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Environmental Pressure in Supply Chains: Pass-Through Effects on R&D and Innovation *

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This paper investigates the pass-through of environmental compliance costs along supply chains. We compile a firm-level dataset linking regulated firms in pollution-intensive industries with their top five clients and suppliers. We find that clients of regulated firms invest less in R&D, employ fewer skilled R&D staff, and produce fewer innovations than clients of less regulated firms, while no comparable effects are observed for suppliers. The pass-through is stronger with larger trade volumes, higher input prices faced by clients, and in markets where regulated firms hold greater market power or clients face intense competition. Policy simulations suggest that green technology incentives for regulated firms and R&D subsidies for their clients can mitigate these adverse effects and raise social welfare by enhancing both innovation and environmental quality.

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1 Introduction

Addressing environmental challenges inherently involves a fundamental trade-off between economic costs and environmental benefits. Economists have long studied this tension, seeking to design regulatory frameworks that mitigate environmental damage while minimizing economic distortions. However, conventional evaluation of environmental regulation may systematically underestimate their full economic costs, particularly by overlooking the pass-through of regulatory burdens across production networks. Firms subject to stringent environmental regulations may not bear the entire compliance burden themselves. Instead, they may pass on a portion of these costs to their supply chain partners, which potentially affects the partners' resource allocation, investment decisions, and innovation activities. These pass-through effects might be economically meaningful but have received limited empirical attention.

In this paper, we investigate the pass-through effects of environmental regulatory costs along supply chains. Specifically, we address three research questions: Do firms pass environmental compliance costs on to their clients and suppliers? How does such pass-through affect partner firms' investments in R&D, human capital, and innovation? What are the mechanisms underlying such supply chain pass-through? By addressing these questions, we aim to quantify the often-overlooked pass-through effects of environmental pressures and enhance the understanding of its broader economic implications.

We begin with a model that illustrates the core mechanism. When firms are subject to environmental regulation, compliance raises their marginal production costs, and therefore they set higher prices for their outputs. Their clients, who use these regulated firms' outputs as intermediate inputs, consequently face increased production costs. This risen cost lowers the marginal returns to R&D investment, thereby discouraging innovation efforts. Building on this conceptual framework, we proceed to empirically test these mechanisms using detailed firm-level data.

Our empirical strategy builds on [He et al. \(2020\)](#), who pioneered the use of a quasi-natural experiment exploiting China's water pollution monitoring system to identify exogenous variation in environmental regulation. Since 2003, the Chinese central government has used real-time readings from surface water monitoring stations to evaluate the pollution control performance of local governments. Since upstream discharges directly affected water quality readings, it motivated local officials to impose stricter inspections and enforcement on upstream firms relative to the stations. Consequently, upstream firms, located just above monitoring points, face substantially greater environmental scrutiny and abatement requirements than downstream firms located just below. This regulatory structure creates a sharp discontinuity in environmental compliance across the monitoring stations, providing a favorable setting for a spatial regression discontinuity (RD)

design.

To construct a valid RD design, we restrict our sample to firms located within a 20-kilometer radius of monitoring stations and verify that key covariates, such as meteorological, geographic, and socioeconomic conditions, are smooth across the cutoff (Lee, 2008). Furthermore, we apply the density continuity test proposed by Bugni and Canay (2021) and confirm the absence of sorting or manipulation around the cutoff (Lee, 2008; Lee and Lemieux, 2010). We observed that less than 2 percent of firms in our sample changed their locations between 1998 and 2014, and excluding them does not affect our results.

Furthermore, we construct a comprehensive firm-level dataset linking three groups: regulated firms located near monitoring stations in pollution-intensive industries, their top five clients by transaction volume, and their top five suppliers. Clients and suppliers are located outside the 20-kilometer monitoring radius and are not directly subject to the regulatory variation induced by the monitoring stations. We find that clients of upstream regulated firms, who face stricter environmental enforcement, exhibit significantly lower R&D investment, employ fewer skilled R&D staff, and produce fewer innovations than those connected to downstream regulated firms. We show that a 1.0% increase in environmental regulatory stringency imposed on regulated firms is associated with an approximate 0.50%, 0.53%, and 0.31% reductions in the total R&D expenditure, R&D staff, and innovations of their client firms. Nevertheless, we find no significant evidence on the R&D activities of regulated firms' suppliers.

In order to understand the mechanism behind the main results, we first show that the pass-through effects are more pronounced for larger trade volumes between regulated firms and their clients. Second, clients of upstream regulated firms have higher unit costs of production, which indicates that they partially bear the environmental compliance costs via higher input prices. Third, the extent of pass-through depends on market structure: pass-through is more salient when the regulated firm possesses stronger market power, or when clients operate in highly competitive markets. Last, clients are more likely than suppliers to respond to environmental cost pass-through by reducing transaction volumes or switching trading partners. These adjustments impose additional frictions, such as search and switching costs, technical incompatibilities, and delays, which could collectively depress clients' R&D activities.

Finally, we extend the baseline model to incorporate environmental externalities and government interventions to derive policy implications. Using the calibrated model, we show that, given the stringency of environmental regulation and its pass-through effects, green technology incentives that lower regulated firms' compliance costs can stimulate R&D investment by their client firms. Likewise, R&D subsidies for client firms, which raise the marginal return to innovation, can also increase their R&D investment. From a social welfare perspective, accounting for both

consumption and environmental quality, we find that both green technology incentives and R&D subsidies move the economy closer to the social optimum. This finding echoes the insights of [Aghion et al. \(2025\)](#), who emphasize that environmental taxation alone is insufficient to achieve optimal welfare in the presence of innovation externalities.

This paper contributes to the literature in three main ways. First, it contributes to the growing literature on supply chain by documenting the pass-through of environmental regulatory costs. Prior research has examined the pass-through of financing costs ([Emran et al., 2021](#); [Hendricks and Singhal, 2005](#)), energy prices ([Ganapati et al., 2020](#)), and other input shocks ([Alvarez et al., 2024](#); [Minton and Wheaton, 2023](#); [Genakos and Pagliero, 2022](#); [Barrot and Sauvagnat, 2016](#); [Nakamura, 2008](#)). Within the environmental domain, existing studies have primarily examined carbon cost pass-through in electricity markets ([Hintermann, 2016](#); [Fabra and Reguant, 2014](#); [Sijm et al., 2012](#); [Chernyavs'ka et al., 2008](#)). For example, [Fabra and Reguant \(2014\)](#) use data from Spain and show that firms can almost fully pass through carbon emission costs to wholesale electricity prices during peak periods. On this point, [Dominguez-lino \(2025\)](#) use an equilibrium analysis to evaluate how the transmission of various environmental policy occurs along a supply chain in the presence of market distortions. Building on this line of research, we provide novel evidence on the pass-through of environmental regulatory compliance costs and their effects on client firms' R&D investment and innovation performance in a broader industrial context.

Second, it contributes to the literature on the evaluation of economic costs of environmental regulation. While a substantial literature has emphasized the potential for environmental regulation to stimulate innovation ([Cui et al., 2022](#); [Aghion et al., 2016](#); [Ambec et al., 2013](#); [Porter and van der Linde, 1995](#)), other studies underscore the productivity and financial burdens of compliance ([Fan et al., 2025](#); [Fan et al., 2021](#); [He et al., 2020](#); [Fowlie et al., 2016](#); [Ryan, 2012](#); [Stokey, 1998](#)). Our findings offer a more nuanced perspective: even if regulated firms may innovate or adapt, their trading partners, particularly clients, may suffer indirect innovation setbacks. This suggests that environmental regulation can generate additional economic costs not captured in regulated firm-level evaluations. By focusing on R&D and innovation, which are the key drivers of long-run productivity and firm competitiveness ([Arora et al., 2021](#); [Bhaskarabhatla et al., 2021](#); [Flammer and Kacperczyk, 2016](#); [Aghion et al., 2005](#)), the paper highlights a critical and yet underexplored channel through which environmental regulation may affect economic growth. The findings emphasize the importance of accounting for supply chain linkages in policy evaluation and call for regulatory designs that minimize unintended distortions across production networks.

Finally, our findings contribute to the debate on policy design for supply chains and production networks. A growing literature emphasizes the importance of integrating sustainability into supply chain management ([Diebel et al., 2024](#); [Lee and Tang, 2018](#); [O'Rourke, 2014](#); [Hofmann et](#)

al., 2014; Linton et al., 2007). In parallel, network-based analyses show that targeted interventions can improve environmental outcomes by minimizing unintended distortions. For example, Acemoglu et al. (2012) demonstrate that optimal climate policy requires a combination of carbon taxation and green R&D subsidies; while King et al. (2019) show that reforms targeting sectors by their network centrality yield greater aggregate emission reductions than policies focused only on direct emitters. More recently, Aghion et al. (2025) develop a dynamic model showing that, even with Pigouvian taxation, targeted greenification subsidies for downstream firms along the supply chain are often necessary to achieve the social optimum. Building on this literature, we show that environmental compliance costs are passed through to client firms' R&D activities. This implies that policies combining green technology support for regulated firms with R&D subsidies for their clients can enhance social welfare.

The remaining of this paper proceeds as follows. Section 2 provides a description of the institutional background. Section 3 presents a model to motivate our analysis. Section 4 describes empirical strategy and data. Section 5 presents main empirical results. Section 6 explores the potential mechanisms. Section 7 provides policy implications. Section 8 concludes the paper.

2 Institutional Background

2.1 Environmental Compliance Variation

China's water quality monitoring network exhibits significant variation in environmental intervention across the upstream–downstream dimension. In the 1990s, the Chinese government began establishing a long-term surface water monitoring system aimed primarily at hydrological data collection and water-related disaster forecasting.¹ To ensure consistent access to surface water data, the monitoring infrastructure, comprising sampling pipes and pumps, was predominantly installed along the main streams of rivers, as well as key lakes and reservoirs (see Figure A.1). Notably, the siting of these monitoring stations was determined centrally and based solely on hydrological considerations, independent of local industrial activity. This implies that the monitoring network was initially designed without regulatory or enforcement objectives.

It was not until 2003 that these stations began to serve an environmental supervisory function, following the central government's introduction of ambitious targets for water pollution control. These targets were devolved to local governments, and the centrally collected water quality data became a direct and objective basis for evaluating the environmental performance of local officials.

¹The monitored indicators fall into two main categories: general water quality metrics, such as temperature, chroma, and pH, and hazardous substances including heavy metals like chromium and cadmium, as well as organic pesticides. In addition, many stations are equipped to measure river flow velocity and discharge for the purpose of flood prevention.

In response, motivated by political accountability and career advancement incentives, local governments began to adopt stricter discharge standards and carried out more frequent inspections, especially targeting water-polluting firms.

Critically, regulatory enforcement became spatially asymmetric: upstream firms were subject to more stringent controls because their discharges would affect downstream water quality readings observed by the central government. This dynamic created a strong regulatory incentive for local officials to focus on upstream pollution sources. Consequently, upstream firms were pushed to invest more heavily in cleaner technologies, adopt advanced environmental management practices, and conduct routine monitoring of their production processes to mitigate environmental risks such as improper waste disposal, oil spills, or toxic emissions.

Empirical evidence demonstrates that upstream firms face tighter environmental regulations and emit fewer pollutants per unit of output. [He et al. \(2020\)](#) find that this increased regulatory stringency imposes substantial compliance costs, resulting in a decline in total factor productivity (TFP) among upstream firms. This upstream–downstream regulatory asymmetry creates a quasi-natural discontinuity in environmental regulatory pressure. In this study, we explore how such regulatory pressure imposed on upstream and downstream firms are transmitted to their supply chain partners, including both clients and suppliers, and affects their production and innovation behaviors.

2.2 Regulated Firms, Clients, and Suppliers

This study focuses on three interconnected groups: firms subject to environmental regulation, the clients, and the suppliers of these regulated firms. It is important to clarify that throughout the paper, “upstream” and “downstream” refer to a firm’s location relative to water quality monitoring stations along the river flow, not to positions along the supply chain. To avoid confusion, we use the terms clients and suppliers to refer to a firm’s downstream and upstream partners in the supply chain, respectively.

First, regulated firms are those operating in water pollution-related industries and located within a 20-kilometer radius of a water quality monitoring station. Based on their location relative to the river flow and the station, we categorize them into upstream regulated firms and downstream regulated firms. As discussed in Section 2.1, upstream regulated firms are subject to substantially more frequent and stringent environmental inspections than their downstream counterparts. Our empirical evidence shows that upstream regulated firms exhibit significantly lower pollutant discharge intensity compared to downstream regulated firms.

Second, clients of regulated firms are defined as the top five customers of each regulated firm (upstream or downstream), based on transaction volume. On average, these clients account for

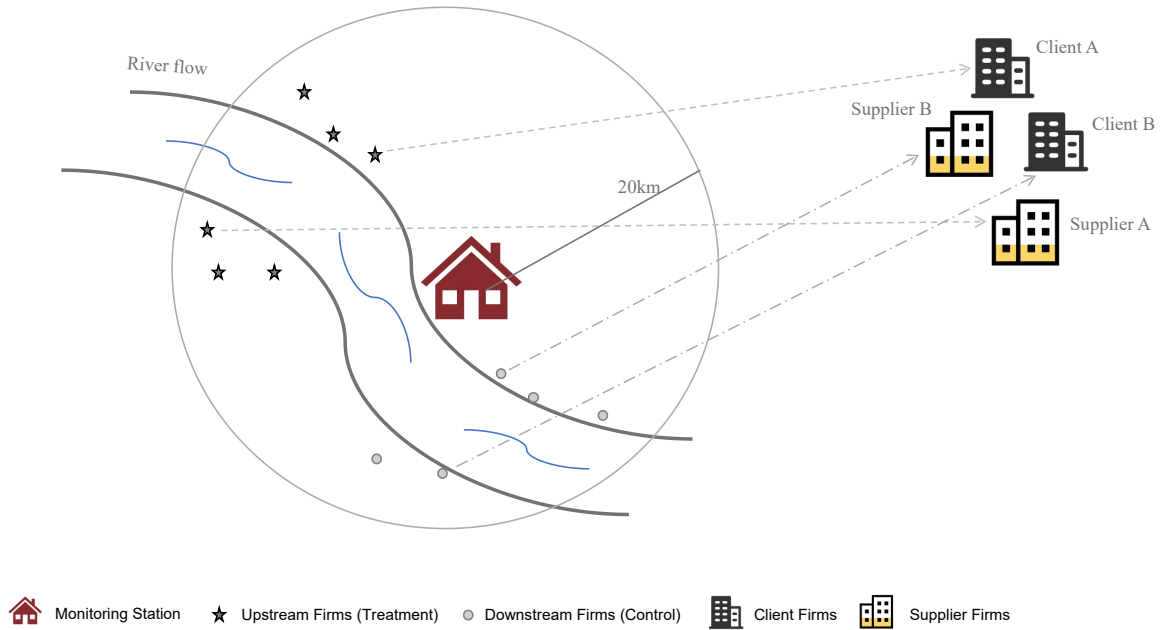


Figure 1: Illustration of Research Design

over 60% of the regulated firm's total sales revenue. Importantly, these client firms are not located within the 20-kilometer radius of the monitoring stations and may or may not operate in pollution-intensive industries. As shown in Figure 1, these clients are not subject to any direct regulatory variation based on location or industry. Therefore, any variations in regulatory pressure they face may arise indirectly through their relationship with the regulated firms. Our hypothesis is that clients of upstream regulated firms are more likely to be exposed to transmitted environmental pressure. Specifically, upstream regulated firms may pass on part of their abatement costs via input prices, thereby transmitting regulatory burdens to their clients through commercial transactions.

Third, suppliers of regulated firms are defined as the top five input providers of each regulated firm (upstream or downstream), again based on transaction volume. On average, these suppliers account for approximately 40% of the regulated firm's total intermediate input costs. Like clients, these suppliers are located outside the 20-kilometer radius and may not be directly involved in pollution-related industries. As shown in Figure 1, they are also not subject to systematic regulatory variation. However, they may indirectly experience environmental pressure depending on their customers' exposure. Our hypothesis is that suppliers of upstream regulated firms are more likely to face transmitted environmental pressure, but the extent of this transmission may depend on their market power. For example, powerful suppliers may have more leverage in resisting cost pass-through or renegotiating contract terms.

By exploring this institutional setting, our study addresses a central research question: how does environmental regulatory pressure pass through supply chains, particularly with regard to firms' R&D investments? Furthermore, we explore the underlying mechanisms, including cost pass-through, bargaining power, and relational dependence, that shape the strength and direction of such pass-through effects.

3 An Illustrative Model

We begin by presenting a model of firm decision-making to clarify the underlying mechanisms and to provide a foundation for our quantitative analysis. The model features a vertically linked economy consisting of two types of agents: regulated firms and their client firms. The regulated firms produce differentiated intermediate inputs and are heterogeneous in environmental compliance costs. The client firms purchase intermediate inputs to produce consumption goods and invest in R&D to enhance productivity. We draw upon the theory proposed by [Weyl and Fabinger \(2013\)](#), which integrates imperfect competition in intermediate input markets and cost pass-through mechanism along the supply chain. In our model, we assume a perfectly elastic supply curve to simplify the characterization of pass-through, which allows us to focus exclusively on the incidence effects arising from the demand side.

3.1 Regulated Firms

There exists a continuum of producers operating in pollution-intensive industries, such as energy, chemicals, and metal materials. Each firm is indexed by $j \in [0, 1]$. Environmental regulation is modeled as a per-unit tax or abatement mandate imposed on these polluting producers. Each firm draws an environmental cost coefficient κ_j from a distribution $G(\cdot)$. The firm's marginal cost of production is given by

$$MC_j = w + \kappa_j \tau \quad (1)$$

where w denotes the wage rate and τ represents the per-unit environmental compliance cost. Firms located upstream in the supply chain are assumed to possess market power. With a constant markup μ_r , the regulated firm's optimal pricing decision is given by

$$P_{M,j} = (1 + \mu_r)(w + \kappa_j \tau), \quad (2)$$

where $\mu_r = 1/(\sigma - 1)$. The incorporation of environmental compliance increases regulated firms' marginal costs, and in response, these regulated firms raise their product prices accordingly. This pricing adjustment implies that at least a portion of the regulatory burden is passed through to

their client firms via higher input prices.

3.2 Client Firms

Client firms are positioned downstream in the supply chain, where they specialize in the production of final consumption goods and serve as the primary drivers of R&D and innovation. These firms produce combining a continuum of intermediate inputs $M = \left(\int_0^1 M_j^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}$, with inputs price index $P_M = \left(\int_0^1 P_{M,j}^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}}$, where $\sigma > 1$ denotes the elasticity of substitution across varieties. Each client firm i is characterized by an idiosyncratic base productivity level $\theta_i \sim H(\cdot)$. The firm chooses labor $L_{c,i}$, intermediate input M_i , and R&D investment R_i to produce outputs $Y_i = P_Y A_i L_i^\alpha M_i^\beta$, $A_i = \theta_i + \gamma R_i$, where θ_i is firm i 's base productivity, $\gamma > 0$ is the R&D productivity parameter, and $0 < \alpha, \beta$ with $\alpha + \beta < 1$ imply decreasing returns to scale. Under perfect competition, the firm takes the output price (P_Y) as given and maximizes profit:

$$\max_{L_i, M_i, R_i \geq 0} \left\{ P_Y Y_i - w L_i - P_M M_i - \frac{(1-s)\varphi}{2} R_i^2 - f \right\}, \quad (3)$$

where $f > 0$ is a fixed cost and w is the wage rate. The first-order condition with respect to R&D yields the firm's optimal R&D investment:

$$R_i^* = \frac{P_Y \gamma}{(1-s)\varphi} \left[\frac{\alpha P_Y (\theta_i + \gamma R_i^*)}{w} \right]^{\frac{\alpha+\beta}{1-\alpha-\beta}} r^{\frac{\beta}{1-\alpha-\beta}}, \quad (4)$$

where $r \equiv \frac{\beta}{\alpha} \frac{w}{P_M}$. The details of the solution of the problem of clients and regulated firms are in Appendix A and B, respectively.

3.3 Equilibrium Pass-through

It is a clear mechanism that an increase in the environmental compliance cost borne by regulated firms translates into a higher composite input price for their client firms. This risen input price increases the client firms' production costs and reduces their R&D investment, i.e., $\frac{d \ln R}{d \ln P_M} = - \frac{\beta (\theta + \gamma R^*)}{(1-\alpha-\beta) \theta + [1-2(\alpha+\beta)] \gamma R^*} < 0$. An analogous argument applies to increases in regulated firms' markups μ_r , which amplify pass-through and further suppress client firms' production and R&D. We formalize these insights into the following propositions.

Proposition 1. *Environmental regulatory costs can be passed through from regulated upstream firms to their downstream clients. This pass-through effect reduces both the equilibrium output and R&D investment of client firms. Specifically, $\frac{d \ln Y_i^*}{d \ln \tau} < 0$ and $\frac{d \ln R_i^*}{d \ln \tau} < 0$.*

Proposition 2. *A higher markup among upstream regulated firms intensifies the pass-through of environmental costs to downstream client firms. As a result, the distortion on client firms' production and innovation is magnified. Specifically, $\frac{d \ln Y_i^*}{d \ln \mu_r} < 0$ and $\frac{d \ln R_i^*}{d \ln \mu_r} < 0$.*

4 Empirical Strategy and Data Description

4.1 Spatial Regression Discontinuity (RD) Design

We employ a spatial regression discontinuity (RD) design that leverages the variation in environmental regulation between upstream and downstream firms located around water quality monitoring stations, following the approach proposed by [He et al. \(2020\)](#). In this setting, firms located just downstream of a water quality monitoring station serve as a valid counterfactual for those located just upstream, under the assumption that these firms are otherwise similar but face different intensities of environmental regulation.

We focus primarily on the clients and suppliers of these upstream and downstream regulated firms. Importantly, these clients and suppliers are located outside the 20-kilometer radius surrounding the monitoring stations and are thus not subject to direct regulatory heterogeneity. Furthermore, we construct the sample such that each client or supplier is exclusively linked to either an upstream or downstream regulated firm, but never to both. This non-overlapping structure ensures that differences in outcomes between these two groups can be attributed to the regulatory intensity faced by their associated regulated firm, rather than to overlapping exposure.

Consequently, clients of upstream regulated firms can be compared to clients of downstream regulated firms to identify the pass-through effects of environmental regulation. Since these clients are otherwise observationally similar, e.g., located outside the regulatory zones, and not subject to regulatory treatment themselves, any observed difference in outcomes can be interpreted as being transmitted via upstream firms' exposure to environmental pressure, such as through input prices or changes in transaction terms. Accordingly, our benchmark empirical specification is defined as follows:

$$Y_{ist} = \alpha_1 upstream_i + \alpha_2 f(Dist_i) + \alpha_3 upstream_i \times f(Dist_i) + X_{ist} + \lambda_s + \eta_t + \epsilon_{ist}, \quad (5)$$

subject to the condition $-h \leq Dist_i \leq h$. Y_{ist} denotes the outcome variable of interest for firm i , located near monitoring station s , in year t . The key treatment variable, $upstream_i$, is a binary indicator equal to 1 if firm i is a client of an upstream regulated firm, and 0 if it is a client of a downstream regulated firm. The coefficient α_1 captures the local average treatment effect at the cutoff, i.e., the discontinuous change in outcomes driven by the asymmetric environmental

regulation. $Dist_i$ denotes the distance from firm i to the corresponding monitoring station, and $f(Dist_i)$ is a flexible function of distance, for which we employ the mean squared error (MSE)-optimal bandwidth selection method proposed by [Calonico et al. \(2014\)](#).

The vector X_{ist} includes firm-level control variables such as firm age and sales. We include station fixed effects λ_s to absorb unobserved spatial heterogeneity across stations, year fixed effects η_t to control for time-varying shocks, and two-digit industry fixed effects to account for industry-specific technological or regulatory conditions. The control of these fixed-effects ensures that we are comparing clients (or suppliers) in the same industry, located around the same monitoring station, and observed in the same year.

4.2 Threats to Causal Identification

To interpret the RD estimates as causal effects, two key identification assumptions must hold. First and foremost, local random assignment of firms around the cutoff. In the RD framework, this requires that firms are as good as randomly assigned to locations just upstream or downstream of the monitoring stations. While we cannot directly observe the assignment mechanism, [Lee \(2008\)](#) and [Lee and Lemieux \(2010\)](#) suggest that this assumption can be supported by testing for the continuity of predetermined covariates at the cutoff. In our setting, we define a 20 km-radius neighborhood around each monitoring station, restricted to areas within the same county and subject to similar meteorological conditions. This setup facilitates straightforward tests for smooth variation in predetermined geographic, meteorological, and socioeconomic characteristics.

Second, no precise manipulation of firm locations. This requires that firms cannot precisely sort themselves to upstream or downstream locations in anticipation of regulatory differences. For example, pollution-intensive firms may have incentives to locate downstream to avoid stringent enforcement. To test this, we follow the density test approach recommended by [Lee and Lemieux \(2010\)](#) and implement the approximate sign test developed by [Bugni and Canay \(2021\)](#). The results suggest no statistically significant discontinuities in the density of firm locations around the monitoring stations, indicating an absence of significant strategic sorting behavior. Additionally, we examine firm location records between 1998 and 2014 and find that very few firms changed their location in the upstream–downstream dimension over time. To ensure robustness, we exclude those rare cases from our estimation sample.

Overall, these empirical checks support the validity of our spatial RD design. The identification relies on the assumption that firms located just downstream of a monitoring station serve as an appropriate counterfactual for those located just upstream. By the same logic, clients (or suppliers) of downstream regulated firms provide valid comparisons for clients (or suppliers) of upstream regulated firms, allowing us to isolate the causal effect of transmitted environmental

pressure along supply chains.

4.3 Data Description and Sampling Process

4.3.1 Data Sources

This study relies on four primary data sources. They are: the *Surveys of Science and Technology Activities of Industrial Firms* (SSTA); the *China Stock Market and Accounting Research* (CSMAR) database; the *Environmental Survey and Reporting* (ESR) database; and water quality monitoring station records. Together, these datasets allow for a comprehensive examination of the environmental regulatory framework and its pass-through effects across firms along the supply chain.

SSTA Database. The SSTA is an annual census-type survey conducted by the National Bureau of Statistics (NBS) of China. It includes industrial firms with independent science and technology activities and provides detailed information on their R&D input and output. Specifically, the database records firm-level data on R&D expenditures, the number of R&D personnel, innovation outcomes, and access to R&D-related policies, such as High and New Technology Enterprise (HNTE) status and associated tax benefits. Firms participating in the SSTA are required to maintain dedicated accounting for R&D activities and to submit a standardized form annually. The dataset covers the period from 2008 to 2014. The SSTA is aggregated into the *China Statistical Yearbook on Science and Technology*, an authoritative official publication.

CSMAR Database. Data on the top five clients and suppliers of listed firms are obtained from the *China Stock Market and Accounting Research* (CSMAR) database. This dataset provides transaction-level information, including partner firm names, registration codes, and trade volumes. We further link these records to administrative business registration data to retrieve the geographic location of each trading partner, allowing us to spatially match them with the monitoring station zones and identify their upstream or downstream positioning relative to regulated firms.

ESR Database. The *Environmental Survey and Reporting* (ESR) database is maintained by the Ministry of Ecology and Environment (formerly MEP) and covers major polluting firms in China, representing approximately 80% of total industrial pollution emissions. The ESR contains rich firm-level data on water pollution indicators, such as Chemical Oxygen Demand (COD), industrial wastewater discharge, and ammonia nitrogen (NH_3/NH_4^+), as well as air pollutants (SO_2 , NO_x , total exhaust), energy consumption, and pollution abatement facilities. We employ the ESR database to validate regulatory intensity by testing for discontinuities in firms' environmental outcomes near water monitoring stations. Firms are matched across ESR and SSTA using official enterprise registration codes. Where direct matching is unavailable, we apply fuzzy matching based on registered enterprise names.

Water Quality Monitoring Stations. Geographical and regulatory data on water quality monitoring stations are also sourced from the Ministry of Ecology and Environment. In 2010, there were 970 state-supervised monitoring stations nationwide. Following ArcGIS-based spatial analysis, we first geo-coded each station using its latitude and longitude, then mapped their locations across China (Figure A.1). Using surrounding elevation data, we inferred the direction of river flow. At each station, we constructed a perpendicular line to the river to separate upstream from downstream regions. Firms located upstream of a given station are designated as upstream firms, while those downstream are labeled downstream firms. To define the local neighborhood, we constructed a 20km-radius buffer around each station. Monitoring stations situated on lakes, where flow direction cannot be determined, and stations with substantial buffer overlaps (within 20km) were excluded from the sample. After these exclusions, our final sample comprises 720 effective water monitoring stations nationwide.

4.3.2 Sampling Process

Table 1 provides descriptive statistics on the matched sample. The core regulated firms in our analysis are publicly listed companies engaged in water-polluting industries and located within a 20-kilometer radius of the water quality monitoring stations. These firms are identified and categorized as upstream or downstream depending on their spatial relationship to the stations, as described above. Table A.1 provides descriptive statistics on the environmental and operational performance of these regulated firms.

Table 1: Data Matching and Sampling

Matching Process	Number of Firms	Number of Observations
Upstream firms matched with listed firms	372	1,552
Downstream firms matched with listed firms	383	1,498
upstream firms' client firms (including unlisted firms)	631	3,250
Upstream firms' supplier firms (including unlisted firms)	419	2,417
Downstream firms' client firms (including unlisted firms)	389	1,758
Downstream firms' supplier firms (including unlisted firms)	400	1,969

Notes: This study examines regulated firms, their top-five clients, and top-five suppliers. “Upstream” and “downstream” refer to locations relative to river flow and water quality monitoring stations, rather than supply chain positions. In the supply chain, we use “clients” and “suppliers” to denote downstream and upstream partners, respectively.

In contrast, the clients and suppliers of these regulated firms are not required to be listed companies and are not necessarily involved in water-polluting activities. The sample of trading partners was constructed using the CSMAR database and consists of the top five clients and suppliers by transaction volume for each regulated firm. On average, these top five partners account

for over 60 percent of total sales (clients) and more than 40 percent of total input costs (suppliers) of the focal firms, ensuring economic relevance in supply chain linkages. Table A.2 reports detailed characteristics of the clients and suppliers of the regulated firms, focusing on their R&D, innovation, and transaction behaviors.

To ensure identification validity, we retain only those client and supplier firms that are linked exclusively to either upstream or downstream regulated firms, thus avoiding contamination due to cross-exposure. These partner firms are also located outside the 20km regulatory radius, meaning that they are not directly affected by local environmental interventions. The final dataset includes a diverse set of firms spanning 46 two-digit manufacturing industries, distributed widely across China, enabling both cross-sectional and spatial comparisons within a consistent econometric framework.

5 Empirical Results

5.1 Pass-through Effects on Client Firms

In this section, we examine whether environmental regulatory pressure imposed on polluting firms is propagated through the supply chain to their clients, focusing specifically on client firms' R&D investment and innovation activities.

Figure 2 provides a visual representation of the core findings from the spatial RD design. The horizontal axis represents the running variable, $Dist_i$, which measures the geographic distance between firms and the nearest water quality monitoring station. The vertical line at $Dist_i = 0$ denotes the location of the monitoring station. Firms located to the right of the cutoff are classified as upstream, while those to the left are downstream. The plotted dots indicate the binned local means (with a bin width of 5 kilometers), and the dashed lines represent the corresponding 95 percent confidence intervals. The vertical axis in panels (a)–(c) depicts residualized outcomes for total R&D expenditure, the number of R&D employees, and total innovation, respectively, after controlling for monitoring station fixed effects, industry fixed effects, and year fixed effects. The graphical evidence indicates a clear and statistically significant drop in these outcomes at the cutoff point. We observe that, clients of upstream firms display markedly lower levels of R&D investment, R&D personnel, and innovation output relative to clients of downstream firms. In contrast, we observe no comparable or statistically significant discontinuities among their suppliers.

Table 2 presents the estimates of the pass-through effects of environmental regulation on client firms' R&D and innovation. Across all panels, Columns (1), (3), (5), and (7) control for firm-level characteristics (firm size and age), year fixed effects, and monitoring station fixed effects.

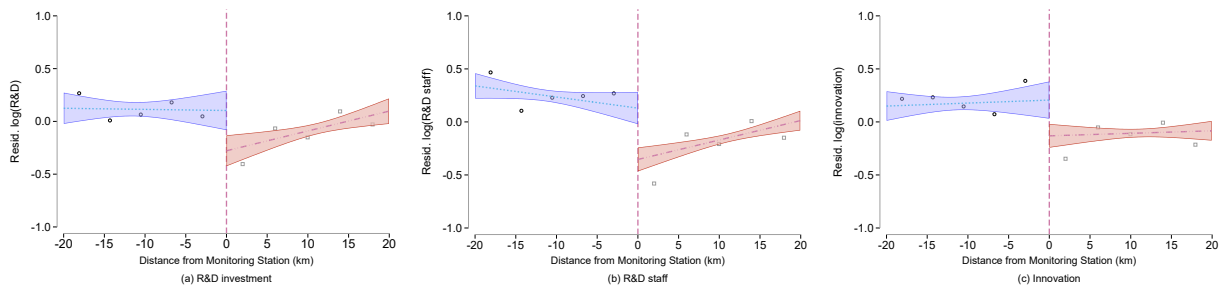


Figure 2: Pass-through Effects on Client Firms: Varying by Transaction

Notes: The horizontal axis represents the running variable, $Dist_i$, which measures the geographic distance between firms and the nearest water quality monitoring station. The vertical line at $Dist_i = 0$ denotes the location of the monitoring station. Firms located to the right of the cutoff are classified as upstream, while those to the left are downstream. The plotted dots indicate the binned local means (with a bin width of 5 kilometers), and the dashed lines represent the corresponding 95 percent confidence intervals.

Columns (2), (4), (6), and (8) present the preferred specifications with the additional inclusion of industry fixed effects to absorb time-invariant heterogeneity across industries. All regressions cluster standard errors at the monitoring-station level. The RD estimates are obtained using the robust bias-corrected procedure with a triangular kernel, following [Calonico et al. \(2014\)](#).

We find that top-five clients of upstream polluting firms invest approximately 44.7% [$(e^{0.370} - 1)\%$] less in total R&D expenditure compared to those clients of downstream firms. This reduction is concentrated in two key components: R&D personnel wages and equipment expenses (Panel A). It is noteworthy that the observed reductions in clients' R&D investment are associated with a substantial 88.7% decrease in water pollutant discharges by their upstream regulated partners (See Section 6.5). This implies that a 1.0% increase in environmental regulatory stringency imposed on regulated firms is associated with an approximate 0.50% reduction in the total R&D expenditure of their client firms. Panel B shows that a 1.0% increase in environmental regulatory stringency imposed on regulated firms leads to approximately 0.53% [$(e^{0.384} - 1)/88.7\%$] reduction in total R&D employment of client firms, with the sharpest reductions observed among employees with higher educational attainment, specifically, PhD, master's, and bachelor's degrees. These findings suggest that more stringent regulation of upstream firms may result in a significant deterioration in the quality of client firms' R&D teams. Consistent with the reduction in R&D inputs, Panel C shows a significant decrease in total patents among upstream clients, compared to their downstream counterparts.

5.2 Pass-through Effects on Supplier Firms

We next examine whether environmental regulatory pressure is transmitted to the suppliers of regulated firms. Supplier firms, typically positioned at the upstream stage of the supply chain,

Table 2: Pass-through Effects on Client Firms' R&D, Human Capital, and Innovation

Panel A: Effects on Client Firms' R&D								
	log(c. R&D)							
	(1)	(2)						
RDD (upc_i)	-0.333***	-0.370***	log(c. R&D wage)		log(c. R&D instrument)			
	(0.121)	(0.138)	(3)	(4)	(5)	(6)		
RDD (upc_i)			-0.476***	-0.491**	-0.045	-0.531**		
			(0.162)	(0.223)	(0.303)	(0.259)		
Bandwidth	5.776	5.326	5.623	5.246	4.404	5.696		
Panel B: Effects on Client Firms' Human Capital								
	log(c. R&D staff)							
	(1)	(2)						
RDD (upc_i)	-0.247**	-0.384***	log(c. phd)		log(c. master)		log(c. bachelor)	
	(0.112)	(0.107)	(3)	(4)	(5)	(6)	(7)	(8)
RDD (upc_i)			-0.356**	-0.240*	-0.445**	-0.498***	-0.162	-0.388**
			(0.176)	(0.137)	(0.187)	(0.158)	(0.131)	(0.175)
Bandwidth	5.661	6.241	3.572	4.052	4.460	5.025	7.786	6.079
Panel C: Effects on Client Firms' Innovation								
	log(c. total innovation)							
	(1)	(2)						
RDD (upc_i)	-0.191*	-0.245*	log(c. green innovation)					
	(0.114)	(0.126)	(3)	(4)				
RDD (upc_i)			0.040	0.056				
			(0.118)	(0.140)				
Bandwidth	6.533	5.926	6.964	4.958				
Kernel type	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Client controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes	No	Yes	No	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	5,181	5,180	5,181	5,180	5,181	5,180	5,181	5,180

Notes: The outcome variables are the R&D activities of regulated firms' client firms, measured in logarithmic form. The MSE-optimal bandwidth is selected based on the default kernel type recommended by Calonico et al. (2014). Firm-level controls include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

often operate in resource- and capital-intensive sectors such as energy, chemicals, and materials. These firms usually possess stronger market power, greater bargaining leverage, and more flexibility in client selection. As such, they might be less vulnerable to external shocks and cost pass-through originating from their downstream clients.

Using a similar empirical strategy as in the previous section, Table 3 reports the estimated discontinuities in R&D inputs across suppliers of upstream and downstream regulated firms. Across all key R&D categories, total R&D expenditure, R&D wages, and capital investment in R&D equipment, we find no statistically significant differences between the two groups. This result suggests

Table 3: Pass-through Effects on Supplier Firms' R&D, Human Capital, and Innovation

Panel A: Effects on Supplier Firms' R&D								
log(s. R&D)								
	(1)	(2)						
RDD (<i>ups_i</i>)	-0.150	-0.214	log(s. R&D wage)		log(s. R&D instrument)			
	(0.222)	(0.219)	(3)	(4)	(5)	(6)		
RDD (<i>ups_i</i>)			-0.749	-0.481	-0.498	-0.190		
			(0.612)	(0.679)	(0.741)	(0.859)		
Bandwidth	4.109	4.513	2.537	2.911	2.524	2.649		
Panel B: Effects on Supplier Firms' Human Capital								
log(s. R&D staff)								
	(1)	(2)						
RDD (<i>ups_i</i>)	-0.028	-0.052	log(s. phd)		log(s. master)		log(s. bachelor)	
	(0.163)	(0.167)	(3)	(4)	(5)	(6)	(7)	(8)
RDD (<i>ups_i</i>)			0.034	0.028	-0.117	-0.133	0.002	-0.162
			(0.289)	(0.214)	(0.232)	(0.222)	(0.176)	(0.172)
Bandwidth	4.221	4.864	2.769	3.172	3.554	4.076	4.176	4.478
Panel C: Effects on Supplier Firms' Innovation								
log(s. total innovation)								
	(1)	(2)						
RDD (<i>ups_i</i>)	0.252	0.193	log(s. green innovation)					
	(0.160)	(0.149)	(3)	(4)				
RDD (<i>ups_i</i>)			0.418***	0.135				
			(0.161)	(0.117)				
Bandwidth	3.496	3.763	5.339	6.485				
Kernel type	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Supplier controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes	No	Yes	No	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	3,711	3,708	3,711	3,708	3,711	3,708	3,711	3,708

Notes: The outcome variables are the R&D activities of regulated firms' supplier firms, measured in logarithmic form. The MSE-optimal bandwidth is selected based on the default kernel type recommended by Calonico et al. (2014). Firm-level controls include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

that environmental regulatory pressure can barely be transmitted through supply chain linkages to suppliers, at least not in ways that measurably affect R&D investment.

6 Mechanisms

This section explores the mechanisms through which environmental regulatory pressure is transmitted to client firms along the supply chain. Specifically, we examine (i) how this pass-through varies by inter-firm transactions; (ii) how the cost pass-through channel is associated with client

firms' production costs and output values; (iii) whether this pass-through varies by client and regulated firms' market power; and (iv) whether partner firms strategically respond by adjusting their trading relationships under intensified environmental regulation.

6.1 Pass-through by Transaction

To assess the strength of pass-through mechanism, we estimate a complementary model to quantify the marginal effect of transaction intensity on client firms' R&D and innovation:

$$Y_{ist} = \beta_1 upstream_i \times ln pur_{it} + \beta_2 ln pur_{it} + X_{ist} + \xi_i + \delta_s + \eta_t + \iota_{ist}, \quad (6)$$

where $ln pur_{it}$ denotes the logarithmic value of the transaction amount between a regulated firm and its client. ξ_i represents client firm fixed effects, which account for time-invariant unobserved heterogeneity at firm level, providing a more rigorous identification of the marginal pass-through effects.

As shown in Table 4, Columns (2) of Panels A–C report that a 1 percent increase in purchase transactions with upstream regulated firms is associated with 3.9%, 4.1%, and 4.0% decrease in total R&D investment, R&D staff, and innovation output, respectively. A subcomponent analysis further reveals that each category of R&D expenditure, such as wages and equipment, declines with increased transaction intensity. While the coefficient on green innovation is negative, it is not statistically significant, perhaps reflecting its relatively longer gestation and indirect exposure to regulatory burdens. The evidence suggests that the magnitude of the pass-through effect is amplified by the intensity of inter-firm transactions, consistent with the theoretical mechanism in which environmental compliance costs are passed through trading relationships, such as through higher input prices, thereby crowding out clients' resources for innovation investment.

Table E.1 in the appendix presents the marginal effect of transaction volume on supplier firms' R&D behavior. Again, the estimates consistently indicate no statistically significant relationship between the volume of transactions with regulated firms and suppliers' investment in R&D or innovation. Moreover, the lack of observable impact on suppliers adds credibility to our earlier findings regarding client firms. Specifically, these null results enhance the robustness of the identification strategy by demonstrating an asymmetric transmission pattern, where regulatory shocks are passed downstream but not upstream of supply chain. This asymmetry is consistent with theoretical predictions from supply chain economics and industrial organization, where client firms often face greater exposure to input price shocks and have fewer options to substitute away from affected suppliers, while supplier firms retain more pricing power and client diversification strategies (Antràs and Chor, 2013).

Table 4: Pass-through Effects on Client Firms: Varying by Transaction

Panel A: Effects on Client Firms' R&D								
		log(c. R&D)						
		(1)	(2)					
$upc_i \times Inpur_{it}$		-0.102***	-0.039**	log(c. R&D wage)		log(c. R&D instrument)		
		(0.032)	(0.018)	(3)	(4)	(5)	(6)	
$upc_i \times Inpur_{it}$				-0.161***	-0.036**	-0.154**	-0.055*	
				(0.050)	(0.015)	(0.064)	(0.029)	
R-squared		0.457	0.906	0.755	0.983	0.695	0.967	
Panel B: Effects on Client Firms' Human Capital								
		log(c. R&D staff)						
		(1)	(2)					
$upc_i \times Inpur_{it}$		-0.141***	-0.041***	log(c. phd)		log(client's master)		log(c. bachelor)
		(0.031)	(0.014)	(3)	(4)	(5)	(6)	(7) (8)
$upc_i \times Inpur_{it}$				-0.099***	-0.036**	-0.196***	-0.061*	-0.175*** -0.065**
				(0.036)	(0.017)	(0.065)	(0.031)	(0.048) (0.025)
R-squared		0.427	0.900	0.276	0.825	0.356	0.865	0.325 0.804
Panel C: Effects on Client Firms' Innovation								
		log(c. total innovation)						
		(1)	(2)					
$upc_i \times Inpur_{it}$		-0.068**	-0.040*	log(c. green innovation)				
		(0.027)	(0.021)	(3)	(4)			
$upc_i \times Inpur_{it}$				-0.140**	-0.027			
				(0.062)	(0.034)			
R-squared		0.380	0.711	0.240	0.696			
Client controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Client firm FE		No	Yes	No	Yes	No	Yes	Yes
Station Clustered		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation		4,701	4,680	4,701	4,680	4,701	4,680	4,701 4,680

Notes: The outcome variables are the R&D activities of regulated firms' client firms, measured in logarithmic value. $Inpur_{it}$ refers to the transaction volume between the regulated firms and the client firms. Control variables at the client-firm level include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

6.2 Pass-through Effects on Production Cost

We have shown that clients of heavily regulated upstream firms exhibit significant reductions in R&D investment. We now investigate the pass-through effects on client firms' production inputs and outputs. In the absence of direct observations on transaction prices, we proxy cost pass-through using the unit cost of output, defined as the ratio of material inputs to output value (M/Q).

Given that the client firms in our sample are among the top five trading partners of regulated firms, with large transaction volumes, we expect cost shocks to manifest in observable changes

in unit production costs. Panel A of Table 5 shows that, for clients of upstream firms, both total production cost (M) and output value (Q) decline significantly. However, the decline in output is larger than the decline in input costs, resulting in a statistically significant increase in unit output cost (M/Q). This indicates that part of the environmental compliance burden borne by regulated firms is likely passed through to their clients via higher input prices.

Consistent with this interpretation, Panel C of Table 5 further shows that a 1 percent increase in transaction volume with upstream regulated firms is associated with significant increase in the client's unit cost of output. These patterns are not observed for supplier firms, as shown in Panels B and D, where all coefficients remain statistically insignificant. These findings suggest that environmental regulatory costs are transmitted downstream to clients through price channels, reinforcing the decline in R&D and innovation activities among affected firms.

6.3 Market Power

The extent to which environmental regulatory cost is transmitted through the supply chain likely depends on the market structure in which firms operate. Specifically, firms with strong market power may have greater capacity to absorb or deflect environmental costs, while those in highly competitive markets may have limited options but to bear the cost increases directly. We proxy market power using the Herfindahl–Hirschman Index (HHI), a standard measure of industry concentration.²

Figure 3 (a)-(c) plots the estimated RD coefficients for client firms' total R&D expenditure, R&D employment, and innovation, across different levels of market concentration in the regulated firm's industry. We find that as the HHI increases, indicating greater market power of the regulated firm, the negative pass-through effects on client firms' R&D become more pronounced and statistically significant. This suggests that dominant firms in concentrated industries have stronger ability to pass compliance costs downstream. In contrast, Figure 3 (d)-(e) plots the transmission effects by the client firm's own market concentration. Here, we observe a dampening effect: when client firms operate in more concentrated markets (i.e., possess stronger bargaining power), the magnitude of the negative transmission weakens and becomes statistically insignificant. This asymmetry supports the hypothesis that environmental burdens are more likely to be borne by less powerful firms in competitive markets.

To complete the analysis, Figure 4 applies the same heterogeneity analysis to supplier firms. Panels (a)-(c) indicate that, to some extent, supplier firms' R&D investment is negatively affected

²The Herfindahl-Hirschman Index (HHI) is a commonly used measure of market concentration, which reflects the degree of competition within an industry. The HHI is calculated by summing the squares of the market shares of all firms within a market: $HHI = \sum_{i=1}^N s_i^2$, where s_i is the market share of firm, expressed as a percentage, and N is the total number of firms in the market.

Table 5: Pass-through Effects on Clients' and Suppliers' Production Costs

	Client firms			Supplier firms		
	log(M/Q)	log(M)	log(Q)	log(M/Q)	log(M)	log(Q)
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: RD estimate (upc_i)	1.211*** (0.229)	-0.168* (0.090)	-0.408** (0.191)	Panel B: RD estimate (ups_i)	-0.282 (0.202)	-0.413 (0.377)
Bandwidth	4.558	6.684	8.289	6.723	5.975	4.451
Kernel type	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes
Observation	4,902	5,180	5,180	3,704	3,708	3,708
Panel C: estimate on coefficient of $upc_i \times \ln(pur)_{it}$	0.110*** (0.024)	0.006 (0.047)	-0.011 (0.018)	Panel D: estimate on coefficient of $ups_i \times \ln(sup)_{it}$	0.028 (0.050)	-0.030 (0.034)
R-squared	0.888	0.754	0.937	0.801	0.766	0.915
Client controls	Yes	Yes	Yes	Yes	Yes	Yes
Client firm FE	Yes	Yes	Yes	/	/	/
Supplier firm FE	/	/	/	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Observation	4,680	4,680	4,680	2,998	2,998	2,998

Notes: M/Q refers to unit cost of output, calculated as the ratio of production costs (M) to output value (Q). $\ln pur_{it}$ refers to the transaction volume between the regulated firms and the client firms. The MSE-optimal bandwidth is selected based on the default kernel type recommended by [Calonico et al. \(2014\)](#). Firm-level controls include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

when their downstream clients (i.e., regulated firms) operate in highly concentrated markets. However, the confidence intervals are wider and the statistically significant regions are narrower compared to client firms, suggesting that the upward pass-through of environmental pressure is generally weaker. Panels (d)-(e) further show that when supplier firms themselves are in concentrated markets, the R&D impact diminishes and becomes insignificant, again reflecting their ability to negotiate favorable terms or exit unprofitable relationships. Notably, a large portion of suppliers in our data are indeed situated in concentrated suppliers' sectors, which explains why the significant pass-through effects are limited and only observable in specific subsamples.

In sum, these findings provide evidence for a market-structure-based mechanism: the pass-through effects of environmental regulation are mediated by the relative market power of trading

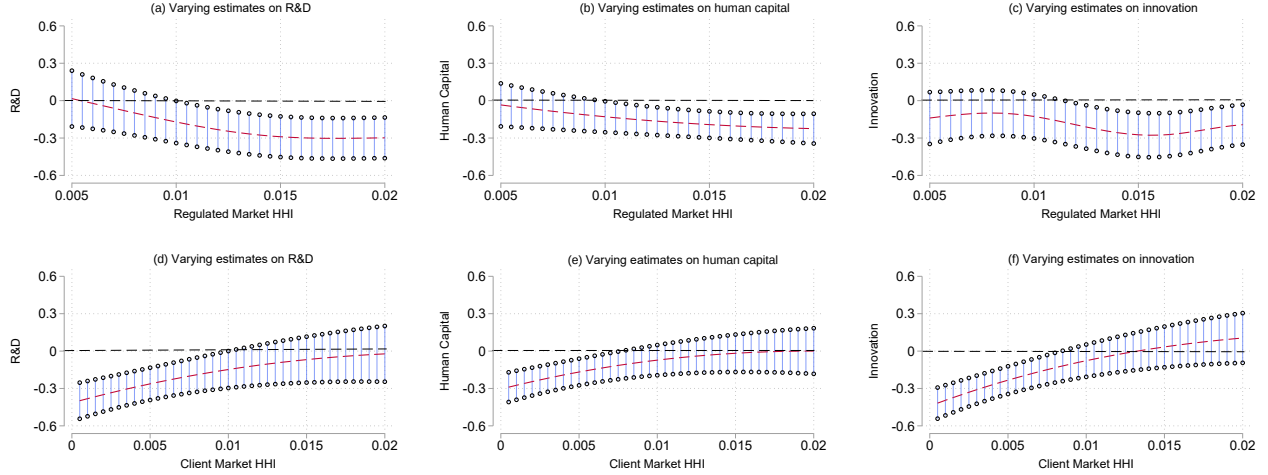


Figure 3: Pass-through Effects on Clients Differentiated by Market Power

Notes: The Herfindahl-Hirschman Index (HHI) serves as a proxy for market power, with higher values indicating greater market concentration. In Panels (a)–(c), the x-axis represents the level of regulated firms’ market concentration. In Panels (d)–(f), the x-axis represents the level of client firms’ market concentration.

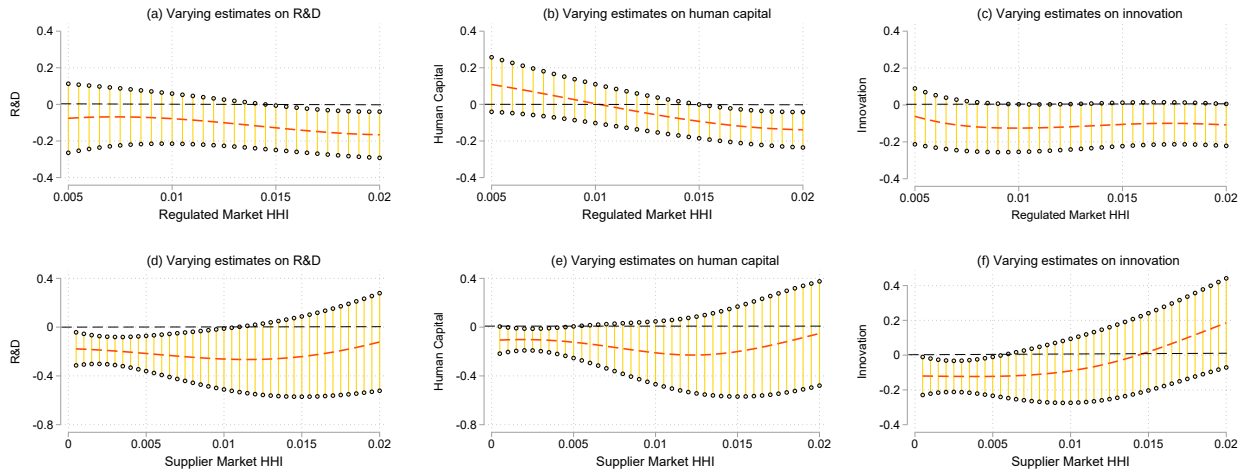


Figure 4: Pass-through Effects on Suppliers Differentiated by Market Power

Notes: The Herfindahl-Hirschman Index (HHI) serves as a proxy for market power, with higher values indicating greater market concentration. In Panels (a)–(c), the x-axis represents the level of regulated firms’ market concentration. In Panels (d)–(f), the x-axis represents the level of supplier firms’ market concentration.

partners. Regulatory burdens tend to be passed from dominant regulated firms to clients operating in competitive markets but are less likely to flow upstream to suppliers.

6.4 Switch and Transaction Adjustment

In real-world supply chains, relationships between firms, particularly between core clients and suppliers, are often governed by long-term collaborations. These relationships are embedded in production routines, technical standards, customized product specifications, and frequently for-

malized through long-term contracts. As such, switching trading partners is not frictionless and may entail adjustment costs. Nevertheless, when regulated firms face increased environmental compliance costs and attempt to pass them on through higher prices or reduced service reliability, their trading partners may be forced to respond, either by reducing transaction volumes or by terminating the relationship entirely.

Table 6: Clients and Suppliers Adaptions: Switch and Reduce Transaction

Panel A: Switch and Transactions with Clients				
	log(client switch)		log(client transaction value)	
	(1)	(2)	(3)	(4)
RDD upc_i	0.082** (0.036)	0.076** (0.037)	-0.711*** (0.205)	-0.433** (0.223)
Bandwidth	9.481	9.089	3.237	3.170
Kernel type	Triangular	Triangular	Triangular	Triangular
Client controls	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes
Observation	3,724	3,724	4,701	4,701
Panel B: Switch and Transactions with Suppliers				
	log(supplier switch)		log(supplier transaction value)	
	(5)	(6)	(7)	(8)
RDD ups_i	-0.007 (0.016)	-0.006 (0.016)	-0.319 (0.213)	-0.527 (0.373)
Bandwidth	7.193	7.445	8.309	5.236
Kernel type	Yes	Yes	Yes	Yes
Client controls	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes
Observation	2,618	2,618	3,029	3,029

Notes: "Client switch" is a binary indicator equal to 1 if a client drops out of the top five clients of the regulated firm during the sample period, and 0 otherwise. "Client transaction value" refers to the logarithm of the transaction value, serving as a continuous measure of relationship intensity. The denotations are the same apply to suppliers. The MSE-optimal bandwidth is selected based on the default kernel type recommended by [Calonico et al. \(2014\)](#). Firm-level controls include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

To empirically assess these adaptive responses, we examine clients' and suppliers' adjustments in terms of partner switching decision and transaction volume. In Panel A of Table 6, Column (1) uses a binary indicator variable, "client switch", which equals 1 if the client drops out of the top five clients of the regulated firm during the sample period, and 0 otherwise. Column (2) examines the logarithm of transaction value as a continuous measure of relationship intensity. We find

that clients of upstream regulated firms are 7.8 percentage points more likely to terminate their partnerships relative to clients of downstream regulated firms. Moreover, Column (4) shows a significant reduction in transaction volume for these same clients, suggesting that the upstream regulated firms' attempts to shift environmental costs are met with resistance by their clients. These findings are consistent with the idea that environmental cost pass-through creates frictions in business relationships, prompting clients to re-optimize their supplier portfolios. However, such adjustments may come with their own costs, including search and adaptation costs, production delays, and technical mismatches, which may indirectly crowd out investment in innovation and R&D.

In contrast, Panel B investigates analogous outcomes for supplier firms. Here, we find no statistically significant evidence that suppliers switch away from regulated firms or reduce their transaction volumes. This asymmetry underscores a key structural feature of supply chains: suppliers, especially those upstream in capital-intensive or resource-based industries, often possess greater market power and bargaining strength, making it more difficult for downstream firms to renegotiate or substitute away from entrenched supplier relationships.

A potential identification concern arises from client switching. Specifically, if a client firm decides to terminate or substantially reduce its transactions with a regulated firm in the subsequent period, thereby dropping out of the top five clients, this decision could be endogenous to the firm's R&D investment in the current period. If such switching occurs on a large scale, it could bias our main estimates. To address this concern, we conduct a robustness check by excluding client firms that drop out of the top five client transactions during the sample period. The results reported in Table F.1 show that our main findings remain unchanged.

6.5 Quantifying Environmental Compliance

In this subsection, we examine the extent to which upstream firms located near water quality monitoring stations are subject to more stringent environmental regulation compared to their downstream counterparts. This analysis provides important context for interpreting the direction and magnitude of the estimated treatment effects reported in earlier sections.

Based on the results in Panel A of Table 7, we interpret the estimated treatment effects on R&D outcomes as reflecting the consequences of substantial reductions in pollution emissions by regulated firms. Specifically, relative to downstream firms, upstream firms subject to more frequent and stringent inspections reduced their discharges of wastewater, chemical oxygen demand (COD), and ammonia nitrogen by approximately 88.7%, 81.6%, and 112.3%, respectively. Thus, the treatment effects reported in earlier sections, such as the decline in client firms' R&D investment, employment, and innovation, can be interpreted as the pass-through impact of upstream firms'

environmental compliance efforts of this magnitude. These sharp reductions in pollutant emissions capture the intensity of the regulatory burden faced by upstream firms, and serve as a proxy for the environmental stringency transmitted through supply chain relationships.

Next, we evaluate whether such stringent regulation serves as a productivity-enhancing incentive or imposes economic burdens on the regulated firms. While the Porter Hypothesis posits that well-designed environmental regulations may stimulate efficiency and innovation by inducing firms to optimize resource use and modernize production processes, such positive effects are more likely under flexible, market-based instruments. In contrast, command-and-control regulations, which typically prescribe emission limits and compliance mechanisms, may exert substantial compliance costs that distort firms' investment and financial decisions. Panel B of Table 8 documents the impact of stringent regulation on firms' financial performance. The evidence reveals that upstream firms experience significant declines in both profitability and capital investment, while at the same time showing a marked increase in debt levels. These findings are consistent with those reported in [He et al. \(2020\)](#), and indicate that the heightened regulatory pressure acts primarily as a financial burden, rather than as a productivity-enhancing stimulus.

Table 7: Discontinuities in Environmental Compliance

Panel A: Environmental Outcomes						
	log(wastewater)		log(COD)		log(NH)	
	(1)	(2)	(3)	(4)	(5)	(6)
RD estimate (upr_i)	-0.619** (0.266)	-0.635** (0.299)	-0.619*** (0.231)	-0.597** (0.291)	-0.824*** (0.290)	-0.753** (0.321)
Bandwidth	4.102	3.916	4.838	4.280	4.286	3.967
Kernel type	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Firm controls	Yes	Yes	Yes	Yes	No	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes	No	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes
Observation	3,000	2,999	3,000	2,999	3,000	2,999
Panel B: Financial Standing						
	log(profit)		log(investment)		log(debt)	
	(7)	(8)	(9)	(10)	(11)	(12)
RD estimate (upr_i)	-0.287*** (0.090)	-0.297*** (0.089)	-0.552*** (0.207)	-0.501** (0.201)	0.364*** (0.086)	0.266*** (0.103)
Bandwidth	5.691	5.547	9.168	9.167	5.568	4.892
Kernel type	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Firm controls	Yes	Yes	Yes	Yes	No	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes	No	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes
Observation	3,000	2,999	3,000	2,999	3,000	2,999

Notes: The outcome variables represent the environmental and financial performance of regulated firms, measured in logarithmic form. The MSE-optimal bandwidth is selected based on the default kernel type recommended by [Calonico et al. \(2014\)](#). Firm-level controls include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

7 Quantitative Analysis

7.1 Model Extension

To derive policy implications, we extend the baseline model presented in Section 3 to incorporate environmental externalities, government interventions, and a welfare-based policy evaluation framework. Specifically, we consider two policy instruments in addition to the environmental regulation: a green technology incentive program targeting regulated firms and an R&D subsidy policy for client firms.

First, we introduce a green technology incentive program of scale δ , which is designed to reduce the emission intensity of regulated firms from κ_j to $\kappa_j - \delta$. This intervention can take the form of green technology incentives or other industrial policy supports that enhance production efficiency and lower emissions per unit of output. Under the assumption that emissions are proportional to output, aggregate emissions in the economy are given by

$$E(\tau, \delta) = \int_0^1 (\kappa_j - \delta) M_j dj. \quad (7)$$

Here, κ_j implies the emissions generated per unit of intermediate output.

Second, we introduce an R&D subsidy for client firms, denoted by $s \in [0, 1]$, which reduces the private cost of R&D investment from φR_i to $(1 - s)\varphi R_i$. This policy is motivated by the cost pass-through mechanism: environmental regulation increases intermediate input prices, which in turn suppresses the marginal production of R&D of client firms. A subsidy helps counteract this distortion and restore R&D incentives.

With these extensions, the government has three policy instruments at its disposal: environmental regulation, τ , to internalize pollution externalities; green technology incentive, δ , to lower emissions through firm-level cleaner production; and R&D subsidies, s , to correct the underinvestment in innovation induced by cost pass-through.

To evaluate optimal policy design, we define social welfare as: $W = C - \alpha E^p$, where $C = \int_0^1 F(L_{c,i}, M_i, R_i) di$ represents the aggregate consumption of final goods, and $\alpha > 0, p > 1$ capture the marginal social damage from pollution. This welfare function reflects the trade-off between economic output and environmental degradation. The government's objective is to choose the optimal policy mix that generates the socially efficient allocation. Specifically, the government sets a series of instruments $(\tau, s, \delta) = (\tau^*, s^*, \delta^*)$, such that the decentralized equilibrium replicates the social planner's allocation. This framework provides a basis for evaluating the complementarities and trade-offs among environmental regulatory stringency, green technology incentive, and R&D subsidies in achieving welfare-maximizing outcomes.

7.2 Counterfactual Policies

We conduct a series of counterfactual simulations examining the effects of various combinations of environmental regulation, green technology incentives for regulated firms, and R&D subsidies for client firms. These exercises are designed to assess the extent to which different policy mixes can improve production efficiency and enhance social welfare. We calibrate the parameters in Section .

Green Technology Incentive. We first analyze the joint effects of environmental regulation

and green technology incentives for the regulated polluting firms. Specifically, we simulate a set of scenarios in which regulated firms are subject to increasingly stringent environmental standards (i.e., higher compliance costs), while they receive varying levels of green technology incentives to reduce their emission intensities.

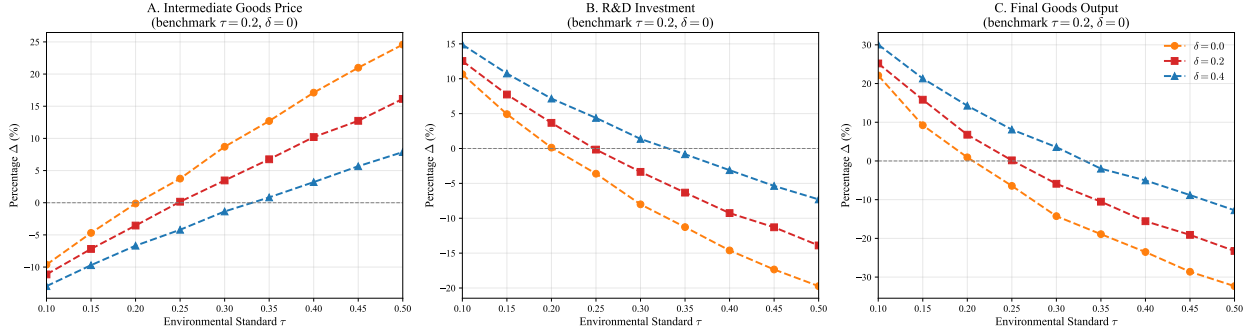


Figure 5: Counterfactual policies: Alternative environmental standard and green tech incentives

Notes: The benchmark policy regime is defined by an environmental tax rate of $\tau = 0.2$, with no R&D subsidies ($s = 0$) and no green technology incentives ($\delta = 0$). The x-axis plots the environmental regulation parameter τ , where higher values indicate stricter regulation. The y-axis shows the percentage change in key economic outcomes for client firms relative to the benchmark.

In Figure 5, we assume a benchmark policy regime with an environmental tax rate of $\tau = 0.2$, and no R&D subsidies ($s = 0$) or green technology incentives ($\delta = 0$). The x-axis denotes the environmental regulation parameter τ , with higher values corresponding to stricter regulatory regimes. The y-axis reports the percentage change in key economic outcomes for client firms, relative to the benchmark model. As discussed above, Figure 5 shows that increasing environmental stringency increase the price of intermediate goods, and thus decrease client firms' R&D investment and outputs. In addition, the green technology incentives target at regulated firms' emission intensity. The blue, red, and orange lines represent results under green technology incentive rates of 40%, 20%, and 0%, respectively. Panel A shows that increasing the level of green technology incentives reduces the price of intermediate goods, as it lowers the per-unit compliance cost for regulated firms. This cost reduction is partially passed through to client firms in the form of lower intermediate input prices. As a result, Panels B and C show that client firms have a higher return on R&D, leading to increased investment in R&D and higher outputs.

R&D Subsidy for Client Firms. In Figure 6, Panel A displays the effect of increasing environmental stringency on the price index of intermediate goods. As expected, higher values of τ raise the prices of intermediates. This effect is mechanically driven by the fact that environmental regulation imposes a per-unit compliance cost on polluting producers, which is then passed through into prices attributable to their possession of market power. The blue, brown, and green lines represent results under R&D subsidy rates of 0%, 10%, and 20%, respectively. Notably, variations in R&D subsidies do not affect intermediate input prices. This is because the R&D subsidy

parameter s only enters the client firms' decision problems and does not alter the pricing behavior of regulated firms.

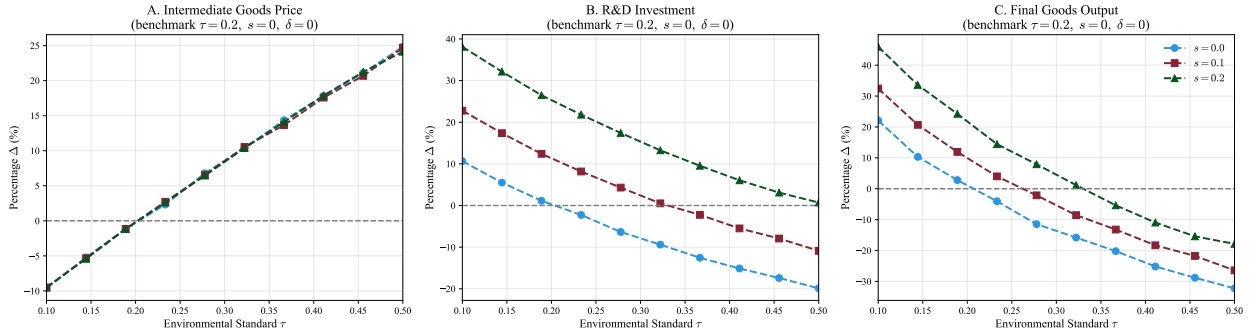


Figure 6: Counterfactual policies: Alternative environmental standard and R&D subsidies

Notes: The benchmark policy regime is defined by an environmental tax rate of $\tau = 0.2$, with no R&D subsidies ($s = 0$) and no green technology incentives ($\delta = 0$). The x-axis plots the environmental regulation parameter τ , where higher values indicate stricter regulation. The y-axis shows the percentage change in key economic outcomes for client firms relative to the benchmark.

Panels B and C of Figure 6 present the effects of environmental regulation and R&D subsidies on client firms' R&D and output. Intuitively, a more stringent environmental standard increases the price of intermediate inputs for client firms. This increase in production cost crowds out their output and R&D investment, as it reduces the marginal return to R&D. However, the presence of R&D subsidies counteracts this effect by directly enhancing the marginal return to R&D. Consequently, client firms respond by increasing their R&D investment, which leads to higher productivity and output.

Market Concentration. Figure 7 explores the role of market power in shaping the pass through of regulatory costs. Consistent with theoretical predictions, a higher markup, reflecting greater pricing power of regulated firms, enables them to pass a larger share of their environmental compliance costs onto client firms. Panel A shows that as the markup increases, intermediate input prices rise accordingly. The resulting increase in input costs reduces client firms' output and weakens their incentive to invest in R&D. Panels B and C show that client firms' R&D investment and output decline monotonically with the markup level of their regulated suppliers.

Social Welfare. We evaluate social welfare by comparing the decentralized market equilibrium with the socially optimal allocation. We characterize how a combination of environmental regulation and relevant policies can align decentralized outcomes with the social optimum. Appendix derives the optimal environmental standard that fully internalizes the pollution externality and the associated optimal subsidy rate that induces efficient levels of R&D investment.

Panel A of Figure 8 shows that, in the absence of R&D subsidies, increasing the stringency of environmental regulation reduces marginal social welfare, which remains below the socially optimal level. This result echoes the insight of Aghion et al. (2025), who highlight that environmental

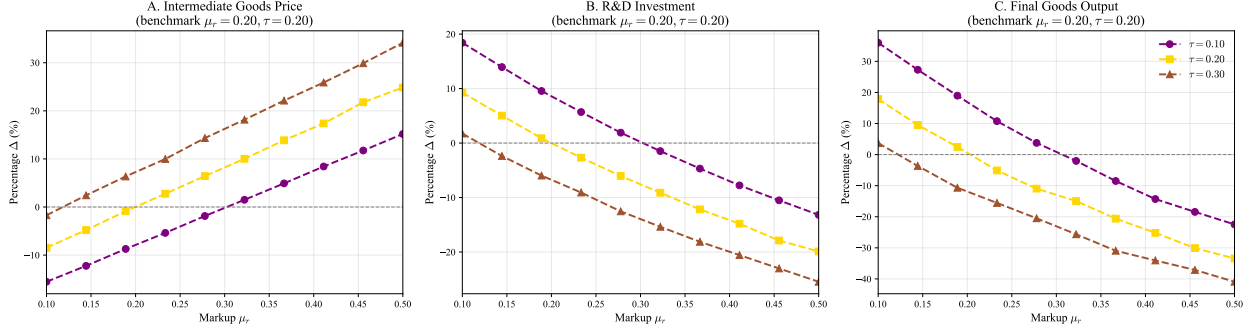


Figure 7: Counterfactual policies: Alternative environmental standard and market concentration

Notes: The benchmark policy regime is defined by an environmental tax rate of $\tau = 0.2$, with no R&D subsidies ($s = 0$) and no green technology incentives ($\delta = 0$). The x-axis plots the environmental regulation parameter τ , where higher values indicate stricter regulation. The y-axis shows the percentage change in key economic outcomes for client firms relative to the benchmark.

taxation alone is insufficient to restore optimal welfare in the presence of innovation externalities. In contrast to their framework, our model emphasizes the role of cost pass-through: regulated firms with markup power shift part of their compliance costs onto client firms, exacerbating distortions in the R&D margin. We find that a combination of environmental regulation and industrial support policies can restore efficiency. Beyond tightening environmental regulations to internalize externalities, pairing those regulations with an R&D subsidy or a green-technology incentive can raise the economy to a higher welfare level.

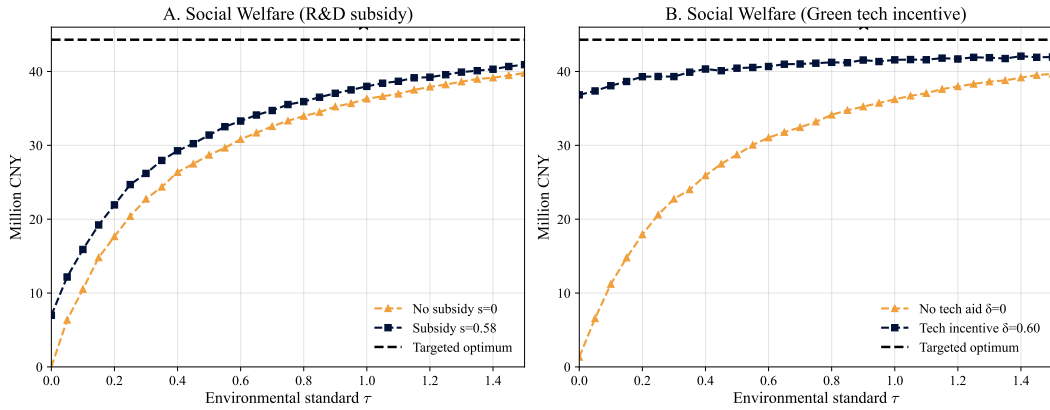


Figure 8: Counterfactual policies: Achieve social optimum

8 Conclusion

This paper highlights the importance of taking a network perspective when evaluating the consequences of environmental regulation. Policy effectiveness requires a comprehensive understanding not only of direct impacts, but also of the indirect economic distortions that can arise through

production networks. In this paper, we provide novel evidence on how environmental compliance costs pass through along the production chain, particularly affecting client firms' R&D activities.

Using a spatial RD design based on the location of water quality monitoring stations, we find that upstream firms demonstrate substantial reductions in pollutant emissions (wastewater, COD, and NH), but also suffer from lower profits, reduced investment, and higher debt levels, suggesting that regulatory compliance imposes real financial pressure. Importantly, this pressure does not remain isolated: client firms of these upstream regulated firms exhibit significantly lower R&D investment, reduced R&D staff, especially among highly educated staff, and a decline in innovation.

Furthermore, we find that the magnitude of these negative effects increases with transaction volume, indicating that environmental compliance costs can be passed through via input prices. In contrast, supplier firms do not show significant changes in R&D outcomes, possibly due to their greater market power and reduced exposure to pass-through pressures. We also find that the pass-through effects on client firms depends on market structure. Pass-through effects are stronger when regulated firms possess greater market power, and weaker when client firms have stronger bargaining positions. This suggests that the ability to absorb or deflect environmental compliance costs is unequally distributed across firms in the supply chain.

These findings yield important policy implications. While environmental monitoring and enforcement are essential for achieving pollution control goals, regulators should be aware of the broader economic costs that may arise from supply chain pass-through, particularly the unintended discouragement of innovation among downstream firms. To mitigate such effects, complementary policies, such as R&D subsidies, should be targeted at client firms that are indirectly affected by environmental regulations, especially those with limited market power.

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Appendix

A Descriptive Statistics



Figure A.1: Location of Water Quality Stations

Notes: The dataset includes 970 water quality monitoring stations established prior to 2010. We exclude stations located on lakes or reservoirs, as well as those with significant geographic overlap. The final sample consists of 720 distinct monitoring stations, which are displayed on the map. Red dots indicate the locations of these stations.

Table A.1 provides descriptive statistics on the environmental and operational performance of regulated firms located within the 20-kilometer radius of water quality monitoring stations. Specifically, the environmental performance is measured by firms' emissions of industrial wastewater, COD, and ammonia nitrogen, which serve as key indicators of water pollution. In terms of business performance, we include core firm-level financial metrics such as profits, capital investment, and total debt levels, which reflect the firms' operational health and financing conditions under environmental regulatory constraints.

Table A.2 reports detailed characteristics of the clients and suppliers of the regulated firms, focusing on their R&D, innovation, and transaction behaviors. Panel A presents the R&D expenditure breakdown, including total R&D spending, R&D personnel wages, and R&D equipment and materials expenses. These variables provide insights into the intensity and composition of R&D input. Panel B describes the human capital structure of the R&D workforce by educational attainment, capturing the number of researchers holding Ph.D., master's, and bachelor's degrees.

Table A.1: Statistics Description on Upstream and Downstream Firms

	Upstream Firms	Downstream Firms
Panel A: Water Pollutants		
$\log(\text{wastewater})$	1.054 (0.439)	1.072 (0.561)
$\log(\text{COD})$	9.437 (2.762)	9.129 (3.085)
$\log(\text{NH})$	6.775 (3.075)	6.627 (2.853)
Panel B: Finance Standing		
$\log(\text{profits})$	1.115 (0.446)	1.298 (0.360)
$\log(\text{investments})$	0.678 (0.702)	0.840 (0.773)
$\log(\text{debt})$	1.000 (0.566)	0.975 (0.567)
Number of firms	372	383
Number of observations	1,552	1,489

Notes: This table presents descriptive statistics on the environmental and operational performance of regulated firms located within a 20-kilometer radius of water quality monitoring stations. The terms “upstream” and “downstream” refer to the firms’ geographic positions relative to river flow and the monitoring stations, rather than their roles in the supply chain.

This breakdown enables us to evaluate the skill distribution and the potential innovation capacity embedded in firms’ labor force. Panel C presents outcome-based innovation metrics, including indicators for productive innovation (such as new product introductions or process improvements) and green innovation (such as the development of environmentally friendly technologies or pollution-reducing processes). These measures help capture not only the quantity but also the orientation of firms’ innovative activities. Panel D summarizes the trade linkages between these clients/suppliers and their corresponding upstream or downstream regulated firms. We employ transaction volumes to understand the economic intensity and potential exposure of these trading partners to environmental regulatory spillovers.

Table A.2: Summary Statistics on Client and Supplier Firms

	Client Firms		Supplier Firms	
	Upstream's	Downstream's	Upstream's	Downstream's
Panel A: R&D Expenditure				
R&D (thousand CNY; log)	3.379 (0.687)	3.552 (0.712)	3.099 (0.625)	3.042 (0.658)
R&D wage (thousand CNY; log)	1.777 (1.511)	1.579 (1.547)	1.102 (1.561)	0.804 (1.374)
R&D instrument (thousand CNY; log)	1.962 (1.711)	1.717 (1.770)	1.067 (1.912)	1.001 (1.730)
Panel B: R&D Staff				
R&D staff (#; log)	1.835 (0.627)	1.736 (0.571)	1.609 (0.531)	1.520 (0.532)
R&D phd (#; log)	0.237 (0.592)	0.254 (0.492)	0.346 (0.581)	0.275 (0.556)
R&D master (#; log)	1.013 (1.032)	0.942 (1.012)	0.824 (0.920)	0.642 (0.891)
R&D bachelor (#; log)	1.251 (0.875)	1.087 (0.836)	1.009 (0.774)	0.884 (0.798)
Panel C: Innovation				
Total innovation (#; log)	0.523 (0.635)	0.441 (0.572)	0.379 (0.534)	0.316 (0.507)
Green innovation (#; log)	0.289 (0.698)	0.279 (0.769)	0.224 (0.671)	0.162 (0.567)
Panel D: Transaction				
Transaction (CNY; log)	16.039 (1.264)	18.431 (1.134)	18.367 (1.153)	18.447 (1.051)
Number of firms	631	419	389	400
Number of observations	3,250	2,417	1,758	1,969

Notes: This table presents descriptive statistics on the R&D activities of regulated firms' clients and suppliers, as well as their transactional relationships. The data are sourced from the SSTA database.

B Regulated Firm's Problem

Each upstream firm $j \in [0, 1]$ produces a single differentiated intermediate variety used as an input in a CES aggregator. The upstream industry operates under Dixit–Stiglitz monopolistic competition: firms are infinitesimal relative to the continuum of varieties but retain market power over their own product. Let $\sigma > 1$ denote the elasticity of substitution across varieties. Cost minimization by the downstream sector implies the following conditional demand function:

$$M_j = M \left(\frac{P_{M,j}}{P_M} \right)^{-\sigma}, \quad P_M = \left[\int_0^1 P_{M,j}^{1-\sigma} dj \right]^{1/(1-\sigma)}, \quad (\text{B.1})$$

where M is the aggregate quantity of intermediate inputs used by the client firms, and P_M is the corresponding CES price index.

Firm j produces using labor as the sole input, facing the marginal cost:

$$MC_j = w + \kappa_j \tau, \quad (\text{B.2})$$

where κ_j is the firm's idiosyncratic pollution-abatement coefficient, and τ is the environmental tax rate.

Taking the aggregate variables (M, P_M) as given, the regulated firm chooses its price $P_{M,j}$ to maximize static profits:

$$\max_{P_{M,j}} \pi_j(P_{M,j}) \equiv [P_{M,j} - MC_j] M_j. \quad (\text{B.3})$$

Substituting the demand function (B.1) into the profit function (B.3) and differentiating yields the firm's optimal pricing rule:

$$P_{M,j} = \frac{\sigma}{\sigma - 1} MC_j, \quad \mu_r \equiv \frac{P_{M,j} - MC_j}{MC_j} = \frac{1}{\sigma - 1}. \quad (\text{B.4})$$

Using Equations (B.1) and (B.4), equilibrium profits can be written as:

$$\pi_j = \frac{1}{\sigma} P_{M,j} M_j = \frac{1}{\sigma} \left(\frac{\sigma}{\sigma - 1} \right)^{1-\sigma} M P_M (MC_j)^{1-\sigma}. \quad (\text{B.5})$$

Equation (B.4) illustrates that a higher elasticity of substitution σ implies that varieties are closer substitutes. This reduces the markup $\mu_r = 1/(\sigma - 1)$, thereby attenuating the degree of cost pass-through from marginal costs MC_j to intermediate prices $P_{M,j}$.

C Client Firm's Problem

Each client firm i produces a homogeneous final good by labor L_i , the CES aggregate of intermediates M_i , and R&D R_i via a multiplicative, diminishing-returns function

$$Y_i = P_Y A_i L_i^\alpha M_i^\beta, \quad A_i = \theta_i + \gamma R_i. \quad (\text{C.1})$$

$\theta_i \sim H(\theta)$ is an exogenous productivity draw. In perfect market competition, a client firm takes the output price P_Y as given and solves the maximization problem

$$\max_{L_i, M_i, R_i \geq 0} \left\{ P_Y Y_i - w L_i - P_M M_i - \frac{(1-s)\varphi}{2} R_i^2 - f \right\}, \quad (\text{C.2})$$

where $f > 0$ is a fixed entry cost and $s \in [0, 1]$ is an R&D subsidy. First-order conditions yield

$$M_i = \frac{\beta}{\alpha} \frac{w}{P_M} L_i, \quad L_i^* = \left(\frac{\alpha P_Y A_i r^\beta}{w} \right)^{\frac{1}{1-\alpha-\beta}}. \quad (\text{C.3})$$

The optimal R&D investment is given by

$$R_i^* = \frac{P_Y \gamma}{(1-s) \varphi} \left[\frac{\alpha P_Y (\theta_i + \gamma R_i^*)}{w} \right]^{\frac{\alpha+\beta}{1-\alpha-\beta}} r^{\frac{\beta}{1-\alpha-\beta}}. \quad (\text{C.4})$$

With fixed cost f , the marginal entrant θ^+ satisfies

$$P_Y Y_i(R^*, \theta^+) = C_i(R^*, \theta^+) + \frac{(1-s)\varphi}{2} (R^*)^2 + f.$$

Since production costs C_i rises with P_M , which reduces both output and profits, higher pass-through removes low productive innovators, i.e., $\partial \theta^+ / \partial P_M > 0$.

Now we have shown that a higher intermediate-input price P_M therefore depresses R&D both at the intensive margin (R_i^*) and at the extensive margin (θ^+), providing the mechanism through which environmental cost shocks propagate to client R&D.

D General Equilibrium

D.1 Decentralized Equilibrium

Given policy instruments (τ, s, δ) , representing, respectively, the environmental regulatory tax, the R&D subsidy rate for client firms, and the scale of green technology aid for regulated firms, a decentralized equilibrium is defined by a set of allocations and prices $\{P_{M,j}, M_j, M_i, L_{r,i}, L_{c,i}, R_i\}$, such that Labor, intermediate input, and final goods markets clear; Government revenues from environmental taxation finance both R&D subsidies for client firms and technology aid to regulated firms; Regulated firms set prices according to their profit-maximization markup-pricing rule; Client firms choose inputs and R&D optimally given their individual first-order conditions.

Specifically, the decentralized equilibrium is characterized by the following system.

Final Goods Market Clearing:

$$Y = C = \left(\int_0^1 Y_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \quad (\text{D.1})$$

where Y is aggregate output and C is total final consumption.

Resource Constraint:

$$\int_0^1 L_{c,i} di + \int_0^1 L_{r,j} dj + \int_0^1 R_i di = 1, \quad (\text{D.2})$$

which ensures that total labor allocated to downstream production, upstream production, and R&D does not exceed the economy-wide labor endowment (normalized to 1).

Government Budget Constraint:

$$G_c = \int_0^1 s\phi R_i di, \quad G_r = \int_0^1 \delta_j dj, \quad G_c + G_r = T, \quad (\text{D.3})$$

where G_c is total government spending on R&D subsidies, G_r is total green tech-aid expenditure, and the total revenue T is generated from environmental taxation, based on aggregate emissions E .

D.2 Social Optimal Equilibrium

To determine the optimal policy configuration, we consider the problem faced by a social planner who internalizes environmental externalities. The planner chooses allocations $\{M_j, M_i, L_{r,i}, L_{c,i}, R_i\}$ to maximize aggregate social welfare:

$$\max_{\{L_{D,i}, M_i, R_i, M_j\}} W = C - \alpha E^p, \quad (\text{D.4})$$

subject to the following constraints.

Resource Constraint:

$$\int_0^1 L_{c,i} di + \int_0^1 L_{r,j} dj + \int_0^1 R_i di = 1. \quad (\text{D.5})$$

Intermediate Market Clearing:

$$\int_0^1 M_i di = \int_0^1 M_j dj. \quad (\text{D.6})$$

Emissions Identity:

$$E = \int_0^1 \kappa_j M_j dj. \quad (\text{D.7})$$

The first-order condition for emissions yields the optimal Pigouvian tax, $\tau^* = (\alpha p) E^{p-1}$, which internalizes the marginal social cost of pollution. The planner also corrects distortions in the R&D decisions of client firms caused by regulated firms' price markups, ensuring that the marginal private return to R&D aligns with its social return under imperfect input pricing. Finally, the optimal green technology aid δ^* is chosen to adjust the emissions coefficient κ_j downward, allowing the planner to achieve the targeted emissions level E^* at a lower required regulatory tax τ .

E Pass-through Effects on Supplier Firms

Table E.1: Pass-through Effects on Supplier Firms: Varying by Transaction

Panel A: Effects on Supplier Firms' R&D								
	log(s. R&D)							
	(1)	(2)						
$ups_i \times lnsup_{it}$	-0.001	-0.036	log(s. R&D wage)		log(s. R&D instrument)			
	(0.004)	(0.028)	(3)	(4)	(5)	(6)		
$ups_i \times lnsup_{it}$			0.093	-0.003	0.097	-0.034		
			(0.082)	(0.020)	(0.110)	(0.054)		
R-squared	0.450	0.900	0.760	0.985	0.736	0.978		
Panel B: Effects on Supplier Firms' Human Capital								
	log(s. R&D staff)							
	(1)	(2)						
$ups_i \times lnsup_{it}$	0.032	-0.033	log(s. phd)		log(s. master)		log(s. bachelor)	
	(0.045)	(0.026)	(3)	(4)	(5)	(6)	(7)	(8)
$ups_i \times lnsup_{it}$			0.050	-0.023	0.089	-0.029	0.056	-0.029
			(0.051)	(0.030)	(0.080)	(0.080)	(0.066)	(0.039)
R-squared	0.479	0.890	0.352	0.818	0.426	0.844	0.423	0.818
Panel C: Effects on Supplier Firms' Innovation								
	log(s. total innovation)							
	(1)	(2)						
$ups_i \times lnsup_{it}$	-0.006	0.010	log(s. green innovation)					
	(0.032)	(0.038)	(3)	(4)				
$ups_i \times lnsup_{it}$			0.035	0.027				
			(0.033)	(0.059)				
R-squared	0.380	0.626	0.343	0.608				
Supplier controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Supplier firm FE	No	Yes	No	Yes	No	Yes	No	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	3,029	2,998	3,029	2,998	3,029	2,998	3,029	2,998

Notes: The outcome variables are the R&D activities of regulated firms' supplier firms, measured in logarithmic value. $lnsup_{it}$ refers to the transaction volume between the regulated firms and the supplier firms. Control variables at the supplier-firm level include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

F Robustness Check: Switching

Table F.1: Pass-through Effects on Client Firms' R&D, Human Capital, and Innovation

Panel A: Effects on Client Firms' R&D								
	log(c. R&D)				log(c. R&D wage)		log(c. R&D instrument)	
	(1)	(2)			(3)	(4)	(5)	(6)
RDD (upc_i)	-0.390**	-0.385**						
	(0.155)	(0.190)						
RDD (upc_i)					-0.422**	-0.551**	-0.531**	-0.651**
					(0.185)	(0.249)	(0.267)	(0.282)
Bandwidth	4.297	4.030			4.968	4.660	4.648	4.963
Panel B: Effects on Client Firms' Human Capital								
	log(c. R&D staff)				log(c. phd)		log(c. master)	
	(1)	(2)			(3)	(4)	(5)	(6)
RDD (upc_i)	0.111	-0.205**						
	(0.118)	(0.101)						
RDD (upc_i)					-0.456*	-0.462**	-0.106	-0.561**
					(0.267)	(0.200)	(0.338)	(0.285)
Bandwidth	3.913	5.807			2.827	3.356	3.180	3.328
							5.576	6.734
Panel C: Effects on Client Firms' Innovation								
	log(c. total innovation)				log(c. green innovation)			
	(1)	(2)			(3)	(4)		
RDD (upc_i)	-0.015	-0.074						
	(0.100)	(0.101)						
RDD (upc_i)					-0.047	0.081		
					(0.128)	(0.150)		
Bandwidth	7.617	7.613			6.576	5.072		
Kernel type	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Client controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes	No	Yes	No	Yes
Station Clustered	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	4,393	4,392	4,393	4,392	4,393	4,392	4,393	4,392

Notes: The outcome variables are the R&D activities of regulated firms' client firms, measured in logarithmic form. The MSE-optimal bandwidth is selected based on the default kernel type recommended by [Calonico et al. \(2014\)](#). Firm-level controls include firm age and total assets. Standard errors, clustered at the monitoring station level, are reported in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

G Parameterization

We begin by externally calibrating a set of structural parameters using macroeconomic statistics. The elasticity of substitution across intermediate varieties is set to $\sigma = 5.76$, consistent with the midpoint of the manufacturing sector range in literature (Hsieh and Klenow, 2009; Atkeson and Burstein, 2008). Based on the ratio of total labor compensation to gross output from the 2021 Input–Output Table published by the National Bureau of Statistics, the labor and intermediate goods share in gross output is calibrated to $a = 0.35$ and $\beta = 0.3$, respectively. The upstream supplier price markup is set to $\mu_r = 0.21$, reflecting the average price–cost margin observed in upstream sectors of supply chain such as energy and raw materials, as reported in the 2015 CIED industrial survey. The setting of γ is based on the SSTA firm-level survey, which calculates R&D expense per R&D employee.

To capture the environmental regulatory environment, we leverage observed emission intensity data for firms located upstream and downstream of water quality monitoring stations. We normalize the emission standard for downstream firms to one. The observed discontinuity in Chemical Oxygen Demand (COD) emission intensity across upstream and downstream firms implies that upstream firms are subject to an environmental standard approximately $\tau = 0.20$. Accordingly, we set the baseline environmental regulation at $\tau = 0.20$ for upstream firms. In line with our baseline policy simulation, we also assume no green technology assistance ($\delta_0 = 0$) and no R&D subsidies ($s_0 = 0$).

The remaining parameters specific to our model are jointly estimated by matching the model simulated moments with their data counterparts. Specifically, we assume that regulated firms' emission intensity follows a log-normal distribution with mean μ_k and standard deviation σ_k , while client firms' productivity follows a normal distribution with mean μ_θ and standard deviation σ_θ . These firm-level shocks are assumed to be independently and identically distributed. Let $\Omega = \{\mu_k, \sigma_k, \mu_\theta, \sigma_\theta, \gamma\}$ denote the vector of parameters to be estimated. For a given candidate Ω , we simulate 10,000 regulated firms and 10,000 client firms. We solve for the optimal pricing and R&D investment decisions at firm level and aggregate these to obtain the corresponding simulated moment vector $m_{\text{model}}(\Omega)$. The parameter vector Ω is estimated by minimizing the distance between model-generated and data moments:

$$\hat{\Omega} = \arg \min_{\Omega} [m_{\text{model}}(\Omega) - m_{\text{data}}]' W [m_{\text{model}}(\Omega) - m_{\text{data}}], \quad (\text{G.1})$$

where W is a bootstrapped weighting matrix. m_{model} represents the simulated moments regarding regulated firms' emission distribution and client firms' productivity distribution, and m_{data} represents the corresponding data moments. Table G.1 reports the calibrated parameter values and

Table G.1: Result of the Structural Estimates

	CES elasticity	L-M share	Markup	Environmental standard	R&D costs
Parameter	σ	$\alpha; \beta$	μ_r	τ	ϕ
Estimates	5.76	0.35; 0.3	0.21	0.20	2.99
	Regulated firms' emission intensity		Client firms' productivity		R&D elasticity
Parameter	μ_κ	σ_κ	μ_θ	σ_θ	γ
Estimates	-9.028	0.602	0.101	1.110	0.305
Standard Errors	0.015	0.017	0.025	0.040	0.017

Notes: We construct our moment conditions using information on client firms' intermediate input prices, R&D expenditures, and productivity.

robust standard errors. All parameters are statistically significant at the 5% level. In particular, we estimate the elasticity of R&D with respect to productivity to be $\gamma = 0.31$ (s.e. = 0.02), suggesting that a 1-percentage-point increase in R&D intensity raises firm productivity by approximately 0.31%. Sensitivity analyses indicate that the main quantitative results are robust to doubling the number of bootstrap replications and to varying the elasticity of substitution σ within the range [3, 9].