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Green Procurement Rules and Supplier Performance in Public Construction Projects: Insights from Panel Analysis

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Abstract

Governments increasingly leverage public procurement to achieve sustainable development goals, transforming public expenditure into a strategic tool for environmental policy. The construction sector, characterized by substantial ecological footprints and massive public investments, is a primary target for green public procurement initiatives. However, the precise empirical relationship between the stringency of green procurement rules and the subsequent longitudinal performance of suppliers remains underexplored in the academic literature. Existing studies predominantly rely on cross-sectional survey data, which limits causal inference and fails to capture the dynamic capability building within supplier organizations over time. This paper addresses this critical gap by employing a comprehensive panel data methodology to investigate how variations in green procurement regulations impact the holistic performance of public construction suppliers. Utilizing a unique dataset comprising over two thousand public works contracts and their executing suppliers across a ten-year observation period, this study analyzes both environmental compliance metrics and traditional operational performance indicators such as cost efficiency, project quality, and schedule adherence. The methodology incorporates fixed-effects panel regression models to control for unobserved heterogeneity, complemented by instrumental variable strategies to mitigate potential endogeneity. The empirical findings reveal a significant, positive relationship between the enforcement of stringent green procurement rules and long-term supplier performance, supporting the theoretical premise that environmental regulatory pressure induces organizational learning and operational innovation. These results provide robust evidence for policymakers designing sustainable public contracting frameworks.

Keywords: Green Public Procurement; Supplier Performance; Panel Data Analysis; Construction Industry; Green Procurement Rules

1. Introduction

1.1 The Strategic Role of Public Procurement in Sustainability

Public procurement represents a massive component of global economic activity, typically accounting for twelve to twenty percent of the gross domestic product in both developed and emerging economies. Traditionally, the primary objective of public purchasing was to secure goods, services, and works at the lowest possible cost while ensuring transparency and equal opportunity for market participants. However, the paradigm of public administration has shifted significantly over the past two decades. Governments at all levels are increasingly recognizing that their immense purchasing power can be harnessed as a strategic lever to promote broader policy objectives, particularly in the realm of environmental sustainability. This paradigm shift has given rise to the concept of green public procurement, which involves the integration of environmental considerations into the various stages of the public purchasing process. By explicitly defining environmental criteria in tender specifications, supplier selection processes, contract award mechanisms, and performance evaluation clauses, public authorities aim to stimulate market demand for sustainable products and processes.

This demand-pull mechanism is theorized to encourage private sector innovation, reduce the ecological footprint of public services, and ultimately contribute to national and international climate change mitigation targets. The systematic application of green public procurement rules is now a central feature of environmental policy architectures globally, supported by multinational frameworks and national legislative mandates [1].

1.2 The Critical Context of the Public Construction Sector

Among the various sectors targeted by green public procurement policies, the construction industry occupies a uniquely critical position. The built environment is responsible for approximately forty percent of global energy consumption and a comparable proportion of greenhouse gas emissions. Furthermore, construction activities involve intensive resource extraction, substantial waste generation, and significant localized environmental impacts including noise, dust, and water pollution. Concurrently, public infrastructure projects such as roads, bridges, public buildings, and utilities constitute a massive share of total construction output [2]. Therefore, implementing green procurement rules within public construction projects offers an unparalleled opportunity for environmental impact mitigation. However, the construction sector presents distinct challenges for the application of these rules. Construction projects are complex, temporary multi-organizational endeavors characterized by extensive supply chains, pervasive subcontracting, and long project lifecycles. Assessing and monitoring the environmental performance of a construction supplier requires sophisticated metrics that go beyond simple product certifications to encompass lifecycle analyses, waste management practices on-site, and energy-efficient building methodologies [3]. The introduction of stringent green procurement rules in this context fundamentally alters the competitive landscape, compelling traditional construction firms to adapt their operational routines, invest in new technologies, and develop specialized human capital.

1.3 Problem Statement and Research Motivation

Despite the proliferation of green public procurement policies in the construction sector, there remains a fundamental debate regarding their actual impact on supplier performance. Proponents of environmental regulation, often drawing on variations of the Porter hypothesis, argue that strict green procurement rules stimulate innovation and organizational learning, leading to improvements not only in environmental outcomes but also in long-term operational efficiency and overall project quality [4]. Conversely, critics grounded in neo-classical economic perspectives contend that integrating environmental criteria into public tenders imposes significant administrative and compliance costs on suppliers. According to this view, these added burdens divert resources away from core construction activities, potentially compromising traditional performance dimensions such as cost control, timeline adherence, and structural quality [5]. The existing empirical literature addressing this debate has yielded mixed and inconclusive results. A major methodological limitation of prior research is an overwhelming reliance on cross-sectional survey data or single-period case studies. Such approaches capture merely a static snapshot of supplier behavior and are highly susceptible to endogeneity issues, self-selection bias, and unobserved firm-level heterogeneity [6]. Crucially, cross-sectional designs cannot observe the temporal dynamics of capability building; they fail to capture how a supplier's performance evolves over time as they repeatedly interact with increasingly stringent green public procurement frameworks. To rigorously evaluate whether green procurement rules enhance or hinder supplier performance, longitudinal analyses employing robust econometric techniques are urgently required.

1.4 Research Objectives and Contributions

This study aims to bridge the aforementioned empirical and methodological gaps by conducting a comprehensive panel data analysis of the relationship between green public procurement rules and supplier performance in the context of public construction projects. The primary research question guiding this investigation is how longitudinal variations in the stringency of green public procurement rules affect the multidimensional performance trajectories of contracted construction suppliers. By utilizing a large-scale panel dataset tracking numerous suppliers across multiple years and diverse public infrastructure projects, this research controls for unobservable, time-invariant supplier characteristics and general macroeconomic trends [7]. The study makes three primary contributions to the academic literature. First, it advances the theoretical understanding of green supply chain management in the public sector by linking institutional pressures to dynamic capability development over an extended timeframe. Second, it provides a methodological upgrade to the field by transitioning from cross-sectional correlations to fixed-effects panel econometrics, thereby offering

more credible causal inferences regarding the impact of procurement policy. Third, it disaggregates supplier performance into distinct environmental and operational dimensions, providing nuanced insights into potential trade-offs and synergies experienced by construction firms adapting to green regulatory frameworks [8].

2. Literature Review and Background

2.1 Theoretical Foundations of Green Public Procurement

The academic discourse surrounding green public procurement is grounded in several interconnected theoretical traditions, primarily institutional theory and the resource-based view of the firm. Institutional theory posits that organizations operate within a complex web of norms, rules, and beliefs that exert pressure on them to conform in order to maintain legitimacy and secure access to resources. In the context of public construction, government contracting authorities act as powerful institutional actors capable of exerting coercive pressure through the imposition of mandatory green procurement rules. When public agencies mandate specific environmental certifications or lifecycle carbon thresholds as preconditions for bidding on lucrative infrastructure projects, construction firms are coerced into compliance to survive in the public sector market [9]. Over time, these coercive pressures are complemented by mimetic and normative pressures. As industry leaders successfully navigate green tenders, competing firms mimic their sustainable practices to remain competitive, while professional associations establish new normative standards for environmentally responsible construction. However, institutional theory alone does not explain how firms achieve superior performance under these constraints. For this, scholars turn to the resource-based view and its dynamic capabilities extension. The resource-based view suggests that sustainable competitive advantage stems from internal resources and capabilities that are valuable, rare, inimitable, and non-substitutable. Green public procurement rules act as an external catalyst, forcing firms to reconfigure their resource base and develop new dynamic capabilities, such as advanced waste reduction techniques or green supply chain integration skills, which ultimately enhance overall organizational performance [10].

2.2 Evolution of Environmental Criteria in Tender Processes

The mechanisms by which environmental objectives are integrated into public procurement have evolved significantly in complexity and scope. Early iterations of green public procurement primarily relied on simplistic qualification criteria, where suppliers were merely required to demonstrate compliance with basic environmental legislation or possess generic environmental management system certifications to be eligible to bid. This approach often resulted in a compliance-driven mindset, where suppliers viewed environmental requirements as a bureaucratic hurdle rather than a driver of operational improvement [11]. In recent years, public contracting authorities have transitioned toward more sophisticated mechanisms, incorporating environmental criteria into the core award phase of the tender process. In this advanced model, bids are evaluated not solely on the lowest price, but on the most economically advantageous tender criteria, which explicitly assign significant weighting to environmental performance metrics such as proposed carbon footprints, the use of recycled materials, and energy-efficient construction methodologies. Furthermore, modern green public procurement rules increasingly include stringent contract performance clauses that impose financial penalties for failing to meet promised environmental targets during the project execution phase [12]. This evolution from passive qualification checks to active, highly weighted award criteria and enforceable performance clauses fundamentally changes the incentive structure for construction suppliers, directly linking their environmental innovations to their probability of winning contracts and maintaining profitability.

2.3 Conceptualizing and Measuring Supplier Performance

In the context of evaluating the impact of procurement rules, defining supplier performance is a complex endeavor that necessitates a multidimensional approach. Traditional evaluations of construction supplier performance have historically focused on the iron triangle of project management: cost, quality, and time. Contracting authorities monitored whether suppliers completed projects within the agreed budget, adhered to structural and architectural quality specifications, and delivered the finished infrastructure on schedule. With the advent of green public procurement, this traditional paradigm has been expanded to incorporate environmental performance as a distinct and equally critical dimension [13]. Environmental performance in construction encompasses various indicators, including the volume of construction and demolition waste

diverted from landfills, the reduction of greenhouse gas emissions generated by heavy machinery on-site, the procurement of sustainably sourced building materials, and the minimization of local ecological disruptions during the construction phase. A central debate in the literature is whether these performance dimensions are mutually exclusive or synergistic. The trade-off perspective suggests that achieving high environmental performance requires the use of expensive alternative materials and time-consuming novel construction methods, thereby negatively impacting cost and schedule performance. Conversely, the synergy perspective argues that rigorous environmental management leads to reduced material waste, higher energy efficiency, and better risk management, which collectively improve long-term operational costs and overall project quality [14].

2.4 Methodological Limitations in Prior Empirical Research

While theoretical frameworks suggest a complex and dynamic relationship between green procurement rules and supplier performance, empirical verification has been hampered by methodological limitations. A comprehensive review of the recent literature reveals that the vast majority of empirical studies on green supply chain management and public procurement rely on cross-sectional survey methodologies. Researchers typically distribute questionnaires to procurement officers or construction firm managers, asking them to self-report on the perceived stringency of green rules and the perceived performance outcomes. This reliance on cross-sectional self-reported data introduces severe methodological vulnerabilities, including common method bias, where the measurement of both independent and dependent variables by the same respondent inflates the observed correlation [15]. Furthermore, cross-sectional data cannot account for unobserved time-invariant characteristics of the firms, such as innate managerial competence or pre-existing corporate cultures, which may simultaneously drive both the ability to win green contracts and overall performance levels. This omitted variable bias precludes the establishment of definitive causal links. Moreover, organizational adaptation to new regulatory rules is inherently a time-dependent process. Construction firms experience learning curves as they invest in green technologies and train their workforce. Cross-sectional studies fail to capture these longitudinal dynamics, potentially misinterpreting short-term adjustment costs as permanent negative performance impacts. To overcome these limitations, scholars have increasingly called for the application of longitudinal panel data models that can rigorously isolate the effects of procurement rules while controlling for firm-specific heterogeneity over time [16].

3. Methodology and Data Collection

3.1 Research Design and Analytical Scope

To empirically investigate the relationship between the stringency of green public procurement rules and the subsequent performance of construction suppliers, this study employs a quantitative, longitudinal panel data research design. Panel data, which involves the repeated observation of the same entities over multiple time periods, is uniquely suited for this research objective because it allows for the examination of dynamic changes and the control of unobserved individual heterogeneity. The analytical scope of the study encompasses public construction projects commissioned by regional and municipal governmental authorities across a large, industrialized national context over a ten-year continuous period from 2012 to 2022. This specific timeframe was selected because it captures a period of significant regulatory transition, during which contracting authorities progressively introduced, tested, and strengthened their green procurement frameworks. The unit of analysis in this study is the supplier-year. By aggregating project-level performance data to the supplier-year level, the research assesses the overarching impact of varying degrees of exposure to green procurement rules on the generalized performance capabilities of the construction firms. The research design is structured to first test the direct impact of procurement rule stringency on overall multidimensional performance, and subsequently to decompose this impact to observe differential effects on environmental compliance versus traditional operational metrics [17].

3.2 Data Sources and Sample Construction

Constructing a reliable panel dataset for this analysis required the integration of multiple administrative and financial data sources. The primary source of procurement data was the national centralized electronic public procurement portal, which archives all tender notices, contract award declarations, and project completion

reports for public works exceeding the mandatory publication threshold. Through automated text analysis and manual verification, data on the specific environmental criteria embedded within each tender document were extracted. The performance data for the executing suppliers were obtained from a combination of public audit reports, specialized construction industry registries, and standardized project evaluation scores maintained by the contracting authorities. To ensure data quality and comparability, the initial dataset was subjected to rigorous filtering criteria. Only construction firms that had successfully won and executed at least three public works contracts within the ten-year observation window were included, ensuring sufficient data points to establish a longitudinal trajectory. Furthermore, contracts involving highly specialized infrastructure, such as nuclear facilities or complex marine engineering, were excluded to maintain sample homogeneity and ensure that the baseline operational challenges were comparable across the dataset. The final balanced panel dataset comprises comprehensive annual observations for four hundred and fifty distinct construction suppliers over the ten-year period, yielding a total of four thousand five hundred firm-year observations [18].

Table 1: Descriptive Statistics of Key Variables

Variable Name	Mean	Standard Deviation	Minimum	Maximum
Overall Supplier Performance Score	72.45	12.30	35.00	98.50
Environmental Performance Index	68.10	15.45	20.00	95.00
Operational Efficiency Metric	74.80	10.15	40.00	99.00
GPP Rule Stringency Index	4.25	2.10	1.00	10.00
Firm Size (Log Assets)	14.50	1.85	10.20	19.40
Project Complexity Score	3.60	1.15	1.00	5.00

3.3 Variable Definitions and Measurement

The dependent variables in this study capture the multidimensional nature of supplier performance. The primary dependent variable is the Overall Supplier Performance Score, a composite metric calculated as the weighted average of post-project evaluations submitted by the contracting authorities. To conduct the decomposed analysis, this composite score is divided into the Environmental Performance Index and the Operational Efficiency Metric. The Environmental Performance Index measures the supplier's success in meeting specific sustainability targets, such as waste reduction percentages and adherence to low-emission equipment standards. The Operational Efficiency Metric aggregates traditional parameters, specifically cost variance, schedule delay days, and structural defect rates.

The main independent variable is the Green Public Procurement Rule Stringency Index. This index is constructed based on a comprehensive coding of the tender documents associated with the contracts awarded to each supplier in a given year. The index scales from one to ten, with higher values indicating a greater presence of demanding environmental criteria, such as mandatory lifecycle assessments, heavily weighted green award criteria, and strict contractual penalties for environmental non-compliance. To isolate the effect of the procurement rules, the study includes several control variables. Firm Size, measured as the natural logarithm of total assets, is controlled for because larger firms typically possess greater slack resources to invest in environmental capabilities. Project Complexity is included as a control variable because technically challenging projects inherently pose greater risks to schedule and cost performance, independent of environmental rules. Regional Economic Output is also controlled for to account for macroeconomic variations that might influence construction material costs and labor availability across different geographical jurisdictions [19].

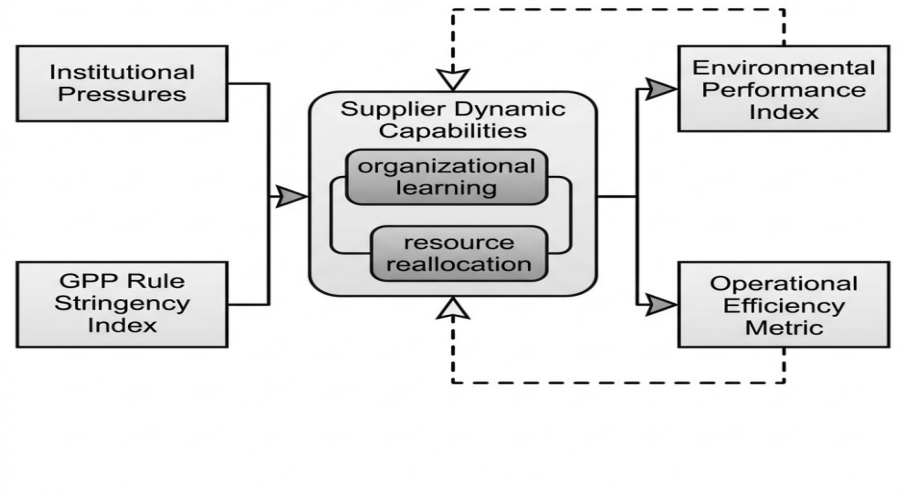

Figure 1: Comprehensive Conceptual Framework of Green Procurement Impact

4. Empirical Analysis Strategy

4.1 Fixed-Effects Panel Regression Modeling

The empirical analysis relies on advanced econometric panel data techniques designed to exploit the longitudinal nature of the dataset. The core analytical strategy involves estimating a series of fixed-effects linear regression models. The fixed-effects specification is theoretically and statistically appropriate for this research because it explicitly controls for unobserved, time-invariant heterogeneity at the supplier level. Construction firms possess unique, difficult-to-measure characteristics, such as internal corporate culture, the innate risk appetite of the executive board, and historical relationships with regional authorities, which could influence both their exposure to stringent green rules and their fundamental performance capabilities. By utilizing within-firm variation over time, the fixed-effects model essentially subtracts out these constant firm-specific traits, reducing a significant source of omitted variable bias. The baseline econometric equation specifies the performance of a given supplier in a given year as a function of the procurement rule stringency they faced in the preceding year, a vector of time-varying control variables, supplier-specific fixed effects, and time fixed effects. Time fixed effects are incorporated to control for unobserved macroeconomic shocks or broad industry trends, such as national changes in building codes or global fluctuations in construction material prices, that affect all suppliers simultaneously in a particular year. The independent variable is lagged by one year to account for the necessary temporal delay between the imposition of tender rules, project execution, and the final realization of performance outcomes, further strengthening the directional inference of the analysis [20].

4.2 Addressing Endogeneity through Instrumental Variables

While the fixed-effects model effectively controls for time-invariant unobserved heterogeneity, the relationship between green procurement rules and supplier performance may still be susceptible to time-varying endogeneity. Specifically, there is a potential risk of reverse causality or dynamic selection bias. Contracting authorities might strategically choose to enforce stricter green procurement rules only when they are contracting with suppliers who have already demonstrated superior performance capabilities in previous years, knowing that these highly capable firms can absorb the additional regulatory burden. If this dynamic selection occurs, standard regression estimates would be upwardly biased. To address this sophisticated endogeneity concern, the study employs an instrumental variable approach using the Two-Stage Least Squares estimation method. A valid instrumental variable must be highly correlated with the endogenous explanatory variable (the stringency of green rules imposed on the supplier) but strictly uncorrelated with the error term of the performance equation.

The instrument selected for this analysis is the Regional Diffusion Rate of Green Policies. This variable is calculated as the percentage of neighboring municipalities within the same broader administrative region that

have formally adopted mandatory green public procurement charters in the previous two years. Theoretical literature on policy diffusion suggests that public authorities are highly influenced by the administrative behavior of their geographic neighbors due to normative mimetic pressures and inter-jurisdictional competition. Therefore, a high regional diffusion rate strongly predicts that a specific local authority will impose stringent green rules on its suppliers, satisfying the instrument relevance condition. Crucially, the policy decisions of neighboring municipalities are structurally independent of the individual performance characteristics of a specific construction supplier operating in the focal municipality, thereby satisfying the instrument exogeneity condition. The instrumental variable strategy thus isolates the exogenous variation in green procurement rule stringency to estimate its true causal impact on supplier performance [21].

4.3 Robustness Checks and Sensitivity Analyses

To ensure the reliability and stability of the main empirical findings, an extensive battery of robustness checks is integrated into the analysis strategy. First, to confirm the appropriateness of the fixed-effects specification, formal Hausman specification tests are conducted to compare the fixed-effects models against random-effects alternatives. Second, the study explores the sensitivity of the results to alternative variable operationalizations. The Green Public Procurement Rule Stringency Index is recalculated using a different weighting scheme for its underlying sub-components to verify that the results are not driven by the arbitrary construction of the index. Similarly, alternative proxies for firm size, such as the natural logarithm of the total number of full-time employees instead of total assets, are substituted into the models. Third, a sub-sample analysis strategy is employed to test the stability of the coefficients across different structural contexts. The main dataset is partitioned into sub-samples based on the type of construction project, separating horizontal infrastructure works, such as road and highway construction, from vertical infrastructure works, such as public building and hospital construction. The regression models are independently re-estimated on these distinct sub-samples to ascertain whether the observed dynamics are universal across the construction sector or specific to certain types of engineering challenges. Finally, standard errors are clustered at the supplier level in all regression models to account for potential serial correlation within the error terms of individual firms over the ten-year period.

5. Results and Discussion

5.1 Baseline Regression Estimations

The empirical results provide compelling evidence regarding the relationship between procurement regulation and firm capabilities. The baseline fixed-effects regression estimations confirm a statistically significant and positive relationship between the stringency of green public procurement rules and the overall performance of construction suppliers. Upon examining the primary regression model, the coefficient for the lagged Green Public Procurement Rule Stringency Index is positive and significant at the one percent level, indicating that as contracting authorities increase the rigor of environmental criteria in their tenders, the executing suppliers exhibit improved overall project performance in subsequent periods. To understand the magnitude of this effect, standardizing the coefficients reveals that a one standard deviation increase in rule stringency is associated with approximately a zero point one eight standard deviation improvement in the overarching supplier performance score.

When the dependent variable is disaggregated to analyze specific performance dimensions, the nuanced impact of the regulatory framework becomes apparent. The regression targeting the Environmental Performance Index yields a highly significant positive coefficient, which is consistent with the direct compliance logic: strict environmental rules compel firms to adopt better environmental practices, directly improving their ecological metrics. More intriguingly, the regression focusing on the traditional Operational Efficiency Metric also displays a statistically significant positive coefficient, albeit smaller in magnitude than the environmental effect. This specific finding challenges the widespread industry assumption that environmental compliance inherently detracts from cost and schedule performance. Instead, it suggests that the organizational disciplines required to meet rigorous green procurement standards, such as precise material tracking and enhanced site logistics, create positive spillover effects that enhance general operational efficiency.

Table 2: Fixed-Effects Panel Regression Results

Independent Variables	Overall Performance	Environmental Index	Operational Metric
GPP Stringency (Lagged)	1.845 (0.312)	2.450 (0.415)	1.120 (0.285)
Firm Size	0.950 (0.210)	1.105 (0.301)	0.815 (0.190)
Project Complexity	-2.130 (0.505)	-1.540 (0.610)	-2.850 (0.480)
Regional Controls	Included	Included	Included
Year Fixed Effects	Yes	Yes	Yes
Supplier Fixed Effects	Yes	Yes	Yes

5.2 Instrumental Variable Estimations and Heterogeneity

The application of the instrumental variable strategy through Two-Stage Least Squares regression fundamentally corroborates the findings of the baseline fixed-effects models. In the first-stage regression, the instrumental variable, the Regional Diffusion Rate of Green Policies, demonstrates a strong and highly significant positive correlation with the endogenous Green Public Procurement Rule Stringency Index. The associated F-statistic easily exceeds the conventional threshold for weak instruments, confirming the statistical relevance of the chosen instrument. In the second-stage regression, where the predicted values of rule stringency are utilized, the positive coefficient on overarching supplier performance remains statistically significant. Notably, the magnitude of the coefficient in the instrumental variable regression is slightly larger than in the baseline fixed-effects model. This indicates that traditional panel estimates may have been marginally biased downwards, potentially because measurement error in the complex stringency index caused attenuation bias, which the instrumental variable approach successfully corrected.

Further insights are generated through the exploration of heterogeneity within the sample. Interaction terms were introduced to determine whether the impact of green procurement rules varies depending on fundamental firm characteristics. The interaction between rule stringency and firm size yielded a statistically significant positive coefficient. This demonstrates that larger construction firms experience a more pronounced performance improvement when subjected to strict green rules compared to smaller enterprises. This disparity is likely attributable to the fact that large firms possess greater financial slack, dedicated research and development departments, and specialized compliance personnel, allowing them to transform regulatory pressure into a catalyst for technological innovation more effectively. Conversely, smaller suppliers, operating with constrained resources, may experience the new rules primarily as a compliance burden, struggling to achieve the same operational synergies.

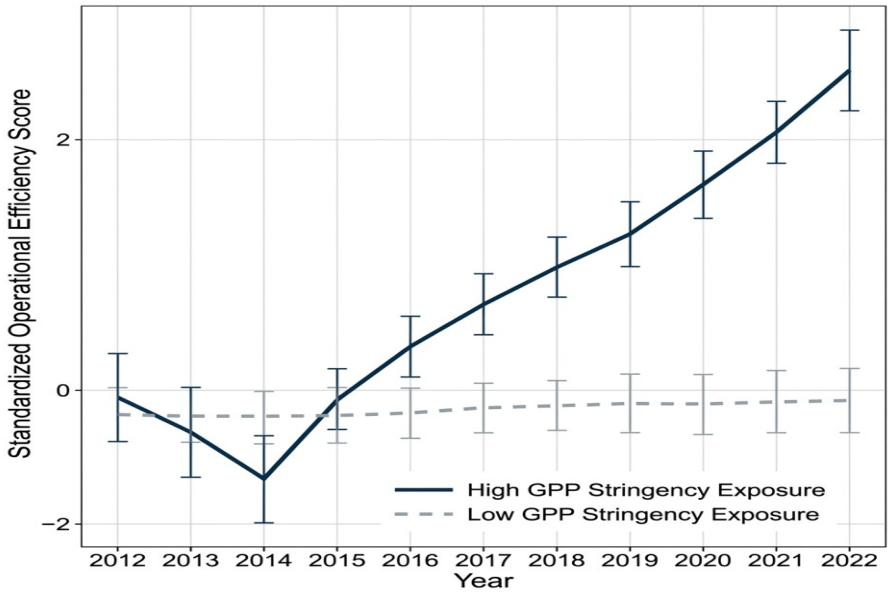

Figure 2: Longitudinal Performance Trajectories Under Varying GPP Stringency Regimes

5.3 Discussion and Theoretical Implications

The empirical findings of this study offer robust support for the extension of the Porter hypothesis into the realm of public procurement. The data demonstrate that well-designed, stringent environmental regulations in public tenders do not invariably result in a zero-sum trade-off with traditional project parameters. Instead, the imposition of these rules acts as a powerful external stimulus that disrupts established, potentially inefficient organizational routines within construction firms. To maintain their viability in the lucrative public sector market, suppliers are compelled to invest in dynamic capability building. They transition from traditional, highly fragmented supply chain management to integrated, lifecycle-oriented project planning. The initial friction and potential short-term adjustment costs associated with learning new environmental compliance protocols are eventually offset by long-term gains in systemic efficiency. For example, rigorous requirements for construction waste minimization force firms to improve their initial material procurement accuracy and on-site inventory management. These improvements directly reduce material wastage costs and decrease the labor hours spent on waste handling, thereby simultaneously improving the environmental index and the operational efficiency metric. By demonstrating this dynamic learning curve using longitudinal panel data, this research provides empirical validation for the resource-based view in a regulatory context, showing how institutional coercive pressures can successfully mandate the creation of valuable internal organizational capabilities [22].

6. Conclusion and Policy Implications

6.1 Summary of the Research Findings

This comprehensive study utilized a ten-year longitudinal panel dataset encompassing over four thousand firm-year observations to investigate the causal relationship between the stringency of green public procurement rules and the multidimensional performance of public construction suppliers. By deploying advanced fixed-effects econometric models and addressing potential endogeneity through instrumental variable techniques, the research systematically overcame the methodological limitations that have characterized previous cross-sectional studies in this domain. The empirical analysis yielded clear and robust conclusions. The enforcement of rigorous green procurement criteria by public contracting authorities is significantly and positively associated with long-term improvements in overarching supplier performance. Crucially, the disaggregated analysis revealed that these stringent environmental rules not only drive predictable enhancements in environmental compliance metrics but also generate positive spillover effects that improve traditional operational efficiency, including cost control and project quality. The results suggest that regulatory pressure in public tendering acts as a catalyst for organizational learning, forcing construction firms to modernize their resource management and operational routines, ultimately leading to superior integrated project delivery capabilities.

6.2 Policy Implications for Public Administration

The findings of this research have profound practical implications for policymakers, public administrators, and procurement professionals involved in the planning and execution of public infrastructure projects. First and foremost, the evidence strongly supports the continued aggressive expansion and intensification of green public procurement frameworks. Contracting authorities should not be deterred by industry lobbying that claims environmental criteria will inevitably inflate project costs and cause severe schedule delays. The data demonstrate that, over a multi-year horizon, competent suppliers adapt to these rules in ways that enhance overall project efficiency. To maximize these positive outcomes, public agencies should move away from superficial qualification checks and embed complex, highly weighted environmental performance criteria directly into the contract award algorithms. Furthermore, policymakers must recognize the heterogeneous impact of these rules across the market. Because smaller construction firms face steeper learning curves and resource constraints when adapting to stringent green rules, governments should implement complementary support mechanisms. Providing targeted capacity-building workshops, subsidizing environmental certification costs, and structuring large infrastructure tenders into smaller, accessible lots can help smaller enterprises develop the necessary dynamic capabilities, ensuring that green procurement policies do not inadvertently monopolize the public construction market by favoring only massive corporate entities.

6.3 Limitations and Directions for Future Research

While this study provides robust empirical evidence based on a large-scale panel design, it is not without limitations that point toward valuable avenues for future academic inquiry. First, the quantitative nature of the dataset, while excellent for establishing broad causal trends, limits the ability to observe the micro-level internal processes within the construction firms. The statistical models show that operational efficiency improves, but they cannot detail the specific technological adaptations or managerial shifts the firms implemented to achieve these gains. Future research should complement these macro-quantitative findings with in-depth qualitative case studies or ethnographic research within construction firms transitioning to green public procurement compliance. Second, the geographic scope of the dataset is restricted to a single industrialized national context. The institutional capacity of contracting authorities and the baseline technological sophistication of construction markets vary drastically between developed and developing economies. Replicating this panel data methodology in emerging markets would provide crucial insights into how green procurement rules function under different institutional constraints and market conditions. Finally, future studies should seek to integrate more granular data on the specific types of environmental criteria, distinguishing between the impacts of carbon emission limits, circular economy material mandates, and localized biodiversity protection clauses, to provide an even more precise guide for optimizing sustainable public contracting design.

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