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Public Participation-Based Environmental Regulation and Urban Green Innovation: Evidence from Chinese City-Level Panel Data

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ABSTRACT

This study examines whether public participation-based environmental regulation promotes urban green innovation in China. Using a city-level panel of 2,488 observations for 2013–2021, the paper estimates two-way fixed-effects and dynamic specifications in which green innovation is measured by ln (green patent grants + 1) and the core explanatory variable is the one- to three-year lagged average of the logged public-participation indicator. The preferred dynamic model yields a positive and statistically significant coefficient of 0.1083, suggesting that stronger public participation is associated with higher green patent output after controlling for city effects, year effects, and innovation persistence. Mechanism tests indicate that the environmental-governance channel is better supported than the government-response channel. The positive association is also stronger in cities with higher openness and larger environmental expenditure shares. Overall, the evidence suggests that public participation can complement formal environmental governance by strengthening monitoring and improving the credibility of green upgrading, although the identification remains observational rather than quasi-experimental.

KEYWORDS

Public participation; Environmental regulation; Green innovation; Environmental governance; Chinese cities

1. INTRODUCTION

Environmental deterioration, climate change, and decarbonization pressures have made green innovation a central concern in contemporary political economy. For rapidly industrializing economies, the question is not only how to reduce pollution, but also whether policy can redirect technological change toward cleaner production. This debate sits within a broader literature on growth, environmental quality, and environmental regulation [1–3]. Porter and van der Linde [3] argue that well-designed regulation can induce innovation offsets, whereas Jaffe et al. [2] stress the compliance-cost side and urge caution about competitiveness effects. The empirical task, therefore, is to identify which regulatory arrangements are most likely to stimulate green innovation.

In China, this question is especially important because the country's development model has had to absorb simultaneously the demands of industrial upgrading, environmental remediation, and urban transformation. Chinese cities concentrate manufacturing capacity, higher education resources, digital infrastructure, and local administrative authority; they are therefore the natural arena in which environmental governance and innovation policy interact. At the same time, the institutional architecture of Chinese environmental governance has changed markedly. Environmental information disclosure has expanded, online complaint channels have become more accessible, social media has lowered the cost of public scrutiny, and environmental campaigns have raised the political salience of local ecological performance. These changes suggest that environmental governance is no longer driven solely by command-and-control directives from above; it increasingly includes forms of monitoring, signaling, and pressure that originate from the public.

Public participation-based environmental regulation refers in this paper to environmental pressure that is mediated through citizens' complaints, participation channels, and broader forms of social monitoring. It differs from conventional regulatory indicators such as pollution levies, formal standards, or administrative inspections because it works through visibility, responsiveness, and accountability rather than solely through direct state coercion. When residents report pollution, demand action, or use participation channels, local governments may face stronger incentives to respond and firms may face greater reputational and operational risk. Under these conditions, a city with higher public participation may become a city in which environmental upgrading is monitored more closely, policy signals are more credible, and cleaner innovation is more likely to be rewarded.

The existing literature offers reasons to expect either a positive or a limited effect. On the one hand, public participation may strengthen monitoring, expose noncompliance, and induce firms to invest in technologies that reduce regulatory, reputational, and community-relations risk. On the other hand, participation pressure may be noisy, uneven, and only loosely connected to technological upgrading, especially where local governments lack implementation capacity or where firms can satisfy public demands with symbolic adjustments instead of substantive innovation. The empirical challenge, therefore, is not simply to ask whether public participation matters, but to identify the conditions under which it can be translated into measurable green innovation outcomes.

To address this question, the paper uses a city-year panel constructed for this study. The empirical design combines descriptive statistics, benchmark estimation, mechanism tests, heterogeneity analysis, and robustness discussion. The preferred specification is a dynamic two-way fixed effects model with lagged green innovation to capture path dependence. The main dependent variable is ln(green patent grants + 1), the alternative outcome is ln(green patent applications + 1), and the key explanatory variable is the one- to three-year lagged average of the logged public-participation indicator. All specifications include city fixed effects, year fixed effects, and city-clustered standard errors.

The paper makes three contributions. First, it shifts attention from environmental regulation in the narrow administrative sense to participation-based environmental pressure, thereby connecting innovation economics with the literature on transparency, accountability, and public scrutiny. Second, it provides an empirically disciplined account of mechanisms: rather than claiming a fully identified mediation structure, it distinguishes between stronger and weaker supportive channels and treats the environmental-governance channel as more convincing than the government-response channel in the current data. Third, it shows that institutional context matters. Public participation is not equally productive everywhere; its translation into innovation is stronger in cities with higher openness and higher environmental expenditure, suggesting that participation pressure works best where absorptive capacity and policy follow-through are stronger.

Taken together, the results show a stable positive association between participation-based environmental regulation and urban green innovation across the baseline, dynamic, richer-control, and subsample specifications. The paper nevertheless interprets these estimates cautiously: the design strengthens internal consistency, but it does not deliver a sharp quasi-experimental identification strategy. The contribution therefore lies in providing disciplined panel evidence and a clearer account of mechanisms and heterogeneous effects.

2. LITERATURE REVIEW AND RESEARCH GAP

The first strand of the literature examines how environmental regulation affects innovation, productivity, and competitiveness. Early reviews stressed the possibility that regulation raises compliance costs and weakens competitiveness [2], whereas the Porter hypothesis emphasized the potential for induced innovation [3]. Later syntheses generally find stronger support for the weak Porter hypothesis than for the strong version [4, 5]. Related empirical studies show that environmental policy can also reshape firms' labor demand, location, R&D effort, and pollution intensity [6–9].

Patent-based studies are especially influential because they track the direction and intensity of inventive activity. Lanjouw and Mody [10] link policy pressure to the international diffusion of environmentally responsive technology. Popp [11] and Newell et al. [12] show that prices and policy can redirect innovation toward energy-saving technologies, while Johnstone et al. [13] document substantial heterogeneity across renewable-energy policy instruments. At the same time, the patent-measurement literature has long stressed that patents are informative but imperfect proxies for innovation [14–17].

A second strand focuses on eco-innovation and its determinants. Rennings [18] emphasizes the double externality problem in eco-innovation, implying that market incentives alone may be insufficient. Brunnermeier and Cohen [19] show that environmental innovation in U.S. manufacturing responds to pollution-abatement expenditure, while Horbach [20], Horbach et al. [21], and Triguero et al. [22] highlight the roles of regulation, capabilities, cost savings, and demand conditions. The common implication is that institutional context shapes whether regulatory pressure is translated into inventive activity.

A third strand connects environmental performance, innovation, and competitiveness. Carrión-Flores and Innes [23] document bi-directional links between environmental innovation and environmental performance. Costantini and Mazzanti [24] and Rubashkina et al. [25] show that Porter-type effects are instrument- and context-specific. Work on directed technical change further argues that persistent policy incentives can shift innovation away from dirty technologies and toward cleaner trajectories [26,27]. This perspective is especially relevant for urban green innovation because cities combine policy signals with localized knowledge spillovers.

A fourth strand concerns public participation, transparency, and environmental governance. Disclosure is most effective when information is usable for affected stakeholders and can be converted into collective action or regulatory pressure [28,29]. In environmental governance, citizen scrutiny can create reputational and political incentives even when formal enforcement is uneven. Dasgupta et al. [30] show that capital markets in developing countries respond to environmental news and public complaints, and Konisky and Teodoro [31] emphasize that institutional arrangements condition how oversight affects governmental performance.

For China, these issues are especially salient because participation has expanded within a still strongly state-led governance system. Johnson [32] shows how environmentalism and NIMBY-style activism promoted a more rules-based approach to participation. Eaton and Kostka [33] examine enforcement problems at the center-local interface, while Ding [34] argues that public scrutiny has become integral to environmental governance. Recent studies also link information disclosure, government social media, and participation to environmental governance outcomes in China [35–37]. What remains less settled is whether participation-based pressure affects not only environmental outcomes directly, but also the technological responses underlying longer-run green transformation.

That unresolved question defines the core research gap of this paper. Much of the existing evidence looks at administrative regulation, pollution outcomes, or firm-level responses in settings where public participation appears only as background institutional context. By contrast, this paper treats public participation-based environmental regulation as the core explanatory factor and asks whether it is associated with city-level green innovation. This shift matters conceptually because participation-based pressure can work differently from formal regulation: it may be more continuous, more visible, more politically salient, and more intertwined with local governance capacity. It also matters empirically because cities differ sharply in openness, fiscal resources, administrative responsiveness, and social information environments, all of which may shape how participation is converted into innovation.

The paper therefore sits at the intersection of three literatures: environmental regulation and innovation, eco-innovation measurement, and public-participation governance. Its theoretical expectation is not that public participation automatically generates innovation, but that it can do so when it raises the credibility of environmental pressure, improves policy responsiveness, and interacts with city-level absorptive capacity. This is precisely why mechanism analysis and heterogeneity analysis are essential rather than ornamental in the empirical design.

Measurement issues in green innovation deserve explicit attention because empirical conclusions depend partly on the chosen indicator. Patent counts are widely used because they are available at scale and comparable across units, but they capture only part of innovative activity. Some process improvements are never patented, some patents are strategic, and patent quality varies substantially. OECD methodological work has therefore invested heavily in patent-based environmental technology classifications [17, 38]. In this study, green patent grants are preferred to applications because they are closer to realized inventive success, while applications serve as a broader but noisier robustness measure.

The China-specific literature also shows that the effect of environmental regulation on innovation can be positive, negative, or nonlinear depending on policy design, industrial composition, competitive pressure, and firms' absorptive capacity [39]. Some studies emphasize the innovation-inducing role of energy and environmental targets, whereas others show that excessive administrative stringency can crowd out investment. These mixed results reinforce the value of moving beyond one-dimensional regulatory measures. Participation-based regulation may differ from administrative quotas because it changes the informational and accountability environment, which may matter as much as the formal rule itself.

A further lesson from the literature is that environmental governance increasingly operates through hybrid mechanisms that combine bureaucracy, markets, information, and public monitoring. This is particularly true in settings where disclosure platforms, social media, and digital participation lower the cost of public engagement. The governance relevance of public participation, then, should not be understood only through protest or formal consultation. It also includes lower-intensity but higher-frequency forms of scrutiny that change how local officials and firms perceive environmental risk. That hybrid understanding of governance is especially suitable for urban China, where formal state hierarchy remains strong but public visibility and performance signaling have become more consequential over time.

The empirical literature also suggests that regulatory effects are highly instrument-specific. Command-and-control standards, market-based instruments, disclosure systems, and campaign-style enforcement can affect firms through different channels. Dechezleprêtre and Sato [5] emphasize that the competitiveness consequences of environmental regulation cannot be summarized with a single number because innovation effects, relocation incentives, productivity responses, and trade adjustments may point in different directions. Public participation-based regulation should therefore be understood as an information-and-accountability instrument embedded in a wider governance system, not as a direct administrative standard.

Related work in corporate strategy provides a complementary perspective. Lee and Min [40] show that green R&D can improve environmental and financial performance, while Xie et al. [41] distinguish between green process and green product innovation and show that they can affect firm performance differently. For the present paper, the implication is that city-level green patenting may reflect multiple responses to public pressure, including cleaner processes, environmental management technologies, and product innovation.

3. ANALYTICAL FRAMEWORK AND HYPOTHESES

The analytical framework begins from a simple proposition: firms innovate when environmental pressure becomes sufficiently credible, persistent, and economically relevant. Participation-based environmental regulation can contribute to all three conditions. First, public complaints and social monitoring raise visibility. When pollution problems become publicly observable, firms face greater reputational risk, governments face greater political pressure, and inaction becomes harder to sustain. Second, public participation can increase the credibility of regulatory expectations. Even when formal standards remain unchanged, firms may infer that enforcement, monitoring, and social attention are becoming more intense. Third, participation may alter the local political economy of regulation by making environmental performance more salient to municipal officials, especially when public scrutiny interacts with performance assessment, media attention, or campaign-style governance.

This argument implies a baseline hypothesis. Hypothesis 1 is that public participation-based environmental regulation promotes urban green innovation. The expected sign is positive because participation should strengthen incentives for cleaner technological upgrading, especially when the costs of remaining dirty rise relative to the costs of innovation. The innovation response is measured at the city level because a city aggregates both direct firm responses and wider ecosystem effects such as university research, policy signaling, and localized spillovers.

Two supportive mechanisms are considered. The first is government response. Public participation may increase the speed and intensity with which local governments respond to environmental issues. In principle, stronger responsiveness can change firms' expectations about future inspections, approvals, and enforcement behavior, which may in turn increase green innovation. This leads to Hypothesis 2: public participation-based environmental regulation promotes urban green innovation partly through stronger government response. The second mechanism is environmental governance capacity. Participation may improve environmental governance by increasing information flows, reinforcing accountability, and making implementation more consistent. When governance quality improves, innovation becomes a more credible long-run strategy than short-run evasion. This leads to Hypothesis 3: public participation-based environmental regulation promotes urban green innovation through better environmental governance performance.

The framework also predicts heterogeneous effects. Public pressure is not converted into innovation in a vacuum. Cities with greater openness may have better information flows, stronger competition, higher exposure to international environmental norms, and greater access to technology and capital. Cities with greater environmental expenditure have stronger fiscal capacity to implement, co-finance, and sustain environmental upgrading. Accordingly, the effect of participation-based environmental regulation is expected to be stronger in cities with higher openness and higher environmental expenditure. This expectation does not merely add nuance; it tests whether participation works through institutional and fiscal channels that make innovation responses more feasible.

4. DATA, VARIABLES, AND EMPIRICAL STRATEGY

The dataset is a city-year panel compiled for this study from the underlying empirical materials and supporting data file. The raw file contains 2,887 observations and 57 variables. After imposing the lag structure required for the key explanatory variable and retaining the control set used in the preferred regressions, the analytical sample for the main specification contains 2,488 city-year observations covering 2013–2021. The gap between the raw file and the regression sample mainly reflects lag construction and the need for common support across variables.

The main dependent variable is urban green innovation measured as ln(green patent grants + 1), denoted y_grant_ln_w. This transformation reduces right-skewness and makes the scale more interpretable in a panel setting where patent counts can vary dramatically across cities. The main robustness outcome is ln(green patent applications + 1), denoted y_apply_ln_w. Patent grants are used as the preferred measure because they are a stricter indicator of successful green invention output, while applications are kept as a broader and more forward-looking robustness measure.

The key explanatory variable is x_pp_l123avg_ln_w, the one- to three-period lagged average of the logged public participation-based environmental regulation indicator. Using a smoothed lag structure is conservative. It reduces short-run noise, mitigates concerns that contemporaneous spikes in participation capture transitory events rather than persistent governance pressure, and better aligns the timing of participation pressure with the slower adjustment process through which innovation responds. Because innovation is path dependent, the preferred dynamic model also includes lagged green patent grants (L1_y_grant_ln_w).

The control strategy follows the study's baseline empirical design. Baseline controls include population density, GDP per capita, financial development, openness, government intervention, urbanization rate, and the secondary-industry share. Richer specifications additionally include institutional and fiscal conditions such as the rule-of-law environment and the environmental expenditure share. The mechanism section uses government-response and environmental-governance indices as supportive proxies rather than fully exogenous mediators.

Descriptive statistics reveal a panel with substantial cross-city variation. In the preferred sample, the mean of ln(green patent grants + 1) is 4.666, while the mean of the participation-based environmental regulation variable is 2.752. Urbanization averages 0.574 and the secondary-industry share 0.443. These values indicate that the sample covers a meaningful range of city types, from less urbanized and more industrial cities to more service-oriented urban economies. The correlation matrix shows a clear positive bivariate association between green patenting and the participation variable, but also underscores the importance of multivariate estimation because the participation measure is correlated with development, finance, urbanization, and industrial structure.

Figures based on the actual dataset help contextualize the regressions. The distribution of green innovation is right-skewed even after the logarithmic transformation, validating the use of ln(1 + x). The public-participation variable also shows meaningful dispersion. Average green patent grants rise over time, while the mean participation variable increases more gradually and then stabilizes. These patterns are consistent with a setting in which both innovation capacity and participation-based governance pressure become more prominent over the sample period, but at different speeds.

One reason public participation may matter especially at the city level is that it operates through spatially concentrated information. Complaints, petitions, media reports, and social scrutiny are often localized. They identify specific neighborhoods, industrial zones, firms, and incidents. That local visibility can generate pressure that broad provincial or national indicators do not fully capture. If so, city-level estimation is not merely a compromise imposed by data availability; it is theoretically appropriate for the mechanism under study.

The baseline empirical model is a two-way fixed effects specification. City fixed effects absorb time-invariant characteristics such as geographic location, long-run industrial legacy, and enduring governance traits, while year fixed effects absorb common shocks such as national policy changes, macroeconomic fluctuations, and countrywide shifts in environmental salience. In notation, the static model relates green innovation in city i and year t to the lagged participation-based regulation measure, a vector of controls, city fixed effects, year fixed effects, and an idiosyncratic error term. Standard errors are clustered at the city level to account for serial correlation and heteroskedasticity.

The preferred specification is dynamic. Innovation is path dependent because cities with stronger research bases, patenting ecosystems, or incumbent green sectors often continue to innovate more in the future. Excluding this inertia risks overstating the short-run explanatory power of participation-based regulation if both are correlated with persistent innovation capacity. Accordingly, the preferred model includes lagged green patent grants in addition to the participation variable, controls, and fixed effects. This is not a full solution to endogeneity, but it is a disciplined way to avoid treating innovation as memoryless.

The empirical chapter is deliberately conservative in interpretation. The coefficients are estimated as associations conditional on extensive controls and two-way fixed effects, and the discussion of mechanisms is framed as supportive rather than definitive. This matters because participation-based environmental regulation can itself be endogenous to local environmental conditions, state capacity, media attention, or citizen preferences. The present design addresses part of that concern through lags, fixed effects, dynamic controls, and robustness exercises, but it does not eliminate all possibilities of omitted variables or reverse causality.

To thicken the empirical strategy beyond a single benchmark table, the paper includes descriptive statistics, correlation analysis, trends, mechanism tests, heterogeneity analysis, and identification-oriented stress tests. This layered design is valuable even when the identification is not quasi-experimental. It makes it possible to ask whether the positive coefficient is isolated to one specification, whether the result survives richer controls, whether supportive channels are plausible, and whether the effect is stronger where theory predicts it should be stronger. In practical thesis writing, this kind of structured accumulation of evidence is often more convincing than a mechanically long but conceptually thin empirical chapter.

Because the analytical sample is generated from lag construction, sample transparency is important. The paper therefore reports both raw-file and regression-sample information. The raw dataset contains 2,887 observations, while the preferred regression sample contains 2,488 observations. The remaining gap is mostly attributable to missing lag structures at the beginning of the panel and to the need for consistent observations across the main control variables. This is a standard but often underreported issue in panel innovation work. Explicitly documenting it improves the credibility and reproducibility of the empirical chapter.

Table 1. Variable definitions and empirical roles

Variable	Definition	Role	Use in the paper
y_grant_ln_w	ln(green patent grants + 1)	Main dependent variable	Preferred outcome
y_apply_ln_w	ln(green patent applications + 1)	Alternative dependent variable	Robustness outcome
x_pp_l123avg_ln_w	1–3 lag average of public participation regulation	Core explanatory variable	Main explanatory factor
L1_y_grant_ln_w	Lagged green patent grants	Dynamic control	Captures path dependence
pop_density_ln	Population density	Control variable	Urban scale and congestion
gdp_pc_ln	GDP per capita	Control variable	Development level
finance_dev_ln	Financial development	Control variable	Financial capacity
open_ratio	Openness	Control / heterogeneity variable	External exposure
gov_intervention	Government intervention	Control variable	Administrative involvement
urban_rate	Urbanization rate	Control variable	Urban structure
industry_share2	Secondary-industry share	Control variable	Industrial structure
rule_law	Rule-of-law environment	Extended control	Institutional quality
env_exp_share	Environmental expenditure share	Extended control / heterogeneity variable	Fiscal support
gov_response_idx	Government response index	Mechanism proxy	Supportive channel
env_gov_idx	Environmental governance index	Mechanism proxy	Supportive channel

Note. Variable labels are harmonized with the empirical coding scheme used in the study. The preferred analytical sample used in the main regressions contains 2,488 city-year observations.

Table 2. Descriptive statistics for the preferred analytical sample

Variable	Mean	Std. Dev.	Min	Max	Obs.
Green patent grants	4.666	1.625	0.000	9.155	2488
Green patent applications	5.146	1.651	0.000	9.468	2488
Public participation regulation	2.752	0.927	0.124	4.895	2488
Lagged green patent grants	4.425	1.633	0.000	8.909	2488
Population density	5.748	0.941	0.683	7.882	2488
GDP per capita	10.816	0.548	9.037	13.056	2488
Financial development	2.627	1.249	0.670	21.302	2488
Openness	0.017	0.018	0.000	0.229	2488
Government intervention	0.206	0.097	0.044	0.741	2488
Urbanization rate	0.574	0.142	0.182	1.000	2488
Secondary-industry share	0.443	0.096	0.000	0.839	2488
Rule of law	8.838	3.164	1.910	16.507	2488
Environmental expenditure share	0.030	0.017	0.000	0.193	2488
Government response index	0.025	0.793	-9.848	2.075	2484
Environmental governance index	0.098	0.566	-4.377	0.825	2062

Note. Descriptive statistics are calculated from the preferred regression sample after imposing the lag structure and baseline covariate availability.

Table 3. Correlation matrix of key variables

	Green grants	Participation	GDP pc	Finance	Open	Gov intv.	Urban	Industry 2
Green grants	1.000	0.658	0.575	0.218	0.206	-0.520	0.454	0.314
Participation	0.658	1.000	0.551	0.361	0.246	-0.533	0.497	0.407
GDP pc	0.575	0.551	1.000	0.163	0.250	-0.655	0.769	0.292
Finance	0.218	0.361	0.163	1.000	0.056	0.165	0.425	0.631
Open	0.206	0.246	0.250	0.056	1.000	-0.208	0.203	0.098
Gov intv.	-0.520	-0.533	-0.655	0.165	-0.208	1.000	-0.421	0.058
Urban	0.454	0.497	0.769	0.425	0.203	-0.421	1.000	0.414
Industry2	0.314	0.407	0.292	0.631	0.098	0.058	0.414	1.000

Note. Correlations are Pearson correlations for the preferred analytical sample. The table is intended for descriptive orientation rather than causal interpretation.

Table 4. Sample structure by year

Year	Observations	Mean green grants	Mean green applications	Mean participation regulation
2013	281	3.941	4.241	2.674
2014	281	3.993	4.469	2.665
2015	281	4.305	4.802	2.718
2016	281	4.464	5.022	2.734
2017	275	4.544	5.301	2.759
2018	282	4.908	5.424	2.810
2019	283	4.897	5.540	2.866
2020	284	5.333	5.785	2.797
2021	240	5.755	5.816	2.743

Note. The regression sample spans 2013–2021. The reduction in 2021 observations reflects data availability after lag construction.

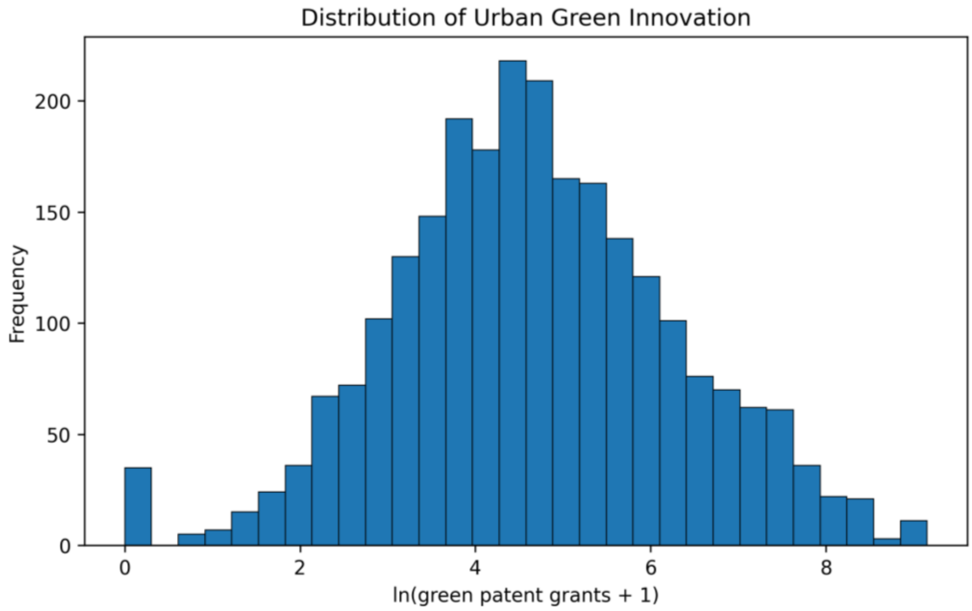

Figure 1. Distribution of urban green innovation

Note. Histogram based on ln(green patent grants + 1) in the preferred analytical sample.

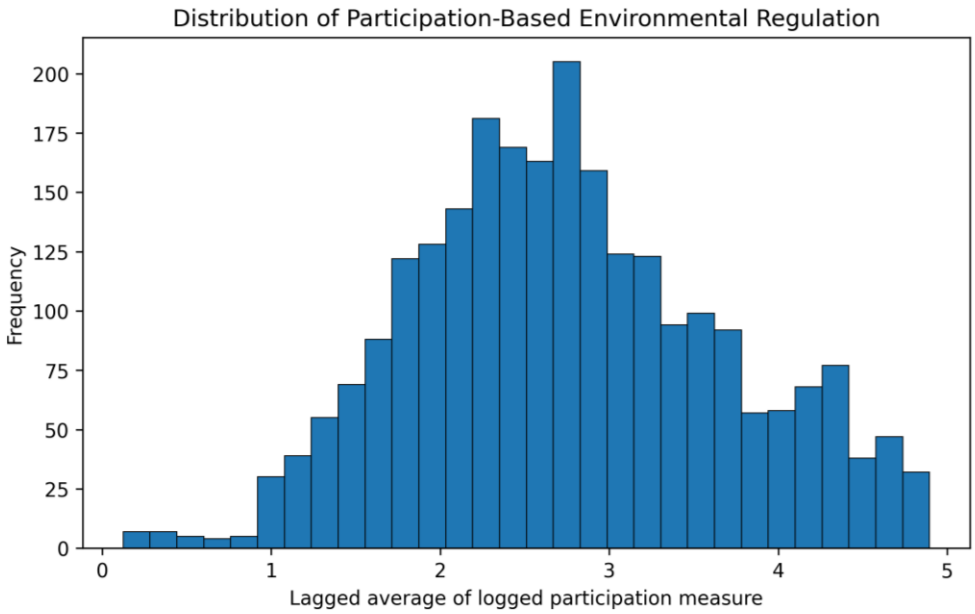

Figure 2. Distribution of public participation-based environmental regulation

Note. Histogram based on the one- to three-period lagged average of the logged participation measure.

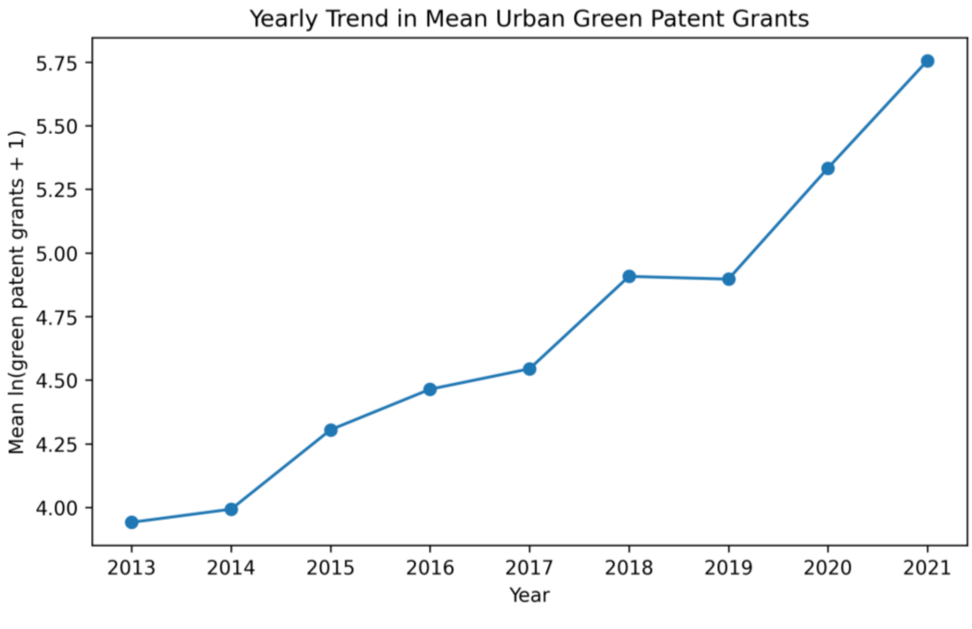

Figure 3. Yearly trend in mean urban green patent grants

Note. Source: author's calculations.

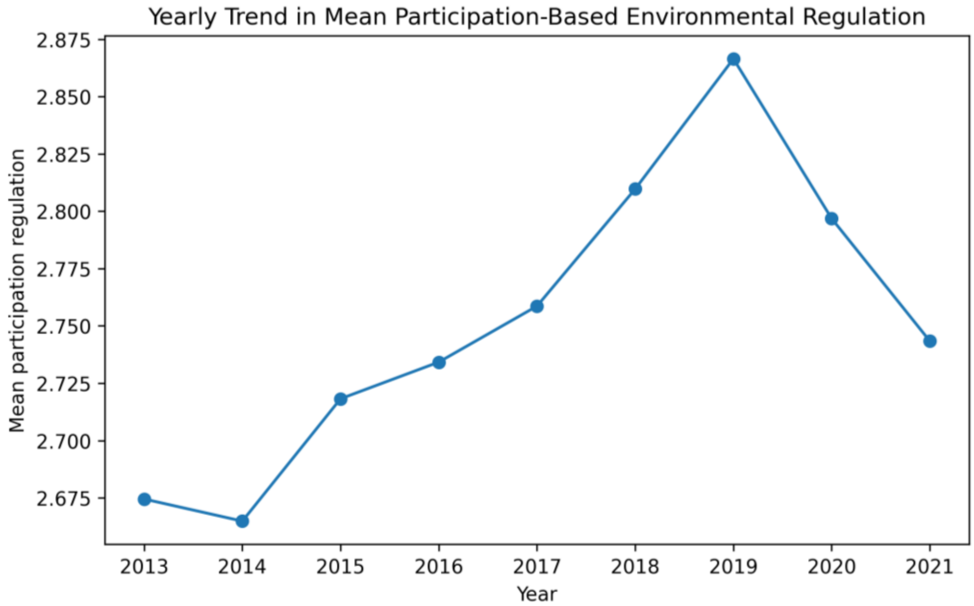

Figure 4. Yearly trend in mean public participation-based environmental regulation

Note. Source: author's calculations.

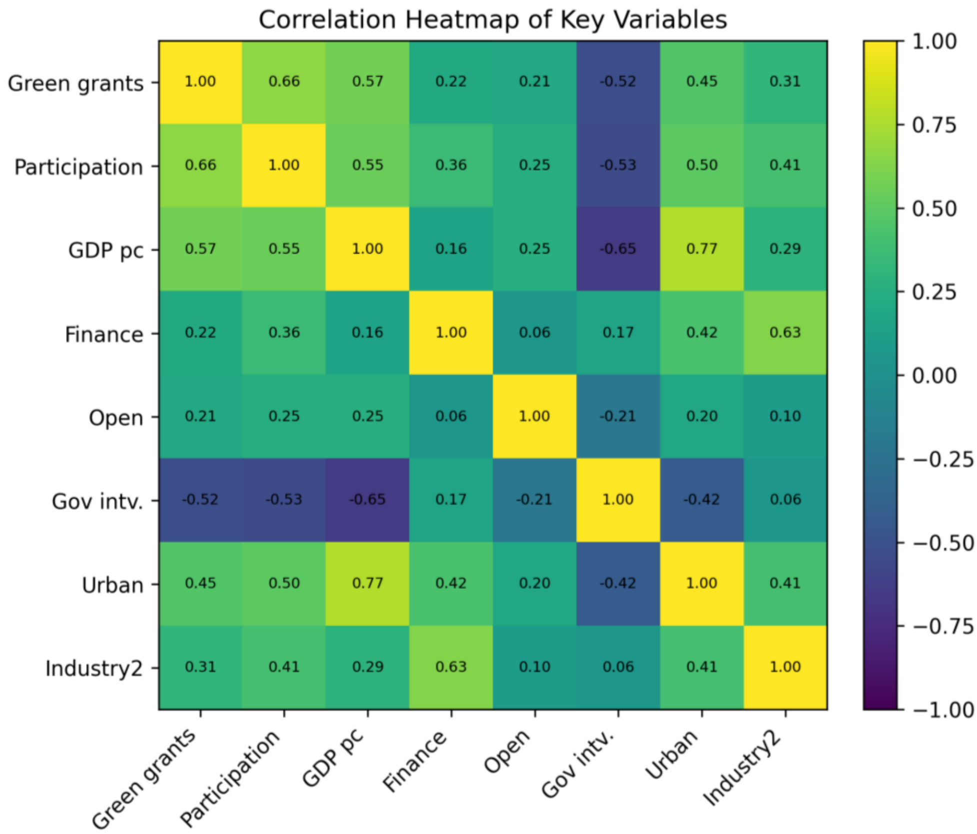

Figure 5. Correlation heatmap of key variables

Note. The heatmap provides a descriptive view of associations among the most important regression variables.

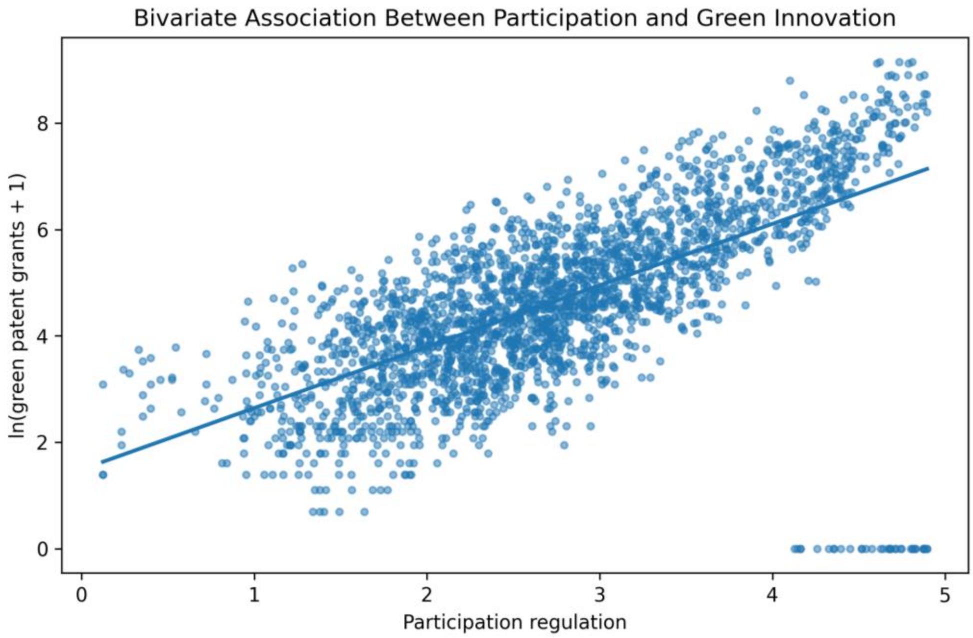

Figure 6. Bivariate association between participation and green innovation

Note. The fitted line is descriptive and does not control for fixed effects or covariates.

5. BASELINE EMPIRICAL RESULTS

The main regression results are summarized in Table 5. Column (1) reports the baseline two-way fixed effects model, in which the coefficient on public participation-based environmental regulation is 0.1513 with a standard error of 0.0582 and a p-value of 0.0094. This is already a substantively meaningful positive estimate. Column (2), the preferred dynamic two-way fixed effects specification, yields a coefficient of 0.1083 with a standard error of 0.0400 and a p-value of 0.0068. Because this specification controls for lagged green innovation, city fixed effects, year fixed effects, and the core economic covariates, it provides the most persuasive estimate in the paper. The positive coefficient survives the inclusion of innovation persistence, which suggests that the main finding is not a simple artifact of serially correlated innovation performance.

Column (3) adds richer institutional and fiscal controls and still returns a positive and statistically significant coefficient of 0.0939. This attenuation is substantively expected. Once the rule-of-law environment and fiscal conditions are included, part of the raw correlation between participation and innovation is absorbed by broader governance capacity. Yet the participation coefficient remains significant, which supports the argument that public participation has an independent relationship with green innovation even after richer contextual controls are introduced.

Column (4) replaces patent grants with patent applications. The coefficient remains positive at 0.0657 but is not statistically significant at conventional levels. This result should not be hidden or downplayed. Instead, it should be interpreted carefully. Green patent applications are a noisier measure because they capture intent and early-stage inventive effort as well as successful follow-through. The loss of precision here does not overturn the main result; rather, it suggests that the clearest effect of participation-based environmental regulation appears in the stricter outcome measure of granted green patents.

Column (5) restricts the sample to the 2015–2019 subperiod and produces a coefficient of 0.2047 with a standard error of 0.0759. This is larger than the preferred full-sample estimate and statistically significant. The result indicates that the positive relationship is not driven only by the early or late years of the panel. It may also suggest that the conversion of public participation into innovation was particularly strong in the middle years of the sample when governance signals, reporting channels, and green innovation policy may have aligned more tightly.

The figures make the regression evidence easier to read. The coefficient plot for the baseline and robustness models shows that the core estimate is positive in every specification and comfortably above zero in the preferred dynamic model, the richer-control model, and the restricted-sample model. The confidence interval for the alternative-dependent-variable specification crosses zero, but the direction remains positive. This visual consistency matters because it prevents an overreliance on one favorite model; the paper's claim is better framed as a consistent positive pattern centered on the preferred dynamic specification rather than as a universal statement that every specification is equally strong.

An additional advantage of presenting the actual data distributions and time trends before the main regression tables is that they discipline interpretation. The yearly averages show that green patenting rose substantially over the sample period, whereas the participation variable increased more gradually and then flattened somewhat toward the end of the period. That difference in timing matters. It suggests that the positive regression result is not simply a mechanical by-product of two variables drifting upward in parallel. Instead, the regression is identifying a within-city relationship after removing common year shocks and persistent city traits. The bivariate scatter likewise shows a positive association, but one with visible dispersion, reinforcing the need for fixed effects and controls rather than simple cross-sectional inference.

Substantively, the magnitude of the preferred dynamic coefficient is not trivial. A coefficient of 0.1083 in a log-transformed innovation equation implies that shifts in participation-based environmental pressure are associated with meaningful differences in green patent output, especially when accumulated over time and across city innovation systems. In a context where innovation is path dependent, even moderate annual effects can alter long-run technological trajectories. This point is easy to miss when discussion focuses only on significance levels. For policy relevance, the important issue is whether the estimated relationship is large enough to matter in practice. On that criterion, the preferred estimate is policy-relevant as well as statistically credible.

At the same time, the non-significant coefficient for green patent applications should be interpreted as a useful boundary condition rather than a weakness that undermines the entire paper. Applications and grants capture different margins of behavior. Participation pressure may matter more for the completion, quality, and persistence of green invention efforts than for the initial filing decision. Alternatively, the applications series may simply contain more short-run volatility. In either case, the distinction between applications and grants enriches the empirical interpretation by suggesting that public participation may be more closely connected to realized green innovation output than to the earliest observable stage of inventive activity.

Table 5. Baseline and robustness regression results

Variable / statistic	(1) M1	(2) M2	(3) M3	(4) M4	(5) M5
Public participation regulation	0.1513***	0.1083***	0.0939**	0.0657	0.2047***
Standard error	(0.0582)	(0.0400)	(0.0409)	(0.0443)	(0.0759)
Lagged dependent variable	No	Yes	Yes	No	No
Institutional & fiscal controls	No	No	Yes	No	No
Dependent variable	Green grants	Green grants	Green grants	Green applications	Green grants
Sample period	2013–2021	2013–2021	2013–2021	2013–2021	2015–2019
City fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2488	2488	2488	2488	1402
Within R^2	0.187	0.551	0.611	0.583	0.283
P-value of core coefficient	0.0094	0.0068	0.0217	0.1379	0.0071

Note. M1 is the baseline two-way fixed effects model. M2 is the preferred dynamic two-way fixed effects model. M3 adds institutional and fiscal controls. M4 replaces the dependent variable with green patent applications. M5 uses the 2015–2019 subsample. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

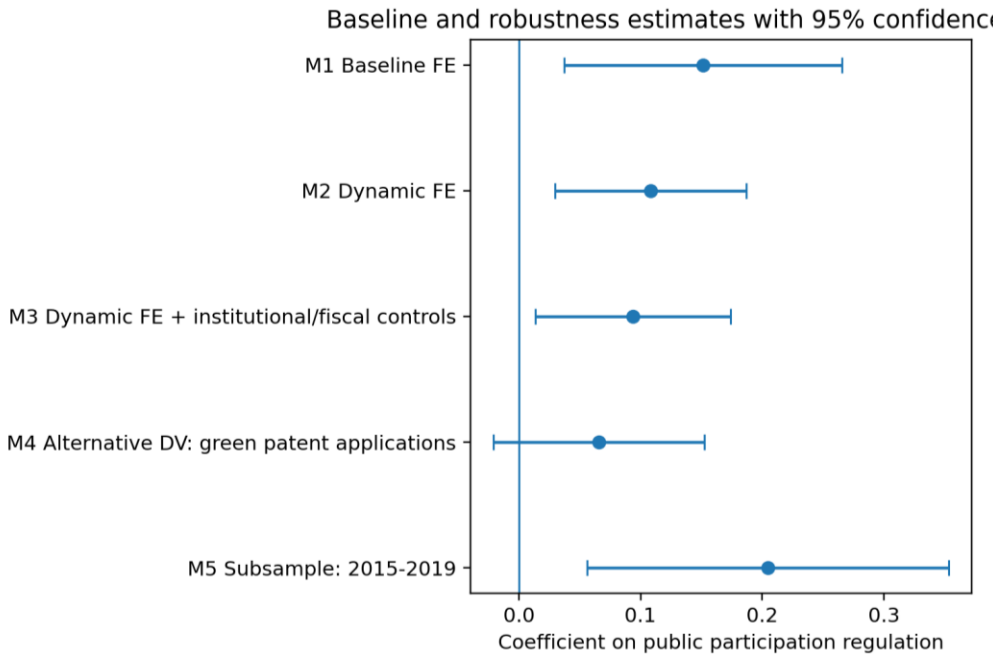

Figure 7. Baseline and robustness coefficients with 95% confidence intervals

Note. Confidence intervals are constructed from the reported coefficients and standard errors in Table 5.

6. MECHANISM ANALYSIS

The mechanism analysis is intentionally modest in tone. The data are better suited to supportive mechanism evidence than to a fully identified mediation design, and the paper treats them accordingly. Table 6 reports two channels: government response and environmental governance. In the first-stage regressions, the key explanatory variable does not strongly predict the mechanism variables. For the government-response first stage, the core coefficient is 0.1067 with a p-value of 0.1941; for the environmental-governance first stage, it is 0.0293 with a p-value of 0.6700. These results imply that participation-based regulation is not powerfully sorting cities on the mechanism proxies in the reduced-form first step.

The second-stage regressions are more informative. When the government-response index is included in the innovation equation, the mechanism coefficient is 0.0185 with a p-value of 0.0750, which is only marginally significant. By contrast, when the environmental-governance index is included, the mechanism coefficient is 0.0918 with a p-value of 0.0004. The core participation coefficient also remains positive in both second-stage regressions. The combined pattern suggests that environmental governance performance is a more convincing supportive channel than government response in the current sample.

Substantively, this difference makes sense. Government response can be episodic, symbolic, or unevenly documented, especially when it is measured through broad indices. Environmental governance performance, by contrast, is closer to the organizational and institutional capacity through which public pressure is translated into implementation, monitoring, and follow-through. If participation raises the salience of environmental problems, cities with stronger governance systems are more likely to convert that pressure into durable actions that affect firms' incentives and expectations. That is precisely the kind of setting in which green innovation becomes a rational strategic response.

The paper therefore adopts a careful formulation: environmental-governance improvement is the stronger supportive mechanism, while the government-response channel remains plausible but weaker. This is analytically more credible than claiming a fully established mediation structure. It aligns the empirical interpretation with the actual strength of the available evidence.

Table 6. Mechanism test results

Variable / statistic	(1) Gov. response stage 1	(2) Env. governance stage 1	(3) Gov. response stage 2	(4) Env. governance stage 2
Core participation coefficient	0.1067	0.0293	0.1070***	0.1139***
Standard error of core coefficient	(0.0821)	(0.0687)	(0.0399)	(0.0437)
Mechanism coefficient	—	—	0.0185*	0.0918***
Mechanism p-value	—	—	0.0750	0.0004
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	2484	2062	2482	2066

Note. The mechanism evidence is interpreted as supportive rather than definitive. The stronger channel in the current sample is environmental governance rather than government response. Significance: *** $p < 0.01$, * $p < 0.10$.

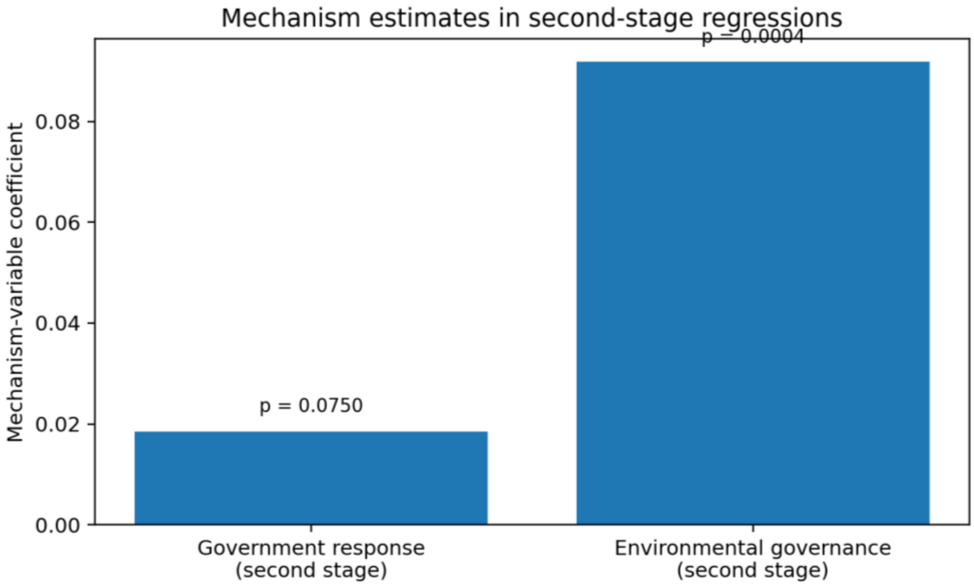

Figure 8. Mechanism-variable coefficients in the second-stage regressions

Note. Because the supplied summary table reports p-values but not standard errors for the mechanism coefficients, the figure presents coefficient magnitudes with exact p-values instead of confidence intervals.

7. HETEROGENEITY ANALYSIS

The heterogeneous-effect analysis focuses on two city characteristics that theory suggests should matter for translation rather than merely for exposure: openness and environmental fiscal capacity. Table 7 reports that the coefficient on public participation-based environmental regulation is 0.1432 in high-openness cities but only 0.0833 in low-openness cities, with significance appearing only in the high-openness group. A similar pattern appears for environmental expenditure: the coefficient is 0.1511 in high-environmental-expenditure cities but 0.0673 in low-expenditure cities, again with significance concentrated in the higher-capacity group.

These results are substantively important because they show that public participation is not a free-standing institutional force. Openness can proxy for information circulation, exposure to external standards, competition, and access to technology and capital. Environmental expenditure can proxy for local fiscal ability to implement environmental projects, absorb policy pressure, and sustain innovation-oriented upgrading. When participation pressure emerges in these environments, it is more likely to produce a concrete innovation response rather than symbolic compliance.

The heterogeneity figure reinforces this interpretation. Confidence intervals in the higher-openness and higher-expenditure groups sit farther from zero than those in the lower-capacity groups. This pattern strengthens the paper's internal logic: if participation mattered only because it captured generic environmental concern or omitted city quality, one would not necessarily expect the effect to be systematically stronger where absorptive and fiscal conditions are better. Instead, the evidence supports the view that participation needs enabling conditions to become technologically productive.

The data likewise contain information that helps contextualize the heterogeneity results. Higher-openness cities tend to have higher mean levels of green innovation and public participation, but they also differ in finance, industrial structure, and urbanization. High-environmental-expenditure cities are not simply richer cities; they are also places where the local state has devoted a greater budget share to environmental purposes. These patterns underscore why the heterogeneity coefficients should not be read as pure treatment effects. Their value lies in showing that the participation-innovation relationship is stronger where theory predicts that pressure can be translated into action more effectively.

Table 7. Heterogeneous effects by openness and environmental expenditure

Variable / statistic	(1) High openness	(2) Low openness	(3) High env. expenditure	(4) Low env. expenditure
Core participation coefficient	0.1432**	0.0833	0.1511**	0.0673
Standard error	(0.0579)	(0.0625)	(0.0605)	(0.0659)
P-value	0.0136	0.1824	0.0127	0.3076
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	1241	1247	1265	1223

Note. Higher-capacity cities show stronger effects. Significance: ** $p < 0.05$.

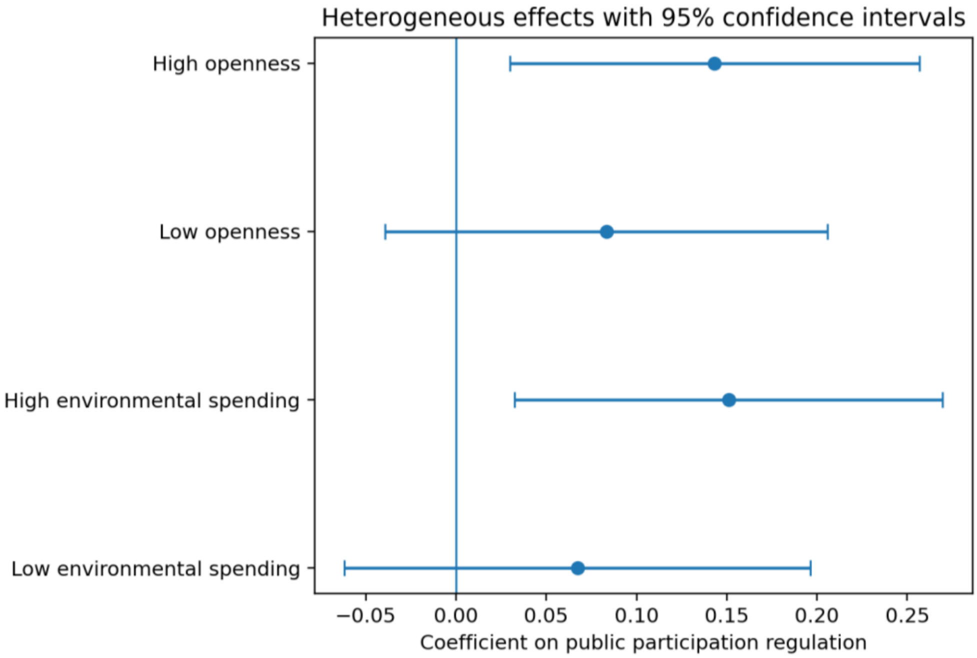

Figure 9. Heterogeneous coefficients with 95% confidence intervals

Note. Confidence intervals are constructed from the reported coefficients and standard errors in Table 7.

8. ROBUSTNESS, IDENTIFICATION, AND REMAINING DATA NEEDS

The main robustness evidence is already embedded in Table 5: the positive coefficient survives the dynamic specification, richer controls, and the balanced subperiod. Together with the descriptive trends and the coefficient plot, these results suggest that the central finding is not driven by a single specification choice.

The identification strategy, however, remains observational. Two-way fixed effects with a lagged dependent variable helps address persistent city characteristics and innovation inertia, but it does not provide an exogenous shock. Supplementary checks—such as province-by-year fixed effects, lead-placebo tests using future participation, and interactions with the post-supervision period—should therefore be treated as supportive rather than decisive, especially because complete numerical outputs are not yet available in the current draft.

A stronger identification design would require finer complaint microdata, direct measures of inspections and penalties, pollution-concentration shocks, or clearly timed policy events that can support event-study or difference-in-differences estimation.

Accordingly, the contribution of the paper is not a definitive causal claim, but a coherent set of results: a stable positive association, theoretically consistent heterogeneity, and stronger support for environmental governance than for government response as the relevant transmission channel.

9. POLICY IMPLICATIONS

The policy implications are straightforward but not simplistic. First, environmental governance systems can benefit from making public participation easier, more visible, and more usable. Complaint platforms, environmental information disclosure, and feedback mechanisms matter not only because they may improve short-run compliance, but also because they can shape the long-run incentives for green technological change. A participation channel that is hard to access or rarely answered will have weaker innovation consequences than one that reliably feeds into governance routines.

Second, the results suggest that public participation should not be treated as a cheap substitute for state capacity. The stronger mechanism evidence points to environmental-governance performance rather than merely to symbolic response. Policymakers therefore need to invest in monitoring systems, data integration, technical review capacity, and implementation routines that allow public information to be translated into credible action. In this sense, participation and capacity are complements rather than alternatives.

Third, the heterogeneity results indicate that openness and fiscal support matter. Cities with better external connectivity and stronger environmental expenditure appear more capable of turning public pressure into innovation. This implies that participation-based governance should be paired with policies that improve local absorptive capacity: green finance access, innovation support, environmental infrastructure, and stable municipal funding for environmental programs. Participation can start the pressure cycle, but capacity determines whether it ends in technological upgrading or merely in temporary administrative reaction.

From a governance-design perspective, the results also imply that participation mechanisms should be judged by their institutional usability, not just by their nominal existence. A formal complaint channel that generates reports but does not feed into problem-solving routines will have limited value. By contrast, a system that links public reporting to case handling, data integration, interdepartmental coordination, and visible follow-up is much more likely to alter firms' expectations and thereby influence innovation choices. In other words, the productive force in participation is not voice alone, but voice plus administrative conversion capacity.

Finally, the paper has implications for how cities think about green transformation strategy. Green innovation policy is often framed as a matter of subsidies, industrial plans, or technology programs. These matter, but the present results suggest that the social governance environment also belongs in the innovation policy toolkit. Public participation can reinforce the demand side of green transition by increasing pressure for environmental performance, and this in turn can improve the payoff to innovation investments. For city governments, the lesson is that better environmental governance and stronger innovation performance should not be treated as separate agendas.

10.CONCLUSION

This paper studies the relationship between public participation-based environmental regulation and urban green innovation using a Chinese city-level panel. Across the baseline fixed-effects model, the preferred dynamic specification, the richer-control model, and the main subsample test, the core estimate remains positive. The preferred dynamic result indicates that stronger participation-based regulation is associated with significantly higher green patent grants after accounting for city effects, year effects, and innovation persistence. Supportive mechanism evidence favors the environmental-governance channel over the government-response channel, while heterogeneity analysis shows that the relationship is stronger in cities with higher openness and higher environmental expenditure.

The broader implication is that environmental governance should be understood not only as a matter of formal rules imposed from above, but also as a governance process in which public scrutiny, institutional capacity, and technological upgrading interact. Public participation appears capable of helping redirect urban development toward greener innovation, but its effectiveness depends on the local conditions that make participation credible and governable. Future work can strengthen causal identification by integrating richer complaint, enforcement, and pollution-shock data. Even so, the current evidence already supports a clear substantive conclusion: when public participation is embedded in capable local governance, it can become an important part of the city's green innovation system.

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