policies. How institutional design can constrain  
55 urban industrial pollution behavior is therefore a central question in water resource  
56 economics and public policy research.

57 Under a decentralized governance system in which the central government sets  
58 regulations and local governments implement them, policy effectiveness depends more  
59 on local incentive arrangements than on the formal allocation of fiscal authority.  
60 Although fiscal decentralization and environmental decentralization can in some respects  
61 strengthen a region's capacity to manage resources, they do not automatically translate  
62 into reductions in pollutant emissions (Xu, 2022). Targeted policies have at times been  
63 more effective in improving specific aspects of pollution within short time horizons; for  
64 instance, empirical evidence indicates that initiatives such as the "Water Ten Plan" have  
65 improved urban water quality and reduced wastewater discharge (Chen, 2024; Zheng et  
66 al., 2022). Yet such one-time policy shocks rarely alter the underlying incentive  
67 constraints that shape local officials' day-to-day behavior, and emission levels often  
68 rebound once external pressure subsides. Through unified central deployment in 2016,  
69 the River Chief System linked water environmental quality vertically to local officials'

70 political careers, thereby generating sustained upward accountability pressure. In  
71 institutional design, it directly addresses the core problem of weak incentive mechanisms  
72 in decentralized governance (Liu & Bai, 2022; She et al., 2019). It is worth situating the  
73 River Chief System within the broader range of water governance arrangements at this  
74 point, because the choice of this institution as the analytical object is substantively  
75 motivated. Decentralized water governance elsewhere has been organized around at least  
76 three alternative designs: independent environmental regulatory agencies that  
77 concentrate enforcement authority in a specialized bureaucracy, integrated river basin  
78 commissions that align jurisdiction with hydrological rather than administrative  
79 boundaries, and market-based instruments such as tradable discharge permits that price  
80 pollution directly. Each addresses the fragmentation problem from a different angle.  
81 What distinguishes the River Chief System is that it leaves the existing administrative  
82 map intact while attaching personal, named responsibility for specific water bodies to  
83 individual leading officials and embedding water quality outcomes within the political  
84 career evaluation those officials already face. Its distinctive feature is therefore not a new  
85 enforcement agency or a new market, but a re-engineering of the incentive structure  
86 surrounding officials who were already in place. Studying this design speaks to a general  
87 question in the governance literature, namely whether decentralized accountability that  
88 works through career incentives rather than through institutional redesign can deliver  
89 environmental improvement, and under what conditions it does so.

90 Existing research on the policy effects of the River Chief System has taken several  
91 different approaches. The system has shown some restraining effect on agricultural non-  
92 point source pollution, although its effectiveness against pollutants such as chemical  
93 oxygen demand remains contested (Li et al., 2020; Li & Huang, 2021). Firm-level  
94 analyses have identified time lags and even short-term increases in pollutant  
95 concentrations following the reform (Zuo et al., 2026). Promotion incentives and the  
96 personal characteristics of local officials shape the depth of policy implementation to  
97 varying degrees (Li et al., 2024; Tang et al., 2025), and some cities exhibit weak  
98 compliance behavior in which non-assessed pollutants are effectively ignored (Wang &  
99 Zhao, 2025). In sum, although the literature has examined how the effects of the River

100 Chief System vary across spatial scales, the city-specific conditions that drive such  
101 variation, particularly how the transmission intensity of political pressure, north–south  
102 differences in water resource endowment, and disparities in fiscal implementation  
103 capacity jointly shape policy effectiveness, remain largely unexplored.

104 Does the River Chief System reduce urban industrial wastewater discharge intensity?  
105 Does the political rank of the provincial chief river official strengthen the downward  
106 transmission of policy pressure? Do regional differences in water resources lead to  
107 systematic variation in implementation? And are cities with greater fiscal autonomy more  
108 effective in achieving emission reductions in practice?

109 Drawing on an unbalanced panel dataset of 285 prefecture-level cities from 2013 to  
110 2020, this paper constructs a staggered difference-in-differences model that exploits  
111 cross-provincial variation in the timing of policy implementation to address these  
112 questions systematically.

113 The contributions are threefold, and the central one concerns not whether the River  
114 Chief System reduces discharge but the conditions under which a decentralized  
115 accountability arrangement is translated into compliance. The first contribution reframes  
116 the question of policy effectiveness. Rather than asking in binary terms whether  
117 institutional accountability works, this study advances the view that the effectiveness of  
118 the River Chief System is contingent on the joint configuration of political, ecological, and  
119 fiscal conditions, and it documents how each condition shapes the strength of the  
120 response. This moves the discussion from a question about average effects toward one  
121 about institutional and environmental complementarities, namely which combinations of  
122 downward political pressure, resource-driven governance motivation, and fiscal  
123 execution capacity allow a paper mandate to become enforced behavior. The second  
124 contribution is empirical. The study targets urban industrial wastewater discharge  
125 intensity, complements it with the discharge of chemical oxygen demand and ammonia  
126 nitrogen, and exploits exogenous provincial variation in policy rollout to construct a  
127 quasi-experimental design, providing robust evidence through systematic checks using  
128 the Callaway–Sant’Anna and Sun–Abraham estimators. The third contribution is to trace  
129 how the policy operates, with the accountability arrangement raising local environmental

130 enforcement effort and encouraging a shift toward cleaner industrial activity, which offers  
131 evidence on the channels through which decentralized environmental policy works rather  
132 than treating the effect as a black box. From a policy standpoint, the findings provide  
133 direct guidance for institutional reform and incentive design in jurisdictions seeking to  
134 enhance water environmental governance under decentralized arrangements, with  
135 broader relevance for other developing and transition economies.

## 136 **2 Literature Review and Hypothesis Development**

### 137 **2.1 Literature Review**

138 The governance of water environments in China lies at the heart of ecological  
139 civilization construction, and industrial wastewater, the principal source of surface water  
140 pollution, has long attracted attention regarding both its emission reduction pathways  
141 and the policy responses available. The literature on factors influencing industrial  
142 wastewater discharge is now relatively comprehensive. With respect to pollution sources,  
143 industrial activity remains the central driver of water body pollution in China, reflecting  
144 both firm-level discharge behavior and the strength of regional regulatory capacity; the  
145 combined pressure of agricultural non-point source pollution, domestic sewage, and  
146 industrial discharge poses an increasingly severe challenge for water quality protection.  
147 With respect to the institutional environment, fiscal decentralization significantly shapes  
148 local governments' willingness to invest in environmental protection and their actual  
149 governance performance. Areas with greater fiscal capacity tend to exhibit higher  
150 implementation standards but do not necessarily achieve lower aggregate emissions  
151 simply by gaining more autonomy (Xu, 2022). The literature on technological pathways  
152 has also identified threshold effects: the suppressive effect of technological progress on  
153 water pollution intensity becomes more pronounced under sufficiently strong regulatory  
154 pressure (Ma et al., 2020). Although most studies describe mechanisms that may  
155 influence industrial wastewater discharge, detailed assessment of how specific policies  
156 and regulatory measures translate into emission outcomes remains limited.

157 Empirical evaluations of China's water environmental governance policies have  
158 grown rapidly. Among the institutional reforms whose effects on water quality are now  
159 relatively well established, several findings stand out. Evidence from cities in the Yangtze

160 River Economic Belt indicates that the River Chief System produces a substantial  
161 reduction in surface water pollution, with effects more pronounced in smaller cities and  
162 in those with weaker baseline regulation and lower economic capacity (She et al., 2019).  
163 Dynamic firm-level analysis suggests a delayed emission-reduction effect: it typically  
164 takes two to three years before chemical oxygen demand declines noticeably, and certain  
165 pollutants exhibit short-term spikes following policy introduction (Zuo et al., 2026).  
166 County-level evidence shows that the River Chief System reduces water pollution from  
167 livestock and poultry wastewater shocks but cannot fully restrain non-point source  
168 pollution from fertilizer use (Li & Huang, 2021). Other research based on provincial  
169 monitoring data identifies signs of surface-level governance and notes that path  
170 dependence favoring economic development can undermine the system's expected effects  
171 across all pollutants (Li et al., 2020). Beyond the River Chief System, work on other  
172 elements of China's ecological civilization framework suggests that linking officials'  
173 performance evaluation directly to environmental quality targets can improve  
174 implementation, though weak local execution capacity continues to generate substantial  
175 regional variation in policy outcomes (Chen, 2024; Li et al., 2024; Zheng et al., 2022).  
176 The divergence among these findings is itself informative rather than a set of  
177 contradictions to be averaged away. Firm-level studies capture immediate adjustment  
178 costs and the lumpy timing of abatement investment, which can register as a transitory  
179 rise in measured concentration, whereas city-level studies observe the net behavioral  
180 response once adjustment has occurred; results tend to be stronger for assessed  
181 pollutants that enter official evaluation than for those outside the assessment scope; and  
182 studies that end early or rely on a conventional two-way fixed effects specification under  
183 staggered adoption may understate effects that accumulate over time. Reading the prior  
184 evidence in this light clarifies the gap this study addresses, since working at the city level,  
185 examining an intensity measure alongside the discharge of the two assessed pollutants,  
186 and relying on estimators designed for heterogeneous and staggered treatment together  
187 recover a behavioral response that is comparable across the conflicting prior findings.

188 Building on these contributions, the existing literature has accumulated empirical  
189 evidence on the effects of the River Chief System at the city, firm, and county levels but

190 has not systematically examined how policy effects vary across regions under a unified  
191 institutional framework. In particular, few studies investigate how the strength of  
192 political pressure transmission, regional differences in water resource endowment, and  
193 disparities in urban fiscal capacity jointly shape the spatial structure of the system's  
194 emission-reduction effects. Political incentives determine whether accountability  
195 pressure can be transmitted effectively to municipal-level executive bodies; resource  
196 scarcity shapes the intensity with which local officials pursue implementation; and fiscal  
197 capacity ensures that institutional deployment is backed by adequate resources and  
198 enforcement strength. These three factors operate through distinct channels but jointly  
199 determine ultimate policy effectiveness. Without explicit attention to these conditioning  
200 factors, the underlying drivers of cross-city variation in River Chief System outcomes  
201 remain obscured, and it is difficult to design targeted policies suitable for different urban  
202 governance contexts. Drawing on an unbalanced panel of 285 prefecture-level cities from  
203 2013 to 2020, this paper applies a staggered difference-in-differences approach to  
204 integrate these three categories of city-level characteristics into a unified analytical  
205 framework, providing a more nuanced understanding of the spatial heterogeneity of the  
206 River Chief System's emission-reduction performance.

## 207 **2.2 Hypothesis Development**

208 According to environmental federalism theory, the central government sets general  
209 environmental improvement goals while local governments adopt specific strategies  
210 appropriate to their circumstances under the relevant incentives and constraints. The  
211 River Chief System ties leadership accountability directly to environmental protection  
212 objectives at every level and transmits responsibility downward through the  
213 administrative hierarchy when water pollution control fails to meet expectations.  
214 Industrial wastewater is now a major contributor to water pollution across prefectures,  
215 reflecting both firm operating behavior and the strength of government regulation (Hong  
216 et al., 2020). Prior to the implementation of the River Chief System, the principal  
217 problems in river protection were diffuse responsibility, fragmented management, and  
218 weak incentive mechanisms (Wang & Chen, 2020). According to the principal-agent  
219 model, as monitoring costs fall and incentive-compatibility constraints tighten, agents'

220 actions increasingly reflect the principal's interests (Levačić, 2009; Miller & Whitford,  
221 2007). Through mechanisms such as the "one-vote veto" and annual performance  
222 appraisal of river chiefs, the new incentive structure makes it infeasible for local officials  
223 to evade responsibility for polluted water bodies in their jurisdictions, generating tangible  
224 regulatory pressure on enterprises that discharge wastewater. This leads to the following  
225 hypothesis:

226 **H1:** *Implementation of the River Chief System decreases the intensity of urban*  
227 *industrial wastewater discharge.*

228 Effectiveness can vary substantially across localities under the same institutional  
229 framework, and the strength of political pressure transmission is one important  
230 conditioning factor. Political incentive theory offers a specific expectation here, but its  
231 application to the River Chief System depends on a feature of the Chinese cadre system  
232 that deserves to be stated explicitly rather than assumed. In a promotion-tournament  
233 setting, the behavior of a subordinate official responds most strongly to signals that  
234 originate from the level with authority over that official's advancement, and the  
235 credibility of such a signal rises with the rank of the official who issues it (Chen et al.,  
236 2017). When the provincial chief river official is the provincial party secretary or governor,  
237 water environmental performance is no longer one objective among many delegated to a  
238 functional department; it becomes a priority owned by the leader who controls the  
239 evaluation of every city-level official in the province. The mechanism therefore runs  
240 through the structure of the cadre evaluation system rather than through any change in  
241 formal regulatory authority. The scope condition is that this expectation applies where  
242 promotion is centrally managed and where a higher-ranked principal can credibly attach  
243 career consequences to a specific outcome, which is the situation of provincial leadership  
244 in China. When the provincial chief river official is the provincial party secretary or  
245 governor, environmental management becomes a high-salience responsibility at the  
246 provincial level, the risk of regulatory laxity at city and county levels declines, and local  
247 officials become more strongly motivated to strengthen pollution prevention within their  
248 jurisdictions. This pattern is particularly pronounced in China's governance model, where  
249 direct supervision by senior officials can rapidly translate written policy plans into on-

250 the-ground action (Kornreich, 2025; Schubert & Alpermann, 2019). Conversely, when the  
251 chief river official holds a relatively low rank, command authority is weaker, local  
252 enforcement enjoys more discretion, and policy effectiveness is correspondingly  
253 diminished. Hence:

254 **H2:** *The higher the political rank of the river chief, the greater the emission-*  
255 *reduction effect of the River Chief System.*

256 Beyond political motivation, the natural environment of a city can also shape  
257 officials' governance behavior. Resource scarcity theory holds that the effort an actor  
258 devotes to safeguarding a resource rises with the scarcity of that resource (Hassani-  
259 Mahmooei & Parris, 2013). The theory was originally developed for private resource users  
260 facing the prospect of depletion, so its transfer to the behavior of bureaucratic officials  
261 calls for a bridging argument rather than a direct transplant. That bridge is the political  
262 salience of scarcity. In northern Chinese cities, low per capita water availability raises the  
263 cost of water supply, tightens the carrying capacity of local water environments, and turns  
264 water shortage into a visible source of public concern and potential social instability.  
265 Under these conditions, water becomes a resource whose mismanagement carries  
266 political risk for the official, so the official internalizes the scarcity that residents face and  
267 treats water environmental governance as a higher priority. The scope condition for  
268 applying the theory to officials is thus that scarcity is politically salient enough to enter  
269 the official's own objective function, which holds where water shortage is severe and  
270 locally visible. Northern Chinese cities generally have far lower per capita water resources  
271 than their southern counterparts, face greater pressure on water environmental carrying  
272 capacity, and contend not only with higher water supply costs but also with potential  
273 social stability concerns associated with water scarcity. These conditions give local  
274 officials in the north stronger incentives to advance River Chief System implementation.  
275 In the south, where water environmental constraints are typically less severe, officials  
276 retain more flexibility in policy execution, and full institutionalization is harder to ensure.  
277 Studies of local government behavior find that officials tend to allocate administrative  
278 resources toward the points of greatest governance pressure (Agranoff, 2014); the scarcer  
279 a region's water resources, the stronger the actual governance pressure, and the greater

280 the deterrent effect of policy. Accordingly:

281 **H3:** *Cities with scarcer water resources exhibit a larger emission-reduction effect*  
282 *under the River Chief System.*

283 Governance motivation must be matched by governance capacity to produce results.  
284 Fiscal federalism theory in its classical form assumes autonomous subnational  
285 jurisdictions that set their own taxes and tailor public goods provision to local preferences,  
286 and it links the quality of that provision to local fiscal capacity (Zhuravskaya, 2000). The  
287 Chinese fiscal system departs from this benchmark in an important respect, because local  
288 governments operate under substantial central constraints on both revenue authority and  
289 expenditure mandates, so they cannot freely adjust taxation to fund local priorities. The  
290 relevant insight from the theory survives this departure once it is framed in terms of fiscal  
291 capacity rather than fiscal autonomy. What matters for the River Chief System is whether  
292 a city can mobilize the resources required to give the policy effect, and a city with a higher  
293 ratio of own revenue to expenditure has greater discretionary room to finance  
294 environmental infrastructure and enforcement even within a centrally constrained  
295 system. The theory is therefore applied here in its capacity formulation, which suits a  
296 setting where jurisdictions lack tax-setting power but still differ markedly in the fiscal  
297 slack available for discretionary policy implementation. The River Chief System requires  
298 the construction and maintenance of online monitoring equipment, upgrading of  
299 wastewater treatment facilities, and strengthening of environmental enforcement  
300 capacity, all of which depend on sustained fiscal support. Cities with greater fiscal  
301 capacity are better positioned to convert high-quality development standards into  
302 binding rules on enterprise wastewater discharge through environmental funds,  
303 improved enforcement efficiency, and related instruments. Fiscally constrained cities, by  
304 contrast, often confine implementation to formal documents without the supporting  
305 measures needed to give policy effect. Classic studies of public policy implementation  
306 likewise emphasize that implementation capacity is a key determinant of whether policy  
307 goals are ultimately achieved (O'Toole Jr, 2000; Williams, 2021). This leads to:

308 **H4:** *Cities with higher fiscal self-sufficiency achieve larger emission reductions*  
309 *under the River Chief System.*

### 310 **3 Methodology**

#### 311 **3.1 Data Sources**

312 This study constructs an unbalanced panel dataset of 285 prefecture-level cities in  
313 China from 2013 to 2020. Information on the timing of River Chief System  
314 implementation was hand-collected from official documents and government work  
315 reports, including the year in which each prefecture-level city's province formally issued a  
316 comprehensive plan for advancing the system, which is treated as the policy  
317 implementation year. Data on industrial wastewater discharge volumes and related water  
318 pollution indicators are drawn from the China Environmental Statistics Yearbook and the  
319 China Urban Statistical Yearbook; regional economic and social regulatory variables  
320 come from the China Urban Statistical Yearbook and provincial statistical yearbooks.  
321 City-level discharge of chemical oxygen demand and ammonia nitrogen in industrial  
322 wastewater is obtained from the China Economic Information Network statistical  
323 database, whose figures derive from data published by local statistical bureaus. The count  
324 of green patent authorizations at the city level is drawn from the China National  
325 Intellectual Property Administration records. Data on the personal characteristics of  
326 officials are obtained from a comprehensive database of provincial, municipal, and  
327 county-level officials in China provided by CnDataSeed, which is used to construct  
328 measures of the political rank of river chiefs.

#### 329 **3.2 Variable Definitions**

330 Industrial wastewater discharge intensity (WINT): the annual industrial wastewater  
331 discharge volume of each city divided by total industrial output value in the same year,  
332 expressed in logarithmic form to mitigate heteroskedasticity. As an alternative measure,  
333  $\log(\text{WASTE})$  is also used.

334 The core explanatory variable is the River Chief System implementation dummy  
335 (RIVER), which equals 1 if the province in which the prefecture-level city is located has  
336 officially issued a comprehensive plan for implementing the River Chief System and the  
337 system is in effect during the corresponding year, and 0 otherwise. Because the central  
338 government issued a unified deployment plan at the end of 2016 and provinces  
339 completed implementation between 2017 and 2018, the staggered timing of provincial  
340 rollouts provides exogenous variation suitable for a staggered difference-in-differences

341 design.

342 The study further examines interaction effects between three city-level  
343 characteristics and the River Chief System policy. River chief political rank (RANK)  
344 equals 1 when the provincial party secretary or governor personally serves as the  
345 provincial chief river official; a higher political rank implies stronger downward  
346 transmission of accountability pressure, and the interaction with RIVER is expected to be  
347 significantly negative. Water resource endowment (WATER) measures per capita water  
348 resources at the city level; in water-scarce northern regions, the urgency of environmental  
349 governance is greater, and the River Chief System's effect on industrial wastewater  
350 control is expected to be more pronounced. Fiscal self-sufficiency (FISCAL) is defined as  
351 the ratio of local general public budget revenue to expenditure; cities with higher fiscal  
352 autonomy possess greater capacity to support environmental infrastructure construction.  
353 These three variables capture, respectively, political pressure transmission, natural  
354 condition constraints, and fiscal execution capacity.

355 Two mechanism variables are used to characterize how the policy operates.  
356 Environmental enforcement intensity (ENV) is measured as completed investment in  
357 industrial pollution control projects divided by industrial output, capturing the effort that  
358 local governments devote to enforcement and abatement. Green patent intensity (GPAT)  
359 is the logarithm of one plus the annual number of authorized green patents in each city,  
360 capturing the extent to which the local economy is shifting toward cleaner production.

361 The control variables include per capita GDP (PGDP) to capture scale effects of  
362 economic growth on emissions; the share of industrial output in GDP (IND) to account  
363 for differences in industrial structure; the logarithm of actual utilized foreign direct  
364 investment (FDI); and the logarithm of population density (POP).

### 365 **3.3 Empirical Strategy**

366 Variation in the timing of formal River Chief System adoption across provinces is  
367 used to construct a staggered difference-in-differences (SDD) model. Because  
368 deployment was directed centrally, the staggered rollout offers a favorable setting for  
369 estimating the net policy effect while ruling out most forms of self-selection bias by  
370 provinces. The baseline specification is given below:

371 
$$WINT_{it} = \alpha + \beta RIVER_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

372 where  $WINT_{it}$  is the industrial wastewater discharge intensity of city  $i$  in year  $t$ ;  
 373  $RIVER_{it}$  is the core explanatory variable;  $X_{it}$  is a set of time-varying control variables;  $\mu_i$  is  
 374 the city fixed effect, absorbing time-invariant city-level differences;  $\lambda_t$  is the year fixed  
 375 effect, controlling for common time trends; and  $\varepsilon_{it}$  is the random error term.

376 **4 Results**

377 **4.1 Descriptive Statistics**

378 Table 1 reports descriptive statistics for the main variables. The mean industrial  
 379 wastewater discharge intensity (WINT) is 1.352, with a standard deviation of 0.824,  
 380 indicating substantial cross-city variation in wastewater discharge performance and  
 381 providing sufficient cross-sectional contrast for comparison. The mean of the River Chief  
 382 System dummy (RIVER) is 0.423, indicating that about four-tenths of the city-year  
 383 observations correspond to post-implementation periods, with provinces gradually  
 384 rolling out the system during 2017 and 2018. The distribution of control variables is  
 385 broadly consistent with expectations: the mean of per capita GDP (PGDP) is 10.682,  
 386 corresponding to typical prefecture-level per capita output; the mean industrial output  
 387 share (IND) is 0.412, reflecting a manufacturing-oriented industrial structure across the  
 388 sample. All variables fall within reasonable empirical ranges, with no extreme outliers  
 389 attributable to observational bias.

390 **Table 1.** Descriptive Statistics

Variable	N	Mean	SD	Min	Max
WINT	1,986	1.352	0.824	-1.203	3.847
WASTE	1,986	7.218	1.134	3.562	10.241
COD	1,986	9.864	1.057	5.913	12.736
NH <sub>3</sub> N	1,986	7.142	1.218	3.047	10.358
RIVER	1,986	0.423	0.494	0.000	1.000
PGDP	1,986	10.682	0.512	9.143	12.084
IND	1,986	0.412	0.112	0.108	0.692
FDI	1,986	11.243	1.876	5.234	15.682
POP	1,986	5.847	0.734	3.621	8.143
ENV	1,986	0.012	0.008	0.001	0.063

Variable	N	Mean	SD	Min	Max
GPAT	1,986	3.964	1.472	0.000	8.216
FISCAL	1,986	0.487	0.213	0.092	1.058

## 391 4.2 Benchmark Results

392 Table 2 reports the baseline regression estimates. Column (1) includes only city and  
393 year fixed effects, while column (2) additionally incorporates the full set of control  
394 variables. Both columns indicate that River Chief System implementation produces an  
395 identifiable suppressive effect on industrial wastewater discharge intensity. In the  
396 absence of control variables, the coefficient on RIVER is  $-0.087$ , significant at the 5%  
397 level; because WINT is log-transformed, this coefficient implies that industrial  
398 wastewater discharge intensity declines by approximately 8.3% following implementation.  
399 With control variables included, the coefficient narrows to  $-0.074$ , remaining significant  
400 at the 5% level and corresponding to a reduction of approximately 7.1%. This moderate  
401 contraction suggests that part of the unconditional estimate is confounded by systematic  
402 city-level characteristics, but the direction and magnitude of the policy effect remain  
403 stable, leaving the core conclusion substantively unchanged.

404 **Table 2.** Baseline Results

Variable	(1) WINT	(2) WINT
RIVER	$-0.087^{**}$ (-2.34)	$-0.074^{**}$ (-1.98)
PGDP		$-0.312^{***}$ (-4.21)
IND		$0.643^{**}$ (2.47)
FDI		$-0.031$ (-1.12)
POP		$0.124^*$ (1.87)
City FE	Yes	Yes
Year FE	Yes	Yes

Variable	(1)	(2)
N	1,986	1,986
R <sup>2</sup>	0.689	0.708

405 *Note: t-statistics in parentheses; \*\*\*, \*\*, \* indicate significance at the 1%, 5%, and 10% levels,*  
406 *respectively. Standard errors are clustered at the city level. All the subsequent tables are consistent*  
407 *with the current table.*

408 Several control variables, including fiscal self-sufficiency, per capita GDP, industrial  
409 structure, and foreign direct investment, are plausibly related to one another, so it is  
410 useful to check that this overlap does not distort the estimates. Table 3 reports variance  
411 inflation factors for the baseline specification. The values are uniformly low, with a  
412 maximum of 2.41 for PGDP and a mean of 1.87 across the regressors, comfortably below  
413 both the conventional threshold of 10 and the more demanding threshold of 5.

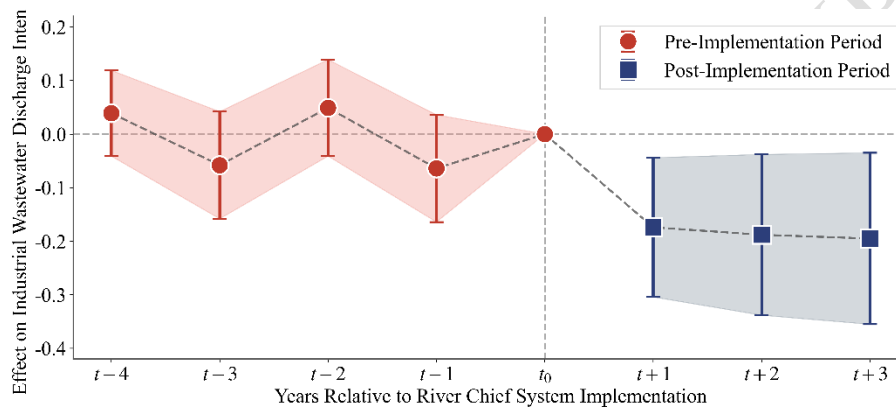
414 **Table 3.** Variance Inflation Factors

Variable	VIF
PGDP	2.41
FDI	2.13
FISCAL	2.06
IND	1.78
POP	1.52
ENV	1.34
Mean	1.87

### 415 **4.3 Robustness Checks**

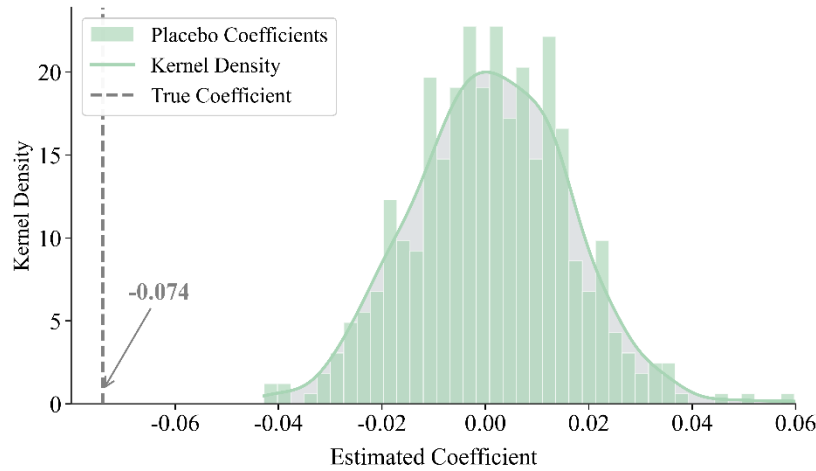
416 The validity of staggered difference-in-differences estimation rests on the parallel  
417 trends assumption: treated and control cities should display similar pre-implementation  
418 trajectories of industrial wastewater discharge intensity. To assess this assumption, an  
419 event study model is estimated to obtain period-specific policy coefficients, and the  
420 corresponding patterns are presented in Figure 1. The estimated coefficients for all four  
421 pre-implementation periods are close to zero, with confidence intervals that comfortably  
422 contain zero, providing reasonable empirical support for the parallel trends assumption.  
423 From the implementation year onward, the coefficients move steadily in a negative

424 direction over the next three periods before stabilizing. This pattern indicates that the  
 425 emission-reduction effect of the River Chief System is not a one-time impulse but  
 426 accumulates gradually with the depth of implementation, consistent with the practical  
 427 reality that the system typically requires several adjustment phases before generating  
 428 clearly observable effects. The figure plots the event study coefficients together with their  
 429 95% confidence intervals, with the period immediately preceding implementation serving  
 430 as the base period; the horizontal axis measures event time in years relative to  
 431 implementation and the vertical axis measures the estimated coefficient on WINT.



432  
 433 **Figure 1. Parallel Trends Test**

434 A placebo test is also conducted by randomizing treatment timing across the sample.  
 435 Policy implementation years are assigned randomly to sampled cities, and 500 simulated  
 436 regressions are used to construct the empirical distribution of placebo RIVER coefficients.  
 437 As shown in Figure 2, the empirical distribution is concentrated around zero, while the  
 438 actual baseline coefficient of  $-0.074$  lies in the left tail, far from the center of the placebo  
 439 distribution. This pattern indicates that the estimated policy effect is unlikely to arise  
 440 from chance variation or omitted variable bias. The figure note records that the  
 441 distribution is constructed from 500 random reassignments of treatment timing, and the  
 442 actual estimated coefficient of  $-0.074$  is marked against this distribution, lying far below  
 443 the bulk of the simulated coefficients.



**Figure 2.** Placebo Test

444

445

446 Additional robustness checks reported in Table 4 reinforce the baseline conclusion.

447 Column (1) employs propensity score matching combined with difference-in-differences

448 (PSM-DID), using city-level 2013 control variables as matching covariates and applying

449 one-to-one nearest-neighbor matching before re-estimation; the RIVER coefficient is

450  $-0.069$ , significant at the 10% level, with a sign and magnitude broadly consistent with

451 the baseline. Column (2) replaces the dependent variable with the logarithm of industrial

452 wastewater discharge volume (WASTE); the coefficient is  $-0.091$ , significant at the 5%

453 level, indicating that the River Chief System's compression of industrial wastewater

454 discharge behavior is robust across alternative measurement choices. Column (3) further

455 includes the number of pollutant discharge permits issued (the logarithm of the annual

456 number of enterprises in each city receiving a discharge permit) and an environmental

457 protection tax dummy (equal to 1 from the year in which the provincial government

458 completes local rate filing and officially begins collection, generally from 2018 onward) in

459 order to absorb potential confounding from concurrent reforms in the discharge permit

460 system and the environmental protection tax. After these adjustments, the RIVER

461 coefficient is  $-0.071$ , significant at the 10% level and close in magnitude to the original

462 estimate; the policy effect remains identifiable once concurrent reforms are accounted for.

463 The coefficients on the discharge permit count and the environmental protection tax

464 dummy are both significant at conventional levels and consistent with their expected

465 emission-reducing effects, but their inclusion does not materially alter the main result.

466 Column (4) re-estimates the model after excluding provincial capitals and cities with

467 independent planning status; the coefficient is  $-0.078$ , still significant at the 10% level  
 468 and close to the baseline, suggesting that the inclusion of a small number of politically  
 469 and economically prominent cities does not drive the overall conclusion.

470 **Table 4.** Robustness Checks

Variable	(1) PSM-DID	(2) WASTE	(3) Concurrent Policies	(4) Excl. Capitals
RIVER	$-0.069^*$ (-1.89)	$-0.091^{**}$ (-2.16)	$-0.071^*$ (-1.91)	$-0.078^*$ (-1.94)
Permit (log)			$-0.134^{**}$ (-2.08)	
ENVTAX			$-0.056^*$ (-1.72)	
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	1,724	1,986	1,986	1,742
R <sup>2</sup>	0.701	0.681	0.715	0.705

471 Because staggered implementation can produce heterogeneous treatment dynamics  
 472 across cohorts, Table 5 reports aggregated average treatment effects estimated using the  
 473 Callaway–Sant’Anna and Sun–Abraham methods, respectively (Callaway & Sant’Anna,  
 474 2021; Sun & Abraham, 2021). The first method constructs clean comparison cohorts for  
 475 each treatment period and aggregates cohort-specific average treatment effects; the  
 476 second decomposes the two-way fixed effects coefficient into a weighted sum of period-  
 477 specific contributions through an interaction-weighted procedure. Both methods provide  
 478 unbiased aggregate estimates under heterogeneous treatment effects. The two estimators  
 479 yield ATTs of  $-0.068$  and  $-0.071$ , both significant at the 5% level and very close to the  
 480 TWFE estimate of  $-0.074$ . The joint significance test for the pre-treatment period yields a  
 481 p-value of 0.331 and does not reject pre-treatment parallelism, in line with the visual  
 482 evidence in Figure 1; overall robustness is therefore satisfactory.

483

484

**Table 5.** Callaway–Sant’Anna & Sun–Abraham

Variable	Callaway–Sant’Anna	Sun–Abraham
	WINT	WINT
Overall ATT	–0.068** (–2.19)	–0.071** (–2.08)
Pre-test p-value	0.331	
Controls	Yes	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
N	1,986	1,986

#### 486 4.4 Pollutant-Specific Outcomes

487 The intensity measure used so far captures discharge per unit of industrial output,  
488 which reflects firm behavior and the administrative effort behind it. It is natural to ask  
489 whether the same effect appears in the pollutants that the water quality assessment  
490 system actually targets, since chemical oxygen demand and ammonia nitrogen are the  
491 two pollutants written into China’s binding water quality evaluation. A policy that  
492 tightens water governance, rather than merely compressing aggregate wastewater volume,  
493 should leave a mark on the discharge of these two substances in particular. Table 6 re-  
494 estimates the baseline specification with the logarithm of industrial chemical oxygen  
495 demand discharge (COD) and the logarithm of industrial ammonia nitrogen discharge  
496 (NH<sub>3</sub>N) as outcomes, keeping the full set of controls and fixed effects.

497 The results are in line with the baseline finding. In column (1), the coefficient on  
498 RIVER for chemical oxygen demand is –0.083, significant at the 5% level, implying a  
499 reduction of roughly 8.0% following implementation. In column (2), the coefficient for  
500 ammonia nitrogen is –0.078, significant at the 10% level, corresponding to a reduction of  
501 roughly 7.5%. The response is somewhat sharper for chemical oxygen demand than for  
502 ammonia nitrogen, which fits the greater prominence of chemical oxygen demand in the  
503 assessment framework, and the broad similarity in magnitude across the two assessed  
504 pollutants and the intensity measure suggests that the reduction reflects a real change in  
505 pollution behavior.

**Table 6.** Pollutant-Specific Outcomes

Variable	(1)	(2)
	COD	NH <sub>3</sub> N
RIVER	-0.083** (-2.02)	-0.078* (-1.86)
Controls	Yes	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
N	1,986	1,986
R <sup>2</sup>	0.727	0.703

#### 508 4.5 How the Policy Operates

509 Establishing that the River Chief System lowers discharge raises the question of how  
510 the effect comes about. Among the channels that the institutional logic of the system  
511 suggests, two can be examined with the data at hand. The accountability arrangement  
512 operates first on local government, which may respond to heightened evaluation pressure  
513 by raising its enforcement and abatement effort, and this enforcement effort may in turn  
514 press the local economy toward cleaner production, which lowers discharge per unit of  
515 output. Table 7 examines these two channels in turn, using environmental enforcement  
516 intensity (ENV) and green patent intensity (GPAT). For each channel, columns report the  
517 association of the policy with the channel and then the joint association of the policy and  
518 the channel with discharge, so that the portion of the effect running through the channel  
519 and the portion remaining direct can be read together.

520 Columns (1) and (2) trace the enforcement channel. In column (1), the policy is  
521 associated with an increase in ENV of 0.002, significant at the 5% level. In column (2),  
522 where both RIVER and ENV enter the discharge regression, ENV carries a coefficient of  
523 -3.200 on WINT, significant at the 5% level, and the direct coefficient on RIVER is  
524 -0.068, also significant at the 5% level, so the portion of the effect running through  
525 enforcement is close to -0.006 and the two pieces together recover the baseline estimate  
526 of approximately -0.074. Columns (3) and (4) trace the cleaner-production channel. In  
527 column (3), the policy is associated with an increase in GPAT of 0.094, significant at the 5%  
528 level. In column (4), GPAT carries a coefficient of -0.170 on WINT, significant at the 5%

529 level, and the direct coefficient on RIVER is  $-0.058$ , significant at the 10% level, so the  
 530 portion running through cleaner production is close to  $-0.016$  and again the two pieces  
 531 together return the baseline estimate. These patterns indicate that stronger enforcement  
 532 effort and a shift toward cleaner production each account for part of the headline effect  
 533 while a direct association remains, which fits the technology literature, in which the  
 534 pollution-reducing role of innovation is stronger under heavier regulatory pressure (Ma  
 535 et al., 2020), and evidence that performance assessment under the River Chief System  
 536 encourages green innovation by enterprises (Tang et al., 2025).

537

**Table 7.** How the Policy Operates

Variable	(1) ENV	(2) WINT	(3) GPAT	(4) WINT
RIVER	0.002** (2.31)	-0.068** (-1.99)	0.094** (2.18)	-0.058* (-1.71)
ENV		-3.200** (-2.27)		
GPAT				-0.170** (-2.05)
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	1,986	1,986	1,986	1,986
R <sup>2</sup>	0.682	0.719	0.747	0.717

538

#### 4.6 Further Investigation

539

Building on the baseline results, interaction terms between three city-level  
 540 characteristics and the River Chief System are introduced to examine whether policy  
 541 effects vary systematically across cities, as specified below:

542

$$WINT_{it} = \alpha + \beta_1 RIVER_{it} + \beta_2 RIVER_{it} \times M_{it} + \beta_3 M_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

543

where  $M_{it}$  is replaced in turn by RANK, WATER, and FISCAL, and  $\beta_2$  captures the  
 544 strengthening or weakening effect of each city characteristic on the system's emission-  
 545 reduction performance. The results are reported in Table 8, with the three columns  
 546 examining how policy effects diverge along the dimensions of political pressure

547 transmission, water resource endowment, and fiscal execution capacity.

548 Column (1) presents the interaction between RIVER and river chief political rank  
 549 (RANK). The interaction coefficient is  $-0.089$  and significant at the 5% level, while the  
 550 main effect of RIVER is  $-0.052$  and statistically insignificant. This suggests that in cities  
 551 whose provincial chief river official is not the principal provincial leader, the direct  
 552 emission-reduction effect of the River Chief System is comparatively modest, whereas a  
 553 higher political rank can substantially amplify this effect. When the provincial party  
 554 secretary or governor takes the lead, accountability pressure is transmitted directly  
 555 downward to municipal and county governments, regulation of polluting enterprises  
 556 within their jurisdictions is strengthened, and enforcement intensity rises accordingly, a  
 557 pattern that resonates strongly with the "top-leader effect" repeatedly observed in China's  
 558 water environmental governance experience.

559 **Table 8.** Further Investigation

Variable	(1)	(2)	(3)
	WINT	WINT	WINT
RIVER	$-0.052$ (-1.24)	$-0.083$ (-1.53)	$-0.043$ (-1.02)
RIVER $\times$ RANK	$-0.089^{**}$ (-2.18)		
RANK	$0.034$ (0.87)		
RIVER $\times$ WATER		$0.023^*$ (1.87)	
WATER		$-0.018^{**}$ (-2.14)	
RIVER $\times$ FISCAL			$-0.124^{**}$ (-2.03)
FISCAL			$-0.087$ (-1.43)
Controls	Yes	Yes	Yes
City FE	Yes	Yes	Yes

Variable	(1)	(2)	(3)
Year FE	Yes	Yes	Yes
N	1,986	1,986	1,986
R <sup>2</sup>	0.716	0.714	0.718

560 Column (2) reports the interaction between RIVER and per capita water resources.  
561 The interaction coefficient is 0.023 and significant at the 10% level, indicating that the  
562 suppressive effect of the River Chief System on industrial wastewater discharge weakens  
563 as water resource availability increases. The main effect of WATER is  $-0.018$  and the  
564 coefficient on RIVER alone is statistically insignificant, implying that the policy's  
565 emission-reduction effect operates substantially through resource-endowment conditions.  
566 Water-stressed northern cities face heavier pressure on water environments, generating  
567 stronger official enthusiasm for implementing the River Chief System and  
568 correspondingly more rigorous enforcement, whereas in water-rich southern regions  
569 where governance demand is weaker, implementation is comparatively relaxed and policy  
570 effectiveness is reduced. The pronounced regional imbalance in China's water resources is  
571 therefore reflected directly in spatial differences in policy outcomes.

572 Column (3) reports the interaction between RIVER and fiscal self-sufficiency  
573 (FISCAL). The interaction coefficient is  $-0.124$ , significant at the 5% level, while the main  
574 effect of RIVER is  $-0.043$  and statistically insignificant. This pattern indicates that fiscal  
575 capacity substantially conditions the magnitude of the system's emission-reduction effect.  
576 Fiscally stronger cities can provide robust financial support for the institutional  
577 infrastructure of the River Chief System, including online monitoring equipment,  
578 supporting wastewater treatment facilities, and complementary regulatory capacity, and  
579 can sustain incentive and accountability arrangements that anchor environmental  
580 enforcement, thereby reinforcing the durability of emission-reduction effects. In fiscally  
581 constrained cities, by contrast, the system risks remaining a paper exercise that fails to  
582 generate genuine governance pressure. Taken together, the three columns demonstrate  
583 that the policy effects of the River Chief System are not uniform across cities: whether  
584 political pressure is effectively transmitted downward, whether water resource scarcity  
585 provides strong governance motivation, and whether fiscal capacity supports institutional

586 implementation jointly shape the spatial heterogeneity of the system's emission-  
587 reduction performance.

## 588 **5 Discussion**

589 The findings of this study extend the existing literature in two connected respects.  
590 With respect to the principal direction of policy effects, prior quasi-experimental work  
591 has generally concluded that the institutional accountability arrangement introduced by  
592 the River Chief System constrains industrial wastewater discharge, while the literature  
593 has repeatedly noted a pattern that warrants careful consideration, namely that under  
594 path dependence favoring economic development local officials often confine  
595 institutional implementation to visible compliance indicators and tacitly tolerate certain  
596 forms of discharge that satisfy headline criteria (Li et al., 2020; Wang & Zhao, 2025).  
597 This study focuses on emissions per unit of output, which more directly reflects an  
598 administrative intent to advance cleaner production, whereas other studies that examine  
599 aggregate emissions are more susceptible to confounding from industrial structural  
600 adjustment, so that observed declines may partly reflect production constraints rather  
601 than pollution control. The pollutant-specific results add to this picture, since the  
602 reduction appears in chemical oxygen demand and ammonia nitrogen, the two pollutants  
603 that enter the assessment system, which speaks to a response in the pollutants officials  
604 have the strongest reason to address.

605 With respect to the conditions and channels that shape policy effects, this study  
606 moves the discussion beyond the binary question of whether the system works toward the  
607 more policy-relevant question of which urban conditions translate institutional  
608 constraints into actual emission reductions, and how the translation occurs. As the  
609 political rank of the provincial chief river official rises, the scope for city-level officials to  
610 evade accountability narrows, a conclusion consistent with research on government  
611 behavior grounded in promotion tournament logic (Li et al., 2024). Regional differences  
612 in water resource endowment reflect the geographical roots of city-level governance  
613 motivation, since cities with lower per capita water resources face greater environmental  
614 carrying capacity risks and exhibit stronger internal incentives to strengthen institutional  
615 construction, whereas relatively water-rich cities retain considerable flexibility in

616 implementation. The role of fiscal capacity points to the material foundations of  
617 implementation, since monitoring equipment, treatment infrastructure, and sustained  
618 enforcement expenditures all depend on stable fiscal support. These conditions connect  
619 naturally to the channels documented above, in that political pressure governs how  
620 forcefully enforcement effort is activated while fiscal capacity governs whether a city can  
621 finance the enforcement that the first channel requires, so that the conditions for  
622 effectiveness and the channels of effectiveness are two aspects of the same process. The  
623 River Chief System works well not because of the rigor of its design alone but because  
624 that design interacts with a specific configuration of political, ecological, and fiscal  
625 conditions, and because the accountability pressure it creates is carried through  
626 government enforcement and a shift toward cleaner production.

## 627 **6 Conclusion**

628 Drawing on a panel dataset of 285 prefecture-level cities from 2013 to 2020, this  
629 paper shows that the River Chief System reduces urban industrial wastewater discharge  
630 intensity, with a magnitude and stability that hold across alternative estimation strategies,  
631 and that the reduction is also present in the discharge of chemical oxygen demand and  
632 ammonia nitrogen. Policy effectiveness varies systematically, being greater where  
633 political accountability pressure is strongly transmitted downward, where water resource  
634 scarcity reinforces local officials' sense of mission, and where fiscal autonomy provides  
635 the financial foundation needed to translate institutional responsibilities into enforceable  
636 behavior. The policy works in part through a process that begins with stronger local  
637 environmental enforcement and continues with a shift toward cleaner industrial activity,  
638 so that political pressure, resource endowment, and fiscal capacity together shape the  
639 spatial pattern of emission-reduction performance across Chinese cities.

640 These findings carry concrete implications for institutional design. The first concerns  
641 who is placed in charge. Because the response is concentrated in cities where the  
642 provincial party secretary or governor personally serves as the chief river official, the  
643 practical lesson is to assign the lead role at the level of principal provincial leadership  
644 rather than delegating it to a functional department head, since it is the rank of the  
645 responsible official that determines how forcefully accountability pressure reaches city

646 and county governments. The second concerns the form of fiscal support. A uniform  
647 transfer leaves the cities that most need help underserved, whereas a transfer formula  
648 that grants larger support to cities combining high environmental need with weak fiscal  
649 capacity directs resources where implementation would otherwise stall; in operational  
650 terms, such a formula would weight per capita water resources so that water-scarce cities  
651 receive more, weight the ratio of fiscal self-sufficiency so that fiscally constrained cities  
652 receive more, and use baseline pollution as a supplementary criterion. The third concerns  
653 the mix of instruments. Because the policy works through enforcement effort and a shift  
654 toward cleaner production rather than through a single lever, monitoring infrastructure,  
655 enforcement funding, and innovation support are best deployed together as  
656 complementary parts of one package. For other emerging economies confronting  
657 industrial water pollution under decentralized governance, the broader lesson is that  
658 incentive-compatible institutional design, paired with fiscal support differentiated by  
659 need, is more likely to deliver durable improvements in water resource management than  
660 repeated short-term policy shocks whose effects fade as external pressure subsides. The  
661 qualification is that the system works through the cadre evaluation structure, so  
662 transferring the approach calls for identifying the locally available mechanism, whether  
663 electoral accountability, statutory enforcement authority, or fiscal conditionality, through  
664 which responsibility for a named outcome can be made to carry real consequences for the  
665 responsible official.

666 Several features of the data mark out promising directions for further work. The  
667 sample runs through 2020, so a natural next step is to extend the panel as later data  
668 become available and examine how the effect matures over a longer horizon, which would  
669 speak directly to the durability of accountability-based governance. The treatment is  
670 dated by provincial rollout and applied at the provincial level, so the estimates are best  
671 read as the average response to provincial onset, and richer local implementation records  
672 would allow future research to distinguish the speed and depth of adoption across cities  
673 within a province. The pollutant-specific outcomes measure discharge of chemical oxygen  
674 demand and ammonia nitrogen, which speaks closely to firm behavior and administrative  
675 effort, and pairing these series with ambient monitoring records in future work would

676 connect discharge behavior to realized in-stream quality, since ambient conditions are  
677 additionally shaped by hydrology, upstream sources, and non-industrial activity. On the  
678 empirical side, the centrally mandated and staggered rollout is what makes the design  
679 informative, and although a credible external instrument is difficult to construct in this  
680 setting because plausible candidates would themselves be related to the conditions that  
681 influence discharge, the combination of event-study evidence, placebo testing,  
682 heterogeneity-robust estimators, and matching addresses the principal concerns within  
683 the available design and provides a solid foundation that finer-grained local data can  
684 build upon.

685

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687 The authors report there are no competing interests to declare.

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#### 691 **Data Availability Statement**

692 The data presented in this study are available on request from the corresponding author  
693 due to third-party restrictions.

694

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