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Analyzing the influence of regulatory capture on environmental efficiency within institutional frameworks

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Introduction: Regulatory capture presents a significant obstacle to achieving environmental efficiency, which is essential for the sustainable development of China's economy. Many efforts to enhance environmental efficiency are fundamentally shaped by the institutional frameworks underpinning them. This study investigates the theoretical and empirical relationship between regulatory capture and environmental efficiency, emphasizing the mediating role of institutional factors such as government quality and legal frameworks.

Methods: This research adopts a dual approach, combining theoretical analysis with empirical evaluation. It utilizes provincial-level panel data from China and applies the Slack-Based Measure (SBM) model to assess environmental efficiency. Key institutional variables—including indicators of government quality and legal robustness—are incorporated to examine how they interact with and influence the effects of regulatory capture.

Results: Findings reveal that regulatory capture significantly hinders regional environmental efficiency. However, a strong institutional environment mitigates this negative impact. Specifically, the legal framework has a pronounced regulatory effect in regions with low government quality but high legal strength. Conversely, in areas with high government quality but weak legal systems, local governments play a more corrective role. Importantly, the adverse effects of regulatory capture diminish only when the institutional environment surpasses a certain threshold of effectiveness.

Discussion: The study underscores the critical need to address regulatory capture in the environmental governance process. Enhancing institutional quality—through improved government functioning and robust legal systems—can create a synergistic effect that improves regulatory effectiveness and environmental outcomes. Policymakers must recognize the distorting influence of regulatory capture and implement measures to strengthen institutional integrity, thereby fostering green and sustainable regional economic growth.

KEYWORDS

regulatory capture, institutional framework, governmental efficacy, legal framework, environmental efficacy

1 Introduction

The pressing need for sustainable development in China highlights the need of addressing regulatory capture as a major impediment to environmental efficiency. Regulatory capture transpires when regulatory authorities prioritize the interests of specific corporations over broader public goals, often resulting in weakened environmental regulations and decreased efficiency (Dal Bó, 2006). This issue is particularly pronounced in developing economies where institutional frameworks are evolving. Improving environmental efficiency is vital for achieving sustainable economic growth, and understanding how institutional contexts influence the relationship between regulatory capture and environmental outcomes is critical. The institutional environment, encompassing the quality of governance and the legal framework, has a dual role by either mitigating or exacerbating the adverse impacts of regulatory capture (Fan et al., 2011a). The quality of governance, reflecting the integrity and competency of public institutions, and the legal environment, signifying the rule of law and legal intermediaries, are crucial for assessing regulatory efficacy (Castiglione et al., 2018a). This study examines the impact of regulatory capture on environmental efficiency, highlighting the mediating and regulatory roles of institutional frameworks. This study utilizes the SBM model to comprehensively evaluate environmental efficiency among Chinese provinces, employing panel data to analyze the diverse impacts of institutional factors. Research indicates that robust institutional contexts, particularly in regions characterized by high governmental quality or effective legal systems, might alleviate the detrimental effects of regulatory capture, hence enhancing environmental efficiency. The results underscore the imperative for policy interventions to strengthen institutional capacities and alleviate regulatory distortions, hence promoting regional green development (Aigner et al., 1977; Atkinson and Tsionas, 2016a).

2 Literature review

Regulatory capture, a significant issue in environmental governance, transpires when regulatory agencies favor corporate interests over public welfare, resulting in less enforcement and inefficiencies in environmental policy (Dal Bó, 2006). In China, increasing industrialization has intensified environmental issues, and regulatory capture has led to the establishment of "pollution hotspots" as companies pursue areas with lax environmental rules to reduce compliance expenses (Huang et al., 2016a). The institutional environment is vital in alleviating these consequences, since robust governance frameworks increase transparency, diminish rent-seeking behavior, and strengthen regulatory enforcement (Fan et al., 2011b). Research demonstrates that the quality of government, assessed by administrative efficiency and anti-corruption initiatives, mitigates the negative impacts of regulatory capture by aligning environmental policies with public interests instead of corporate influence (Castiglione et al., 2018b). A robust legal framework, defined by autonomous judicial review and rigorous enforcement protocols, is crucial for mitigating regulatory distortions (Aigner et al., 1977; Atkinson and Tsionas, 2016b). China's regional differences lead to varied environmental outcomes, with places possessing poor governance structures seeing greater regulatory capture and environmental degradation than those with robust institutional safeguards (Graham et al., 2011a). The rivalry among local governments to secure investment has exacerbated this issue, resulting in a "race to the bottom" on environmental norms (Kamp et al., 2017a). Considering these complexity, comprehending the interaction between regulatory capture, institutional quality, and environmental efficiency is crucial for devising effective policy interventions that improve environmental governance and foster sustainable development.

3 Theoretical framework

This study's theoretical framework is based on the interaction of regulatory capture, institutional governance, and environmental efficiency within China's changing regulatory landscape. Regulatory capture, as defined by van Zwanenberg (2020), transpires when governmental regulatory authorities favor corporate interests over public welfare, resulting in diminished environmental regulations and inefficiencies. This study combines institutional theory and public choice theory to elucidate how differences in government quality and legal structures affect the extent of regulatory capture and its repercussions on environmental efficiency. Institutional theory posits that the efficacy of environmental control depends on the robustness of institutions, encompassing governmental integrity and the rule of law (Andrés et al., 2015). An effective institutional framework helps alleviate regulatory capture by promoting transparent decision-making and rigorous enforcement of environmental policies (Ang, 2007). In contrast, feeble institutions intensify the detrimental impacts of regulatory capture, creating a milieu where companies exercise excessive influence to weaken rules for economic advantage (Huang et al., 2016b). Furthermore, public choice theory asserts that government officials and regulators may pursue self-interest, seeking political or financial advantages from private enterprises in return for leniency in environmental regulation (Esso, 2010). This study posits that areas with superior government quality and robust legal frameworks exhibit greater resilience to regulatory capture, thereby enhancing environmental efficiency. The conceptual model demonstrates that institutional governance serves as a moderating variable, either exacerbating or mitigating the adverse impacts of regulatory capture on environmental outcomes. This research empirically examines these links, contributing to the broader conversation on regulatory efficacy, environmental governance, and sustainable economic growth.

4 Research questions

China's economy has attained significant accomplishments that have garnered global attention; yet, it has also resulted in environmental inefficiencies, substantial ecological degradation, and a deterioration in environmental quality. A variety of issues has arisen. Environmental pressure is unparalleled, and the enhancement of environmental efficiency is urgently required. The escalating environmental issues adversely impact public

health and degrade the living environment, while also significantly obstructing the progress of economic structural adjustment. Previous research indicates that environmental decentralisation, openness to external influences, industrial structure enhancement, and urbanization level are significant determinants of regional environmental efficiency in China (Graham et al., 2011b). Currently, China's economy has transitioned into a new normal characterized by the overlapping of three phases. The institutional environment is increasingly refined, and the nation promotes the green development philosophy that views "green water and lush mountains as invaluable assets." Nonetheless, environmental inefficiency and regional disparities in China have become increasingly pronounced, with numerous environmental issues being unresolved or inadequately addressed over an extended period (Li et al., 2017). Why does China prioritise environmental sustainable development, although the outcomes remain unsatisfactory? What are the causes of environmental turmoil in China and the ineffectiveness of local governmental environmental management? This is undoubtedly connected to the conflict and collision throughout China's social revolution phase; yet, regulatory capture may be an inescapable dilemma (Steinzor, 2012a). Consequently, the abduction of local officials by vested interests and the deviation in governmental regulatory enforcement result in the formation of regulatory policy throughout both its formulation and implementation stages. The outcome is advantageous for the regulated entity. Business organisations, as a crucial component of the market economy, pursue investment sites characterised by minimal government regulations across diverse regions, intending to persuade the government to ease local rules and establish "pollution hotspots" (Huang et al., 2016). The tax burden on business organisations in the jurisdiction is substantial, the expenditure required for environmental compliance is considerable, and the penalties for infractions are very minimal. To achieve substantial profits and competitive advantages, they exert pressure on regulatory agencies by infiltrating government departments, causing government regulation to become disorganised or ineffective, which leads to a decrease in the effectiveness of environmental regulation (Steinzor, 2012b). China's regional benchmarking competitions and championships have compelled local governments to participate in a prolonged "race to the bottom" and "race to the worst" in environmental regulation to attract capital investment. By diminishing governmental regulatory requirements, they compromise environmental integrity for economic advancement, resulting in a decline in environmental efficiency. Kamp et al. (2017b) Regulatory capture, a consequence of China's imperfect economic transition reform, not only leads to local administrative corruption and elevated operating expenses but also fundamentally impacts the sustainable development of the surrounding environment. This research analyses the mechanism of regulatory capture on environmental efficiency from a theoretical standpoint and utilises provincial-level data from China to empirically test the theoretical hypothesis (Lopolito et al., 2022). This paper integrates the institutional environment into the research paradigm concerning the relationship between regulatory capture and environmental efficiency, acknowledging that the effects of regulatory capture on environmental efficiency fluctuate with alterations in the institutional context. This paper's primary contributions, in contrast to the current literature, are as follows: It examines the motivations behind the inadequacies of government regulation and regulatory independence, elucidates the internal dynamics of regulatory capture impacting environmental efficiency within the specific context of China, and enhances the existing body of work on regulatory theory, institutional environment, and environmental efficiency. The current literature predominantly emphasises the unilateral effects of environmental regulation, with limited empirical study on regulatory capture. This work examines the extent of regulatory capture throughout different regions of China to do empirical research, serving as a valuable complement to existing studies and contributing significant theoretical insights to the domains of regulatory capture and environmental efficiency. This paper analyses the moderating influence of the institutional environment on the relationship between regulatory capture and environmental efficiency, considering regional heterogeneity. It offers valuable insights for local governments to enhance the institutional environment and modify regulatory policies according to their specific circumstances.

5 Research basis and hypothesis

5.1 Description of regulatory capture

The term "regulation" originates from the English phrase "Regulatory Constraint," initially translated by Japanese scholar Masushi Uekusa. It is characterised by the government, society, and other public sectors establishing regulations to limit particular activities of economic enterprises and persons (Gouldson et al., 2008). American academic Marver introduced the term "capture" to characterise the collusion between regulatory agencies and regulated firms that undermines the public interest (Usman and Balsalobre-Lorente, 2022). The theory of regulatory capture emerged from the discourse surrounding public interest theory. It denotes the appropriation of government politicians, regulatory bodies, and law enforcement officials by interest groups. This idea offers scientific direction for the US Environmental Protection Agency to develop policies and regulations that prevent "regulatory capture" in environmental governance. Subsequently, the novel regulatory economics provided a fresh interpretation of the theory of regulatory capture. It introduced the element of information asymmetry. The distortion of information led regulated companies to exhibit diminished incentives and efficiency, while the manipulation of information might directly influence regulatory outcomes. Conversely, it dismantled the government's opaque supply chain of conventional regulatory capture, designated regulatory agencies as intermediates, and delegated regulatory tasks, so circumventing the issues of non-institutional public involvement and "free riding". Theory of regulatory capture is extensively applied in the analysis of regulatory behaviour within the agency relationship among various interest groups. Usman et al. (2022). The unique status of traditional regulatory agencies confers upon them discretionary authority. The regulated entities seeking optimal advantages are incentivised to corrupt and influence regulatory bodies, making regulatory capture challenging to prevent. In recent years, academics have increasingly focused on the subject of regulatory capture in China. Yang Shaozheng indicated that there are just indications of regulatory

capture in China, and its attributes are not representative of the West (Trianni et al., 2016). Chen Kang and colleagues assert that governmental regulatory failures are more prevalent during transitional periods. In the design and formulation of government incentive systems, it is essential to avert the capture of administrative officials by specific interest groups (Twum et al., 2021). Li Jian employed the subjective evaluation approach to assess the regulatory capture index and determined that the present degree of regulatory capture in China is at a moderate level (USEIA, 2021). The regulatory capture theory encompasses both the formulation and establishment of the internal framework of the regulatory entity, as well as the oversight and execution of the regulatory process within the external context (Wang and Wei, 2014). Lazarus' research indicates that local government departments and regulatory agencies frequently experience capture due to their vulnerable status, bureaucratic nature, and internal staffing, subsequently adapting into new forms within their respective environments (World Population Review, 2022). Through the collection, categorisation, and synthesis of pertinent literature, three primary instances of regulatory capture in China have been identified: first, regulated entities engage in bribery or inducement of government officials to skew policy and regulatory formulation in their favour; second, these entities undermine independent regulatory agencies under the pretext of governmental authority or persuade officials and agencies to neglect the enforcement of national policies and laws; third, regulated parties co-opt government officials via private payments, shared interests, and revolving door practices. The prevailing role of government agencies in the nation's reform efforts is progressively enhancing, with intensified anti-corruption measures and integrity promotion, alongside an increasingly robust legal system development. Nonetheless, significant enhancement in regional green competitiveness and environmental efficiency remains possible (Young and Sheehan, 2014). Interest groups will continue to influence government agencies and law enforcement officials through bribery and the trade of interests, leading to a departure from fairness, reason, justice, and efficiency. The interplay between governmental governance and environmental efficiency is influenced by several forms of regulatory capture.

5.2 The impact of regulatory capture on environmental efficiency

The execution of regulatory public policy relies on the dual administrative delegation-agent relationship between the government and regulatory agencies, as well as between regulatory agencies and regulated firms. Local governments delegate regulatory bodies to impose limitations on regulated entities for the public's benefit. Regulatory agencies, as representatives of local governments, mandate that regulated entities implement technical solutions or effective strategies to attain environmental regulatory objectives, thus enhancing environmental efficiency. Following the 2008 government agency reform, environmental protection agencies in various regions of China have transitioned from being directly subordinate to local governments to a structure jointly overseen by the Ministry of Environmental Protection and local governments. Local governments are tasked with the distribution of funding and the hiring and dismissal of personnel within regulatory agencies. The fundamental control over regulatory agencies has remained mostly unchanged for an extended period, and the autonomy and independence of local regulatory agencies are evidently deficient (Alvarado et al., 2021). Regulatory agencies, as implementers of regulatory policies and representatives of local governance, are susceptible to influence from various factors, including the strength of central regulation, local government evaluation metrics, and interest groups pursuing rent-seeking opportunities. This lack of independence leads to incentive distortion and a decline in rationality (Armsworth et al., 2010). Regulatory agencies possess information technology advantages in environmental governance, whereas regulated entities hold informational advantages on pollution control costs and benefits compared to regulatory agencies. Regulatory agencies can leverage their informational advantages to affect local government policymaking and possess the authority to interpret laws and regulations. Simultaneously, they regulate the timing of the application of environmental regulatory policies during the execution of these policies. Given the fundamental role of regulatory bodies and their capacity to wield discretionary authority, they are particularly susceptible to capture by interest groups. Han Chao et al. discovered that since 2004, the incidence of environmental accidents has been significantly associated with negligence and insufficient oversight by regulatory agency personnel. A succession of news reports indicated that corruption and bribery had emerged as significant factors contributing to the resignation of regulatory agency personnel, thereby implicitly affirming the phenomenon of regulatory capture (Arellano and Bover, 1995).

The influence of regulatory capture on environmental efficiency is shown in the subsequent aspects: Initially, regulatory capture skews the distribution of factor resources, hindering the enhancement of environmental efficiency. Regulatory capture will divert productive resources, including labour and money, to unproductive sectors characterised by rent-seeking and corruption. High-yield non-productive activities compel regulated firms to forgo technological research and development in favour of government capture (Bond, 2002). This illogical distribution of factor resources hinders corporate production and ultimately results in diminished environmental efficiency. Simultaneously, regulatory capture directs government fiscal spending towards public service projects with personal benefits, leading to the neglect of environmental health, science, education, and other initiatives that government funding should ensure. The improper allocation of factor resources hinders the enhancement of regional environmental efficiency. Secondly, as the advancement of local officials is strongly correlated with the economic growth performance of their jurisdiction, local governments are incentivised by both economic and political forces to optimise local GDP growth. The influence of regulatory capture on environmental efficiency is shown in the subsequent aspects: Initially, regulatory capture skews the distribution of factor resources, hindering the enhancement of environmental efficiency. Regulatory capture will divert productive resources, including labour and money, to unproductive sectors characterised by rent-seeking and corruption. High-yield non-productive activities compel regulated firms to forgo technological research and development in favour of government

capture (Burke and Stephens, 2018). This illogical distribution of factor resources hinders business productivity and will ultimately result in decreased environmental efficiency. Simultaneously, regulatory capture directs government fiscal expenditures towards public service initiatives with personal profit potential, leading to the neglect of environmental health, science, education, and healthcare, which ought to be supported by government funding. The improper allocation of factor resources hinders the enhancement of regional environmental efficiency. Secondly, as the advancement of local officials is strongly correlated with the economic growth performance of their jurisdiction, local governments are incentivised by both economic and political forces to optimise local GDP growth. Topics on Environmental Pollution.

Hypothesis 1: Areas exhibiting elevated degrees of regulatory capture demonstrate diminished overall environmental efficiency, and regulatory capture will obstruct enhancements in regional environmental efficiency.

5.3 The impact of the institutional environment on regulatory capture-environmental efficiency

The impact of regulatory capture on environmental efficiency in social governance usually stems from significant collaborative endeavors facing challenges. The effective implementation of collective actions requires a strong institutional structure, including governance quality and the legal context (Cai et al., 2020). The institutional environment includes the interplay between regulatory capture and environmental efficiency across various situations, constraining the potential limits for both organizations. The increase in regulatory capture behavior indicates a decline in the institutional environment. An insufficient institutional framework obstructs the progress of collective environmental regulations and may lead to an infusion of outdated technology capital, intensifying detrimental competition and worsening environmental efficiency losses. The impact of regulatory capture on environmental efficiency is contingent upon the quality of local governance. The government establishes environmental regulations intended to benefit the public; nevertheless, due to promotional and evaluative pressures, it often relaxes oversight of self-regulating firms (Sun et al., 2019). The control of local authorities in China is characterized by complexity and limited autonomy, with capture behavior often interwoven with political influence, resulting in the emergence of political groups or nepotism. This dynamic is embedded within the governmental management structure via relational networks, leading to the distortion of private and public rights, thus exacerbating corruption and inequality. When local governments face constraints from "regulatory" entities, they frequently leverage acquired resources to co-opt officials into their interest coalitions and to forge links for the regulatory capture of regulated enterprises. Research conducted by Liang Pinghan and Gao Nan reveals that local government officials frequently cultivate interpersonal networks with environmental violators. A prolonged term of government officials heightens the probability of their co-optation by regulated enterprises (Caferra and Falcone, 2023). The persistent mutual relationship between polluting companies and government officials provides these regulated organizations with favorable policy backing, while concurrently eroding the regulatory agency's power to execute pollution penalties. This cycle results in a decline in governmental quality and administrative inefficiency, ultimately obstructing progress in environmental efficiency. In contrast, the reasoning concerning the impact of government quality on regulatory capture and environmental efficiency is clear-cut. As governmental quality improves, behaviors that violate regulations will be effectively controlled or rendered unnoticeable, hence enhancing environmental efficiency. The impact of regulatory capture on environmental efficiency in social governance often stems from the challenges faced by extensive collective initiatives. The effective implementation of collective actions requires a strong institutional structure, including governance quality and the legal context (Cai et al., 2020). The institutional environment includes the interplay between regulatory capture and environmental efficiency across various situations, constraining the potential limits for both organizations. The increase in regulatory capture behavior indicates a decline in the institutional environment. 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Hypothesis 2: The institutional environment (government quality and legal environment) has a moderating effect on the relationship

between regulatory capture and environmental pollution, and the institutional environment positively moderates the inhibitory effect of regulatory capture on environmental efficiency.

6 Model and variables

6.1 Model construction

To assess the influence of regulatory capture on regional environmental efficiency within the institutional context, this study utilises pertinent research on environmental efficiency and its determinants by scholars including Yan et al. (2023), Hu et al. (2023), Brunel (2017), and Levinson (2015), in conjunction with the STIRPAT model introduced by York et al. The subsequent test equation is established:

$$Effit = C + \gamma 0\, RCit + \gamma 1\, (RCit \times IEit) + \gamma 2\, Xit + \varepsilon it \quad (1)$$

where:

- *Effit\textit{Eff}_{it}Effit represents the environmental efficiency of region iii in year ttt.*
- *CCC denotes the constant term.*
- *RCit\textit{RC}_{it}RCit signifies the regulatory capture of region iii in year ttt.*
- *RCit×IEit\textit{RC}_{it} \times \textit{IE}_{it}RCit×IEit captures the interaction between regulatory capture and the institutional environment, which includes:*
  - *RCit×GQit\textit{RC}_{it} \times \textit{GQ}_{it} RCit×GQit, the interaction between regulatory capture and government quality.*
  - *RCit×LEit\textit{RC}_{it} \times \textit{LE}_{it}RCit×LEit, the interaction between regulatory capture and the legal environment.*
- *Xit\textit{X}_{it}Xit denotes other factors influencing the environmental efficiency of region iii in year ttt.*
- *εit\varepsilon_{it}εit represents the random disturbance term.*

6.2 Variable selection

The empirical study employs panel data from 30 provinces in China, excluding Hong Kong, Macao, and Taiwan, covering the period from 2004 to 2015. Tibet is excluded from the research sample owing to substantial data inadequacies. The sample period begins in 2004 and ends in 2015, providing a significant volume of data while meeting the needs of a prolonged timeframe for the empirical analysis of the core subjects. This research does not focus on predictive analysis; therefore, the collected data sufficiently clarifies the mechanism of action among variables. The data is derived from the "China Procuratorate Yearbook," "China Statistical Yearbook," "China Energy Statistical Yearbook," "China Environmental Statistical Yearbook," and the China Economic Network Statistical Database, among others, and has been directly obtained, manually compiled, or processed by the author. To mitigate the influence of outliers on the estimation, continuous data from the sample is modified. The central emphasis of this topic is environmental efficiency (Efficientia Environmentalis). At present, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are frequently utilized to evaluate environmental efficiency. Stochastic frontier analysis is characterized by parametric statistics and heavily depends on the assumption of error distribution. Nonetheless, ascertaining the production function and measuring environmental efficiency in the context of many outputs presents difficulties with Stochastic Frontier Analysis (SFA). Data envelopment analysis is a deterministic, non-parametric statistical method that is one of the most effective tools for evaluating the relative efficiency of decision-making units (DMUs) with multiple inputs and outputs. Traditional DEA methodologies prioritize radial and angular distances in assessing efficiency, overlooking the variable slack problem, which may result in skewed efficiency evaluations. Tone (2001) introduced a framework for assessing efficiency, termed the Slack-based Measure (SBM), which utilizes multi-input and multi-output slack variables to tackle this concern.

The assumptions underpinning the SBM model include the assumption that the inputs and outputs are accurately measured and the assumption of a constant returns to scale (CRS) or variable returns to scale (VRS) for different decision-making units (DMUs). However, it is important to note that SBM assumes the existence of a linear relationship between inputs and outputs, which might not always hold in real-world settings. Additionally, the model assumes that the data available is free from errors, which may not always be the case, especially in complex, large datasets. One of the key limitations of the SBM model is its sensitivity to the choice of reference set or benchmarking units, which can affect the robustness of efficiency scores. Another limitation is that it does not account for potential non-linearities in the relationship between inputs and outputs, potentially leading to an underestimation or overestimation of efficiency. Finally, SBM does not directly address the issue of statistical noise in the data, which could distort the accuracy of the efficiency measurements. This study utilizes the non-radial and non-angular SBM distance function to evaluate regional environmental efficiency, drawing on the research of Zhou et al., Wang Bing et al., and Du et al., 2015. Each region is regarded as a decision-making unit (DMU), where $x \in R^{m}$, $y \in R^{\{g1\}}$, and $b \in R^{\{g2\}}$ represent the input vector, desirable output vector, and unacceptable output vector of the DMU, respectively, with m, g1, and g2 indicating the relevant quantities of variables. Define the matrix $X = [x1, \ldots, xn] \in Rm \times n$, $Y = [y1, \ldots, yn] \in Rg1 \times n$, and $B = [b1, \ldots, bn] \in Rg2 \times n$. The SBM value of regional environmental efficiency can be calculated using the subsequent Equation 2:

Data Envelopment Analysis (DEA) model with non-desirable outputs, such as the Slack-Based Measure (SBM) model):

Objective function:

$$E(xt, yt, bt) = \min\left[1 - m1 \sum i = 1m\, xit\, sik-\right] + \left[g1 + g2\, 1\left(g1 \sum r = 1s1\, yrt\, srk+ + g2 \sum l = 1s2\, blt\, slk-\right)\right] \quad (2)$$

Subject to constraints:

$$\sum k\, Xk\, \lambda k + sik- = xit \text{ (Input constraints)}$$
$$\sum k\, Yk\, \lambda k - srk+ = yrt \text{ (Desirable output constraints)}$$

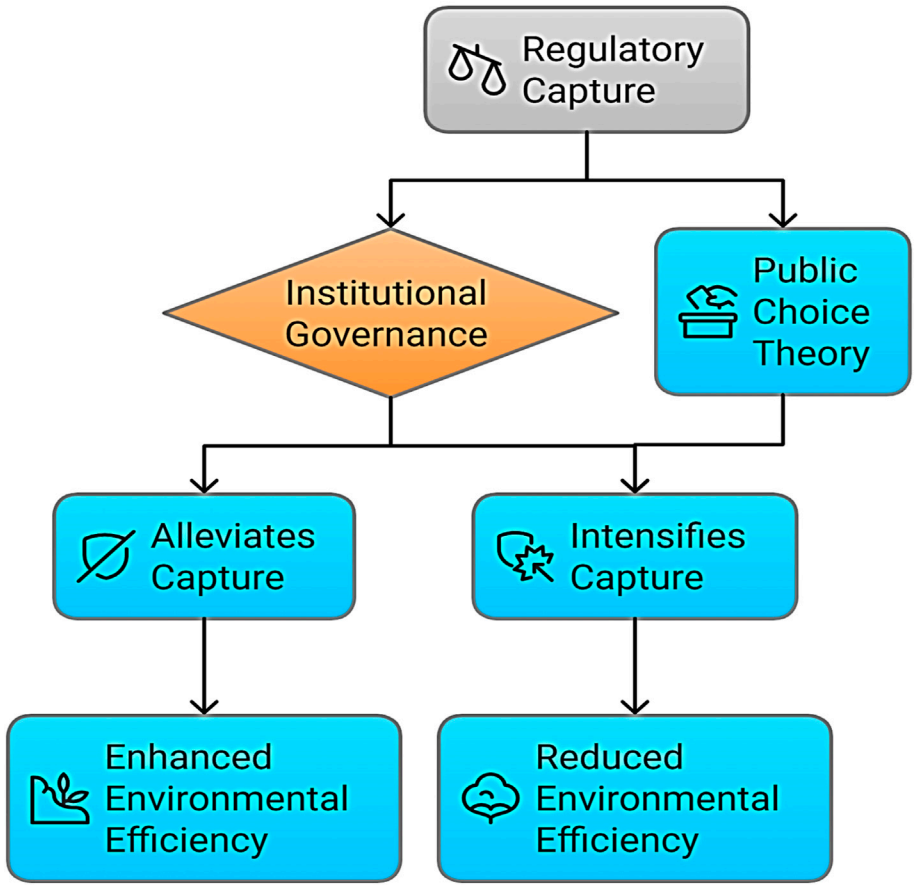

FIGURE 1
Conceptual model of regulatory capture and environmental efficiency. Source: Created by the author using vector graphics software.

$\sum k\ Bk\lambda k + slk- = blt$ (Non-desirable output constraints)
$\lambda k \geq 0, sik- \geq 0, srk+ \geq 0, slk- \geq 0$ (Non-negativity)

Notation explained:

- Variables:
  - *xit*: Input *i* for decision-making unit (DMU) *t*.
  - *yrt*: Desirable output *r* for DMU *t*.
  - *blt*: Non-desirable output *l* for DMU *t* (e.g., pollution).
- Slack Variables:
  - *sik*−: Input slack (unused input).
  - *srk*+: Desirable output slack (unrealized output).
  - *slk*−: Non-desirable output slack (excess pollution).
- Parameters:
  - *m*: Number of input types.
  - *s*1: Number of desirable output types.
  - *s*2: Number of non-desirable output types.
  - *g*1, *g*2: Weights for balancing desirable and non-desirable outputs.
- Weights:
  - λk: Intensity weights for DMUs in the linear combination.

This model aims to measure environmental efficiency by minimizing input waste and non-desirable outputs while maximizing desirable outputs, within institutional or regulatory frameworks.

The value range of E (xt, yt, bt)E (x_t, y_t, b_t)E (xt, yt, bt) spans [0,1][0,1][0,1], where a higher value signifies enhanced input-output efficiency. A score of 1 indicates that the Decision-Making Unit (DMU) is fully efficient and positioned on the production frontier.

This study delineates input variables, desirable output variables (expected variables), and unpleasant output variables (non-anticipated variables) as defined by the theoretical framework. The input variables consist of capital input, labor input, and energy input. Capital input is represented by the regional fixed asset value stock, determined by the perpetual inventory method. Labour input is measured by the number of employees in each region over the years. Energy intake, a significant factor in adverse

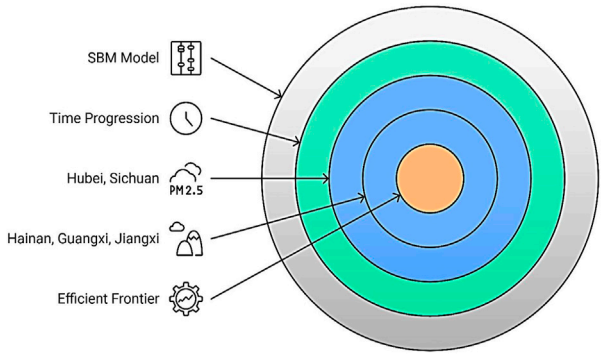

FIGURE 2
Dynamic evolution trend of environmental efficiency in various regions of China. Source: Created by the author using vector graphics software.

output, is measured by terminal energy consumption, articulated in 10,000 tonnes of standard coal. Since improving environmental efficiency is closely linked to technical progress and scientific innovation, investment in R&D funding is incorporated into the measurement system to represent technological innovation. The favorable output variable is regional GDP, adjusted for inflation using a constant price index with 2004 as the base year. This study references the work of Atkinson and Tsionas (2021) concerning detrimental output factors, particularly emphasizing sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions arising from energy consumption. Carbon dioxide emissions are evaluated using the methodologies set by the Intergovernmental Panel on Climate Change (IPCC). The environmental efficiency of several places in China, evaluated by the Slack-Based Measure (SBM) model, exhibits a steady upward trend. Figure 1 depicts the fluctuations and progress in environmental efficiency across provinces from 2005 to 2015. Regions such as Hainan, Guangxi, and Jiangxi have consistently occupied the efficient frontier, with average efficiency values exceeding 0.90, indicating optimal resource utilization and a balanced relationship between economic development and environmental preservation. In contrast, regions like Hubei and Sichuan display reduced environmental efficiency scores (~0.56), signifying inefficiencies in energy input and environmental outputs, particularly for SO_2 and CO_2 emissions. The chart's concentric structure visually illustrates the upward trajectory of environmental efficiency over time (2005, 2010, and 2015), with the progression of colored markers—blue (2005), orange (2010), and grey (2015)—moving towards the outermost boundary (efficiency = 1) (see Figure 2). The findings demonstrate that technological innovation, as shown by R&D expenditures, is crucial for improving efficiency. Regions exhibiting inefficiencies, such as Sichuan, require targeted interventions, including enhanced environmental regulations and the adoption of green technologies, to address inefficiencies while maintaining economic growth. The legal environment (LE) is a crucial factor influencing environmental efficiency. Dai Kuizao asserted that the service quality of intermediary organizations, such as law firms and accountants, should ideally reflect the overall standard of the legal environment (Aigner et al., 1977). This study employs the sub-index of legal intermediary organization development from the China Marketisation Index by Fan Gang et al. (Castiglione et al., 2018c) to evaluate the regional legal environment. This study tackles the issue of temporal inconsistency by employing the methods of Lu Shuli and He Zhen, which entails standardizing data from different time periods to ensure uniformity.

A variety of control variables are included to strengthen the analysis's robustness. Environmental decentralization (END) is evaluated based on the work of Zhang Hua et al., integrating economic scale to alleviate potential endogenous influence. Openness to the global market (OPEN) is measured by the ratio of China's total import and export trade to its GDP. The industrial structure (IND) is defined by the ratio of the production value of the secondary industry to GDP. The Urbanisation Level (ERB) signifies the population density in urban areas, measured by the urbanisation rate obtained from the China Statistical Yearbook to evaluate the degree of urban development in various regions. These control variables offer a thorough foundation for comprehending the aspects that affect environmental efficiency across locations. The findings reveal significant regional disparities, with efficient regions adeptly balancing resource utilization and environmental preservation, whereas unsuccessful regions require targeted governmental interventions and technological advancements to improve environmental outcomes.

7 Empirical analysis

7.1 Benchmark inspection

The regression results in Table 1 demonstrate that the expected coefficients for regulatory capture (RC) across all models are significantly negative, indicating that regulatory capture considerably impedes the improvement of regional environmental efficiency. Regulatory capture substantially undermines environmental efficiency, as seen by a large rise in pollution levels in areas exhibiting greater regulatory capture. This outcome supports study Hypothesis 1. The estimated coefficients for the interaction term (RC × GQ) between regulatory capture and government quality in columns (2) to (5) are all significantly positive at a minimum of the 10% level, indicating that in regions with similar regulatory capture, an increase in local government quality is associated with improved environmental efficiency. This suggests that improving governmental quality can partially alleviate the adverse effects of regulatory capture on environmental efficiency. The reasoning is that the public service system in regions with higher government quality is more complete, enabling the creation of an efficient communication, oversight, and information dissemination mechanism between the government and the citizens. The behavior of regulatory capture is more constrained, diminishing its negative impact on environmental efficiency and resulting in an increase in environmental efficiency. Additionally, to enhance understanding of the economic implications of coefficients, we have incorporated real-world interpretations York et al. (2003). In places with superior government quality, diminished regulatory capture enhances environmental efficiency, leading to reduced pollution levels, particularly in quickly industrializing areas. The coefficient of the

TABLE 1 Impact of regulatory capture on regional environmental efficiency.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RC	−0.099*** (-3.808)	−0.090** (-1.980)	−0.066** (-2.123)	−0.059** (-1.989)	−0.113** (-2.246)	−0.108*** (-2.811)	−0.049** (-1.973)	−0.048** (-2.074)	−0.051* (-1.708)
RC × GQ		0.154*** (2.760)	0.113* (1.754)	0.112* (1.738)	0.265*** (2.793)				
RC × LE						0.115** (1.973)	0.021* (1.748)	0.034** (2.397)	0.039** (2.437)
END		−0.149*** (-2.628)	−0.125** (-2.096)	−0.137** (-2.208)	−0.178*** (-2.768)	−0.130** (-2.300)	−0.098 (-1.626)	−0.115* (-1.820)	−0.116* (-1.830)
OPEN			0.085 (1.284)	0.094 (1.394)	0.209** (2.456)		0.127 (1.516)	0.127 (1.518)	0.141 (1.434)
IND				0.041 (0.712)	0.068 (1.149)			0.048** (2.113)	0.052 (0.848)
ERB					−0.261** (-2.189)				−0.022 (-0.263)
CONS	−0.002*** (-7.057)	−0.001 (-0.028)	−0.628*** (-3.517)	−0.002 (-0.061)	−0.334 (-1.617)	−0.001 (-0.028)	−0.343*** (-2.681)	−0.686*** (-3.538)	−0.328 (-1.433)
Observations	360	360	360	360	360	360	360	360	360
R^2 value	0.703	0.734	0.717	0.783	0.793	0.770	0.781	0.813	0.785

Note: *, **, *** respectively indicate that the statistical values are significant at the 10%, 5%, and 1% levels, and the t values are in brackets. The same applies below.

interaction term (RC × LE) between regulatory capture and the legal environment in Models (6) to (9) is significantly positive at a minimum of the 10% level, indicating that in regions with a favorable legal environment, the adverse effect of regulatory capture on environmental efficiency has been considerably alleviated. The reasoning is that intermediary organizations and legal systems in areas with a strong legal environment are relatively thorough, and the regulated entities operate inside a clearly delineated legal framework. Their conduct regarding regulatory capture has synchronized, therefore alleviating the adverse impacts of regulatory capture on environmental efficiency. As the quality of government and legal frameworks improves, the detrimental impacts of regulatory capture on environmental efficiency will be alleviated. The institutional environment positively affects the relationship between regulatory capture and environmental efficiency, hence confirming research Hypothesis 2. We have further elaborated on regional disparities, elucidating why specific provinces exhibit enhanced resilience to regulatory capture. Regions exhibiting robust local governance institutions, such as provinces with efficient legal and governmental frameworks, have greater resilience to the adverse impacts of regulatory capture. The estimation results for the control variables reveal that the coefficients for industrial structure and urbanization level correspond with the conclusions prevalent in the majority of the literature. The impact coefficients of environmental decentralization are primarily negative, indicating that reducing the level of environmental decentralization can improve regional environmental efficiency. Moreover, the fragmented governance framework skews policy incentives, therefore placing a considerable limitation on environmental efficiency. The impact coefficients of liberalization are uniformly positive, indicating that the continuous advancement of liberalization has, to some extent, improved environmental efficiency.

7.2 Regional heterogeneity test

The impact of regulatory capture on environmental efficiency may be influenced by regional variability. This section employs a group testing methodology to analyse the disparities in the link between regulatory capture and environmental efficiency, as mediated by the quality of local government and the legal environment. The provinces in China are categorised into high and low government quality areas based on the average government quality index. Simultaneously, based on the median value of the legal environment, the provinces are categorised into two regions: those with favourable legal environments and those with unfavourable legal environments. The regression results in Table 2 indicate that the impact coefficient of regulatory capture in the model is strongly negative, demonstrating that regulatory capture adversely affects environmental efficiency, hence reaffirming study Hypothesis 1. The estimated coefficient for the interaction term between regulatory capture and government quality in region 1 is significantly positive at the 1% statistical level, valued at 0.265, suggesting that government quality substantially enhances the effect of regulatory capture on environmental efficiency. Conversely, the estimated coefficient for the interaction term between regulatory capture and legal environment is positive at 0.039, but does not achieve significance at the 10% statistical level, indicating that the legal environment in region 1 only marginally influences the relationship between regulatory capture and environmental efficiency. In region 2, the estimated coefficients for the two interaction terms related to the institutional environment are significantly positive. However, the positive regulatory impact of government quality in region 2 is less pronounced than in region 1. This suggests that the regulatory influence of local governments on regulatory capture and environmental efficiency is more significant in areas with superior government quality. In other words, the government

TABLE 2 Impact of regulatory capture on environmental efficiency.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Region 1: High quality government		Area 2: Low quality of government		Region 3: Excellent legal environment		Region 4: Poor legal environment	
RC	−0.113** (-1.976)	−0.051** (-2.108)	−0.132* (-1.816)	−0.500*** (-2.696)	−0.114* (-1.772)	−0.061* (-1.836)	−0.594*** (-3.730)	−1.106** (-2.267)
RC × GQ	0.265*** (2.793)		0.060* (1.828)		0.263 (1.475)		0.327** (2.011)	
RC × LE		0.039 (1.437)		0.575** (2.327)		0.953** (2.508)		0.684* (1.672)
END	−0.178*** (-2.768)	−0.116* (-1.830)	−0.248 (-1.438)	−0.074 (-0.462)	−0.178*** (-2.757)	−0.119* (-1.881)	−1.994* (-1.942)	−1.001*** (-3.033)
OPEN	0.209** (2.456)	0.141 (1.434)	0.222 (0.372)	0.739 (1.256)	0.211** (2.489)	0.136 (1.385)	−1.179 (-1.064)	−0.882** (-2.524)
IND	0.068 (1.149)	0.052 (0.848)	0.187 (1.555)	0.171 (1.433)	0.067 (1.124)	0.052 (0.859)	−3.905 (-0.969)	−3.222* (-1.688)
ERB	−0.261** (-2.189)	−0.022 (-0.263)	−0.660** (-2.051)	−0.298 (-1.059)	−0.262** (-2.201)	−0.028 (-0.333)	0.706 (0.883)	0.101*** (2.991)
CONS	−0.002*** (-5.060)	−0.015*** (-3.312)	0.290 (0.474)	−0.289*** (-7.872)	−0.003*** (-4.054)	−0.003 (-0.061)	−1.641*** (-3.018)	−1.020 (-1.586)
Observations	156	156	204	204	180	180	180	180
R^2 value	0.724	0.790	0.761	0.776	0.762	0.758	0.718	0.763

quality in region 1 is more effective at mitigating the detrimental effects of regulatory capture on environmental efficiency. Subsequent analysis reveals that in the context of government quality zoning, the legal environment can play a more useful regulatory function in areas typified by worse government quality. This analytical framework indicates that the legal environment more effectively incorporates the role of favorably regulating regulatory capture and environmental efficiency in area 3, while the advantageous regulatory impact of government quality is more evident in region 4. The caliber of governance and the legislative framework positively affect the regulation of the interplay between regulatory capture and environmental efficiency (Rødseth, 2016). The influence of legal standards is more pronounced in regions with poor government quality and a supportive legal framework, whereas local governments can play a more corrective role in places with high government quality and an inadequate legal environment.

7.3 Robustness test

Initially, reassess the regional environmental efficiency. The aforementioned approach utilising the SBM model to assess the environmental efficiency of each region fails to facilitate the ranking and evaluation of decision-making units with an environmental efficiency value of 1, and is limited to sequentially differentiating the environmental efficiency values of ineffective decision-making units. The greatest environmental efficiency determined by the SBM model is 1, which is frequently regarded as truncated data. This research uses the super-efficiency SBM model to reassess the environmental efficiency of different locations in China, thereby mitigating the potential impact of these two issues. This method may entirely differentiate effective decision-making units when assessing DUM efficiency and substitute the input and output of DUM in a linear combination. When the environmental efficiency value equals 1, the super-efficiency SBM model further computes the efficiency value via effective decision-making units to perform a comparative analysis of regional environmental efficiency, thereby overcoming the limitation that the environmental efficiency value cannot surpass 1. This work considers the non-expected result as an environmental input, maintaining the input index and good output index constant, and employs MATLAB software to reassess the environmental efficiency of different places in China for robustness testing. Additionally, this study performs the subsequent robustness checks. The region is restructured. Utilising the aforementioned methodology, the research sample is categorised into four zones based on the two variables of regulatory capture and environmental efficiency: high regulatory capture, low regulatory capture, high environmental efficiency, and low environmental efficiency. Equation 1 is utilised to do group estimation once more. The second is the test for endogeneity. The set of instrumental variables is introduced through the system GMM method, and the standard error of the two-step regression is adjusted using finite sample standard deviation estimation, enhancing the robustness of the system GMM estimation compared to general estimation methods (Zhang et al., 2013). The P values for the residual serial correlation AR test across all models in the regression findings exceed 0.1, whereas the P values for the over-identification constraint Sargan test approach 1. The model configuration and selection of instrumental variables are both rational and efficacious. The third is the placebo examination. This article artificially modifies the regulatory capture variable while keeping other elements constant to determine if regulatory capture, rather than regional features, influences environmental

efficiency. The influence of regulatory capture on environmental efficiency and the beneficial regulatory effect of the institutional environment remain unmitigated, suggesting that certain regional factors may contribute to regulatory capture and positively affect the varied regulatory impact of the institutional environment. Consequently, by maintaining the corresponding control variables, the primary explanatory variables are randomly distributed across each region, effectively nullifying the inhibitory impact of regulatory capture on environmental efficiency and the moderating influence of the institutional environment. This suggests that it is regulatory capture itself, rather than extraneous factors, that influences environmental efficiency. The robustness test results indicate (not provided due to space constraints) that the estimated coefficients and significance of the primary explanatory variables mostly align with the fundamental estimation results, hence affirming the validity of the aforementioned conclusions.

8 Further discussion

Prior research indicates that regulatory capture or institutional context may exert nonlinear influences on environmental efficiency (Canh et al., 2019; Sun et al., 2022). This paper investigates whether the effects of regulatory capture and the institutional environment on environmental efficiency are merely linear relationships or if the institutional environment must surpass a specific threshold to alter the influence of regulatory capture on environmental efficiency. This work utilises the methodology of Li Yushan et al. to enhance the testing of moderating effects and employs the threshold effect model introduced by Hansen (2000) for as shown in Equation 3.

$$Eff_{it} = C_2 + \varphi_0 RC_{it} I\left(IE_{it} \le \eta_1\right) + \varphi_1 RC_{it} \mathrm{I}\left(\eta_1 < IE_{it} \le \eta_2\right) + \ldots + \varphi_n RC_{it} I\left(\eta_{n-1} < IE_{it} \le \eta_n\right) + \varphi_{n+1} RC_{it} I\left(IE_{it} > \eta_n\right) + \tau_1 X_{it} + \varepsilon_{it} \quad (3)$$

Included among the variables:

- *IEitIE_{it}IEit represents the threshold variable.*
- *RCitRC_{it}RCit denotes the primary explanatory variable, which is influenced by the threshold variable.*
- *η\etaη indicates the unknown threshold value of the institutional environment.*
- *φ0,φ1, . . . ,φn,φn+1\varphi_0, \varphi_1, . . . , \varphi_n, \varphi_{n+1}φ0,φ1, . . . ,φn,φn+1* represent the impact coefficients of regulatory capture on environmental efficiency across different threshold value intervals.

If the values of *φ0,φ1, . . . ,φn,φn+1\varphi_0, \varphi_1, . . . , \varphi_n, \varphi_{n+1}φ0,φ1, . . . ,φn,φn+1* exhibit substantial differences, it confirms the effectiveness of the selected threshold variable. The indicator function, *I (·)I (\cdot)I (·)*, is defined such that:

- *I = 1I = 1I = 1 if the condition is satisfied,*
- *I = 0I = 0I = 0 otherwise.*

Utilising the institutional environment as the threshold variable, stepwise regression is conducted under scenarios of no threshold, a single threshold, and dual thresholds. Following 300 statistics of overlapping simulation likelihood ratio tests, the findings for the threshold quantity identification test are obtained. The government quality and legal environment possess a single threshold value of 0.409, along with two threshold values of −0.560 and 0.712, respectively. By further substituting the threshold value of the institutional environment into the threshold measurement model, one may derive the influence coefficients of regulatory capture on environmental efficiency over various intervals of the threshold variable. Table 3 demonstrates that the direction and significance of the influencing coefficients of the explanatory variables are largely consistent, suggesting that the model's structure is both rational and successful. Model (1) indicates that when government quality is below the threshold of 0.409, the estimated coefficient of regulatory capture on environmental efficiency is significantly negative at the 1% level, measuring −0.678. Conversely, when government quality surpasses this threshold, the estimated coefficient of regulatory capture is −0.162, which meets the 5% significance level test. This indicates that the inhibitory impact of regulatory capture on environmental efficiency diminishes as government quality improves, and that government quality moderates the link between regulatory capture and environmental efficiency.

The regression findings of model (2) demonstrate that across different threshold value ranges of the legal environment, the estimated coefficient's direction and degree of regulatory capture on environmental efficiency show considerable variance. When the legal environment falls below the original threshold of −0.560, the regression coefficient for regulatory capture is notably negative at the 1% level, quantified at −0.415. When the legal environment surpasses this threshold yet remains beneath the second threshold of 0.712, the absolute value of the estimated coefficient for regulatory capture on environmental efficiency decreases and achieves the 5% significance level, indicating that within these two threshold intervals, the detrimental effect of regulatory capture on environmental efficiency gradually diminishes as the legal environment enhances. Upon the legal environment exceeding the second threshold, the estimated coefficient for regulatory capture becomes positive at the 1% significance level, signifying that the institutional environment positively influences the relationship between regulatory capture and environmental efficiency. The examination of the threshold effect model verifies that the institutional context significantly affects the correlation between regulatory capture and environmental efficiency. An enhanced regional institutional framework is associated with a greater reduction of the negative influence between regulatory capture and environmental efficiency.

9 Research conclusion and implications

This paper theoretically analyzes the mechanism by which regulatory capture affects regional environmental efficiency within the context of the institutional environment and proposes two research ideas. This paper empirically examines the impact of regulatory capture on environmental efficiency, employing provincial data from China, and assesses the moderating role of the institutional context on both elements. This study utilizes the threshold effect model identification approach to examine how differences in government quality and the legal framework influence the impact of regulatory capture on environmental

TABLE 3 Threshold effect of government quality on the impact of regulatory capture on environmental efficiency.

Variable	(1)		(2)	
RC	GQ < 0.409	−0.678***(-5.531)	LE < -0.560	−0.415***(-3.275)
RC_1	GQ ≥ 0.409	−0.162**(-2.519)	−0.560≤LE<0.712	−0.310**(-2.408)
RC_2			LE≥0.712	0.195***(2.937)
END	0.010 (0.162)		−0.043 (-0.672)	
OPEN	−0.260***(-2.918)		0.540***(5.190)	
IND	0.138 (1.605)		0.175***(2.892)	
ERB	−0.058 (-0.793)		−0.167**(-2.479)	
CONS	−0.076*(-1.906)		−2.635***(-2.933)	
Observations	360		360	
R^2 value	0.783		0.791	

efficiency. The empirical results consistently validate the theoretical framework. Regulatory capture adversely impacts regional environmental efficiency, considerably contributing to the decline of environmental performance. The impact of regulatory capture on environmental efficiency is positively enhanced by the quality of governance and the robustness of the legal framework. Enhancements in governmental quality and the judicial system can significantly alleviate the adverse impacts of regulatory capture. The research indicates that the legal environment exerts a more significant beneficial moderating influence in areas characterized by inadequate government quality. Conversely, regions with higher government quality can more effectively mitigate the adverse effects of regulatory capture. The study indicates that the advantageous impact of the legal system is more pronounced in areas with a strong legal framework. The influence of governance quality is particularly pronounced in areas with an inadequate legal framework. These findings underscore the significance of a cohesive strategy, wherein governance quality and legislative frameworks collaboratively mitigate the detrimental impacts of regulatory capture. The research demonstrates that the impact of regulatory capture on environmental efficiency differs across several levels of the institutional environment. When the institutional environment attains a critical threshold, the adverse effects of regulatory capture on environmental efficiency are significantly intensified. The conclusion of this paper presents substantial policy implications, emphasizing the need for more precise and actionable policy recommendations. The effective technique to alleviate regulatory capture should concentrate on strengthening the institutional framework, hence boosting environmental efficiency. Nonetheless, a "one-size-fits-all" strategy should be eschewed, acknowledging the distorting effects that regulatory capture may exert on the regulatory constraint mechanism (Zhou et al., 2008). Consequently, focused reforms must tackle particular institutional problems in each location.

To effectively counter regulatory capture, various specific measures need be established. Initially, improved anti-corruption measures are essential. A more robust focus is required on sanctioning corrupt behaviors and addressing collaboration between official entities and corporate economic interests. More stringent sanctions for environmental regulatory capture must be implemented, including heightened fines and legal repercussions for individuals involved in unlawful regulatory activities. AI-driven environmental monitoring can be utilized to discover and avert regulatory capture by detecting abnormalities in environmental compliance reports and trends indicative of manipulation or underreporting. Moreover, the implementation of a citizen oversight system is essential. This may encompass a "whistleblower" mechanism to enable citizens to report instances of regulatory capture. Such technologies will enhance openness and ensure government agencies are accountable for their environmental regulatory responsibilities. Adopting a multi-stakeholder governance model that promotes interaction among local, regional, and national governments, alongside corporate enterprises and civil society, would be advantageous. This methodology guarantees that all stakeholders participate in the regulatory process, aiding in mitigating the impact of special interests. Moreover, in accordance with global best practices, China might utilize environmental protection frameworks from the EU and the U.S. The EU's Emissions Trading System (ETS) and the U.S. Clean Air Act serve as effective frameworks for overseeing and sanctioning environmental damage. The EU's strategy for citizen participation via environmental citizen suits, permitting anyone to initiate legal proceedings against non-compliant corporations, can be adapted to the setting of China. These techniques could be incorporated into China's legal system to enable individuals and NGOs to hold the government and enterprises responsible.

Notwithstanding the prospective advantages of these recommendations, the execution of such reforms in China encounters numerous practicality obstacles. Initially, institutional and political limitations must be meticulously evaluated. China's governance framework, defined by a centralized political system, frequently encounters challenges in reconciling local autonomy with national supervision. This poses difficulties in executing consistent reforms across heterogeneous regions with differing degrees of institutional capacity. For example, areas with inadequate governance systems or restricted legal frameworks may find it challenging to implement the suggested modifications efficiently. Furthermore, the political landscape in China may occasionally constrain the autonomy of regulatory agencies, especially where local governments possess economic stakes. The political environment may also oppose anti-corruption initiatives, particularly when powerful industries are implicated.

Furthermore, the absence of openness in regulatory procedures and the restricted opportunities for civil society engagement present considerable obstacles to the development of an efficient public monitoring system. Transforming the political and institutional framework necessitates sustained dedication and cooperation among government, civil society, and private sector entities. Notwithstanding these limitations, gradual reforms can facilitate a more efficient institutional framework. Through the incremental enhancement of local governance capabilities, the promotion of public-private partnerships, and the facilitation of cross-border collaborations, China may progressively augment environmental efficiency. Moreover, China's expertise in digital technologies, such as AI and blockchain, might be utilized to improve regulatory supervision, facilitate the enforcement of environmental norms, and avert regulatory capture.

The study emphasizes the necessity for a thorough, region-specific strategy to tackle regulatory capture and enhance environmental efficiency in China. Despite the difficulty in implementing the proposed reforms, the incorporation of worldwide best practices, along with tangible measures like public oversight and AI-driven monitoring, might substantially alleviate the detrimental impacts of regulatory capture. The efficacy of these reforms will rely on a synthesis of institutional fortification, political resolve, and civic participation, facilitating a more transparent, accountable, and efficient regulatory framework that fosters sustainable growth in China.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

FW: Writing – original draft, Writing – review and editing, Methodology, Formal analysis, Project administration, Investigation, Visualization. FS: Conceptualization, Data curation, Formal Analysis, Investigation, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review and editing. NF: Conceptualization, Methodology, Project administration, Resources, Software, Writing – original draft, Writing – review and editing. CT: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft. FF: Funding acquisition, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review and editing.

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