NBER WORKING PAPER SERIES

COMBATING CROSS-BORDER EXTERNALITIES

Shiyi Chen
Joshua S. Graff Zivin
Huanhuan Wang
Jiaxin Xiong

Working Paper 30233
http://www.nber.org/papers/w30233

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
July 2022

We acknowledge financial support by the Humanity and Social Science Interdisciplinarily Innovative Youth Group Fund of Fundamental Research Funds for the Central Universities of East China Normal University (2021QKT002) and by the Innovation Research Group Project of the National Natural Science Foundation of China (72121002). The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Combating Cross-Border Externalities
Shiyi Chen, Joshua S. Graff Zivin, Huanhuan Wang, and Jiaxin Xiong
NBER Working Paper No. 30233
July 2022
JEL No. D22,H7,K32,Q53,Q56

ABSTRACT

This paper investigates the impact of a pioneering pollution reduction program, the Ecological Compensation Initiative (ECI) in China, which establishes side payments between upstream and downstream provinces along the same river. The program includes both Coasian and pay-for-performance elements. Instructed by a theoretical model, we employ a difference-in-differences empirical design and find strong evidence that the ECI mitigates the spillover effect of water pollution at the province boundary and brings about sharp reductions in water pollutant emissions from upstream firms, especially those in heavily polluting industries. This initiative also reduces upstream firms' output and pollution intensity relative to downstream firms. The impact is stronger for upstream firms closer to the river and the point at which it enters the downstream province. Further evidence shows a significant increase in the rate of firms' entry into neighboring prefectures, but no impact on firms' exit from that region due to the initiative. Evidence from similar programs, later established in other river systems, suggests that cross-jurisdictional negotiations can effectively mitigate cross-border pollution externalities.

Shiyi Chen
School of Economics
Fudan University
220 Handan Rd
Yangpu District
Shanghai
China
shiyichen@fudan.edu.cn

Joshua S. Graff Zivin
University of California, San Diego
9500 Gilman Drive, MC 0519
La Jolla, CA 92093-0519
and NBER
jgraffzivin@ucsd.edu

Huanhuan Wang
East China Normal University
School of Law
Shanghai
China
hhwang@law.ecnu.edu.cn

Jiaxin Xiong
School of Economics
Fudan University
220 Handan Rd
Yangpu District
Shanghai
China
jxxiong20@fudan.edu.cn

1 Introduction

Firms' ability to discharge pollutants into watercourses can impose significant negative externalities on downstream water users. When these users are located in the same administrative jurisdiction as the polluters, local regulations may be sufficient to balance their respective benefits and costs. However, when an administrative border separates these parties, local regulators may fail to consider the portion of damages which accrue to water users in downstream jurisdictions, resulting in excessively lenient regulations. Due to this dynamic, firms may choose (or be encouraged) to locate near jurisdictional boundaries so that the bulk of their pollution damages consist of such "spillovers."

This tension between upstream and downstream parties cannot easily be resolved even in countries such as China, which generally features centralized environmental regulation. In recent years, China has consistently tightened its regulatory stringency by improving environmental legislation formation and enforcement, mandating emission reduction targets, and setting environmental quality improvement goals.[1]

However, since nearly all of these new regulatory instruments are applied at the locality level, rather than at the firm level, they are susceptible to border effects. By strategically relocating polluters towards boundary areas through differential regulation, local governments can improve their local environmental quality for any given quantity of pollution, at the cost of downstream areas. This phenomenon is prevalent in China (Cai et al., 2016; Zhang et al., 2018) and other countries (Gray and Shadbegian, 2004; Helland and Whitford, 2003), as well as between countries (Sigman, 2002; Wolf, 2007). Although the problem is widely understood, few effective solutions have been offered.

Theoretically, Coasian bargaining between upstream and downstream parties should be able to resolve this externality problem.[2] However, negotiated solutions are rarely adopted in reality, either due to the lack of binding international laws (Dinar, 2006), informational constraints, or "yardstick competitions" between local governments (Shleifer, 1985).

In 2011, in order to improve the water quality of the downstream length of the Xin'an River, China established the first inter-jurisdictional ecological compensation mechanism in the Xin'an River Basin, designed to facilitate upstream–downstream cooperation in water pollution regulation. It is known as the Xin'an River Ecological Compensation Initiative (hereafter ECI). The Xin'an River originates in Anhui Province and flows into Zhe-

[1] The Chinese central government has designated several pollutants, including Chemical Oxygen Demand (COD), as principally controlled pollutants and set mandatory national emission reduction targets. The targets are sequentially divided along the governmental hierarchy in provinces, prefectures, and counties. This emission target control regime has been stipulated since 2006 by the Chinese Five-year Plan, its overarching national development plan (Fan et al., 2019).

[2] Lipscomb and Mobarak (2016) also explore the potential of basin committees, which enhance neighboring jurisdictions' ability to cooperate or negotiate.

jiang Province. As the main water source of Qiandao Lake, the largest reservoir in Zhejiang Province, the industrial pollution in the river's upstream length reduces water quality and thereby threatens water safety in Zhejiang Province. In 2011 a fund was set up, jointly financed by the central government (contributing 300M RMB per year), Anhui Province (100M), and Zhejiang Province (100M). The two provinces made an agreement on compensation for the ecological services provided by Anhui Province to clean the river water. As a base payment, the 300 million RMB from the central government would be paid to Anhui in support of its water conservation. If Anhui attained the agreed-upon cross-border water quality target based on the pollution reading at the borderline—one that exceeds federally mandated standards—Zhejiang would pay 100 million to Anhui to compensate its inputs in water quality control; otherwise, Anhui would pay 100 million to Zhejiang for ecological loss due to its failure in upstream water protection.

The ECI is a novel attempt to solve the cross-border pollution problem. Despite the active involvement of the central government in creating the initiative and establishing some baseline rules, its province-level financial flows and pollution goals are based on bilateral agreement between Anhui and Zhejiang provinces. This represents a marked shift towards a semi-market-based mechanism to combat trans-border water pollution externalities. In essence, the ECI aims to better manage inter-regional environmental public goods that are hydrologically, chemically, and biologically linked, and to ensure that the provincial government's provision of ecosystem services goes beyond its own jurisdiction. The results of this program may provide information on whether and to what extent this quasi-market mechanism can fill gaps in command-and-control regulatory rules, which parts of the authority could be devolved to market negotiation, and which must be retained by the government.

To address these concerns, this paper uses the Xin'an ECI to evaluate similar mechanisms' capability to motivate upstream–downstream cooperation, how upstream governments react to environmental protection targets, and how this regulatory response in turn impacts firms' environmental performance. We first construct a theoretical model to illustrate how governments along a river are able to jointly combat trans-border externalities through negotiated side payments. Our model shows that any mutually acceptable compensation arrangement improves water quality at the boundary and (weakly) increases the welfare of both upstream and downstream parties.

We then employ a difference-in-differences (DD) strategy to study the effect of this watershed ecological compensation mechanism by utilizing firm-level pollution data from the Annual Environmental Survey of Polluting Firms (AESPF). We find that China's implementation of the ECI is positively associated with an increased probability of upstream firms reducing water pollution after 2011. We also show that the influence of the initiative is largely attributable to firms in heavily polluting industries in the upstream province, rather than their counterparts in cleaner industries. Next, we investigate the effect of the initiative on firms' pollution intensity and output to see how the emission reductions are realized. The results show that the implementation of the ECI is responsible for a significant decline in pollution intensity and significantly decreased the output of upstream firms. Overall, in response to the compensation initiative, firms are not only producing less (a scale response) but also investing more in pollution abatement (a technique response). Our baseline results pass multiple robustness checks, as described in Section 6.4.

In order to dig deeper into the mechanisms underlying these results, we analyze firms' adjustment in production and abatement strategies. After 2011, relative to downstream firms, the Xin'an ECI reduced total water and fresh water inputs of upstream firms, increased pollution treatment facilities, and lowered water pollution generated during the production process. These aggregate effects, however, may mask substantial heterogeneity across firms. We probe this heterogeneity in two dimensions.

First, considering that the upstream government needs to carefully determine the stringency of its pollution regulation to meet the agreed-upon target (which is stricter than the federally mandated target) without affecting economic growth too much, we examine whether the effects appear uniformly for firms in heavily-polluting industries and less-polluting industries. We find that the policy only has a significant negative impact on the heavily-polluting firms. Second, despite the fact that the ECI applies to 'broad' target areas, its enforcement could be uneven within that area because the harms from pollution differ by proximity to the river. Therefore, we examine the heterogeneous effect across firms with different distances from the river boundary and the bank of the river tributary, due to possible variation brought about by geographic distance. We find that the effect of the ECI is stronger for firms located closer to the provincial border and to the river tributary.

Next, we extend our discussion to examine more implications of this new approach to addressing cross-border externalities. As the ECI clearly focuses on specific target areas, i.e. Huangshan Prefecture and Jixi County in upstream Anhui Province, it is plausible that firms might react by migrating to nearby, less regulated areas. To test that possibility, we group the firms into those in target areas, those in neighboring areas within the same province, and those in neighboring areas in adjacent provinces, then examine responses to the initiative in each group. We find a significant increase in firm exits from the focal areas but a significant increase in entry of industrial firms to neighboring prefectures. These results indicates that firms tend to leave areas executing the ECI then relocate to neighboring areas with comparatively more lenient regulations, which, to a certain extent, verifies an "internal" variant of the polluting havens hypothesis. Consistently, we also find evidence of larger water pollution increases in areas where more firms entered.

Finally, to investigate whether this compensation arrangement could be used in other places, and to identify determinants that might account for its effectiveness in this region, we closely examine later cross-provincial compensation schemes in nine other watersheds across China. We find that similar arrangements also effectively reduce water pollution from the upstream prefectures. This finding confirms the broader applicability of arrangements similar to the Xin'an ECI. The ECI also induces more firms to exit from the upstream markets and impedes firms' entry to these markets. Moreover, these results are significantly driven by greater wealth in downstream prefectures relative to upstream prefectures, perhaps reflecting some arbitrage between differences in the marginal utility of income across locales. The region's economic structure also influences the effectiveness of the ECI: upstream prefectures with less reliance on industrial production and a larger proportion of tourism saw sharper reductions in water pollution.

The rest of this paper is structured as follows. Section 2 presents our contribution to the literature. Section 3 introduces the Xin'an ECI and some stylized facts. Section 4 introduces a theoretical model of using upstream–downstream cooperation to combat cross-border externality. Section 5 describes our empirical design and data sources. Section 6 reports the empirical results. Section 7 raises some extensions to our results, and Section 8 concludes.

2 Contributions to the Literature

This paper speaks to several strands of the literature. First, it provides comprehensive empirical evidence on how to mitigate environmental externalities. Although there is a substantial literature on the negative spillover effects of river pollution, most of that work merely provides evidence without studying potential solutions (Cai et al., 2016; Chen et al., 2018; Dinar, 2006; Kahn, 2004; Kahn et al., 2015; Lipscomb and Mobarak, 2016; Sandler, 2006; Sigman, 2002, 2005; Wolf, 2007). Lipscomb and Mobarak (2016) take Brazil river basin committees as an example and provide some supportive evidence that these committees do enhance inter-jurisdictional cooperation on river regulation. Kahn et al. (2015) discusses whether adding environmental evaluation into the local political promotion criteria in China reduces cross-border pollution. The river basin committee in Brazil seeks to create a forum for negotiation between stakeholders along the river and to approve plans to resolve conflicts among jurisdictions, while the political promotion incentives in China try to internalize the river quality into government officials' achievement evaluations. Even though these methods are adopted with multiple purposes, they have proven effective in internalizing externalities. In contrast, based on Coasian bargaining and pay-for-performance designs, the ECI was developed specifically to tackle cross-border externalities in the watershed. Our results suggest that the ECI provides a promising framework for developing countries that suffer from water quality deterioration due to suboptimal regulation.

Second, this paper fills an important gap in knowledge about combining semi-market regulatory tools with traditional command-and-control and market methods. As for the command-and-control regulations, the US has issued the Clean Water Act (Chakraborti, 2016), and Clean Air Act (Chay and Greenstone, 2005; Greenstone et al., 2012), while China implemented emissions target controls in its 10th and 11th Five-year Plans (Cai et al., 2016; Chen et al., 2018), implemented concentration control for sulfur dioxide in two Control Zones (Cai et al., 2016; Hering and Poncet, 2014), and included in the 12th Five-Year Plan a binding target for carbon dioxide intensity (Cao and Karplus, 2014). Typically, command-and-control regulation is most effective in controlling pollution from well-defined point sources, such as factories or sewage treatment plants (Deily and Gray, 1991; Gray and Deily, 1996), but less effective in regulating non-point sources of pollution and cross-border pollution (Helland and Whitford, 2003; Keiser et al., 2021; Cai et al., 2016; Chen et al., 2018; Dinar, 2006; Kahn, 2004).

Market-based mechanisms could be another solution. For example, Payment for Ecological Services (PES) markets (Kosoy et al., 2007) provide an arena for deals between downstream stakeholders and upstream ecological service providers. Theoretically, both parties could reach a PES contract easily, but that might not be the case in practice, especially when the downstream stakeholders and the upstream ecological service providers are massive and dispersed. Unlike the traditional command-and-control regulation and PES markets, the ECI combines both mechanisms. On behalf of stakeholders distributed in the whole jurisdiction, the local governments sign payment contracts, then translate the new targets into their daily environmental regulations. Our study on ECI thus provides a new mode for local governments' role in environmental protection.

Third, this paper provides comprehensive empirical evidence on firms' response to environmental regulation. A large body of empirical literature has investigated the effect of the Clean Air Act and Clean Water Act on US firms' abatement activity (Chakraborti, 2016), operations (Becker and Henderson, 2000; List et al., 2003; Henderson, 1996; Greenstone, 2002), productivity (Berman and Bui, 2001), competitiveness (Greenstone et al., 2012), and employment reallocation (Walker, 2013), as well as the economic costs (Ryan, 2012). In this paper, we also examine the impact of the ECI on firms' pollution activities and underlying abatement efforts. Moreover, by investigating firms' entry and exit choices in target areas and neighboring areas, we also show their potential relocation to weakly regulated markets.

3 Institutional Background and Stylized Facts

With rare exceptions, pollution in cross-border watercourses can generate inter-regional spillover effects. In practice, upstream jurisdictions may not internalize their cross-border pollution externalities. For example, research shows that cross-border pollution increases when regulations formerly implemented by the US federal government are decentralized to the states (Keiser et al., 2021). China's unitary regulatory system is not a panacea: despite strict bureaucratic control from the central government, local governments still have an incentive to intentionally agglomerate polluting firms near a river boundary. This cross-border externality is difficult to address through traditional regulation when political jurisdictions are not aligned to the watershed itself.

With its lack of unified watershed management, the Xin'an River exemplifies the trans-border externality issues that often pose difficulties for watershed management. The Xin'an runs for 359 km, from Huangshan Prefecture and Jixi County of Xuancheng Prefecture, both in the less-developed Anhui province, into Qiandao Lake in the wealthy, coastal Zhejiang Province. In addition to being a famous tourist attraction, Qiandao Lake is also a crucial source of drinking water for Zhejiang and even Shanghai. Over 60% percent of its inflows originate from the Xin'an River. Qiandao Lake has long suffered from water pollution, leading to eutrophication. The lake's serious blue-green algae outbreaks in 1998 and 2001 drew the Zhejiang provincial government's attention to the water pollution issue, and the subsequent "Nongfu Spring Scandal"[3] in 2009 called national attention to Qiandao Lake and the problem of water pollution in the Xin'an River.

To correct the spillover pollution effect inherent in cross-border watercourses, in 2011 the Ministry of Finance and Ministry of Ecology and Environment joined with the Zhejiang and Anhui provincial governments to establish a joint fund for pollution management. The two provinces made an agreement on compensation for the pollution accommodation capacity provided by Anhui Province. As described earlier, if Anhui attained the agreed-upon cross-border water quality target, Zhejiang would pay 100 million RMB to Anhui to compensate them for their water quality control efforts; otherwise, Anhui would pay 100 million RMB to Zhejiang for ecological damages due to its failure in upstream water protection. These payments were on top of an unconditional base payment of 300 million RMB from the central government to Anhui, in support of its water conservation efforts. The annually averaged pollution intensity on which transfer payments are based is calculated based on monthly readings at the Jiekou monitoring site, at a borderline jointly monitored by the two provinces every month. The agreed-upon standard for water quality was initially based on average

[3] A prominent bottled water brand sourced from Qiandao Lake was revealed to be violating drinking water safety standards.

water quality of the cross-border section from 2008-2010, but it was gradually tightened to exceed national standards. There have been three rounds of compensation so far. However, due to lack of data after 2013, we focus only on the first round of the initiative.[4]

As shown in Figure A1 in the Appendix, the Xin'an River Basin mainly covers Huangshan Prefecture and Jixi County (part of Xuancheng Prefecture) in Anhui Province, as well as the downstream Hangzhou Prefecture in Zhejiang Province. Due to their hydrological distribution, Huangshan Prefecture and Jixi County naturally became the targeted priority area of the ECI, in an endeavor to incentivize upstream regions to consider the well-being of their downstream neighbors when making decisions. Anhui Province specially promulgated regulatory documents to confirm that goal. [5] Subsequently, Anhui Province and Huangshan Prefecture enacted a series of rules on comprehensive pollution control and utilization of compensation funds. Huangshan Prefecture set up a steering group with the mayor and the municipal party secretary as the leaders. Moreover, a catchment management bureau was established in Huangshan Prefecture specially to take charge of the enforcement of the resulting regulations, along with the flow of payments from the compensation scheme. Therefore, to examine the policy's effects in the following empirical analysis, we treat industrial firms in upstream Huangshan Prefecture and Jixi County as the treatment group, while firms in downstream Hangzhou Prefecture are the control group.

While the central government played an enabling role, the, Xin'an ECI mainly relies on the two provinces concerned to negotiate the form, amount, and criteria of the compensation contract. [6] In this sense, the ECI represents a marked shift to a semi-market mechanism to combat cross-border water pollution. It is "semi-market" in the sense that the manner in which intergovernmental commitments are distributed to firms is not necessarily mediated through a market mechanism. The Xin'an ECI therefore allows us to learn about how the resulting commitments by governments are borne by firms.

[4]The AESPF is the only comprehensive database providing firm-level pollution data in China. This data is only released after an extended confidentiality period, so 2013 is the most recent year for which the data is publicly available.

[5]Jixi County is part of the Xuancheng Prefecture of Anhui Province. The ECI only involves Jixi County while the other parts of Xuancheng Prefecture are not substantially engaged in the compensation initiative. This coverage is also clearly reflected in the regulatory documents and the operation of the ECI. For example, Rules on Management of Compensation Found in Xin'an River Basin, issued by the Anhui Provincial Government, explicitly provides that the compensation funds from the Central Government and Zhejiang Province should be used in areas of the river basin, including 7 counties in Huangshan Prefecture and Jixi County in Xuancheng Prefecture (Art. 2).

[6]In fact, the central government completely exited from the initiative in 2018.

Figure 1: Reduction in Wastewater Discharge of Prefectures around the Xin'an River Basin after 2011

Notes: The red line shows the Xin'an River and the green dot marks the river boundary between Anhui Province and Zhejiang Province. Colors show the percentage reductions in wastewater discharge in 2011–2013 relative to 2008–2010.

Figure 1 shows the Xin'an River and the relevant political jurisdictions. The red line shows the course of the Xin'an River and the green dot denotes the river boundary between Anhui and Zhejiang Province. Black lines denote province borders. Here, darker greens represent larger wastewater discharge reductions (by percentage) between 2008–2010 and 2011–2013. We see that prefectures located closer to the Xin'an River reduced their water pollutants by a greater proportion since the initiative has been implemented. Huangshan Prefecture and Jixi County in upstream Anhui have larger proportional reductions than Hangzhou Prefecture, further downstream. Note also that even though distances from the prefectures in Jiangxi Province to the Xin'an River are similar to those of prefectures in the other two provinces, it seems that these areas (which are not included in the ECI) have had smaller changes from their baselines.

With this preliminary evidence in hand, we focus on the responses of upstream firms when exposed to the exogenous (from the perspective of the firm) shock brought about by the ECI. In Figure 2, we present the changes in average wastewater discharge and average wastewater COD of firms in upstream Anhui Province, between 2007 and 2013. A sharp decline in emissions of both pollutants appears around 2011. This suggests that the Xin'an ECI may improve firms' environmental performance by inducing the upstream firms to reduce their water pollution emissions. These stylized facts provide intuitive evidence that this cooperative ecological compensation program influences firms' environmental performance. We will formally identify these effects in subsequent sections.

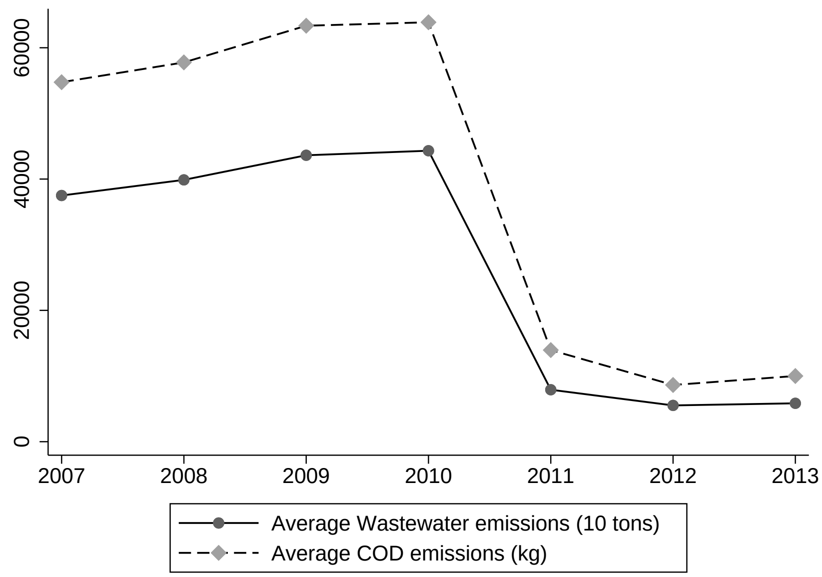


Figure 2: Water Pollutant Emissions from Anhui Firms Along the Xin'an River from 2007 to 2013

Notes: Each dot represents the average water pollutant emissions of the firms located in Huangshan Prefecture and Jixi County of Anhui Provinces. The data source is the AESPF (2007–2013), which is provided by the Ministry of Ecology and Environment.

4 A Simple Model

In this section, we provide a simple, partial equilibrium model including governments, households, and firms along the river, with endogenous choice of environmental regulation and production. The market is perfect competition. We model a river flowing from the upstream province (point 0) to the downstream province (point 1) as a line with boundary point b, so that river length $[0, b)$ belongs to the upstream province and $(b, 1]$ belongs to the downstream province. The distribution of households along the river follows the probability density function $f(x)$.

4.1 Households

Following Lipscomb and Mobarak (2016), we assume that production and consumption are location-specific. At point x, firms produce q_x units of goods, which causes z_x units of pollution. We assume that pollution emissions are linear in output, i.e., $z_x = aq_x$.[7] Each household at point x consumes q_x units of goods at the cost of $c(q_x)$ and gains consumption utility $u(q_x - c(q_x))$, such that the utility function follows $u' > 0$ and $u'' < 0$, and the cost function follows $c' > 0$ and $c'' > 0$. They also suffer disutility which is linear with pollution (Greenstone and Hanna, 2014; Currie and Neidell, 2005; Arceo et al., 2016), and we suppose that one unit of pollution causes γ units of utility loss.

The pollutants emitted at each point affect households at that point as well as all downstream households. We assume that that the pollution concentration declines exponentially in distance from its origin at rate β, so that 1 unit of emission at point x creates $e^{-\beta(t-x)}$ units of pollution at downstream point $t > x$.

Thus, the net utility induced by producing q_x at point x is:

$$U(x) = \left(u(q_x - c(q_x)) - \int_x^b \gamma z_x e^{-\beta(t-x)} f(t) dt \right)$$

4.2 Welfare analysis

We derive the behaviors of the upstream government and the social planner. In the first case, without the ECI, the upstream government chooses q_x at each point to maximize the following welfare:

$$W^u = \int_0^b f(x) \left[u(q_x - c(q_x)) - \int_x^b \gamma z_x e^{-\beta(t-x)} f(t) dt \right] dx$$

Taking the first-order condition with respect to q_x, we see that the optimal production q_x^* in point x satisfies:

$$u'(q_x^* - c(q_x^*))(1 - c'(q_x^*)) = \int_x^b \gamma a e^{-\beta(t-x)} f(t) dt \quad (1)$$

In the second case, the social planner would internalize the downstream welfare loss in its considerations and choose q_x at each point to maximize the total social welfare:

$$W = \int_0^b f(x) \left[u(q_x - c(q_x)) - \int_x^b \gamma z_x e^{-\beta(t-x)} f(t) dt \right] dx - \int_b^1 \gamma P^b e^{-\beta(y-b)} f(y) dy$$

[7] In fact, firms could reduce their emissions by shrinking their production (the "scale effect") and/or upgrading their technology (the "technique effect"). To simplify our model setting, we assume that firms' technological capability, denoted by a, is fixed.

where $P^b = \int_0^b z_x e^{-\beta(b-x)} f(x)dx$ denotes the pollution concentration at boundary b and hence $-\int_b^1 \gamma P^b e^{-\beta(y-b)} f(y)dy$ reflects the negative impact of pollution generated by the upstream on its downstream.[8] Taking the first-order condition with respect to q_x, we see that the optimal production q_x^{**} in point x satisfies:

$$u'(q_x^{**} - c(q_x^{**}))(1 - c'(q_x^{**})) = \int_x^b \gamma a e^{-\beta(t-x)} f(t)dt + \int_b^1 \gamma e^{-\beta(y-b)} f(y)dy a e^{-\beta(b-x)} \quad (2)$$

Comparing the first-order conditions (1) and (2), we have $q_x^* > q_x^{**}$ since $u''(q_x) < 0$ and $c'' > 0$.[9] Hence, the corresponding pollution emission choices are $z_x^{**} < z_x^*$. When the upstream local government only cares about the welfare of its own residents, they allow more pollution than a social planner concerned with overall welfare would allow.

4.3 Compensation Policy

To correct this problem, is there any instrument to facilitate the Coasian bargaining between upstream and downstream parties? Given the public goods nature of the river's ecosystem service, governments could negotiate a compensation plan in which the upstream government operates as a service provider and the downstream as the beneficiary; the downstream area would then compensate its upstream neighbor for its pollution reduction service. Here, we analyze a compensation plan based on the water quality readings monitored at the boundary point, as in the ECI. If the pollution concentration P^b is less than the agreed target $\bar{P}$, the upstream government receives ξ^d from the downstream government. Otherwise, the upstream government has to pay ξ^d to compensate the downstream government due to its failure in providing clean water downstream.

The ecological compensation plan can be explained as a bargaining game. The upstream and downstream governments set the contract which contains the emission target at the river border, as well as the compensation amount the downstream should pay the upstream province $(\xi^d, \bar{P})$. After the upstream and downstream governments sign the contract, the upstream government chooses whether to tighten the environmental regulations on the upstream firms to comply with the emission target at the river border, while the downstream government is obliged to pay the negotiated compensation as long as its upstream neighbor meets the cross-border water quality target it promised.

[8]Note that in the more complicated case where disutility in pollution is non-linear, the upstream planner would optimize based on the derivative of the downstream planner's value function with respect to boundary pollution levels.

[9]Combining (1) and (2), we have $u'(q_x^{**} - c(q_x^{**}))(1 - c'(q_x^{**})) - u'(q_x^* - c(q_x^*))(1 - c'(q_x^*)) = \int_b^1 \gamma e^{-\beta(y-b)} f(y)dy a e^{-\beta(b-x)} > 0$, and thereby $u'(q_x^{**} - c(q_x^{**}))(1 - c'(q_x^{**})) > u'(q_x^* - c(q_x^*))(1 - c'(q_x^*))$. Under the utility maximization condition, the marginal cost should satisfy $c'(q_x) < 1$. Since $u'' < 0$ and $c'' > 0$, then $q_x^{**} < q_x^*$.

We assume that $P^b(q_x^{**}) \leq \bar{P} < P^b(q_x^*)$. If $\bar{P} > P^b(q_x^*)$, the upstream government will emit below the threshold voluntarily to maximize its own residents' welfare, rendering the transfer useless. The upstream government would not reduce the pollution emissions to less than $P^b(q_x^{**})$ since a reduction in pollution emissions beyond $\bar{P} = P^b(q_x^{**})$ reduces total welfare; thus, no Coasian bargain is possible in this range.

The upstream government's welfare maximization problem becomes:

$$\int_0^b f(x)\left[u(q_x - c(q_x)) - \int_x^b \gamma z_x e^{-\beta(t-x)} f(t)dt\right] dx + \xi^d$$

$$s.t. \quad P^b \leq \bar{P}$$

The first-order condition with respect to q_x implies that the optimal output satisfies

$$u'(q_x^p - c(q_x^p))(1 - c'(q_x^p)) = \int_x^b \gamma a e^{-\beta(t-x)} f(t)dt + \lambda a e^{-\beta(b-x)} \tag{3}$$

In the online Appendix, we prove that $q_x^{**} \leq q_x^p < q_x^*$ when $P^b(q_x^{**}) \leq \bar{P} < P^b(q_x^*)$. Hence, the corresponding pollution level $z_x^{**} \leq z_x^p < z_x^*$. This improves downstream welfare, i.e., $W^d(q_x^*) < W^d(q_x^p)$.

Given that the contract in the first stage is $(\xi^d, \bar{P})$, if the upstream government chooses to comply with the contract, the welfare of the upstream government is $W_c^u(\xi^d, \bar{P}) = W^u(q_x^p) + \xi^d$ and that of the downstream province is $W_c^d(\xi^d, \bar{P}) = W^d(q_x^p) - \xi^d$. There exists some ξ^d satisfying $W^u(q_x^*) - W^u(q_x^p) < \xi^d < W^d(q_x^p) - W^d(q_x^*)$. Under this condition, both the upstream and downstream governments can achieve a welfare gain (i.e., $W_c^u(\xi^d, \bar{P}) > W^u(q_x^p)$ and $W_c^d(\xi^d, \bar{P}) > W^d(q_x^p)$).

Based on the previous derivations, we can make the following propositions:

Proposition 1: There exists a mutually acceptable compensation arrangement under which both upstream and downstream welfare increase relative to the no-contract case.

Proposition 2: The compensation arrangement induces the upstream to reduce their pollution through decreased output.

5 Empirical Strategy and Data

5.1 Empirical Design

The implementation of the Xin'an ECI should have had different impacts on firms upstream versus downstream of the province boundary along the Xin'an. Since the downstream region takes P^b as given, and P^b does not feature in its optimal output choice, downstream firms should not adjust their emissions in response to the program.[10] We therefore use the following DD specification to identify the effect of the initiative on upstream firms:

$$Y_{ickt} = \gamma \cdot (Treat_c \times Post_t) + \mathbf{X_{ct}}'\beta + u_i + u_{kt} + \varepsilon_{ickt} \tag{4}$$

where Y_{ikct} denotes the environmental performance (pollutant emissions, pollution intensity, and abatement) and economic performance (output) of firm i in industry k and county c in year t. Here, we use two common measures of water pollution, Chemical Oxygen Demand (COD) and wastewater discharge, to indicate firms' pollution levels. $Post_t$ is a dummy variable that equals 1 for years after 2011, and 0 otherwise. $Treat_c$ is also an indicator variable that equals 1 if county c is located in Huangshan Prefecture or Jixi County. $\mathbf{X_{ct}}$ includes time-varying county-level controls (log population and log GDP). The firm fixed effect u_i account for unobserved time-invariant characteristics of firms so that γ captures only within-firm variation arising from the Xin'an ECI. Furthermore, we use the year-industry fixed effects u_{kt} to capture the common shocks to all firms in a specific industry in each year. When estimating, we cluster ε_{ikct} at the county-year level.[11]

Our main parameter of interest in Equation 4 is γ, which estimates the average effect of the Initiative on the upstream firms. If the ECI indeed exerts a stronger environmental regulation shock on upstream firms, γ should be negative. Due to space constraints, we only report the coefficient of the interaction term in the following empirical results.

5.2 Data

We make use of detailed firm-level pollution data in China to examine the effects of the ECI. The data comes from the AESPF maintained by the Chinese Ministry of Ecology and Environment. The AESPF includes rich information on firms' environmental performance, including emissions of main pollutants (industrial effluent, waste air, NH3, NOx, SO2, smoke and dust, etc.), wastewater chemical oxygen demand (a measure of wastewater pollution), pollution abatement equipment, energy consumption (usage of freshwater, recycled water, coal, fuel, clean gas, etc.), and performance measures such as output. Firms surveyed are included in a key-point environmental survey list if they are in the top 85% of polluters of

[10]The downstream government chooses q_x to maximize the following welfare:

$$W^d = \int_b^1 f(x) \left[u(q_x - c(q_x)) - \int_x^b \gamma z_x e^{-\beta(t-x)} f(t) dt \right] dx - \int_b^1 \gamma P^b e^{-\beta(y-b)} f(y) dy$$

where P^b does not feature in its optimal output choice. Similarly, under the ECI, the emission target at provincial border $\bar{P}$ and compensation plan ξ_d would not affect the downstream optimal production choices.

[11]Taking into account that the total number of the counties impacted by the ECI is quite limited, only 21, we use county-year level clustering in our regressions to avoid too few clusters.

any individual chemical within the county. Once listed, they are obliged to report a wide range of environmental information for the previous year to the environmental authorities. Scrutinized and verified by all upper levels of administrative authorities, these data will be confirmed and included in the database. They are also the sourcing database for calculating macro-level environmental indicators in China's Statistical Yearbook on the Environment.

In this paper, we mainly focus on two measures of water pollution: wastewater chemical oxygen demand (COD) and wastewater discharge (sometimes referred to simply as "wastewater"). COD is a commonly adopted measure of water pollution which indicates the total amount of oxygen required to oxidize the organic compounds present in the discharged wastewater[12], while wastewater discharge simply measures the total amount of wastewater released, not adjusting for possible differences in the concentration of organic compounds. These two measures of pollution are key indicators under daily water pollution control regulations in China. In addition, we also use macro-level data such as county-level variables from the China County Statistical Yearbook and province-level total water pollutant emissions from the China Environmental Statistical Yearbooks.

To further examine the heterogeneous effect of the Ecological Compensation Initiative, we introduce the variation of firm-to-river distance, which might be associated with different regulatory stringency by governments. We use digitized river maps produced by the Arctic Monitoring and Assessment Programme (AMAP) and the geographic coordinates of each firm in the AESPF to calculate two distances for each firm: first, the distance from the river boundary; and second, the distance to the closest tributary of the Xin'an.

In order to examine whether firms relocated to other regions less impacted by the compensation initiative, we utilize the State Administration of Industry and Commerce (SAIC) database, which contains the year of establishment of each firm and provides 2-digit China Industrial Code (CIC) for each firm, and we aggregate the firm-level data into county-industry level data. Thus, we can construct a measure of firm entry in each prefecture.

In our analyses of pollution, we limit our sample to firms located in Huangshan Prefecture and Jixi County in Anhui Province, and in Hangzhou Prefecture in Zhejiang Province. Given that AESPF data are available only before 2013, we restrict our sample to 2007–2013. We provide the summary statistics in Table A1.

[12]High-COD pollution harms river systems by removing oxygen from the environment, causing the deaths of aquatic animals.

6 Empirical Results

6.1 Baseline Results

Table 1 presents our estimates of γ in Equation 4 when we use a firm's level as the dependent variable. All columns include firm fixed effects and year fixed effects. Columns (1) and (3) report the estimation results for water pollution, measured as wastewater COD or wastewater discharge, without other control variables, and the coefficients of interest are both negative and statistically significant at the 1% level. To control for economic and demographic factors, we add log GDP and log county population as regressors in columns (2) and (4). In both columns, the coefficients are negative and statistically significant, which means that compared to firms in Zhejiang, firms in Anhui experienced a detectable reduction in water pollution after ECI implementation. Point estimates suggest that the ECI led to 53.7% ($e^{-0.77} - 1$) and 54.2% ($e^{-0.78} - 1$) reductions in COD and wastewater volume, respectively, for typical upstream firms.

Table 1: The Impact of ECI on Water Pollutant Emissions

	COD		Discharge	
	(1)	(2)	(3)	(4)
Treat×Post	-0.78***	-0.77***	-0.92***	-0.78***
	(0.23)	(0.27)	(0.22)	(0.24)
GDP		-0.10		-1.30**
		(1.16)		(0.81)
Population		-0.14		2.81***
		(2.05)		(1.41)
Firm fixed effect	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes
Observations	7,807	7,807	8,017	8,017
R-squared	0.90	0.90	0.92	0.92

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variables in specifications (1) and (3) are the (log) emissions measured by COD, and in specifications (2) and (4) are the (log) wastewater discharge, respectively.

If, as one may argue, the results in Table 1 only tell whether the inter-regional ECI is effective for emission reduction, then investigating its effect on firms' pollution intensity and output can further inform us how the reductions are realized. A finer within-firm disaggregation is beneficial to more accurately distinguish the role of different underlying forces for pollution reduction. Changes in firms' overall output reflect the within-firm scale effect, while changes in emission intensity indicate the within-firm technique effect through adopting, for instance, cleaner production technologies or better abatement technologies.

Columns (1) and (2) in Table 2 show the estimation results of emission intensity indicated by COD. Columns (3) and (4) report the results indicated by wastewater discharge. Columns

(5) and (6) convey the results of firms' output. All odd columns are without county-level controls while the even columns include the controls. The significantly negative estimations are evidence that, in comparison to their counterparts located downstream, firms in upstream regions face more emission reduction pressure due to ECI and thus saw decreases in both pollution intensity and output. When combining the coefficients in columns (1) and (7) of Table 2 with that in column (1) of Table 1, a back-of-the-envelope calculation shows that around 23% of the COD emission reduction can be explained by within-firm scale effects (-0.18/-0.77), whereas approximate 77% of it is attributable to within-firm technique effects (-0.60/-0.77). The corresponding ratios for wastewater emission of polluting firms are about 22% and 78%, respectively. [13] The results suggest that firms are not only producing less but also modifying their production processes in response to this intervention. Considering the dominant impact of ECI on firms' pollution intensity, we will mainly focus on this aspect in the following analysis.

Table 2: The Impact of Ecological Compensation on Emission Intensities and Output

	COD		Discharge		Output	
	(1)	(2)	(3)	(4)	(5)	(6)
Treat×Post	-0.55***	-0.60***	-0.68***	-0.61***	-0.23***	-0.18**
	(0.19)	(0.23)	(0.19)	(0.19)	(0.07)	(0.08)
County-level controls	No	Yes	No	Yes	No	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,807	7,807	8,017	8,017	8,017	8,017
R-squared	0.90	0.90	0.90	0.90	0.93	0.93

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variables in specifications (1) and (3) are the (log) emission intensity of wastewater COD, in specifications (2) and (4) are the (log) emission intensities of wastewater discharge, and in specifications (5) and (6) are the (log) output, respectively. The county-level controls include (log) GDP and (log) population of the county.

6.2 Dynamic Effects

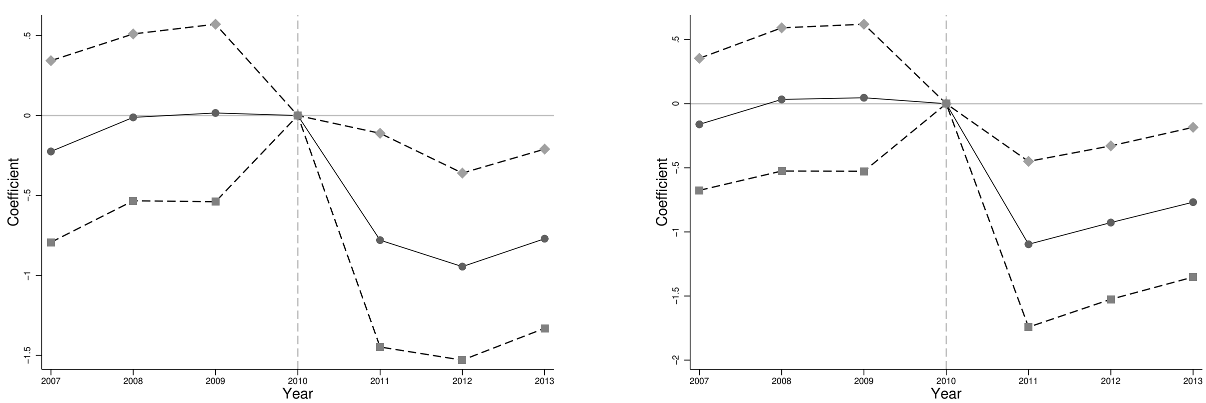
Identification in the DD framework rests on the assumption that the treated observations would, on average, have followed the same trends observed in the untreated group, had they not been treated (conditional on other controls). To gauge whether there were different time trends in the outcome variables between treatment and control groups prior to the onset of the ECI, we estimate the following equation:

$$Y_{ikct} = \sum_t \gamma_t Treat_c \times Year_t + \mathbf{X_{ct}}'\beta + u_i + u_{kt} + \varepsilon_{ikct} \tag{5}$$

[13]This result unsurprisingly enriches our theoretical model by documenting firms' changes in both scale effect and technique effect after ECI implementation.

where $Year_t$ is an indicator variable for year t. The parameter of interest γ_t measures whether upstream firms and downstream firms have different trends prior to the Ecological Compensation Initiative.

The estimated results for wastewater COD and for wastewater discharge are shown in Table A2 in the Appendix. For ease of reference, we plot the estimated yearly effects in Figure 3. Panel A shows the trends for COD from 2007–2013, while Panel B plots the trends for wastewater discharge. As can be seen in Figure 3, firms located in the upstream and downstream provinces had similar trends prior to the implementation of the ECI, in terms of either COD or wastewater discharge. These parallel pre-trends are consistent with our assumption that the upstream firms and downstream firms would have similar pollution patterns in the absence of the ECI. After 2011, $\hat{\gamma}_t$ undergoes a sharp and permanent drop in both Panel A and Panel B, suggesting that our estimated effects decreasing upstream firms' emission and pollution intensity are indeed driven by differential changes beginning in 2011.



Panel A. COD

Panel B. Wastewater discharge

Figure 3: Parallel Trend of Water Pollutant Emissions

Notes: Each dot represents the coefficient of $Treat \times Post_t$ in each year. The dashed lines plot the corresponding 95% confidence interval.

6.3 Mechanisms

In this section, we dig deeper into the underlying mechanisms to understand how upstream firms achieve lower pollution intensity when facing tightened environmental regulations. Facilitated by comprehensive firm-level environmental data, we are able to examine three aspects of firms' responses: water pollution generated during the production process, water use efficiency, and abatement efforts.

First, firms might adopt cleaner production technologies to directly reduce water pollutants generated during the production process. Estimates in columns (1) and (2) in Table 3 verify that the Initiative reduced water pollutants of upstream firms generated during the production process. That is to say, upstream firms upgraded their production technology or invested more in water recycling to minimize effluent discharge.

Second, firms' water pollution is closely related to their water usage. We first test the impact of the Initiative on firms' input of total water and fresh water. As shown in columns (3) and (4) in Table 3, the coefficients are all negative and significant at the 1% level, suggesting that the ECI significantly reduced the total water and fresh water input of upstream firms.

Table 3: The Impact of ECI on Abatement Efforts

	Water pollution production		Water input		Abatement Facilities	
	(1)	(2)	(3)	(4)	(5)	(6)
	COD	Discharge	Total water	Fresh water	Number	Capacity
Treat×Post	-0.97***	-0.72***	-0.65***	-0.71***	0.11*	0.73**
	(0.34)	(0.27)	(0.24)	(0.25)	(0.06)	(0.32)
County-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,733	6,966	8,026	8,026	6,164	6,160
R-squared	0.93	0.92	0.94	0.93	0.88	0.77

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variables in columns (1)–(2) are (log) wastewater by COD and (log) wastewater discharge, respectively. The dependent variables in columns (3)–(4) are (log) total water usage and (log) fresh water usage, respectively. The dependent variables in columns (5)–(6) are (log) total number of abatement facilities and abatement capacity, measured by how many tons of wastewater could be treated in a day, each divided by the firms' COD production in the production process to give a ratio of abatement to pollutants. The county-level controls include (log) GDP and (log) population of the county.

Third, to verify whether firms change their abatement in the treatment process to reduce their emissions to the environment, we repeat the regression with the dependent variable replaced by the total number of abatement facilities and abatement capacity, measured by how many tons of wastewater could be treated within one day. To eliminate scale differences across firms with different levels of pollution production, we divide the number of abatement facilities and abatement ability by the firm's COD of their wastewater in each year. Our estimates in columns (5)–(6) show that, compared to downstream firms, firms in Anhui province experienced a significantly larger increase in pollution abatement capacity after 2011, using either measure.

6.4 Robustness Checks

In this section, we conduct a placebo test by analyzing the effect of the Ecological Compensation Initiative on firms' air pollutant emissions, then employ a random sampling method to rule out possibly omitted variables.

6.4.1 Placebo Test

China has been gradually tightening its environmental regulations in recent years. To further show that omitted differential trends in firms' emission reductions are unlikely to bias our estimates, we conduct a placebo test using air pollutants. Since the ECI concerns only water-related pollutants, the implementation of the initiative should have little impact on air pollutants if our results in Table 1 are not driven by other confounding factors.[14]

The dependent variables in Table 4 are the log amounts of SO_2, NO_x, and industrial smoke and dust, which are three typical air pollutants strictly regulated in China. The DD estimation results for air pollutants are shown in Table 4. We do not find the implementation of the initiative to be significantly associated with changes in air pollution. The apparently contradictory results between Table 4 and those in Table 1 help to rule out confounding factors that might be responsible for the relationship between the ECI and firms' improved water pollution control performance.

Table 4: Air Pollutants for Placebo Tests

	(1)	(2)	(3)
	SO_2	NO_x	Industrial smoke and dust
Treat×Post	0.17	-0.18	-0.25
	(0.12)	(0.15)	(0.23)
County-level controls	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes
Observations	4,112	3,953	4,142
R-squared	0.91	0.91	0.88

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variable in specification (1) is the (log) emission of SO_2 (in kilogram), in specification (2) is the (log) emission of NO_x (in kilograms), and in specification (3) is the (log) emission of industrial smoke and dust (in kilograms). The county-level controls include (log) GDP and (log) population of the county.

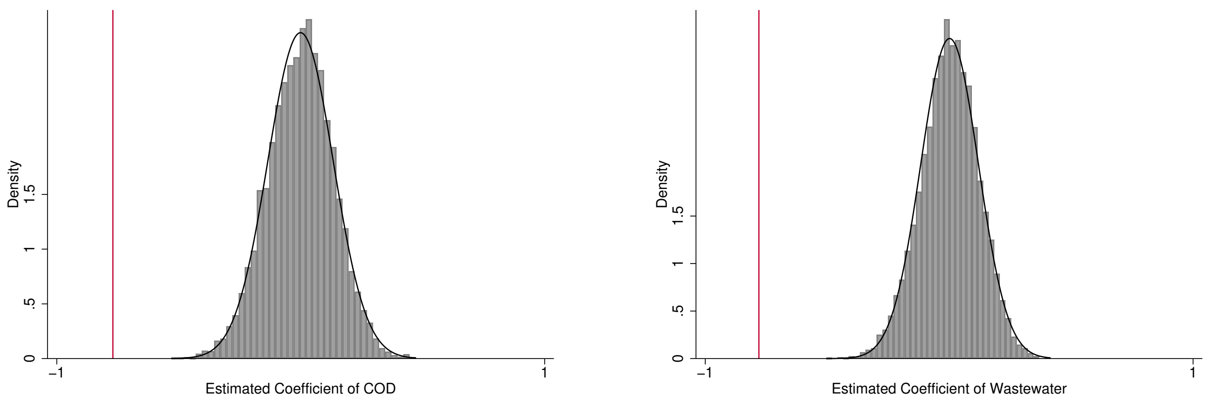
6.4.2 Random Sampling Test

Next, we run a placebo test by randomly selecting counties, among the total number of counties in both upstream and downstream areas of the ECI, as upstream counties in the estimation of Equation 4. Since these counties were not involved in the ECI, we should not routinely detect an "effect" of the ECI in these estimations. Figure 4 presents the distribution of the estimated coefficients from the 10,000 rounds of estimation.

Panel A plots the distribution of these DD estimates of wastewater COD; the mean point

[14] This also rests on the plausible assumption that air and water pollution are not 'excessively' Leontief in output levels.

estimate is -0.00074 while the standard deviation is 0.13. Panel B plots the distribution of DD estimates of wastewater discharges; the mean point estimate is 0.0017 while the standard deviation is 0.12. The red lines refer to the corresponding true DD-estimated coefficients (-0.77 for wastewater COD and -0.78 for wastewater volume) in our baseline results. [15] These placebo tests suggest that it is unlikely that omitted variables severely bias our estimates.



Panel A. Wastewater COD

Panel B. Wastewater discharge

Figure 4: Random Sampling

Notes: This figure presents the distribution of estimated coefficients for 10,000 rounds of estimations on randomly assigned upstream counties which are affected by the Ecological Compensation Plan. The red lines refer to the corresponding true DD-estimated coefficients in our baseline results.

6.5 Heterogeneity

6.5.1 Triple Differences

Given that that tightened environmental regulations mainly target polluting firms or dirty industries, we apply a DDD (triple differences) strategy to identify the differential effects on dirty relative to clean industries.[16] The specification is as follows:

$$\begin{aligned} Y_{ikct} =& \alpha_1 Post_t \times Treat_c + \alpha_2 Post_t \times Treat_c \times Dirty_k + \alpha_3 Post_t \times Dirty_k \\ & + \mathbf{X_{ct}}'\beta + u_i + u_{kt} + \varepsilon_{ikct} \end{aligned} \tag{6}$$

[15]Both the true estimates of COD and wastewater impacts are below the 1% percentile of the placebo estimates, respectively.

[16]The classification of dirty and clean industries is based on the Catalogue of Industrial Classification of Environmental Scrutiny on Listed Companies, enacted by the Ministry of Ecology and Environment of China in 2008, in which 14 industries are identified as heavily-polluting industries. They include food and beverage processing and manufacturing; manufacturing of leather, fur, and feathers; and chemistry.

where $Dirty_k$ is an indicator variable. As polluting firms are the main regulatory targets for regulators, the coefficient on the interaction term $Post_t \times Treat_c \times Dirty_k$ is expected to be significantly negative.

The estimation results are shown in Table 5. Columns (1) and (3) report the results for wastewater COD and wastewater discharge without controls, while columns (2) and (4) further add in county-level characteristics. As is shown, the coefficients of $Treat \times Post$ are insignificant while those of $Treat \times Post \times Dirty$ are all negative and significant in all columns. These results suggest that the compensation initiative has no effect on clean industries. In contrast, the upstream dirty firms experience dramatic drops in water pollutant emissions. The results are consistent with the hypothesis that regulators mainly target heavily-polluting firms. We conduct separate DD analyses for heavily-polluting industries and less-polluting industries separately in Table A3; the results are consistent with Table 5.

Table 5: Triple Difference Estimates on Water Pollutant Emissions

	COD		Discharge	
	(1)	(2)	(3)	(4)
Treat×Post	0.23	0.23	0.03	0.16
	(0.21)	(0.25)	(0.15)	(0.16)
Treat×Post×Dirty	-1.15***	-1.14***	-1.09***	-1.07***
	(0.23)	(0.23)	(0.19)	(0.19)
Post×Dirty	0.45***	0.45***	0.34***	0.36***
	(0.12)	(0.12)	(0.11)	(0.11)
County-level controls	No	Yes	No	Yes
Firm fixed effect	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes
Observations	7,807	7,807	8,017	8,017
R-squared	0.90	0.90	0.92	0.92

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variables in specifications (1) and (3) are the (log) wastewater COD, and in specifications (2) and (4) are the (log) wastewater discharge, respectively. The county-level controls include (log) GDP and (log) population of the county.

To generate more evidence of the heterogeneity across heavily-polluting industries and less-polluting industries, we also conduct dynamic trend analysis for firms in these two industries, in Figure A2 and Figure A3 in the appendix, separately. These results reconfirm our finding that the upstream government appears to target the heavily-polluting industries, rather than using a one-size-fits-all approach to achieve higher water quality goals.

6.5.2 Heterogeneity by Firm-to-River and Firm-to-Boundary Distance

ECI payments are determined based on readings at a particular monitoring station, which aggregates the impacts of water pollution occurring in each of the tributary streams of the

Xin'an River. Even though the regulation applies to broad target areas, application and enforcement may be uneven to reflect the differential impacts across sources. Given this, one might expect the government of Anhui to adjust the stringency of water pollution regulations based on the proximity of polluters to either the monitoring station or to the tributaries of the Xin'an River, as firms which pollute at locations "closer" (either in direct distance or along the course of a stream) to the monitoring station or to a tributary have a larger effect on the key reading.[17]

First, we explore the possibility of heterogeneous effects by distance from the river boundary. In the first two columns of Table 6, we run a triple difference regression in which the triple interaction term is $Treat \times Post \times Dist^{border}$. Columns (1) and (2) report the results for wastewater COD and wastewater discharge, respectively. The coefficients of the triple interaction term are significantly positive both for COD emissions and wastewater discharge, while the coefficients of $Treat \times Post$ are both significantly negative. These findings indicate that the upstream government strategically tightens regulations on firms located closer to the river boundary.

Second, we explore the heterogeneous effect of firms based on their distances to river tributaries, utilizing the hydrological map of the Xin'an River shown in Figure A1. We expect that firms located closer to the river tributaries should have experienced a larger reduction in their water pollution after 2011 than firms further away. The last two columns of Table 6 report the estimation results for water pollutant emissions. These estimates suggest that the effect of the ECI is weaker for firms located farther from the river tributaries.

[17] As for firms located far from the river, they might also discharge their wastewater to other waterbodies connected to the Xi'an River network.

Table 6: Heterogeneous Effects of the ECI

	Distance to river border		Distance to river tributary	
	(1)	(2)	(3)	(4)
	COD	Discharge	COD	Discharge
post×treat	-2.54***	-1.94***	-1.11***	-0.90***
	(0.55)	(0.55)	(0.29)	(0.28)
post×treat×$Dist^{border}$	0.04***	0.03***		
	(0.01)	(0.01)		
post×treat×$Dist^{river}$			0.16***	0.06* **
			(0.03)	(0.02)
County-level controls	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes
Observations	7,314	7,514	7,314	7,514
R-squared	0.91	0.92	0.91	0.92

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variable in specifications (1) and (3) is the (log) wastewater COD, and in specifications (2) and (4) is the (log) wastewater discharge. The county-level controls include (log) GDP and (log) population of the county. $dist_{river}$ is the closest distance from the firm to the river branch (measured in kilometers), and $dist_{border}$ is the distance between the firm and the river boundary (measured in kilometers).

7 Firm Entry and Exit

One might expect strengthened environmental regulations to affect firms' entry and exit choices due to higher production costs. Both compliance and abatement raise firms' production costs, discouraging the entry of new industrial firms or leading more firms to exit the regulated market. In this section, by using county-industry-level data from the China Industrial and Commercial Registration Dataset (2007–2013), we examine how firms make relocation decisions in response to the ECI.[18]

To better show how the ECI affects firms' relocation choices, we focus on both the target area and the neighboring areas. In particular, we consider two types of neighbors: neighboring areas within Anhui and neighboring areas in Jiangxi Province, which was not part of the ECI arrangement. Chizhou Prefecture and Xuancheng Prefecture (excluding Jixi County) are neighboring areas within Anhui Province. Jingdezhen Prefecture and Shangrao Prefecture are two neighboring areas with similar distance to Xin'an River but belong to the adjacent province, Jiangxi Province, and are also not part of the ECI. We present evidence for firms' entry and exit effects in Table 7.

[18]We summarize the firm-level registration data into county-CIC2 industry level (limited to manufacturing industries), then conduct the following DD regression:

$$Y_{kct} = \gamma Treat_c \times Post_t + \mathbf{X_{ct}}'\beta + u_i + u_{kt} + \varepsilon_{kct}$$

where we add in county fixed effects to absorb unobservable time-invariant, county-specific characteristics, as well as industry-year fixed effects to absorb any industry-specific shock in a specific year.

Table 7: Effects of ECI on Firms' Entry and Exit

	Target areas		Neighboring areas in the same province		Neighboring areas in adjacent province	
	(1)	(2)	(3)	(4)	(5)	(6)
	Entry	Exit	Entry	Exit	Entry	Exit
Treat×Post	0.30	0.33**	0.88***	0.15	1.10***	0.15
	(0.33)	(0.13)	(0.34)	(0.15)	(0.33)	(0.09)
County-level controls	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,704	4,704	5,376	5,376	6,496	6,496
R-squared	0.47	0.44	0.46	0.44	0.45	0.43

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variable in specifications (1)–(2) is the number of entering firms, and in specifications (3)–(4) it is the number of exiting firms. The county-level controls include (log) GDP and (log) population of the county. The treatment group in columns (1)–(2) contains the observations in Huangshan Prefecture and Jixi County, columns (3)–(4) contain the observations in Chizhou Prefecture and Xuancheng Prefecture (except Jixi County), while columns (5)–(6) contain the observations in Jingdezhen Prefecture and Shangrao Prefecture. The control group contains the observations in Hangzhou Prefecture.

Columns (1)–(2) of Table 7 report the policy effect for firms in the target areas. The positive but insignificant estimate in column (1) suggests that there were no significant effects on firms' entry to upstream areas, while the significantly positive estimates in column (2) suggest that more firms exited from the target areas. These results and our findings in Table 2 corroborate each other: because focal area governments tighten environmental regulations in response to higher commitment to downstream government, industrial firms decrease their output and may choose to exit the market. Columns (3) and (4) show the DD results for neighboring prefectures in the same province. We observe a significant increase in entry of industrial firms into neighboring prefectures in Anhui, but no impact on their exit from that region. This might be due to the relocation of firms driven away by the tightened environmental regulation in the target areas. Similarly, columns (5) and (6) show the DD results for neighboring prefectures in the adjacent Jiangxi province: we also observe a significant increase in firms' entry, while the change in firms' exit is not significant. These findings support the hypothesis that when facing more stringently enforced environmental regulation, firms tend to relocate to prefectures with looser regulations. Industrial firms' exit from tightly regulated areas and possible relocation in more leniently regulated neighboring areas thus support a pollution haven hypothesis, as they operate across adjacent prefectures sharing similar economic and social conditions, even though some of the relocations might stride over provincial borders.

In order to check whether firms' entry and exit affect neighboring areas' environmental performance, we also investigate the impact of the ECI on neighboring areas' water pollution in Table A4 in the Appendix. Columns (1) and (2) focus on the neighboring areas in Anhui. We observe that, compared to the downstream firms, firms in Chizhou and Xuancheng experience significant increases in wastewater COD after the implementation of ECI, though the change in wastewater is not significant. Columns (3) and (4) show the results for neighboring prefectures in Jiangxi Province near the target area. We do not observe any reduction in COD or wastewater discharge. On contrary, the COD and wastewater discharge increase significantly compared to the downstream firms. The significant increase of firms' emissions in both types of neighboring prefectures brought by the ECI, compared to downstream areas, is due to the comparatively weaker environmental regulation in those prefectures, which is consistent with our finding that more firms have entered the neighboring areas.

8 Generalizability of the Xin'an River Ecological Compensation Initiative

The Xin'an River Ecological Compensation Initiative is different from traditional approaches such as pure environmental regulation, subsidies, or taxes. The combined forms of negotiation between governments and payment for the ecosystem services provided upstream are transformed into evaluable intergovernmental commitments, which are accordingly distributed to firms through traditional regulatory tools. Attracted by the ECI's potential to combat the cross-border externality commonly associated with river pollution, since 2011 similar programs have been implemented across provinces, prefectures, and counties in China. In this section, we assess whether those subsequent "follow-up" programs have had similar effects to the ECI. Due to space constraints, background information on these other cross-provincial ecological compensation programs is presented in Table A5 and the relevant map is shown in Figure A4, both in the Appendix.

8.1 Policy Effects

We now ask whether later cross-boundary ecological compensation programs had similar effects to the ECI, using the empirical specification in Equation 4. Due to a lack of firm-level emissions data, we use prefecture-level data to conduct the regression.[19] We collect prefecture-level wastewater discharge data from China Environmental Statistics Yearbooks, and prefecture-level economic variables including GDP, population, gross industrial output, tourism revenue, tourist numbers, ratio of agricultural industry to GDP, and ratio of manufacturing industry to GDP from the China Statistics Yearbooks, 2007–2019.

[19] As noted earlier, due to confidentiality issues, the firm-level pollution emission data is only available until 2013, and thus cannot be used to analyze these later programs.

Table 8 presents the impact of the follow-up ecological compensation initiatives on the environmental and economic performance of the prefectures involved. Columns (1) and (2) report the policy effect on environmental performance in all of the watersheds implementing a compensation initiative similar to ECI in the Xin'an River Basin. The estimate in column (1) documents the average effect of the respective compensation initiatives on water pollution control in upstream prefectures, relative to the downstream prefectures, whereas column (2) shows that they had no impact on air pollutants, which is consistent with the results shown in Table 4. Similar to our baseline results, the estimate suggests that adoption of these initiatives also effectively controlled water pollution in the upstream regions. In columns (3)–(5), we further examine the initiatives' impact on the upstream prefectures' economic performance. These estimates suggest that the programs were costly, reducing the economic value of upstream production by about 7 percent.

Despite the drop in GDP, reduced pollution might also generate favorable results, such as an expanded tourist industry directly associated with improved ecological environments. Thus, we analyze the impact of these follow-up policies on tourism revenue and number of tourists in columns (3) and (4), respectively. The results confirm our hypotheses that upstream and downstream ecological compensation indeed stimulates tourism in upstream prefectures and encourages the compensated prefectures to gravitate towards cleaner economic structures.[20]

Table 8: Effects of ECIs in Other River Basins

	Pollution		Economic		
	(1)	(2)	(3)	(4)	(5)
	Wastewater discharge	SO_2 emission	GDP	Tourism revenue	Number of tourists
Treat×Post	-0.22**	0.15	-0.06**	0.16***	0.18***
	(0.10)	(0.15)	(0.03)	(0.06)	(0.05)
Prefecture-level controls	Yes	Yes	Yes	Yes	Yes
Prefecture fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	297	297	297	243	224
R-squared	0.94	0.92	1.00	0.98	0.98

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are reported in parentheses. All the dependent variables are logarithmic. The prefecture-level controls include (log) GDP, (log) population, the ratio of primary industry to GDP, and the ratio of secondary industry to GDP.

Next, we proceed to analyze whether firms' relocation choices might also be impacted by the ecological compensation initiatives adopted by other river basins outside Xin'an.

[20] Since reductions in upstream pollution affect downstream water quality, which could in turn increase downstream tourism, the difference in difference estimate should be viewed as a lower bound on the actual impacts.

Evidence shows that, in order to fulfill their commitment to their downstream neighbors, the upstream governments should adopt tighter environmental regulations which may drive incumbent firms away due to increased compliance costs. As for new firms willing to enter the markets, regions covered by ECI might become less attractive for firms in fear of harsher regulatory atmosphere.

Table 9 reports the results. In columns (1) and (2), we investigate the impact of ECIs on firms' entry choices in upstream prefectures. Column (2) further adds in country-level controls based on column (1), and the coefficients of the interaction term in both columns are significantly negative. These results indicate that when a cross-jurisdictional river adopted an ECI, fewer firms would enter the upstream prefecture markets. Similarly, we examine the impact on firms' exit choices in columns (3) and (4). The coefficients of the interaction term are both significantly positive, which confirms our assumption that increasing compliance costs caused by tightened environmental regulation induced more firms to exit the upstream prefecture markets. On average, an ECI leads to about 1.2 fewer firms entering the regulated markets and about 0.25 more firms exiting those markets.

Table 9: Effects of ECIs on Firms' Entry and Exit in Other River Basins

	Firm entry		Firm exit	
	(1)	(2)	(3)	(4)
Treat×Post	-1.17**	-1.27***	0.28**	0.25**
	(0.48)	(0.47)	(0.11)	(0.11)
County-level controls	No	Yes	No	Yes
County fixed effect	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes
Observations	41,056	41,056	41,056	41,056
R-squared	0.51	0.51	0.52	0.52

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variables in specifications (1) and (2) are the number of entry firms, and in specifications (3) and (4) are the number of exit firms. County-level controls includes county-level (log) GDP and (log) population.

8.2 Driven Factors

We showed above that environmental compensation initiatives generally appear useful in solving cross-border pollution. Next, we explore their mechanisms to see whether the effectiveness of this quasi-market bargaining contract may be subject to some constraints.

First, intuitively, the upstream-downstream economic development gap may be an important factor influencing the initiatives' magnitude of impact. Scenarios in which the downstream jurisdiction is richer than its upstream neighbor may lead to higher willingness to pay for pollution reduction and thus more stringent controls in equilibrium. To explore how the program impacts may vary with the discrepancy between the two types of regions involved, we introduce a triple interaction term *Treat* × *Post* × *Gap* in our regression. The statistically significant positive estimate in column (1) of Table 10 shows that in the river basins with larger upstream–downstream economic gaps, the ecological compensation mechanism brings about larger reductions in the wastewater emissions of upstream prefectures.[21]

In column (2) we examine heterogeneity based on ex ante gross industrial production. The statistically significant negative coefficient indicates that the larger the upstream–downstream industrial output gap is, the larger the impact of the initiative.

As a final step, in the last two columns of Table 10, we examine whether upstream regions' industrial structure helps to explain the effectiveness of the compensation initiatives. Column (3) shows that upstream prefectures with a higher ratio of tourism revenue to GDP respond more to the initiatives, perhaps due to their larger gain in tourism revenues for a given reduction in pollution. We also consider the industrial share of GDP in column (4). In contrast to the results in column (3), we find that prefectures with a higher industry/GDP ratio, defined as the prefecture-level value of industrial output divided by prefecture-level GDP, have higher industrial output losses as a result of the implementation of ECI-style programs.

Table 10: Driving Factors of the ECIs in Other River Basins

	(1)	(2)	(3)	(4)
Treat×Post	-0.08	-0.08	-0.04	-0.84***
	(0.12)	(0.12)	(0.12)	(0.23)
Treat×Post × GDP gap	-0.03***			
	(0.01)			
Treat×Post × Industrial output gap		-0.02***		
		(0.01)		
Treat×Post × Tourism-GDP ratio			-0.79***	
			(0.23)	
Treat×Post × Industrial output-GDP ratio				0.53***
				(0.16)
Prefecture-level controls	No	Yes	No	Yes
Prefecture fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	297	297	297	297
R-squared	0.94	0.94	0.94	0.94

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are reported in parentheses. All the dependent variables are in logarithms. The prefecture-level controls include (log) GDP, (log) population, the ratio of primary industry to GDP, and the ratio of secondary industry to GDP. GDP gap refers to the gap between downstream prefectures and upstream prefectures, i.e. (downstream GDP - upstream GDP)/upstream GDP, and the industrial output gap is calculated as log(downstream industrial output - upstream industrial output)/upstream industrial output. The industrial output gap in column (3) refers to the upstream ratio of tourism to GDP, and the industrial output to GDP ratio in column (4) refers to the ratio of upstream industrial share to GDP.

[21] The upstream–downstream economic gaps is calculated by (downstream GDP - upstream GDP)/ upstream GDP.

9 Conclusion

Transboundary externality effects are a common issue inherent in cross-boundary water pollution. Two Chinese provinces in the Yangtze River Delta have attempted to resolve this problem by implementing the Xin'an River Ecological Compensation Initiative. We attempt to establish whether this kind of inter-government agreement and payment is effective in combating cross-border externalities, and how firms' economic and emission decisions are impacted by the changed incentives of their regional government with regard to pollution levels.

We first build a simple theoretical model to clarify the nature of the cross-border externality and motivate our estimation framework. We then employ a difference-in-difference strategy to quantify the policy effect on the polluting activities of the upstream firms. Using China's firm-level pollution data, we show that the Ecological Compensation Initiative is responsible for a sharp emission reduction in water pollutant emissions among the upstream firms. Empirical evidence further shows that the impact of the initiative is largely borne by firms belonging to heavily polluting industries in the upstream province, rather than their counterparts in clean industries. To investigate how the emission reductions are realized, we turn to measures of water use, pollution generation, and internal amelioration.

Our baseline results are robust to using various empirical strategies. We also investigate the heterogeneity of treatment effects across firms with different distances from the river boundary and from the river tributaries, as well as the heterogeneous effect across heavily-polluting and less-polluting industries. Finally, we discuss the policy's effect on firm entry and exit choices, and the effects of similar mechanisms in other river basins.

Our findings suggest that bilateral compensation for ecosystem services appears to successfully reduce pollution and that the upstream province is willing to reduce net income (after subtracting output losses and adding ECI payments) in exchange for reduced pollution, as the theory suggests. Although previous studies indicate that the bargaining between upstream and downstream parties may be inefficient due to the large transaction costs associated with bargaining across jurisdictions (Dinar, 2006; Sigman, 2002), our results suggest that the ECI may be a promising model for cases in which jurisdictional boundaries are nested within a larger national jurisdictional authority that can nudge the parties toward a Coasian solution. The generalizability of these findings to other contexts remains an open and important question for future exploration.

References

Arceo, E., R. Hanna, and P. Oliva (2016). Does the effect of pollution on infant mortality differ between developing and developed countries? Evidence from Mexico City. *The Economic Journal 126*(591), 257–280. Publisher: Oxford University Press Oxford, UK.

Becker, R. and V. Henderson (2000). Effects of air quality regulations on polluting industries. *Journal of political Economy 108*(2), 379–421. Publisher: The University of Chicago Press.

Berman, E. and L. T. Bui (2001). Environmental regulation and productivity: evidence from oil refineries. *Review of Economics and Statistics 83*(3), 498–510. Publisher: MIT Press.

Cai, H., Y. Chen, and Q. Gong (2016). Polluting thy neighbor: Unintended consequences of China's pollution reduction mandates. *Journal of Environmental Economics and Management 76*, 86–104. Publisher: Elsevier.

Cai, X., Y. Lu, M. Wu, and L. Yu (2016). Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. *Journal of Development Economics 123*, 73–85. Publisher: Elsevier.

Cao, J. and V. J. Karplus (2014). Firm-level determinants of energy and carbon intensity in China. *Energy Policy 75*, 167–178. Publisher: Elsevier.

Chakraborti, L. (2016). Do plants' emissions respond to ambient environmental quality? Evidence from the clean water act. *Journal of Environmental Economics and Management 79*, 55–69. Publisher: Elsevier.

Chay, K. Y. and M. Greenstone (2005). Does air quality matter? Evidence from the housing market. *Journal of political Economy 113*(2), 376–424. Publisher: The University of Chicago Press.

Chen, Z., M. E. Kahn, Y. Liu, and Z. Wang (2018). The consequences of spatially differentiated water pollution regulation in China. *Journal of Environmental Economics and Management 88*, 468–485. Publisher: Elsevier.

Currie, J. and M. Neidell (2005). Air pollution and infant health: what can we learn from California's recent experience? *The Quarterly Journal of Economics 120*(3), 1003–1030. Publisher: MIT Press.

Deily, M. E. and W. B. Gray (1991). Enforcement of pollution regulations in a declining industry. *Journal of Environmental Economics and Management 21*(3), 260–274. Publisher: Elsevier.

Dinar, S. (2006). Assessing side-payment and cost-sharing patterns in international water agreements: The geographic and economic connection. *Political Geography 25*(4), 412–437. Publisher: Elsevier.

Fan, H., J. S. G. Zivin, Z. Kou, X. Liu, and H. Wang (2019). Going Green in China: Firms' Responses to Stricter Environmental Regulations. Technical report, National Bureau of

Economic Research.

Gray, W. B. and M. E. Deily (1996). Compliance and enforcement: Air pollution regulation in the US steel industry. *Journal of environmental economics and management 31*(1), 96–111. Publisher: Elsevier.

Gray, W. B. and R. J. Shadbegian (2004). 'Optimal'pollution abatement—whose benefits matter, and how much? *Journal of Environmental Economics and management 47*(3), 510–534. Publisher: Elsevier.

Greenstone, M. (2002). The impacts of environmental regulations on industrial activity: Evidence from the 1970 and 1977 clean air act amendments and the census of manufactures. *Journal of political economy 110*(6), 1175–1219. Publisher: The University of Chicago Press.

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

Greenstone, M., J. A. List, and C. Syverson (2012). The effects of environmental regulation on the competitiveness of US manufacturing. Technical report, National Bureau of Economic Research.

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

Henderson, J. V. (1996). Effects of air quality regulation. *The American Economic Review*, 789–813. Publisher: JSTOR.

Hering, L. and S. Poncet (2014). Environmental policy and exports: Evidence from Chinese cities. *Journal of Environmental Economics and Management 68*(2), 296–318. Publisher: Elsevier.

Kahn, M. E. (2004). Domestic pollution havens: Evidence from cancer deaths in border counties. *Journal of Urban Economics 56*(1), 51–69. Publisher: Elsevier.

Kahn, M. E., P. Li, and D. Zhao (2015). Water pollution progress at borders: the role of changes in China's political promotion incentives. *American Economic Journal: Economic Policy 7*(4), 223–42.

Keiser, D. A., S. M. Olmstead, K. J. Boyle, V. B. Flatt, B. L. Keeler, C. L. Kling, D. J. Phaneuf, J. S. Shapiro, and J. P. Shimshack (2021). A water rule that turns a blind eye to transboundary pollution. *Science 372*(6539), 241–243. Publisher: American Association for the Advancement of Science.

Kosoy, N., M. Martinez-Tuna, R. Muradian, and J. Martinez-Alier (2007). Payments for environmental services in watersheds: Insights from a comparative study of three cases in Central America. *Ecological economics 61*(2-3), 446–455. Publisher: Elsevier.

Lipscomb, M. and A. M. Mobarak (2016). Decentralization and pollution spillovers: evidence from the re-drawing of county borders in Brazil. *The Review of Economic Stud-*

ies 84(1), 464–502. Publisher: Review of Economic Studies Ltd.

List, J. A., D. L. Millimet, P. G. Fredriksson, and W. W. McHone (2003). Effects of environmental regulations on manufacturing plant births: evidence from a propensity score matching estimator. *Review of Economics and Statistics 85*(4), 944–952. Publisher: MIT Press.

Ryan, S. P. (2012). The costs of environmental regulation in a concentrated industry. *Econometrica 80*(3), 1019–1061. Publisher: Wiley Online Library.

Sandler, T. (2006). Regional public goods and international organizations. *The Review of International Organizations 1*(1), 5–25. Publisher: Springer.

Shleifer, A. (1985). A theory of yardstick competition. *The RAND journal of Economics*, 319–327. Publisher: JSTOR.

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

Sigman, H. (2005). Transboundary spillovers and decentralization of environmental policies. *Journal of environmental economics and management 50*(1), 82–101. Publisher: Elsevier.

Walker, W. R. (2013). The transitional costs of sectoral reallocation: Evidence from the clean air act and the workforce. *The Quarterly journal of economics 128*(4), 1787–1835. Publisher: MIT Press.

Wolf, A. T. (2007). Shared waters: Conflict and cooperation. *Annu. Rev. Environ. Resour. 32*, 241–269. Publisher: Annual Reviews.

Zhang, B., X. Chen, and H. Guo (2018). Does central supervision enhance local environmental enforcement? Quasi-experimental evidence from China. *Journal of Public Economics 164*, 70–90. Publisher: Elsevier.

Appendix

Appendix A. Figures and Tables

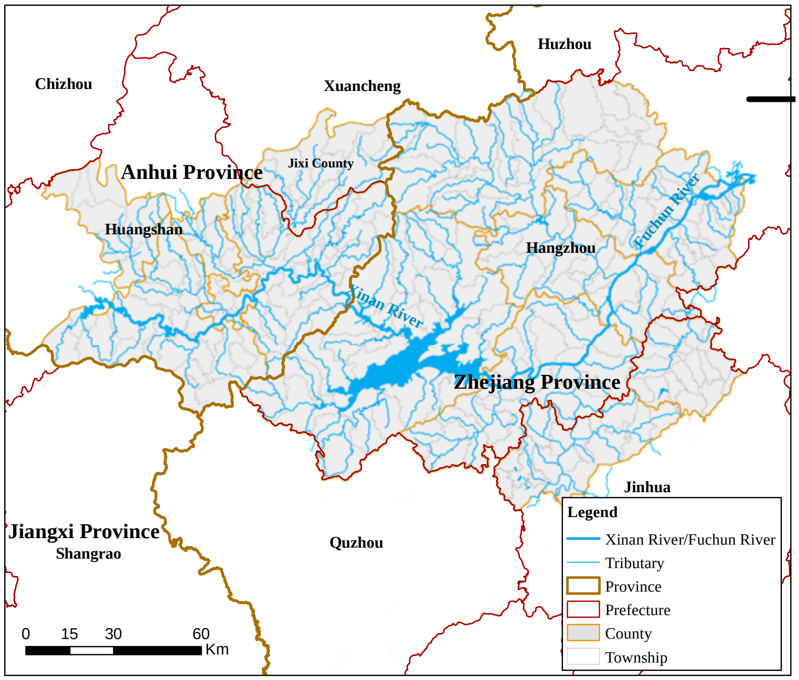
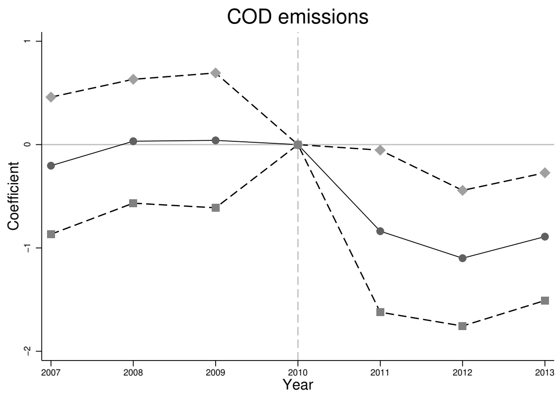
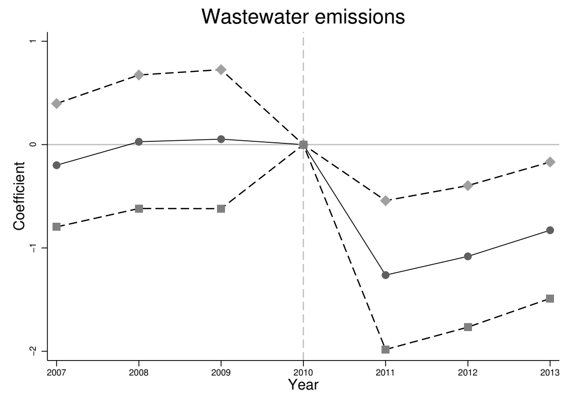


Figure A1: Xin'an River Basin



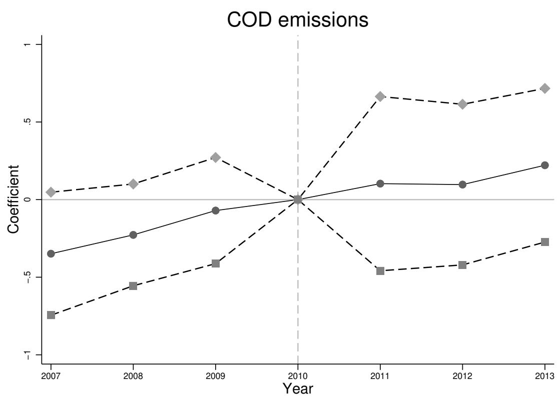
Panel A. COD



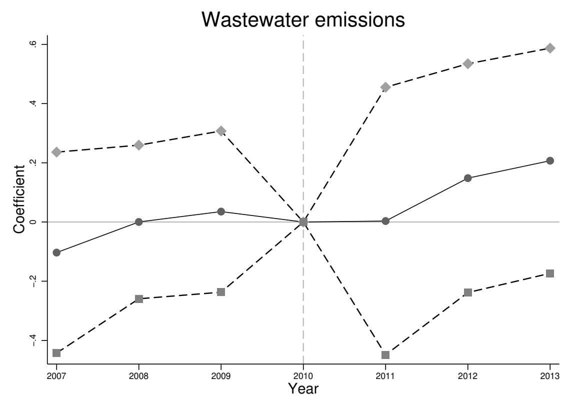
Panel B. Wastewater discharge

Figure A2: Parallel Trend of Water Pollutant Emissions in Heavily-Polluting Industries

Notes: Each dot represents the coefficient of $Treat \times Post_t$ in each year. The dashed lines plot the corresponding 95% confidence interval.



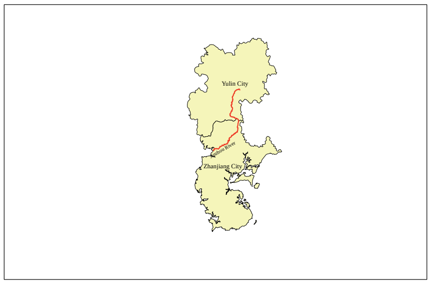
Panel A. COD



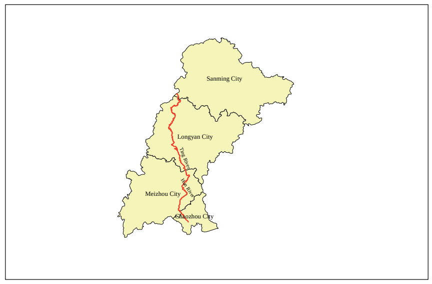
Panel B. Wastewater discharge

Figure A3: Parallel Trend of Water Pollutant Emissions in Less-Polluting Industries

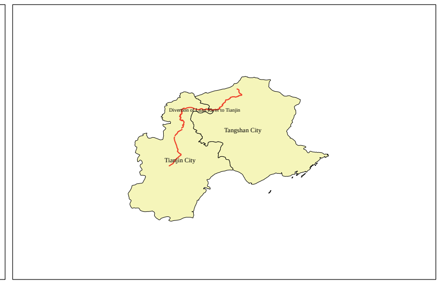
Notes: Each dot represents the coefficient of $Treat \times Post_t$ in each year. The dashed lines plot the corresponding 95% confidence interval.



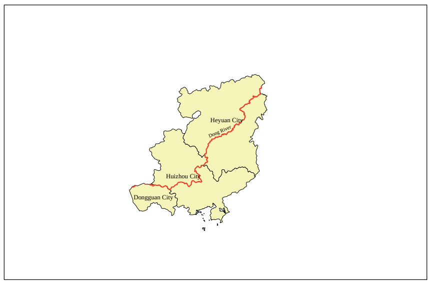
(1) Jiuzhou River



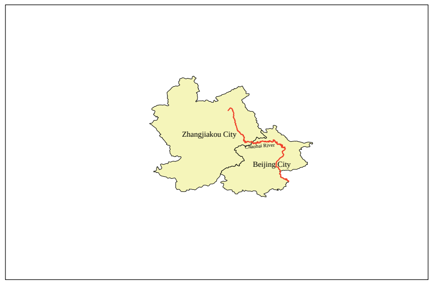
(2) Han-Ting River



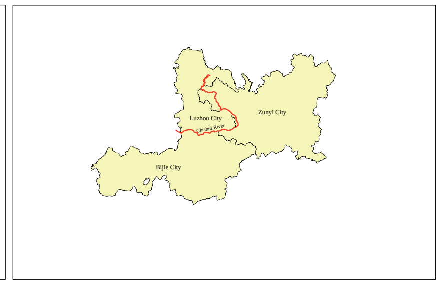
(3) Luan River



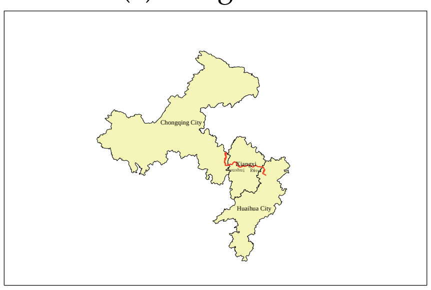
(4) Dong River



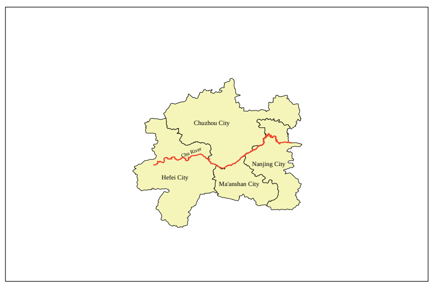
(5) Chaobai River



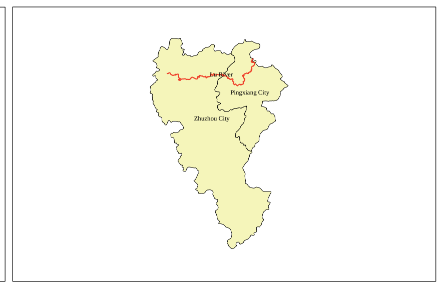
(6) Chishui River



(7) You River



(8) Chu River



(9) Lu River

Figure A4: Other Pilot River Basins

Notes: This figure presents the maps of follow-up watersheds also implementing Ecological Compensation Initiatives like the ECI in Xin'an River Basin. The prefectures are those located in the upstream and downstream stretch of the river, which are also the parties of the cross-provincial compensation contracts.

Table A1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
(log) Wastewater COD	8305	9.015	2.172	-0.357	15.297
(log) Wastewater discharge	8524	11.426	2.106	0.912	17.6
(log) Output	8526	8.494	1.733	2.565	15.096
(log) SO_2	4357	9.734	1.891	0.693	16.041
(log) NO_x	4200	8.774	1.666	4.787	12.109
(log) Industrial smoke and dust	4378	8.453	2.433	0	15.127
(log) COD production	7221	10.698	2.658	0	16.313
(log) Wastewater production	7464	12.515	1.898	5.303	16.649
(log) Total water input	8534	12.297	2.019	6.551	16.446
(log) Fresh water input	8534	11.729	2.035	2.89	17.767
Number of abatement facilities	7802	1.069	0.932	0	30
(log) Abatement ability	7358	6.653	1.981	0.405	14.403

Table A2: Dynamic Effect of the ECI on Water Pollutant Emissions

	All industries		Heavily-polluting industries		Less-polluted industries	
	(1)	(2)	(3)	(4)	(5)	(6)
	COD	Discharge	COD	Discharge	COD	Discharge
Treat×Post2007	-0.22	-0.16	-0.20	-0.20	-0.35*	-0.10
	(0.29)	(0.26)	(0.34)	(0.30)	(0.20)	(0.17)
Treat×Post2008	-0.01	0.03	0.03	0.03	-0.23	0.00
	(0.27)	(0.28)	(0.31)	(0.33)	(0.17)	(0.13)
Treat×Post2009	0.02	0.05	0.04	0.05	-0.07	0.04
	(0.28)	(0.29)	(0.33)	(0.34)	(0.17)	(0.14)
Treat×Post2011	-0.78**	-1.10***	-0.84**	-1.26***	0.10	0.00
	(0.34)	(0.33)	(0.40)	(0.37)	(0.29)	(0.23)
Treat×Post2012	-0.95***	-0.93***	-1.10***	-1.08***	0.10	0.15
	(0.30)	(0.31)	(0.33)	(0.35)	(0.26)	(0.20)
Treat×Post2013	-0.77***	-0.77**	-0.89***	-0.83**	0.22	0.21
	(0.29)	(0.30)	(0.32)	(0.34)	(0.25)	(0.19)
County-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,807	8,017	5,944	6,128	1,849	1,875
R-squared	0.90	0.92	0.89	0.91	0.90	0.91

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variable in specifications (1) is the (log) wastewater emissions by COD, and in specification (2) is the (log) wastewater emissions by discharge amount, respectively. The county-level controls include (log) GDP and (log) population of the county.

Table A3: The Impact of the ECI on Water Pollutant Emissions

	Heavily-polluting industries		Less-polluting industries	
	(1)	(2)	(3)	(4)
	COD	Discharge	COD	Discharge
Treat×Post	-0.90***	-0.92***	0.27	0.25
	(0.29)	(0.26)	(0.27)	(0.19)
County-level controls	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes
Observations	5,944	6,128	1,849	1,875
R-squared	0.89	0.91	0.90	0.91

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the county-year level, are in parentheses. The dependent variable in specifications (1) and (3) is the (log) emissions in COD, and in specifications (2) and (4) it is the (log) emissions by volume.

Table A4: The Effect of the ECI on Emissions in Neighboring Prefectures

	Neighboring areas in the same province		Neighboring areas in adjacent province	
	(1)	(2)	(3)	(4)
	COD	Wastewater	COD	Wastewater
Treat×Post	0.38*	-0.07	1.81***	0.95***
	(0.20)	(0.17)	(0.20)	(0.18)
County-level controls	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes
Year-industry fixed effect	Yes	Yes	Yes	Yes
Observations	9,901	10,116	8,967	9,277
R-squared	0.91	0.93	0.89	0.90

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors, corrected for clustering at the firm level, are in parentheses. The dependent variable in specifications (1) and (3) is the (log) emissions of COD, and in specifications (2) and (4) is the (log) emissions of wastewater. The county-level controls include (log) GDP and (log) population of the county. The treatment group in columns (1)–(2) contains the observations in Chizhou Prefecture and Xuancheng Prefecture (except Jixi County), while columns (3)–(4) contain the observations in Jingdezhen Prefecture and Shangrao Prefecture. The control group is the observations in Hangzhou Prefecture.

Table A5: Pilot River Basins with Ecological Compensation Plans

River Basin	Year	Upstream Prefectures	Downstream Prefectures
Xin'an River	2011	Huangshan and Jixi (county) in Anhui	Hangzhou in Zhejiang
Jiuzhou River	2015	Yulin in Guangxi	Zhanjiang in Guangdong
Han-Ting River	2016	Sanming and Longyan in Fujian	Meizhou and Chaozhou in Guangdong
Luan River	2016	Tang in Hebei	Tianjin
Dong River	2016	Ganzhou in Jiangxi	Heyuan, Huizhou and Dongguan in Guangdong
Chaobai River	2018	Zhangjiakou in Hebei	Beijing
Chishui River	2018	Zunyi in Guizhou	Luzhou in Sichuan
Youshui River	2019	Chongqing	Xiangxi (autonomous region) and Huaihua in Hunan
Chu River	2019	Hefei, Chuzhou and Ma'anshan in Anhui	Nanjing in Jiangsu
Lu River	2019	Pingxiang in Jiangxi	Zhuzhou in Hunan

Notes: This table shows information on other river basins implementing compensation initiatives resembling the Xin'an River ECI. Column (2) is the starting year of the respective initiatives. Columns (3) and (4) provide the upstream and downstream regions involved. The prefecture names are given, unless otherwise stated.

Appendix B. Welfare analysis

When there is a compensation policy for ecosystem service in a watershed, the optimal choice of output q_x satisfies:

$$u'(q_x^p - c(q_x^p))(1 - c'(q_x^p)) = \int_x^b \gamma a e^{-\beta(t-x)} f(t)dt + \lambda a e^{-\beta(b-x)}$$

Comparing the first-order conditions (1) and (2), we see that when $\lambda = 0$, we have $q_x^p = q_x^*$. When $\lambda = \int_b^1 \gamma e^{-\beta(y-b)} f(y)dy$, the optimal solution for upstream welfare maximization under compensation policy should be $q_x^p = q_x^{**}$.

If $P^b(q_x^{**}) < \bar{P} < P^b(q_x^*)$, the Lagrange multiplier λ should satisfy $0 < \lambda < \int_b^1 \gamma e^{-\beta(y-b)} f(y)dy$. When $\bar{P} < P^b(q_x^*)$, the constraints for pollution emission are binding, i.e., $\lambda > 0$. When $P^b(q_x^{**}) < \bar{P}$, the Lagrange multiplier λ should be less than $\int_b^1 \gamma e^{-\beta(y-b)} f(y)dy$ since $u'(q_x^p - c(q_x^p))(1 - c'(q_x^p))$ is monotonically decreasing in q_x.

As λ increases, q_x^p should decrease since $u'(q_x^p - c(q_x^p))(1 - c'(q_x^p))$ is monotonically decreasing in q_x. Given the first-order conditions (1) and (2) and $0 < \lambda < \int_b^1 \gamma e^{-\beta(y-b)} f(y)dy$, we therefore have $q_x^{**} < q_x^p < q_x^*$.

Finally, the impact of the q_x change on global welfare satisfies:

$$\frac{\partial W}{\partial q_x} = u'(q_x^p - c(q_x^p))(1 - c'(q_x^p) - \int_x^b \gamma a e^{-\beta(t-x)} f(t)dt - \int_b^1 \gamma e^{-\beta(y-b)} f(y)dy a e^{-\beta(b-x)}$$

which is less than zero if $q_x^{**} < q_x^p$. Therefore, we have $W^u(q_x^*) + W^d(q_x^*) < W^u(q_x^p) + W^d(q_x^p)$ if $q_x^{**} < q_x^p < q_x^*$, which implies that there exists a mutually acceptable compensation arrangement under which both upstream and downstream welfare increase, relative to the no-contract case.