One Step Forward, Two Steps Back:
Mandatory Quality Verification and Corporate Pollution Emissions

Lin Lin[1]

Wenjun Wang[2]

Abstract

Governments worldwide are increasingly instituting mandatory quality verification measures for critical industries, including the aerospace, automotive, pharmaceutical, cosmetic, and food sectors. In this study, we investigate the impact of mandatory quality verification on corporate pollution emission behavior. Using the introduction of the 2010 Good Manufacturing Practice (GMP) regulation in China's pharmaceutical industry as a quasi-experiment, we find that the adoption of mandatory production standards motivates pharmaceutical manufacturers to increase pollutant emission intensity. Traditional Chinese Medicine (TMC) manufacturers increase their industrial wastewater emission intensity by 24.7% following the implementation of the 2010 GMP regulation, compared with non-TMC manufacturers. This effect is more pronounced in firms with less government ownership, operating in areas with lax environmental regulation, and in regions with limited access to external finance. Mechanism analysis reveals that firms have to spend more on capital expenditures to comply with GMP standards, which drove up their production costs and distress risk, disincentivizing them from investing in pollution abatement measures. Our study provides evidence that mandatory policies intended to enhance product quality can unexpectedly and adversely affect corporate environmental behavior.

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Key Words: Good Manufacturing Practice; mandatory quality verification; pollution emissions; pharmaceutical industry

[1] School of Public Management, East China Normal University. E-mail: llin@fem.ecnu.edu.cn

[2] Investment Banking Division, Agricultural Bank of China. E-mail: wenjunwang00@gmail.com

1 Introduction

To excel in market competition, firms are increasingly focusing on improving the quality of their manufacturing processes and final products. Since the 1990s, a growing number of firms, particularly those aiming to expand their international market presence, have turned to voluntary quality management standards to mitigate quality risks and bolster competitiveness. Notable examples of globally implemented voluntary quality frameworks include ISO 9001, which originated in Europe, and Total Quality Management, adopted in the United States. Concurrently, governments globally are progressively implementing mandatory quality verification measures across critical industries to enforce and enhance best practices in the production processes, such as aerospace, automotive, pharmaceutical, cosmetic, and food industries. Examples of industry-specific mandatory quality management systems include the Aerospace Quality Management System, the Automotive Quality Management System, and the Good Manufacturing Practices specifically tailored to pharmaceutical manufacturing.

While existing research has predominantly focused on the impact of voluntary quality management standards (Hendricks and Singhal, 2001; Corbett et al., 2005; Levine and Toffel, 2010; Gray et al., 2015; Jacobs et al., 2015; Ho et al., 2017; Su et al., 2020), there is a notable scarcity of studies examining the impacts of mandatory quality certification, especially regarding its externalities. Although voluntary quality management systems bear certain similarities to industry-specific mandatory quality management systems, the latter are legally binding and, due to their mandatory nature, are expected to incur higher costs for firms and affect firms' behavior differently. This study fills this gap and investigates how manufacturing firms adapt their environmental behavior in response to the introduction of 2010 Good Manufacturing Practice (GMP) regulation in China's pharmaceutical industry, thus providing initial evidence of the relationship between mandatory quality certification and corporate environmental behavior.

The examination of the interplay between mandatory quality management and corporate pollution activities carries substantial significance, as it sheds light on how firms navigate the trade-offs between allocating capital to production versus investing in pollution reduction. The implementation of quality standards incurs substantial costs for firms, including significant capital outlays and employee efforts (Corbett et al., 2005; Trienekens and Zuurbier, 2008; He et al., 2015a). To finance these increased costs, firms must carefully weigh the benefits and costs of various strategies, including seeking external financing and reducing investments in pollution abatement. Moreover, pollution emissions represent a

negative externality to the society: if firms offset the increased expenses incurred from adapting their production processes by reducing their pollution abatement efforts, this effectively shifts the burden of these costs back onto society. It is therefore relevant to examine whether the GMP unexpectedly exacerbate firm's pollution behavior.

Yet, it remains theoretically ambiguous whether firms would resort to environmentally irresponsible practices to offset the cost increase arising from mandatory quality verification. On the one hand, the adoption of compulsory quality standards could incur substantial fixed cost for affected firms (Buehler and Schuett, 2014; Macedoni, 2022), leading to higher operating leverage and distress risk (Serfling, 2016). As a result, firms may shift toward cash-saving corporate strategies, such as reducing effort in pollution abatement measures, leading to increase in pollution emissions (Xu and Kim, 2022). On the other hand, mandatory quality management may complement corporate environmental activities, as both initiatives involve continuous improvement in production procedure and operation management (King and Lenox, 2001), potentially leading to reduced pollution emissions (Wiengarten and Pagell, 2012; Su et al., 2015). Therefore, the theoretical ambiguity surrounding whether firms modify their pollution emission behavior in response to mandatory quality certification calls for empirical investigation.

Utilizing the implementation of China's 2010 GMP regulations in the pharmaceutical industry as an exogenous shock, this paper empirically estimates the impacts of mandatory quality certification on corporate pollution emissions. Effective in March 2011, pharmaceutical producers operating in China are required to adhere to significantly stricter manufacturing guidelines — the 2010 GMP — which cover production environment, personnel qualifications, and information systems. Pharmaceutical manufacturers that fail to obtain GMP certification before the specified deadlines are prohibited from continuing production. The 2010 GMP regulation has been shown to significantly increase the production cost for pharmaceutical manufacturers, roughly by 20% on average (Chen et al. 2023). Compared to non-TCM manufacturers, Traditional Chinese Medicine (TCM) manufacturers face significantly greater challenges and require higher capital investments to comply with the 2010 GMP guidelines. This is because TCM production processes are more decentralized, less standardized, and have significantly weaker quality control systems.

Using 2006-2013 firm-level data from the Annual Survey of Industrial Firms (ASIF) database and the Environmental Survey and Reporting (ESR) database, we find a significant increase in the industrial wastewater emissions intensity among TCM manufacturers

following the implementation of 2010 GMP regulation. Specifically, compared with non-TCM manufacturers, TCM manufacturers increase their emission intensity of industrial wastewater by 24.7%, which is equivalent to 0.552 tons of wastewater per thousand yuan of output. Our findings are robust to using a propensity score matching method, employing alternative measures for outcome variables, and performing falsification test.

Further heterogeneity analysis reveals that the effects of mandatory quality certification are more pronounced for non-state-owned enterprises, firms subject to less-stringent environmental regulations, and firms with stricter financial constraints. Mechanism analysis shows that, the GMP regulation substantially increases corporate capital expenditures and raises firms' production costs. In response to this financial pressure, firms choose to allocate fewer resources toward pollution abatement measures, particularly the pollution reduction efforts during production process, ultimately resulting in increased pollution emissions intensity.

Our study makes several important contributions to the literature. First, our study is the first to demonstrate a negative externality of mandatory quality verification. Prior studies have predominantly focused on the impacts of voluntary quality verification, such as ISO 9000 and ISO 9001. Given that voluntary quality verification lacks legal enforceability (Corbett, 2005; Terlaak and King, 2006; Gray et al., 2015; Levine and Toffel, 2010; Su et al., 2020), it generally imposes less financial burden on firms than mandatory standards. Indeed, studies have demonstrated that adopting voluntary quality standards can yield positive externalities, such as reducing waste generation and toxic chemical emissions (King and Lenox, 2001; Wiengarten and Pagell, 2012). Conversely, our study shows that mandatory quality verification correlates with increased pollution emissions.

Second, our study joins the growing literature that examines the relationship between environmental pollution and operation management. For example, Mani and Muthulingam (2019) show that environmental inspections during regular production enable firms to develop organizational knowledge and improve their environmental performance. Örsdemir et al. (2019) document that servicization, a business strategy to sell the functionality of a product rather than the product itself, results in an increase a firm's profits and decrease its environmental impact compared with selling products. More recently, Muthulingam et al (2022) show that manufacturing facilities that experienced drought conditions in previous years reduce their toxic releases into the environment.

Finally, our work directly contributes to the literature on the economics of the pharmaceutical industry (see e.g. Lakdawalla (2018) for a comprehensive review). The

pharmaceutical industry represents a considerable and expanding portion of healthcare spending and is subject to extensive governmental regulation and impactful public policies. Existing studies have primarily focused on the economic analysis of research and development, as well as the pricing and marketing behaviors of pharmaceutical firms (Brekke et al., 2009; David et al., 2010; Budish et al., 2015; Zhang and Nie, 2021). We extend this body of research by examining how government regulations influence pharmaceutical manufacturers' pollution emission behaviors, which pose increasingly harmful effects on ecological and human health (Wilkinson et al., 2022).

The remainder of this paper proceeds as follows. Section 2 presents the institutional background. Section 3 discusses the literature review and hypothesis development. Section 4 describes the data, variables and our identification strategy. Section 5 reports the baseline results, and the results of robustness tests. Section 6 investigates the underlying mechanisms. Section 7 concludes.

2 Institutional background

2.1 China's GMP reform

To ensure the quality and safety of pharmaceuticals, governments around the world regulate production processes with reference to the gold standard of Good Manufacturing Practices (GMP). Under GMP guidelines, all aspects of the production process, including facilities, equipment, materials, and personnel, should be appropriately controlled and monitored to prevent contamination, errors, and deviations from expected product specifications. After the thalidomide disaster, the U.S. Food and Drug Administration (FDA) introduced the first official GMP guidelines for the pharmaceutical industry in 1963,[3] which later gradually spread to other countries. So far, more than 100 countries have adopted GMP regulations to supervise the pharmaceutical production process.

The history of GMP implementation in China can be traced back to the 1980s, when the then China State Drug Administration (SDA) issued the first GMP guidelines for the pharmaceutical industry in 1985. At this stage, the GMP was issued merely as a guidance document and lacked enforcement authority. In 1998, the State Food and Drug Administration (SFDA) published revised GMP guidelines.[4], and required that

[3] The Thalidomide disaster of 1962 catalyzed regulatory changes in pharmaceutical safety by the FDA. Thalidomide, initially marketed as a sleeping pill and for morning sickness, caused severe birth defects. This highlighted the critical need for stringent drug testing. In response, the FDA introduced the first official Good Manufacturing Practice (GMP) guidelines in 1963, emphasizing rigorous safety and efficacy testing. These guidelines marked the beginning of modern clinical trial regulations, ensuring that pharmaceuticals were consistently produced to high standards and safe for public use.

[4] The SFDA was established in 1998, replacing the SDA.

pharmaceutical manufacturers must obtain GMP certificates.

Formulated based on the World Health Organization's GMP guidelines for developing countries, China's 1998 GMP standards lagged far behind those implemented in developed countries.[5] In January 2011, to align with international standards prevalent in developed countries like Europe and the United States and boost the presence of Chinese pharmaceuticals in the global market, the SFDA issued the 2010 version of the GMP Guidelines.[6] The 2010 GMP, effective from March 2011, established specific compliance deadlines: pharmaceutical companies producing sterile drugs, such as blood products, vaccines, and injections, were required to secure GMP certificates by the end of 2013. Manufacturers of other drug categories needed to obtain official verification by the end of 2015. Those failing to meet the new GMP requirements were prohibited from continuing drug production after these deadlines.

The 2010 version of GMP significantly enhanced China's standards for drug quality regulation. It introduced major improvements over the 1998 version by emphasizing the continuous stability of production processes and the reliable quality of pharmaceutical products in three key areas. First, it incorporated the concept of quality risk management, raising the standards for the production environment of sterile preparations and instituting more rigorous requirements for real-time monitoring of the production environment. Second, the updated GMP places greater emphasis on personnel qualifications, setting higher standards for the key personnel in pharmaceutical manufacturing firms. Third, it mandates the establishment of a comprehensive quality management system where all stakeholders, from top management to floor-level employees, are accountable for product quality and the development of customized management strategies. These enhancements aim to align more closely with international standards and ensure the production of high-quality pharmaceuticals.

While the 2010 GMP regulations have significantly enhanced the quality monitoring and safety control of Chinese pharmaceutical producers, they have also subjected manufacturers to increased cost pressures. For quality risk management, capital investments in facility construction and equipment have risen substantially due to heightened standards

[5] China's 1998 version of GMP focuses on monitoring the production hardware of physical equipment and facilities, such as machines, tools, and buildings, while developed countries implement cGMP (Current Good Manufacturing Practice), focusing on monitoring production software, such as operators operating in the production process and The behavior of handling emergencies in the management system.
[6] The CFDA was established in 2013 and was later replaced by the National Medical Products Administration (NMPA) in 2018.

for sterility and purification in the production process. Additionally, the 2010 GMP mandates continuous dynamic monitoring of Class A and Class B areas, leading to a marked increase in monitoring expenses.[7] In terms of personnel management, operating costs for pharmaceutical manufacturers have surged as they now require a more educated and experienced management team, alongside providing essential training for previously unqualified staff.

The implementation of the 2010 GMP regulations has notably tightened the regulatory framework, leading to significant increases in capital investment requirements for pharmaceutical manufacturers. According to Chen et al. (2023), the introduction of these regulations resulted in an average production cost increase of 20% for pharmaceutical companies. This financial strain was particularly acute for small manufacturers or those utilizing outdated technology, as they faced substantial challenges in managing the increased financial burden. SFDA statistics from 2016 indicate that approximately 25% of China's 7,179 pharmaceutical manufacturers failed to meet the 2010 GMP certification requirements, leading to a cessation of their production after December 2015.

Among the various pharmaceutical sectors, Traditional Chinese Medicine (TCM) manufacturers, who produce herbal preparations, proprietary Chinese medicines, and decoction pieces, were the most adversely affected. SFDA data shows that the GMP certification pass rate for TCM manufacturers was under 50%, considerably lower than the industry average of about 75%. The decentralized and small-scale nature of these manufacturers often presents significant obstacles to achieving 2010 GMP certification (Tang et al., 2018; He et al., 2015a; He et al., 2015b). For instance, only 30% of traditional Chinese medicine piece manufacturing companies report annual sales exceeding 100 million yuan ($14.6 million). Furthermore, TCM manufacturers often struggle with quality control due to a lengthy supply chain. Contamination risks, from elevated heavy metal levels or pesticide misuse in upstream farming, limited processing methods at midstream production stages, to potential downstream distribution contamination, pose significant quality challenges. Moreover, compared to Western medicine manufacturers, TCM companies often fall short in standardization and transparency within their production processes, complicating the certification process and necessitating further capital investment. Given these challenges, our study specifically targets TCM manufacturers, examining how the

[7] The 2010 version of GMP implements a grading system for clean areas necessary for pharmaceutical production, categorized into four levels: Class A, Class B, Class C, and Class D, from the most to the least stringent cleaning standards.

2010 GMP regulations influence their approaches to managing pollution, compared with non-TCM manufacturers.

2.2 Pollution in pharmaceutical industry

The pharmaceutical industry, a rapidly expanding sector, frequently faces accusations of polluting the environment in ways that detrimentally affect both ecology and human health (Wilkinson et al., 2022). The pharmaceutical industry is marked by a diverse array of pollutants. The production of pharmaceuticals involves numerous chemical reactions and purification processes that release pollutants into the environment through exhaust gases, solid waste, and wastewater, with a notably significant impact on water quality (Imran, 2005; Yaqub et al., 2012; Brems et al., 2013).

Pharmaceutical wastewater typically contains hazardous chemicals such as isopropyl alcohol, acetic acid, ethyl acetate, ethanol, n-heptane, tetrahydrofuran, methanol, toluene, methylene chloride, and acetonitrile. In addition, pharmaceutical manufacturing discharges active pharmaceutical ingredients (APIs) into global water systems, posing health threats to an estimated 471.4 million people (Wilkinson et al., 2022). Notably, antibiotics in pharmaceutical wastewater have led to environmental pollution scandals, particularly involving manufacturers in China and India. China has become the world's largest producer of Active Pharmaceutical Ingredients, with its annual production of two million tonnes accounting for 20 percent of the global output. Recognizing its significant environmental footprint, China's pharmaceutical sector is listed among the top 12 priority industries in the national environmental protection strategy (Gao et al., 2019).

3 Literature review and hypothesis development

3.1 Literature review

Our paper links to two distinct strands of literature. The first strand centers on the effects of quality verification within the operation management literature. Existing research predominantly focus on voluntary quality verification, such as ISO 9000, ISO 9001, Total Quality Management and Six Sigma. These methods are not mandatory and firms choose to implement them based on their developmental goals. It has been documented that the adoption of such voluntary quality management standards leads to enhanced process compliance (Gray et al., 2015), increased productivity (Terlaak and King, 2006; Iyer et al., 2013; Ozbugday, 2019; Su et al., 2020), improved financial performance (Corbett et al., 2005; Lo et al., 2013), higher employee wages, and decreased injury rates (Levine and Toffel, 2010; Trifković, 2017).

Scholars also examine the spillover effects of quality management, and find that

adopting voluntary quality standards can reduce waste generation and toxic chemical emissions. King and Lenox (2001), using ISO 9001 as a context, demonstrate that voluntary quality management complements firms' environmental management activities due to shared features such as continuous improvement. Wiengarten and Pagell (2012) and Su et al. (2015) suggest that ISO 9001 certified firms can leverage their accumulated knowledge to excel when implementing environmental management standards such as ISO 14001.

However, to the best of our knowledge, limited attention has been devoted to examining the impact of mandatory quality verification. GMP, a representative mandatory quality verification, fundamentally differs from voluntary standards because it is legally binding, as stipulated by regulation, and is expected to incur higher costs for firms, thereby influencing their behavior differently. Moreover, GMP focuses on meeting specific quality requirements, whereas voluntary verification emphasizes the general improvement of products and processes. Our study aims to fill this gap by investigating the environmental externalities associated with mandatory quality verification.

The second body of literature delves into the determinants of corporate pollution emissions. Financial circumstances are a significant factor influencing firms' environmental decisions (Andersen, 2017). For instance, the pioneering work of Xu and Kim (2022) find that firms reduce their pollution emissions when their financial constraints are relaxed. Environmental management standards also play a vital role in mitigating corporate pollution. The adoption of ISO 14001, an environmental management standard, has been demonstrated to promote pollution abatement behaviors and reduce overall pollution levels (Nishitani et al., 2012; Djekic et al., 2014; Martín-Peña et al, 2014; Jeong and Lee, 2022).

Recent literature has also engaged in discussions on the impact of fiscal policies (Kong and Zhu, 2022; Qi et al., 2023) and corporate governance (Maung et al., 2016; Liu et al., 2021b; Kong et al., 2023) on firm-level emission decisions. Our contribution to this existing body of literature lies in our comprehensive examination of the factors influencing corporate environmental behavior, specifically through the lens of quality management.

3.2 Hypothesis development

Theoretically, the impact of mandatory quality verification on firms' pollution emissions is ambiguous. One plausible scenario is that manufacturing firms, in their efforts to comply with stringent mandatory quality standards, may reduce their investments in pollution abatement activities, potentially resulting in increased pollution emissions. This scenario is especially probable in countries or regions where enforcement of environmental compliance is lax .

As the largest developing country, China faces significant challenges due to lax enforcement of environmental regulations (Stoerk, 2018). Throughout our sample period, local bureaucrats in China have primarily been evaluated based on GDP growth, which incentivizes them to prioritize economic expansion over environmental considerations (Chen et al., 2018). This dynamic creates incentives for manufacturers to avoid the costly measures required for emission abatement (Liu et al., 2021). Given the relatively minor legal liabilities related to environmental issues, firms may find cost savings by emitting additional pollutants, consequently shifting the associated costs to society.

Moreover, environmental compliance costs typically represent a substantial portion of a firm's operational expenditures. A survey conducted by the U.S. Census Bureau within the manufacturing sector revealed that pollution abatement expenses accounted for over 20% of total capital expenditure for firms (Xu and Kim, 2022). To circumvent these elevated costs associated with adoption of mandatory quality standards, firms might opt to deactivate pollution control facilities or shift away from cleaner production technologies (Liu et al., 2021).

China's pharmaceutical manufacturers have faced substantial cost increases due to stricter mandatory quality verification requirements. The 2010 GMP regulation significantly raised the quality standards for drug products, encompassing design, R&D, production, testing, storage, shipment, and usage. To comply with the GMP regulation, manufacturers had to significantly increase their investments in hardware, software, human resources, and standard operating procedures. They were required to construct new facilities and upgrade equipment to ensure a sterile environment for production and storage. Significant investments were also made in information systems to enhance real-time tracking, supervision, and control of the manufacturing process. According to Chen et al. (2023), the introduction of the 2010 GMP regulations resulted in an average production cost increase of 20% for pharmaceutical companies.

Under the financial strain of substantial capital expenditure and escalating production costs, firms may reduce their pollution reduction efforts, which appear as a more economically viable option. Consequently, we anticipate that the adoption of mandatory quality verification could lead to decreased abatement activities by firms, resulting in increased pollution emissions. Therefore, we propose the following hypothesis:

H1a: *The implementation of 2010 GMP regulation causes firms to increase their pollution emission intensity.*

Conversely, insights from previous literature suggest that quality management

regulations could potentially lead to a reduction in corporate pollution emissions. Quality management complements firms' environmental management activities through shared principles such as continuous improvement (King and Lenox, 2001). By leveraging their accumulated knowledge in quality management, corporations can engage more actively in environmental management. This includes pursuing strategies for abatement reduction, which could result in lower pollution emissions (Wiengarten and Pagell, 2012; Su et al., 2015).

In addition, quality management involves organizational-level strategic goals, including improvements in overall competitiveness and financial performance (Anderson et al., 1999; Corbett et al., 2005). Under such a regime, adopters of mandatory quality standards may systematically implement resource-saving measures, such as reducing energy consumption and fresh water usage. Consequently, quality management can facilitate a more coordinated approach to managing environmental performance (Pagell et al., 2015).

Building on this rationale, we anticipate that the implementation of mandatory quality standards may lead to reduced pollution emissions. Therefore, we propose an alternative hypothesis as follows:

H1b: *The implementation of 2010 GMP regulation causes firms to decrease their pollution emission intensity.*

4 Data

4.1 Data

We have merged two datasets that provide comprehensive information on the production and financial performance of manufacturing firms, along with detailed data on pollutant emissions at the firm level. The first dataset, the Annual Survey of Industrial Firms (ASIF), is collected by the National Bureau of Statistics. It covers private industrial firms with sales exceeding 5 million yuan and all state-owned industrial enterprises across mainland China. The ASIF data provides comprehensive firm-level production and financial information, including output, sales and profits. The second dataset is Environmental Survey and Reporting (ESR) database. Maintained by the Ministry of Environmental Protection, the ESR data provides detailed reports on pollution emissions from industrial firms, including the discharge of waste liquid pollutants, atmospheric pollutants, and solid pollutants.

We match the firms between the ASIF and ESR dataset based on unique identifier, focusing exclusively on pharmaceutical manufacturers. We restrict our sample to the period from 2006 to 2013, encompassing four years prior to the introduction of the 2010 GMP regulation and concluding in the final year covered by the ASIF data. We drop the

observations in the year 2010 to mitigate the concerns that firms may foresee the passage of the new GMP regulation and take actions accordingly. Our final sample comprises 3,150 pharmaceutical manufacturers, resulting in a total of 12,395 firm-year observations.

4.2 Variable construction

4.2.1 Dependent and independent variables

We use the emission intensity of industrial wastewater as the dependent variable, calculated by dividing the total amount of industrial wastewater emitted by the total output value (Qi et al., 2023). To mitigate the impact of outliers, we winsorize the dependent variable at 1% and 99%. We specifically focus on the emissions of industrial wastewater discharged by pharmaceutical manufacturers due to its significant environmental harm and health hazards. Pharmaceutical wastewater is particularly concerning because it contains high levels of pollutants and toxicity and is poorly biodegradable (Imran, 2005; Wilkinson et al., 2022).

Our treatment group variable is a binary indicator that equals one if the firm is a TCM manufacturer, and zero otherwise. TCM, which includes Chinese patent medicine and traditional Chinese medicine decoction pieces, is inherently more complex and less standardized in its manufacturing processes compared to Western medicine. This complexity exposes TCM manufacturers to greater quality risks, making them more susceptible to the impacts of the 2010 GMP regulation, as discussed in Section 2.

4.2.2 Control variables

Following Chen et al. (2021), Kong and Zhu (2022) and Qi et al. (2023), our set of control variables includes firm size, financial leverage, firm tangibility and export dependence. Firm size (*Size*) is measured by the natural logarithm of total assets. Financial leverage (*Leverage*) is defined as the ratio of total liabilities to total assets. Firm tangibility (*Tangibility*) is measured by the proportion of tangible assets, calculated as fixed assets divided by total assets. Export dependence (*Export*) captures a firm's reliance on foreign trade, calculated as the ratio of export output to total sales.

4.2.3 Summary statistics

Table 1 presents key summary statistics for China's pharmaceutical manufacturers. The emission intensity of industrial wastewater averages 22.359 tons per ten thousand yuan, with a standard deviation of 52.090. Firm size shows considerable variation, with a mean value (in natural logarithm) of 11.562 and a standard deviation of 1.353. On average, debt constitutes over half of the assets among pharmaceutical manufacturers, indicating a high level of financial leverage. The sector is capital-intensive, with fixed assets comprising 36.9% of total assets on average. Reflecting the domestic focus of the industry, exports

account for only 9.2% of total output in the pharmaceutical sector in China.

4.4 Identification strategy

Our identification strategy leverages the implementation of 2010 GMP regulation as an exogenous shock and use a differences-in-differences approach to examine the impact of mandatory quality verification on corporate pollution emission behavior. The specification for our baseline regression is as follows:

$$Ln(Emission_{it}) = \alpha_0 + \alpha_1 Treat_i * GMP_t + \alpha_2 X_{it} + \kappa_i + \delta_t + \varepsilon_{it} \quad (1)$$

Where $Ln(Emission_{it})$ is the natural logarithm of emission intensity of industrial wastewater discharged by pharmaceutical manufacturer i in year t, GMP_t is a dummy variable which equals zero for observations between 2006 and 2009, and one for observations during period 2011-2013. $Treat_i$ measures firm i's exposure to the policy shock, which equals one if the firm is a TCM manufacturer and zero otherwise. That is to say, we take the non-TCM manufacturers as the control group and the TCM manufacturers as the treated group. X_{it} represents a set of control variables, including firms size, financial leverage, firm tangibility and export dependence. κ_i and δ_t controls for firm and year fixed effect, respectively. ε_{it} is the error term and we cluster the its standard errors at the firm level.

5 Empirical results

5.1 Baseline results

Table 2 presents the baseline estimates of GMP's impacts on pollution emission intensity among pharmaceutical manufacturers. Column (1) includes firm fixed effects, year fixed effects, and no controls. In column (2), we add two control variables: firm size and financial leverage. Column (3) further includes additional controls for the ratio of fixed assets (*Tangibility*) and export dependence (*Export*). Our results consistently show significant and positive coefficients on *Treat*×*GMP*, indicating that firms increase their pollution emission intensity after the implementation of 2010 GMP regulation. In column (3), the coefficient on the interaction term *Treat*×*GMP* is 0.247, indicating that, on average, compared with otherwise similar manufacturers, traditional Chinese medicine manufacturers increase their emission intensity of industrial wastewater by 24.7%, which is equivalent to 0.552 ($0.247 \times 22.359/10$) tons of wastewater per thousand yuan of output value. Overall, our empirical results lend strong support to the hypothesis that the introduction of GMP regulation leads to more pollution discharge.

5.2 Robustness analysis

In this subsection, we conduct a comprehensive battery of robustness checks to confirm the

validity of our baseline results, which includes 1) testing parallel time trend assumption, 2) implementing a propensity score matched analysis to ensure comparability between treated and control groups, 3) utilizing alternative measures for pollution emissions, and 4) conducting a falsification test.

5.2.1 Dynamic effects of GMP on emission intensity

The key identification assumption of our identification strategy is that firms in the treatment and control groups do not behave systematically differently absent the 2010 GMP reform. To validate the parallel trend assumption, we check whether TCM manufacturers share a similar trajectory in emissions of industrial wastewater with non-TCM manufacturers. We adopt an event study approach, following Bertrand and Mullainathan (2003), to examine dynamic effects of the 2010 GMP regulation on pollution emissions.

$$Ln(Emission_{it}) = \alpha_0 + \sum_{t=2006}^{2013} \theta_t Treat_i \times Year_t + \beta X_{it} + \kappa_i + \delta_t + \varepsilon_{it} \quad (2)$$

where we set 2009 as the reference year. $Year_t$ is an indicator for each year. The time varying coefficient θ_t measures the difference in pollution emission intensity between the treatment group and control group relative to the baseline year. Figure 1 displays the point estimates of θ_t along with the 95% confidence interval. It shows that the estimated θ_t is not statistically significantly different from zero during 2006-2009, suggesting the trends in corporate pollution emission intensity are parallel between the treated and control group, prior to the implementation of the 2010 GMP regulation. This finding validates the parallel trend assumption for our identification strategy and demonstrates that reverse causality are not driving our results. After the 2010 GMP regulation took effect, the estimated θ_t becomes positive and statistically significant. This pattern suggests that traditional Chinese medicine manufacturers increased their pollution emission intensity immediately in response to the 2010 GMP regulation and this effect were long lasting.

5.2.2 PSM-DiD

The difference in pollution emission intensity between treated and control firms could be driven by their systematic difference in attributes. To mitigate this concern, we construct the control groups using Propensity Score Matching method and rerun the differences-in-differences regression using the matched sample. First, we estimate the propensity score of being a treated firm by employing a logit model, regressing the treatment variable (whether the firm is a TCM manufacturer) on firm-level attributes such as firm size, financial leverage, firm tangibility and export dependence, while controlling for firm and year fixed effects. We then match a treated firm to a control firm by performing 1:2 matching on propensity scores

with replacement. Our matched sample comprises 1005 treated firms and 1376 control firms. We re-estimate the differences-in-differences regression using this matched sample and the estimated results are reported in Table 3. The findings continue to demonstrate a significant impact of the GMP regulation on corporate pollution emissions, suggesting that our results are robust to potential biases arising from systematic differences between treated and control firms.

5.2.3 Alternative measures for pollution emissions

Our baseline regression employs the discharge of industrial wastewater as a proxy for pollution emissions. However, pharmaceutical manufacturers also generate other types of pollutants, and the GMP regulation may influence these emissions as well. Given the high concentration of refractory organics in pharmaceutical wastewater, the pollutant loads, particularly in terms of Chemical Oxygen Demand (COD), ammonia and nitrogen (NHN), and sulfur dioxide (SO2), are typically elevated in this industry. To address this, we employ three alternative measures for pollution emissions. The first measure is COD emission, calculated as the natural logarithm of COD emissions divided by the total output value. The second measure is NHN emission, calculated as the natural logarithm of emission of ammonia and nitrogen divided by the total output value. The third measure is SO2 emission, calculated as the natural logarithm of sulfur dioxide emissions divided by the total output value. We then re-estimate the baseline regression using the alternative measures. As shown in Table 4, while coefficient on *Treat*×*GMP* term are positive and statistically significant for COD and NHN emissions (Columns 1 and 2), they are insignificant for SO2 emissions (Column 3). It suggests that the implementation of 2010 GMP regulation may increase water pollution emissions rather than air pollution emissions for the affected manufacturers.

5.2.4 Falsification test by randomly assigning treatment variable

To address the concerns that omitted variables might bias our results, we conduct a falsification test by randomly assigning treatment variables to firms, following Chetty et al. (2009) and La Ferrara et al. (2012). A random data-generation process should yield an insignificant estimate of the impact of 2010 GMP regulation on corporate environmental activities if the treatment effect is not confounded by omitted variables. Otherwise, it would indicate that our differences-in-differences estimation is misspecified. In Figure 2, the blue hollow circles represent the distribution of the estimated coefficients, while the solid lines depict the density distribution of data estimates, and the vertical dash line marks the estimates derived from the actual data. The results show that the estimates from the randomization check are centered around zero and significantly different from our baseline

estimates, suggesting that our main findings are not confounded by omitted variables.

5.3 Heterogeneous analysis

In this subsection, we expand the scope of our investigation to analyze whether the effects of the 2010 GMP regulation on firm pollution activities vary according to firm ownership structure, the stringency of environmental regulations, and corporate financial constraints.

5.3.1 Ownership structure

A salient feature of the Chinese economy is the significant presence of state-owned enterprises (SOEs). SOEs maintain close connections with government agencies (Qi et al., 2023) and are typically subject to more extensive monitoring. Consequently, they often exhibit better quality management practices even before the introduction of the GMP regulation, and are therefore less affected by its implementation. Moreover, SOEs have greater access to financial resources and social capital, which renders them less susceptible to negative economic shocks compared to non-SOEs (Liu et al., 2021). Consequently, we expect that the impact of GMP regulation on pollution activities is more pronounced for SOEs than for non-SOEs.

We classified firms into two ownership groups: SOEs and non-SOEs. Panel A of Table 5 reports the estimation results. Column (1) shows that the implementation of the 2010 GMP regulation did not significantly impact the pollution emission intensity of SOEs. In contrast, as shown in column (2), the regulation had a significant and positive effect on the wastewater discharge of non-SOEs. These results are consistent with our prediction that the effect of GMP on corporate pollution behavior is more pronounced for non-SOEs.

5.3.2 Environmental regulation

The stringency of environmental regulation is an critical factor that influences corporate emissions. Strict environmental regulations enhance monitoring and increase non-compliance costs associated with excessive emission (Liu et al., 2021; Kong and Zhu, 2022), thus disincentivizing firms from reducing pollutant abatement efforts. Therefore, we expect that corporate pollutant emission is less sensitive to the 2010 GMP regulation among firms located in regions with stricter environmental regulations.

To identify regions subject to varying levels of environmental regulation, we use the quota limits for COD emissions set by the central government. During the Eleventh Five-Year Plan period (2006-2010), the State Council issued specific COD reduction targets (as a percentage) for each province. A larger reduction target indicates more stringent environmental regulation.

We divide our sample into two subsamples based on the median of COD reduction

targets. Panel B of Table 5 reports the results. In column (3), the coefficient on the interaction term *Treat*×*GMP* is positive but statistically insignificant. By contrast, the coefficient on the interaction term *Treat*×*GMP* in column (4) is positively significant at the 1% level, suggesting that the impact of the 2010 GMP regulation on pollutant emission is more pronounced for firms located in regions with less stringent environmental regulations.

5.3.3 Financial constraints

Firms' effort to reduce emissions are closely associated with their financial circumstance, as significant financial resources are required to invest in abatement equipment and pollution control technologies (Qi et al., 2023). Firms with easier access to external finance are able to secure more debt to support their emission reduction activities, making them less financially constrained and less vulnerable to negative economic shocks. Therefore, we expect the impact of the 2010 GMP regulation on pollutant emission is less pronounced in firms with lower financial constraints. Following Paravisini (2008) and Butler and Cornaggia (2011), we proxy access to external finance using the ratio of provincial-level supply of bank loans to local GDP. A higher density of credit supply suggests easier access to finance and, consequently, a lower degree of financial constraint.

We categorize firms as financially constrained if they are headquartered in cities where the bank loan density is below the sample median at the end of 2009, and as financially unconstrained if above this median. The results are presented in Panel C of Table 5. The findings indicate that the estimated coefficients on the interaction term *Treat*×*GMP* are negative and insignificant for subgroups with lower degrees of financial constraints, yet significantly positive for subgroups with higher financial constraints. These findings from our heterogeneous analysis across credit density provide evidence that the GMP regulations have a more substantial impact on corporate pollutant emissions in firms facing higher financial constraints.

6 Mechanism analysis

The analysis above shows that the 2010 GMP regulation raises firms' pollution emission intensity. We now explore the potential mechanisms underlying this observed effect. We start by investigating the regulation's impact on manufacturers' capital investment, production cost and financial distress. Subsequently, we examine the mechanisms firms employ to operationalize emission reduction strategies in response to the cost pressures associated with 2010 GMP implementation. Specifically, we examine both end-of-pipe reduction strategies and production process reduction strategies to gain a comprehensive understanding of the multifaceted dynamics at play.

6.1 Impact of GMP on corporate investment, production cost and distress risk

We investigate the impact of the 2010 GMP regulation on pharmaceutical manufacturers' capital expenditure, production costs, and distress risk. The regulation mandates comprehensive standards covering production processes, quality control, packaging, personnel, and facilities. Specifically, it imposes stringent requirements for cleanroom environments, including advanced air purification systems and sterilization equipment. It also sets strict standards for temperature, humidity, static pressure differences, lighting, and ventilation across production and storage areas, which contribute to increased energy costs. To meet these enhanced GMP standards, firms were required to undertake significant investments in new facilities, plant upgrades, and personnel training to ensure compliance (WHO, 2017).[8] Motivated by this rationale, we expect significant increases in manufacturers' capital investments and product costs following the introduction of the 2010 GMP regulation, thereby potentially leading to heightened distress risk.

Table 6 presents our estimation results. Column (1) uses capital expenditure divided by total assets as the dependent variable for investment. The estimated coefficient on the interaction term *Treat*×*GMP* is positive and statistically significant at the 1% level, confirming our hypothesis that the introduction of the 2010 GMP regulation significantly increased investment by pharmaceutical manufacturers. Column (2), with production cost measured as the cost of sales divided by total sales revenue, shows that manufacturing costs have also significantly increased following the implementation of the GMP regulation.

In column (3), we use distress risk as our dependent variable, employing a balance-sheet-based measure developed by Zmijewski (1984). A higher Zmijewski score indicates greater default risk (Acharya et al., 2013).[9] Given the high skewness of the proxy, we follow Nguyen and Phan (2020) and rank Zmijewski-score into quintiles on annual basis (*ZS_Quin*). We define financially distressed firms as those in the first and second quintile of the sample Zmijewski-score annually, and non-financially distressed firms as those in the higher quintiles. The estimation results show that the treated firms experience a significant increase in distress risk following the implementation of the GMP regulation.

6.2 Emission reduction strategy

Our above analysis shows that the introduction of the 2010 GMP regulations drives up

[8] China policies to promote local production of pharmaceutical products and protect public health, World Health Organization, 2017.

[9] The Zmijewski score is a modification of Altman's (1968) Z-score that helps to identify whether a firm is likely to default or not. Each firm's Zmijewski-score is calculated as *Zmijewski-score =-4.3-4.5×NetIncome/TotalAssets+5.7×TotalDebt/TotalAssets-0.004×CurrentAssets/CurrentLiabilities*.

manufacturing cost and corporate financial distress, thereby disincentivizing firms' efforts in reducing pollutant emissions. Firms can reduce pollution emissions in two primary ways: through modifications in the production process and via end-of-pipe reductions (Chen et al., 2021; Qi et al., 2023). We will further examine the mechanisms through which firms raise their emissions following the 2010 GMP.

6.2.1 Reduction in production process

Manufacturers can reduce the generation of industrial wastewater by adopting new technologies or utilizing cleaner energy sources, thus lowering emission intensity. We test whether manufacturers have altered their production processes in response to mandatory quality verification. In columns (1)-(2) of Table 7, we investigate the volume of water used in their production processes. Given that water is a critical input in the pharmaceutical industry, and increased water usage typically correlates with higher wastewater discharge (He et al., 2020), our results indicate that manufacturers have substantially increased their use of water—both total and fresh water. This suggests a reluctance to adopt water-saving technologies in response to stricter regulations.

In column (3), we examines the impacts of GMP regulation on the factor biased technological progress, measured by the natural logarithm of fixed assets divided by the volume of wastewater discharged. The significantly negative coefficient on the interaction term *Treat*×*GMP* supports our hypothesis that technological improvements have not been prioritized. Additionally, to determine if the increase in emission intensity might be attributed to a decrease in output value, we analyze the effect of 2010 GMP on output value in column (4) of Table 7. The insignificant coefficient on the interaction term rules out this possibility. Overall, the results suggests that the 2010 GMP regulation disincentivizes pharmaceutical manufacturers from reducing pollutant emissions within their production processes.

6.2.2 Reduction in end-of-pipeline

End-of-pipeline intervention offers another way that manufacturers can reduce pollutant emission. By constructing additional wastewater treatment facilities and enhancing their capacity, manufacturers can decrease pollution emission intensity. We test whether the pharmaceutical manufacturers have adjusted their use of abatement measures in response to the GMP regulation. Following He et al. (2020) and Qi et al. (2023), we employ three variables as proxies for the extent of abatement measures. The first is removal ratio, calculated as the amount of wastewater removed divided by the total amount of wastewater

generated (i.e., wastewater removed plus wastewater discharged). The second is the natural logarithm of the number of water treatment facilities, and the third is the natural logarithm of maximum water treatment capacity per day. The results, reported in columns (1)-(3) of Table 8, shows that the coefficients on the interaction term are all insignificant, suggesting that the manufacturers have not intensified their efforts in pollution abatement. These findings indicate that the observed increase in wastewater discharge intensities is not driven by changes in firms' end-of-pipe reduction strategies.

7 Conclusion

This study addresses a notable gap in the literature by examining the influence of mandatory quality standards on corporate environmental activities, with a focus on the pharmaceutical industry in China. Our evidence supports the assertion that increased costs resulting from the mandatory quality verification lead to heightened corporate pollution emissions. This finding holds across various robustness checks, including the parallel trend assumption, PSM analysis, the use of alternative measures for key outcome variables, and a falsification test. Our heterogeneous analysis shows that manufacturers with less government ownership, those operating in areas with lax environmental regulation and those in areas with easier access to external finance exhibit stronger response to the implementation of the 2010 GMP regulation.

Our study highlights the importance of understanding the untended consequences associated with the adoption of mandatory quality standards in the corporate sector. Regulatory authorities and business should focus on the environmental impacts of corporate decision-making and strive to balance quality risk management with environmental risk mitigation. A promising trajectory for forthcoming investigation involves scrutinizing the manner in which manufacturers react to compulsory quality verification mandates through alternative channels, such as financial decision-making, tax strategies, and innovation initiatives.

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Figures and Tables

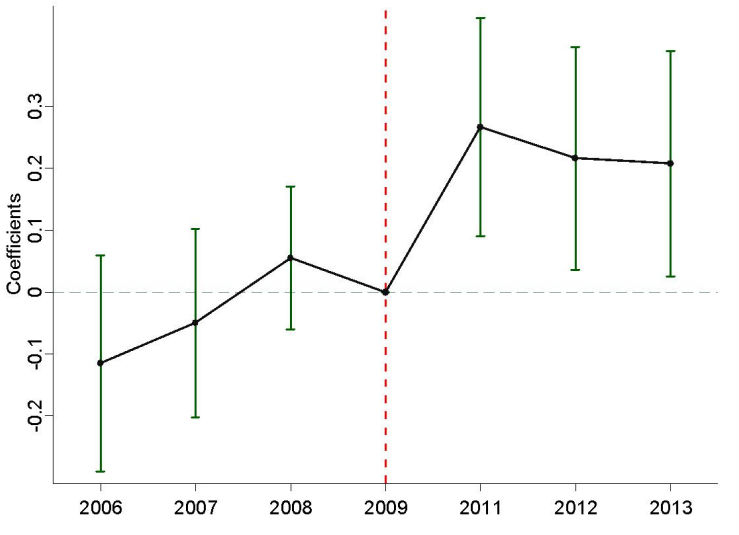

Figure 1 Dynamic effects of the implementation of GMP

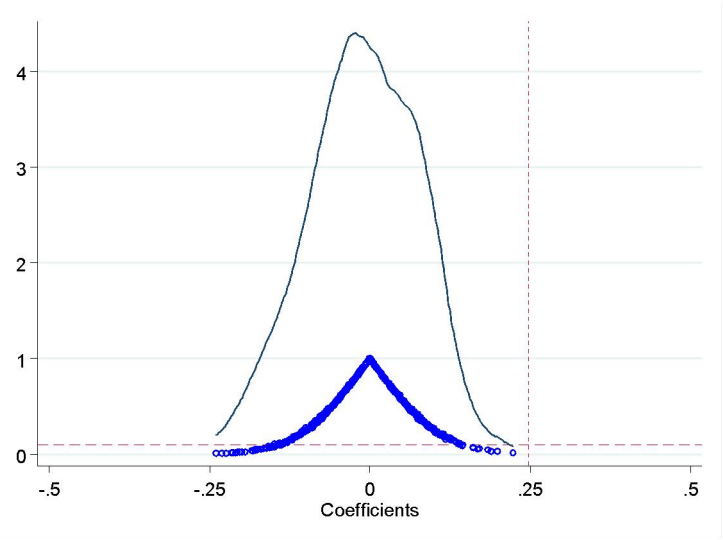

Figure 2 A Falsification Test

Note: This figure shows the results from a falsification test by randomly assigning a TCM manufacturer and re-estimates Equation (1) for 1000 times.

Table 1 Summary Statistics

	Mean	SD	P25	Median	P75
Emission (tons/ten thousand yuan)	22.359	52.09	1.963	5.899	17.381
Ln(Emission)	1.771	1.67	.674	1.775	2.855
Firm Size (ten thousand yuan)	11.562	1.353	10.656	11.455	12.386
Financial Leverage	.522	.281	.324	.506	.7
Tangibility	.369	.201	.215	.346	.499
Export	.092	.224	0	0	.006

Notes: This table presents the descriptive statistics of the key variables. *Emission* is defined as the amount of industrial wastewater discharged (in tons) divided by total output value (in ten thousand yuan). *Ln(Emission)* is defined as the natural logarithm of *Emission*. *Firm Size* is defined as the natural logarithm of total assets (in ten thousand yuan). *Financial Leverage* is defined as total liabilities divided by total assets. *Tangibility* is defined as fixed assets divided by total assets. *Export* is defined as the value of export output divided by total sales.

Table 2 Baseline Results

	Ln(Emission)		
VARIABLES	(1)	(2)	(3)
Treat×GMP	0.263***	0.245***	0.247***
	(0.084)	(0.084)	(0.084)
Firm Size		-0.123***	-0.121***
		(0.044)	(0.045)
Financial Leverage		0.192**	0.194**
		(0.076)	(0.076)
Tangibility			0.077
			(0.101)
Export			-0.092
			(0.129)
Constant	1.729***	3.049***	3.008***
	(0.013)	(0.521)	(0.534)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	12,395	12,395	12,395
R-squared	0.759	0.760	0.760

Notes: This table reports the result for our baseline regression. The dependent variable natural logarithm of emission intensity of industrial wastewater. *GMP* is an indicator that equals zero in 2006-2009 and one in 2011-2013. *Treat* is a dummy variable that equals one if the firm is a TCM manufacturers, and zero otherwise. Standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 3 Results from PSM-DID model

VARIABLES	*Ln(Emission)*		
	(1)	(2)	(3)
Treat×GMP	0.244**	0.227**	0.229**
	(0.099)	(0.099)	(0.099)
Controls	No	Yes/No	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	11,040	11,040	11,040
R-squared	0.764	0.765	0.765

Notes: This table reports the result for difference-in-difference regression for PSM matched sample. The dependent variable natural logarithm of emission intensity of industrial wastewater. *GMP* is an indicator that equals zero in 2006-2009 and one in 2011-2013. *Treat* is a dummy variable that equals one if the firm is a TCM manufacturers, and zero otherwise. Column (1) includes firm and year fixed effects, column (2) add a subset of controls, and column (3) add a whole set of controls. Standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4 Robustness Checks: Alternative Measures for Emission Intensity

VARIABLES	*Ln(COD)*	*Ln(NHN)*	*Ln(SO2)*
	(1)	(2)	(3)
Treat×GMP	0.350***	0.271*	-0.035
	(0.112)	(0.154)	(0.113)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	12,159	8,641	8,850
R-squared	0.780	0.758	0.836

Notes: In column (1), the dependent variable COD, which is measured as the natural logarithm of emission intensity of Chemical Oxygen Demand divided by total output value. In column (2), the dependent variable is NHN, which is measured as the natural logarithm of emission of ammonia and nitrogen divided by total output value. In column (3), the dependent variable is SO2, which is calculated as the natural logarithm of emission of Sulfer Dioxide divided by total output value. *GMP* is an indicator that equals zero in 2006-2009 and one in 2011-2013. *Treat* is a dummy variable that equals one if the firm is a TCM manufacturers, and zero otherwise. All models include a whole set of controls as in the baseline regression, as well as firm and year fixed effects. Standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 5 Heterogeneous Impacts

	Panel A: Ownership		Panel B: Environmental Regulation		Panel C: Financial Constraint	
	SOEs	Non-SOEs	Strict	Lax	Low	High
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Treat×GMP	0.063	0.278***	0.011	0.292***	-0.076	0.506***
	(0.180)	(0.102)	(0.130)	(0.113)	(0.137)	(0.127)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,046	7,329	4,262	8,133	3,445	6,923
R-squared	0.750	0.714	0.739	0.770	0.710	0.782

Notes: The dependent variable natural logarithm of emission intensity of industrial wastewater. In Panel A, we divide the sample into two subgroups, namely, an SOE subgroup and a non-SOE subgroup. In Panel B, we use the target in COD emission reduction during the Eleventh Five-year Plan Period as a proxy for the stringency of environmental regulation. A firm is included in the strict (lax) enforcement group if it is located in a region with reduction target above the sample median. In Panel C, we use city-level supply of bank loans divided by local GDP as a proxy for credit intensity. A firm is included in the high (low) constrained group if it is located in a city with credit intensity above the sample median in 2009. *GMP* is an indicator that equals zero in 2006-2009 and one in 2011-2013. *Treat* is a dummy variable that equals one if the firm belongs to traditional Chinese medicine manufacturers, and zero otherwise. Standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6 Impact of GMP on Investment, Cost and Distress Risk

VARIABLES	Capital Expenditure	Production Cost	Distress Risk
	(1)	(2)	(3)
GMP × Treat	0.032***	0.047***	0.054**
	(0.012)	(0.009)	(0.025)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes
Observations	5,701	12,093	11,740
R-squared	0.560	0.780	0.660

Notes: This table investigates how the introduction of the 2010 GMP regulation affect corporate investment, production cost and distress risk. In column (1), the dependent variable is investment, measured as the capital expenditure divided by total assets. In column (2), the dependent variable is product cost, measured as the sales cost divided by value of total sales. In column (3), the dependent variable is distress risk, which is constructed by using a balance-sheet-based measure developed by Zmijewski (1984). All standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 7 Mechanism Tests: Reduction from Production Process

VARIABLES	Water Use Intensity (1)	Fresh-water Use Intensity (2)	Capital/Wastewater (3)	Product Value (4)
GMP*Treat	0.356***	0.244***	-0.332***	0.038
	(0.082)	(0.081)	(0.079)	(0.046)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	12,394	12,393	12,348	12,395
R-squared	0.767	0.759	0.815	0.894

Notes: This table investigates how the introduction of the 2010 GMP regulation affect manufacturers' pollution abatement in the production process. In column (1), the dependent variable is the intensity of total water used in the production process, measured as the amount of water (including both fresh water and recycling water) used divided by total output value. In column (2), the dependent variable is the intensity of fresh water used in the production process, measured as the amount of fresh water used divided by total output value. In column (3), the dependent variable is factor biased technological progress, measured as the natural logarithm of fixed assets divided by the amount of wastewater discharged. In column (4), the dependent variable is the natural logarithm of total product value. All standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 8 Mechanism Tests: Reduction in End-of-Pipeline

VARIABLES	Removal Ratio (1)	# Treatment Facility (2)	Abatement Capacity (3)
GMP*Treat	0.010	0.026	0.017
	(0.007)	(0.016)	(0.068)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	9,650	9,695	9,697
R-squared	0.524	0.670	0.840

Notes: This table investigates how the introduction of the 2010 GMP regulation affect manufacturers' abatement efforts in end-of-pipeline reduction. In column (1), the dependent variable is removal ratio, calculated as the amount of wastewater removed divided by the total amount of wastewater generated (wastewater removed plus wastewater discharged). In column (2), the dependent variable is the natural logarithm of number of water treatment facilities. In column (3), the dependent variable is the natural logarithm of maximum water treatment capacity per day. All standard errors in parentheses are clustered at the firm level. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.