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When Do Institutions Enable Sustainability? Organizational Trade-offs Between Regulation, Innovation, and Resource Depletion

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ABSTRACT:
Contrary to the conventional notion that institutions are always beneficial for sustainability, we propose a two-sector endogenous growth model with microeconomic foundations that conceptualizes the role of institutions in resource allocation between the production sector and the R&D sector. Our framework predicts three organizational channels through which institutions affect sustainability outcomes: innovation incentives, resource efficiency, and pollution reduction. Crucially, these channels are not unconditional but depend on a sufficiently large initial allocation of human capital to the R&D sector, and on effective regulatory capacity. Using the method of moments quantile regression, we evaluate the empirical relevance of these channels. Our findings show that the effect of institutions varies systematically across the conditional distribution of sustainability outcomes, indicating that similar governance structures can lead to divergent outcomes. This highlights the importance of enforcement and organizational innovation capabilities in navigating ecological limits, with institutional quality serving only as a moderating factor.

Keywords: Endogenous Growth, Net Output Growth, Institutional Quality, Innovation, Natural Resource, Pollution Control

1. Introduction

Sustainability transitions are increasingly conditioned by the way organizations behave, adapt, and coordinate in the face of ecological stress and institutional disruption. Organizations, whether firms, public institutions, or regulatory bodies, are expected to support innovation, environmental protection, and economic viability simultaneously. Yet, these demands are often in conflict, prompting the question of the organizational conditions for effective sustainability driven by governance.

Institutions are at the core of organizational dynamics in the context of sustainability. Earlier studies highlight the importance of institutional quality as a basis for governance and economic performance in the long term (Olson, 1982; North, 1991; Acemoglu & Johnson, 2005). More recent studies on sustainability have built on this literature, but the organizational mechanisms through which institutions support or hinder sustainable economic growth are not well understood. Specifically, the question remains why similar institutional settings lead to different sustainability performance in different countries or organizational contexts.

A major challenge in this respect is the organizational trade-offs created by the presence of these institutions. For instance, while better environmental regulations may lead to a better natural environment, they may also reshape organizational incentives,

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leading to a reduction in innovation due to the increase in costs of compliance (Blind, 2012; Aghion et al., 2023). This, therefore, highlights the fact that the strength of institutions alone is not enough to ensure sustainability. Instead, outcomes depend on how institutions interact with organizational capabilities.

This paper investigates the conditions and channels through which institutional quality contributes to long-run sustainable growth. Relative to Romer (1990) and Cozzi (2017), our framework retains the allocation of human capital between production and research and development (R&D) sectors and the endogenous determination of technological change. We depart from these benchmark models by introducing three additional mechanisms. First, the stock of an exhaustible natural resource evolves subject to regulatory effectiveness, which offsets part of the extraction pressure. Second, institutional capacity plays a role in the R&D sector, where its contribution to innovation is conditioned by regulatory effectiveness. Third, institutional implementation also affects the enforcement of environmental policy and thereby pollution mitigation. Hence, the novelty of our framework lies not in altering the standard source of endogenous technological change, but in showing how its growth contribution becomes jointly conditioned by institutional implementation and ecological constraints. The model reveals two conditions for sustaining long-run economic growth. First, an initial significant level of human capital allocation in the R&D sector should be met, as a reflection of organizational capabilities in generating innovations; second, the effectiveness of regulations should reduce the rate of resource depletion in the presence of ecological limits.

Unlike the Romer–Cozzi benchmark, in which institutional implementation is not an explicit component of the growth mechanism, our framework introduces institutional capacity and regulatory effectiveness as structural modifiers of endogenous innovation and environmental constraints. When the required conditions are met, institutions influence sustainability outcomes through three interrelated organizational channels: innovation incentives, resource efficiency, and pollution mitigation. This perspective helps explain why institutional reforms do not uniformly translate into sustainable outcomes and highlights the importance of regulatory effectiveness and enforcement capacity rather than institutional expansion alone.

We assess the empirical relevance of these mechanisms with the use of the Method of Moments Quantile Regression (MMQR) (Machado & Silva, 2019) for a sample of 107 countries. This approach allows us to capture heterogeneity in organizational and institutional responses across the conditional distribution of sustainable growth. The results indicate that some institutional and organizational mechanisms operate only at specific sustainability levels, while others are robust across contexts. This explains why similar regulatory reforms can produce markedly different outcomes across organizations and economies.

2. Model

The model comprises two sectors: production and R&D. Production results in emissions. The R&D sector consists of inventors who further technological progress.

2.1 Production sector

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The final output sector consists of identical firms that produce a composite good. Building on but diverging from the work of Sriket and Suen (2022), who specified different technologies for resource and human capital inputs, we assume a unified technological factor A_t as depicted in Eq. (1):

$$Y_t = h(f(A_t, R_t, H_{Y,t}), K_t) \quad (1)$$

where Y_t is output at time *t* depending on A_t, the level of technology; R_t, non-renewable natural resources input; $H_{Y,t}$, human capital input used in the production sector; and K_t, physical capital input. The inner and outer functions f and h allow better granulation of inputs, unlike the Solow/Stiglitz-type production function.

Previous studies such as Barbier (1999) considered natural resources as exhaustible, where extraction reduces current stock and constrains long-term growth. We extend the specification by introducing regulatory (or implementation) effectiveness (denoted by λ) to moderate resource depletion and determine its influence on sustainability outcomes. This regulatory effectiveness represents the extent to which institutional capacity is translated into effective economic outcomes. Natural resources at time *t* can now be defined as

$$R_t = R_0 e^{-(s-\lambda)t} \text{ or } \dot{R} = (\lambda - s)R_t, \quad (2)$$

R_0 is the initial stock of natural resources, $s \in (0,1)$ is the extraction rate, and $\lambda \in (0,1)$ is regulatory effectiveness. Resource depletion occurs when the extraction rate exceeds regulatory effectiveness, $s > \lambda$. We focus on the economically relevant case $0 < \lambda < s$, under which the resource stock continues to decline, but regulatory effectiveness partially offsets depletion by reducing the effective depletion rate from s to $s - \lambda$. Thus, higher regulatory effectiveness slows the rate of resource loss without implying regeneration of the non-renewable resource stock.

Firms face a pollution tax τ_p, which is levied on output. This induces abatement $D = \tau_p Y$ and pollution P. The pollution-abatement relationship follows the work of Chu and Lai (2014):

$$P_t = \left(\frac{Y_t}{D_t}\right)^{\frac{1}{b}} \text{ with } \frac{1}{b} > 0 \quad (3)$$

Profit is maximized at time *t* by choosing R_t, $H_{Y,t}$, and K_t:

$$\max_{Y,H_y,K,R} \pi_{y,t} = (1-\tau_p)h\big(f\big(A_t, R_t, H_{Y,t}\big), K_t\big) - p_t R_t - w_{Y,t} H_{Y,t} - r_t K_t \quad (4)$$

Here, p_t, $w_{Y,t}$, and r_t are natural resource rent, wages, and returns to physical capital, respectively. Higher τ_p encourages firms to reduce emissions by utilizing cleaner technologies or by reducing output.

2.2 R&D sector

The R&D sector consists of producers of technology. The price of technology p_A reflects the present value of the discounted streams of net revenue of the monopolist, which depends on the final output. Building on the standard endogenous growth model (Cozzi 2017; Diao et al. 1999; Romer 1990), we introduce an institutional adjustment term that modifies both innovation cost and the price of technology. The price at moment *t* is:

$$p_A = Z^{-\lambda} \int_t^{\infty} e^{-rt}\big(1-\tau_p\big) Y_t \, dt \quad \leq \mathrm{w}_A + \pi_A \quad (5)$$

Here, w_A and π_A are wages and profit in the R&D sector, respectively. Z denotes institutional capacity, defined as the stock of institutional and administrative arrangements available to support economic activity, with $Z \geq 1$. Institutional quality can be now defined.as Z^{λ}. As we assume that $\lambda \epsilon(0,1)$ and that Z≥1, mathematically $\mathrm{Z}^{\lambda} \in (1, \mathrm{Z})$. It means that, while institutional quality can improve over time, it is bounded by the existing institutional capacity Z at a given period. This highlights the influence of social, political, and historical constraints on institutional quality. Conversely, the term $Z^{-\lambda}$ acts as an institutional cost shifter in Eq. (5): greater institutional capacity reduces innovation costs, and this cost-reducing effect becomes stronger when λ is higher, that is when regulatory effectiveness is higher. Institutional quality promotes competition, technological advances, and reduces the prices of technology products and services (Aghion et al., 2013; Huang and Xu, 1999). At equilibrium, p_A is constant, and differentiating p_A for time *t* gives:

$$p_A = Z^{-\lambda}(1-\tau_p)Y_t\left(\frac{1}{r}\right) \tag{6}$$

The aggregate stock of technology evolves as:

$$\dot{A} = \delta A_t H_{A,t} Z^{\lambda}; \quad H_{A,t} \leq H_t \tag{7}$$

where $H_t = H_{A,t} + H_{Y,t}$ is the total human capital, which is assumed to be normalized to 1, while $\delta > 0$ represents the productivity of the R&D. Institutional quality Z^{λ} enhances innovation productivity, while also reducing the price of technological input (p_A) through $Z^{-\lambda}$ in Eq. (5). Together, these effects ensure that institutional improvements increase the net rate of technological growth. This is in line with the work of Barasa et al. (2017), who suggested that institutions are crucial for incentivizing firm-level innovations. The use of λ in both the production-sector resource dynamics and the R&D sector is intentional: it represents a common implementation constraint that determines both how effectively regulation mitigates resource depletion and how effectively existing institutional capacity *Z* is translated into innovation incentives through Z^{λ}.

R&D sector's profit can be written as: $\underset{A,H_A}{max}\, \pi_A = p_A\dot{A} - W_A H_{A,t}$. Substituting $\dot{A}$ in (7) and p_A in (6), the profit function is:

$$\underset{A,H_A}{max}\, \pi_A = \underbrace{(1-\tau_p)Y_t\left(\frac{1}{r}\right)\delta A_t H_{A,t}}_{Price \times Innovation} - w_A H_{A,t} \tag{8}$$

The first-order equilibrium condition for profit maximization is achieved when the wage rate in the R&D sector equals the marginal product:

$$w_A = (1-\tau_p)Y_t\left(\frac{1}{r}\right)\delta A_t \tag{9}$$

Wages and returns on innovation rise with innovation capacity (A_t), net output $(1-\tau_p)Y_t$, and R&D sector productivity (δ). Although institutional quality does not directly influence w_A, its impact is embedded in $\dot{A}$. In addition, from Eq. (9), pollution tax (τ_p) affects the profitability of innovation, thereby aligning economic incentives with sustainability objectives.

2.3 Net output equilibrium growth

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Proposition 1: Given that output and technology follow according to Eqs. (1–7), institutional quality aligns innovation incentives with environmental constraints, thereby influencing net output equilibrium growth. This proposition is subject to an **Institutional Sustainability Offset Condition (ISOC)**, such that:

$$\frac{\partial g^*}{\partial Z^\lambda} > 0 \; if \;\; \delta\left(H_t - H_{Y,t}\right)Z^\lambda \; > \alpha(s-\lambda),$$

The ISOC condition shows that positive environmentally adjusted growth is sustained when the innovation contribution generated by institutionally augmented R&D human capital exceeds the residual resource-depletion burden after regulatory mitigation:

Proof:

First, we derive the growth rate of technology g_A and resource dynamics g_R. From (7), $g_A = \delta\left(H_t - H_{Y,t}\right)Z^\lambda$. $H_t - H_{Y,t} > 0$ ensures that a significant share of human capital is allocated to the R&D sector, allowing the continuous improvement of technology. As such, higher institutional quality (measured by Z^λ) amplifies technological growth.

From Eq. (2), $g_R = \lambda - s$. $0 < \lambda < s$ then $g_R < 0$ indicating continued resource depletion. However, regulatory effectiveness reduces the magnitude of the depletion rate from s to $s - \lambda$. Thus, it mitigates rather than completely eliminate resource depletion.

Next, to derive the environmentally adjusted equilibrium growth rate, we utilize a simple nested Cobb–Douglas production function that satisfies Eq. (1). $Y_t = \left[A_t R_t^\alpha H_{Y,t}^{(1-\alpha)}\right]^\eta K_t^{1-\eta}; \alpha, \eta \in (0,1)$. We derive the motion equation for adjusted net output growth g_Y as:

$$g_Y \; = \eta g_A + \eta\alpha g_R + \; \eta(1-\alpha)g_{H_Y} \; + (1-\eta)g_K \qquad (10)$$

Combining Eqs. (10) and (7) along the equilibrium growth path, where the output-capital ratio remains constant ($g_Y = g_K = g^*$), and assuming a constant share of human capital, the environmentally adjusted equilibrium growth rate is:

$$g^* = \delta\left(H_t \; - H_{Y,t}\right)Z^\lambda - \alpha(s-\lambda) \qquad (11)$$

Institutional quality Z^λ enhances innovation and drives net growth i.e. $\frac{\partial g^*}{\partial Z^\lambda} > 0 \; when \; H_t \; - H_{Y,t} > 0$, while excess resource extraction $s > \lambda$ dampens net growth. A sustainable growth path requires $\lambda > s \Rightarrow g^* > 0$. This ensures a positive return on resource utilization or resource efficiency to sustain g^*.

Additionally, from Eq. (3), we demonstrate that institutional quality mitigate pollution along the equilibrium growth path. We define the effective pollution tax enforcement as $\tilde{\tau}_p = \tau_p Z^\lambda$ and from Eq. (3) $Y = P^b D$ such that effective abatement expenditure is $D = \tilde{\tau}_p Y$. Hence $P = \left(\tilde{\tau}_p\right)^{-\frac{1}{b}}$ and therefore

$$\frac{\partial P}{\partial Z^\lambda} = -\frac{1}{b}\tau_p{}^{-\frac{1}{b}}\left(Z^\lambda\right)^{-\frac{1}{b-1}} < 0 \qquad (12)$$

for $b, \tau_p, Z^\lambda > 0$

$\frac{\partial P}{\partial Z^\lambda} = \; -\frac{P}{bZ^\lambda} < 0$ shows that greater effective institutional quality reduces pollution. This result operates through the environmental enforcement channel:

institutional capacity and regulatory effectiveness increase the effective enforcement intensity of the pollution tax, $\tilde{\tau}_p = \tau_p Z^{\lambda}$, thereby strengthening firms' incentives to undertake pollution abatement. Thus, institutions mitigate pollution not by eliminating production-related environmental pressure, but by increasing the effectiveness with which environmental regulation is implemented.

The three main channels through which institutions affect sustainability are thus:

i. amplifying the effect of innovation on net output growth (Eq. 10);
ii. enabling efficient resource management to stimulate net output growth (Eq. 10);
iii. allowing pollution abatement (Eq. 11).

3. Data and Empirical Specification

3.1 Data

The theoretical framework is microfounded. However, the equilibrium solution and structural implications enable us to derive empirically testable channels under which institutions interact with net output growth. The empirical analysis utilizes country-level data (107 countries, years 2005–2023). The sample is determined by data availability, with adequate representation of broad socio-economic and institutional structures. We measure institutional quality using the Heritage Foundation's Institutional Quality Index, which combines dimensions related to government size, rule of law, regulatory efficiency, and market openness. In the theoretical framework, institutional capacity (Z) and regulatory effectiveness (λ) are distinguished because they represent different mechanisms through which institutions affect innovation and resource use. The composite index, however, does not permit these two theoretical dimensions to be identified separately. We therefore use it as a reduced-form proxy for the overall effective institutional environment represented by Z^{λ} in the model, rather than as a direct empirical measure of either Z or λ individually. This interpretation avoids imposing a one-to-one correspondence between particular index components and the model parameters. Accordingly, the empirical analysis evaluates the combined effect of institutional capacity and regulatory effectiveness, while the separate roles of Z and λ remain theoretical mechanisms that cannot be independently identified with the available data. We acknowledge this as a measurement limitation, as multidimensional and interrelated institutional characteristics are difficult to unbundle empirically. Table 1 presents the variable descriptions and measurements.

Table 1. Variable definitions and measurements

Abv.	Definition	Empirical Measurement	Source
Y_{it}	Final output	Gross domestic product, excluding subsidies and adjusted for inflation and deflation, measured using constant 2015 USD	WDI
g_{it}	Net-output growth rate	Net output growth rate after accounting for environmental degradation via pollution tax. $g_{it} = ln\left(\frac{(1-\tau_{p,it})Y_{it}}{(1-\tau_{p,it-1})Y_{it-1}}\right)$	Authors' computations
$g_{A_{it}}$	Growth rate of innovation	Annual log difference in patent grants: direct and PCT national phase entries by filing office.	WIPO

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$g_{R\,it}$	Growth rate of resource utilization	It refer to annual log differences in rent from hard and soft coal, minerals, forest products, natural gas, oil, and other related natural resources expressed as a percent of gross domestic product (GDP).	WDI
P_{it}	Pollution/emissions	Total greenhouse gas emissions per capita (Mt CO_2eq)	WDI
$g_{H_{it}}$	Growth rate of human capital input	Annual log difference in labor force participation rate, national estimate: ages 15 to 65	WDI
$g_{K\,it}$	Growth rate of physical capital	Annual log difference in private sector's gross fixed capital formation as a percentage of GDP	WDI
IQ_{it}	Institutional quality	A composite index that comprises government size, rule of law, regulatory efficiency, and open market/ease of doing business.	Heritage Foundation
H_{it}	human capital input	Labor force participation rate, national estimate: ages 15 to 65	WDI
$\tau_{p\,it}$	Pollution tax rate	Pollution tax as a proportion of GDP	WDI
Trade openness	Control	Value of exports and imports in USD divided by the real GDP	WTO
Population density	Control	Total mid-year population divided by land area. Measured in persons per square kilometer.	WDI
Fractionalization	Control	Degree of cultural/ethnic diversity within a society, rated from 0 to 1, where 0 = low (homogeneous) and 1 = high (highly fractionalized)	Alesina et al. (2003)

3.2 Empirical Specification

In accordance with Eq. (10), net output growth is expressed as a function of the growth of technology, resource utilization, human capital, and physical capital:

$$g_{it} = b_0 + b_1 g_{A_{it}} + b_2 g_{R_{it}} + b_3 g_{H_{it}} + b_4 g_{K_{it}} + \kappa' controls_{it} + \varepsilon_{it} \quad (13)$$

where $g_{it} = ln\left(\frac{(1-\tau_{p,it})Y_{it}}{(1-\tau_{p,it-1})Y_{it-1}}\right)$, $i = 1,2,3,\ldots,107$, and $t = 1,2,3,\ldots,19$

g_{it} is the net output growth rate, $g_{A_{it}}$ growth of technological progress, $g_{R_{it}}$ resource utilization growth, $g_{H_{it}}$ human capital growth, $g_{K_{it}}$ physical capital growth, $\tau_{p,it}$ pollution tax rate, and Y_{it} the final output. To address omitted-variable bias and reduce systematic variation in the residuals, control variables are added to the model based on earlier environment-growth-nexus literature (Arminen & Menegaki 2019; Papyrakis 2013).

To directly test the central claim of Proposition 1 that institutional quality foster net output growth through innovation mechanism, we examine the relationship between institutional quality and technological growth. The theoretical model shows that $g_A = \delta(H_t - H_{Y,t})Z^{\lambda}$ which implies that technological progress depends on institutional quality and human capital variables. Accordingly, the innovation mechanism is empirically specified as:

$$g_{A_{it}} = \alpha_0 + \alpha_1 IQ_{it} + \alpha_2 H_{it} + \phi' controls_{it} + \varepsilon_{it} \quad (14)$$

where $IQ = Z^{\lambda}$ (institutional quality), $\alpha_1 > 0$ verifies the theoretical prediction that institutional quality enhances technological growth. This provides empirical support for the innovation mechanism through which institutions contribute to net-output growth.

After establishing the baseline empirical specification and the direct institution-innovation mechanism, we extend the empirical specification to assess whether institutional quality conditions the growth effect associated with innovation, resource utilization, and pollution. The specification includes pollution since it enters the equilibrium condition through Eq. (12) but omits $g_{K_{it}}$ and $g_{HY_{it}}$ because, at equilibrium, we assume that output and capital grow at a constant rate while human capital is also constant.

The extended model is:

$$g_{it} = \beta_0 + \beta' X_{it} + \gamma_1 \left(g_{A_{it}} \times IQ_{it}\right) + \gamma_2 \left(g_{R_{it}} \times IQ_{it}\right) + \gamma_3 (P_{it} \times IQ_{it}) + \kappa' controls_{it} + \varepsilon_{it} \quad (15)$$

where P_{it} is pollution intensity, and $X_{it} = \left[IQ_{it}, g_{A_{it}}, g_{R_{it}}, P_{it}\right]$ is the vector of main explanatory variables. The interaction coefficient γ_1, γ_2, and γ_3 shows whether institutional quality conditions the marginal growth effect associated with innovation, resource utilization and pollution, respectively. The parameter $\gamma_1 > 0$ captures whether the growth contribution of innovation varies with institutional quality, $\gamma_2 > 0$ captures whether the growth contribution of resource utilization varies with institutional quality, and $\gamma_3 < 0$ captures whether institutional quality moderates the adverse growth effect of pollution. These interaction effects are interpreted as a conditional extension of the theoretical mechanism rather than as direct tests of the structural relationship derived in the model.

3.3 Estimation

The method of moments quantile regression (Machado & Silva, 2019) is used to estimate Eqs. (13), (14) and (15) in the main text. This approach is chosen over the traditional mean-based estimators because it allows the study to investigate the unique relationships and multiple effects that explanatory variables and in particular the interactions of institutions with innovation, resources, and pollution may have on net output growth. Papers in the econometrics literature, such as those by Firpo et al. (2022) and Haupt et al. (2014), have reaffirmed the usefulness of quantile estimation in panel data as being more flexible than mean-based estimations in providing more insights on the impact of the explanatory variables across stages or distribution of the dependent variable. This is particularly useful as our sample covers countries at different stages of development and institutional levels.

4. Results

4.1 Preliminary and diagnostic analysis

Table 2 summarizes the descriptive statistics. The panel is unbalanced, as is common in cross-country studies, due to differences in data availability across countries and years. The average net output growth rate is 0.02 with relatively low variation across countries (standard deviation = 0.046). Most of the variables, such as trade openness, institutional quality, and pollution vary strongly among countries.

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Table 2. Descriptive Statistics

Variable	Mean	Median	Minimum	Maximum	Std. Dev.	Skewness	Kurtosis	No. of Obs
Net Output Growth (g_{it})	0.02	0.022	-0.362	0.485	0.046	-0.073	15.508	1,926
Innovation ($g_{A_{it}}$)	5.671	5.545	0.00	13.733	2.505	0.163	3.015	1,704
Resource Util. Growth ($g_{R_{it}}$)	0.313	0.549	-9.143	4.179	2.27	-1.092	4.619	1,800
Pollution (P_{it})	8.214	5.987	0.414	79.565	8.908	3.12	16.518	1,995
Institutional Quality (IQ_{it})	63.26	63.5	21.4	89.7	10.083	-0.42	4.039	1,969
Human Capital Growth ($g_{H_{it}}$)	0.002	0.002	-0.112	0.091	0.017	-0.791	10.303	1,923
Physical Capital Growth ($g_{K_{it}}$)	-0.001	0.004	-1.476	1.106	0.128	-0.899	24.58	1,779
Trade Openness	66.464	58.563	8.321	343.488	36.904	2.140	11.374	2028
Population Density	4.345	4.447	0.490	8.983	1.423	-0.199	3.796	1,916
Ethnic Fractionalization	0.395	0.399	0.012	0.93	0.236	0.189	1.961	1,976

The correlation matrix is presented in Table 3. All pairwise correlations among the explanatory variables are below 0.5 in absolute value, indicating relatively low bivariate correlations. In addition, all variance inflation factor (VIF) values are below 2, suggesting that multicollinearity is unlikely to be a concern in the empirical specification.

Table 3. Pairwise Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	VIF
g_{it} (1)	1.00										-
$g_{A_{it}}$ (2)	-0.03	1.00									1.26
$g_{R_{it}}$ (3)	0.08	-0.09	1.00								1.47
P_{it} (4)	-0.07	0.26	0.01	1.00							1.49
IQ_{it} (5)	-0.06	0.23	-0.39	0.40	1.00						1.60
$g_{H_{it}}$ (6)	0.23	0.01	-0.05	0.05	0.08	1.00					1.04
$g_{K_{it}}$ (7)	0.28	-0.03	0.01	0.01	-0.05	0.13	1.00				1.02
Trade Openness (8)	0.09	-0.01	-0.20	0.18	0.20	0.10	0.03	1.00			1.90
Population Density (9)	0.07	0.01	-0.38	-0.27	-0.01	0.01	0.01	0.20	1.00		1.49
Ethnic Frac. (10)	0.01	-0.24	0.29	-0.11	-0.19	-0.09	-0.01	0.01	-0.07	1.00	1.18

4.2 Baseline determinants of net-output growth

Table 4 presents the MMQR estimates of the baseline specification in Eq. (13). Location coefficients reflect how explanatory variables affect the expected value of net output growth whereas scale coefficients capture the propensity that the distribution of a given explanatory variables will diverge or converge toward the conditional mean of net output growth. The results reveal substantial heterogeneity in the determinants of net-output growth across its conditional distribution. Technological growth exhibits a positive and significant association with net-output growth at the 10th quantile, but the association weakens and turns negative for higher levels of net-output growth at the 75th and 90th quantiles. This implies that the association between innovation and net-output growth is not uniform across countries but varies with the level of net output growth. This finding extends the innovation-led growth literature (e.g., Acemoglu et al., 2018) by demonstrating that the association between innovation and net-output growth varies across the

conditional distribution of net-output growth. The result is also consistent with Pinar and Karahasan (2026) and Wang et al. (2013), who report heterogeneous relationships between innovation and economic development across different economic contexts.

Table 4: Method of Moments Quantile Estimation Results
Dependent Variable: Net Output Growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Explanatory Variable	location	scale	qtile_10	qtile_25	qtile_50	qtile_75	qtile_90
$g_{A_{it}}$	-0.00033	-0.00143***	0.00207**	0.00061	-0.00039	-0.00150**	-0.0026***
	(0.00051)	(0.00037)	(0.00082)	(0.00057)	(0.00050)	(0.00058)	(0.00078)
$g_{R_{it}}$	0.00213***	0.00101**	0.00044	0.00147**	0.00217***	0.00295***	0.00373***
	(0.00060)	(0.00044)	(0.00096)	(0.00067)	(0.00060)	(0.00069)	(0.00091)
$g_{H_{it}}$	0.50800***	-0.28632***	0.98868***	0.69538***	0.49704***	0.27581***	0.05487
	(0.09196)	(0.06743)	(0.14941)	(0.10217)	(0.09085)	(0.10506)	(0.13999)
$g_{K_{it}}$	0.09925***	-0.02199**	0.13617***	0.11364***	0.09840***	0.08141***	0.06444***
	(0.01268)	(0.00930)	(0.02038)	(0.01414)	(0.01264)	(0.01460)	(0.01929)
Trade openness	0.00009**	0.00002	0.00006	0.00007*	0.00009**	0.00010**	0.00011**
	(0.00004)	(0.00003)	(0.00006)	(0.00004)	(0.00004)	(0.00004)	(0.00006)
Population density	0.00001	0.00001	-0.00001	0.00001	0.00001	0.00001	0.00001
	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
Ethnic frac.	-0.00368	-0.01154***	0.01569*	0.00387	-0.00412	-0.01304*	-0.02194**
	(0.00579)	(0.00425)	(0.00932)	(0.00645)	(0.00577)	(0.00667)	(0.00881)
Constant	0.01539***	0.03988***	-0.0516***	-0.01072*	0.01691***	0.04773***	0.07850***
	(0.00515)	(0.00378)	(0.00888)	(0.00572)	(0.00499)	(0.00577)	(0.00800)
Observations	1,308	1,308	1,308	1,308	1,308	1,308	1,308

, **, and * represent 10%, 5%, and 1% levels of significance, respectively. Standard error in parentheses.*

From the results, resource-utilization growth and human- and physical-capital growth are positively associated with net-output growth and are statistically significant across most quantiles. These findings are consistent with the growth-accounting literature and empirical studies such as Zallé (2019), who found that human capital, physical capital, and natural resources are important determinants of economic growth, particularly in less developed countries. Among the control variables, trade openness is positively associated with net-output growth and becomes statistically significant from Q25 onward. Ethnic fractionalization exhibits a heterogeneous association with net-output growth, becoming negative and statistically significant toward the upper quantiles. The association between population density and net-output growth is economically small in the specification reported here.

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4.3 Institutional quality and the innovation mechanism

Table 5 examines the innovation mechanism underlying Proposition 1 by estimating Eq. (14), where innovation growth is specified as a function of institutional quality, human capital, and the control variables. Consistent with the theoretical prediction, institutional quality is positively and statistically significantly associated with innovation across the entire conditional distribution. The estimated coefficient ranges from 0.0448 at the 10th quantile to 0.0404 at the 90th quantile and remains significant at the 1% level throughout. The relatively stable coefficients suggest that the positive association between institutional quality and innovation is broadly similar across different parts of the conditional innovation distribution. This finding is consistent with previous research emphasizing the role of institutions in supporting innovative activity (Barasa et al., 2017).

Table 5: Method of Moments Quantile Estimation Results
Dependent Variable: Innovation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Explanatory Variable	location	scale	qtile_10	qtile_25	qtile_50	qtile_75	qtile_90
IQ_{it}	0.04266***	-0.00131	0.04483***	0.04372***	0.04265***	0.04155***	0.04036***
	(0.00754)	(0.00463)	(0.01069)	(0.00837)	(0.00754)	(0.00857)	(0.01122)
H_{it}	0.01737**	0.02136***	-0.01813*	0.00007	0.01752**	0.03565***	0.05514***
	(0.00695)	(0.00427)	(0.00998)	(0.00772)	(0.00696)	(0.00794)	(0.01039)
Trade openness	-0.0071***	-0.0081***	0.00629***	-0.00057	-0.0072***	-0.0139***	-0.0213***
	(0.00163)	(0.00100)	(0.00239)	(0.00181)	(0.00164)	(0.00187)	(0.00246)
Population density	0.00029***	0.00017***	0.00001	0.00015	0.00030***	0.00044***	0.00060***
	(0.00009)	(0.00005)	(0.00012)	(0.00010)	(0.00009)	(0.00010)	(0.00013)
Ethnic fractionalization	-1.8951***	0.02906	-1.94335***	-1.9186***	-1.8948***	-1.8702***	-1.8437***
	(0.28626)	(0.17586)	(0.40596)	(0.31777)	(0.28628)	(0.32547)	(0.42595)
Constant	2.87814***	0.98291***	1.24438*	2.08193***	2.88509***	3.71935***	4.61649***
	(0.52866)	(0.32478)	(0.75128)	(0.58720)	(0.52921)	(0.60154)	(0.78768)
Observations	1,528	1,528	1,528	1,528	1,528	1,528	1,528

, **, and * represent 10%, 5%, and 1% levels of significance, respectively. Standard error in parentheses.*

Human capital exhibits a more heterogeneous relationship with innovation. Its coefficient is negative and statistically weakly significant at the 10th quantile, statistically insignificant at the 25th quantile, and positive and statistically significant from the median to the 90th quantile, with its magnitude increasing toward the upper quantiles. This suggests that the positive association between human capital and innovative activity is particularly pronounced toward the upper part of the conditional innovation distribution. Since the empirical measure captures the aggregate stock of human capital rather than the theoretical allocation of human capital specifically to the R&D sector, these estimates

should be interpreted as indirect evidence on the human-capital mechanism rather than a direct test of R&D-sector human-capital allocation.

4.4 Institutional moderation of sustainability mechanisms

Table 6 reports the extended MMQR specification examining whether institutional quality conditions the relationships between innovation, resource utilization, pollution, and net-output growth. The results reveal substantial heterogeneity across the conditional distribution. The interaction between innovation and institutional quality is negative and statistically significant from the 25th quantile onward, with its magnitude increasing toward the upper quantiles. Since Eq. (14) shows a positive association between institutional quality and innovation, this result should not be interpreted as evidence that stronger institutions inhibit technological progress. Rather, conditional on innovation occurring, the estimates indicate that the marginal contribution of additional innovation to net-output growth diminishes as institutional quality increases, particularly toward the upper part of the net-output-growth distribution.

Table 6: Method of Moments Quantile Estimation Results (Extended Equation 15)
Dependent Variable: Net Output Growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Explanatory Variable	location	scale	qtile_10	qtile_25	qtile_50	qtile_75	qtile_90
$g_{A_{it}}$	0.01405***	0.00207	0.01049	0.01289***	0.01428***	0.01567***	0.01708***
	(0.00391)	(0.00291)	(0.00743)	(0.00478)	(0.00380)	(0.00371)	(0.00457)
$g_{R_{it}}$	0.00918*	0.00969***	-0.00747	0.00374	0.01026**	0.01672***	0.02331***
	(0.00484)	(0.00360)	(0.00923)	(0.00589)	(0.00469)	(0.00458)	(0.00567)
P_{it}	-0.00505***	-0.00022	-0.00467	-0.00492**	-0.0051***	-0.0052***	-0.0053***
	(0.00169)	(0.00126)	(0.00321)	(0.00206)	(0.00164)	(0.00160)	(0.00197)
IQ_{it}	0.00068*	-0.00014	0.00092	0.00076*	0.00067*	0.00058	0.00049
	(0.00038)	(0.00028)	(0.00072)	(0.00046)	(0.00037)	(0.00036)	(0.00044)
$g_{A_{it}} \times IQ_{it}$	-0.00021***	-0.00005	-0.00014	-0.0002***	-0.0002***	-0.0003***	-0.0003***
	(0.00006)	(0.00004)	(0.00011)	(0.00007)	(0.00006)	(0.00006)	(0.00007)
$g_{R_{it}} \times IQ_{it}$	-0.00010	-0.0002***	0.00015	-0.00002	-0.00012*	-0.0002***	-0.0003***
	(0.00007)	(0.00005)	(0.00013)	(0.00009)	(0.00007)	(0.00007)	(0.00008)
$P_{it} \times IQ_{it}$	0.00006***	0.00000	0.00006	0.00006**	0.00006***	0.00007***	0.00007**
	(0.00002)	(0.00002)	(0.00005)	(0.00003)	(0.00002)	(0.00002)	(0.00003)
Trade openness	0.00015***	0.00003	0.00010	0.00013***	0.00015***	0.00017***	0.00019***
	(0.00004)	(0.00003)	(0.00007)	(0.00005)	(0.00004)	(0.00004)	(0.00005)
Population density	0.00000	-0.00000	0.00000	0.00000	0.00000	-0.00000	-0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Ethnic frac.	-0.01071*	-0.00716*	0.00159	-0.00669	-0.01151**	-0.0163***	-0.0212***
	(0.00554)	(0.00412)	(0.01053)	(0.00675)	(0.00538)	(0.00525)	(0.00647)
Constant	-0.02645	0.04274**	-0.09991**	-0.05045*	-0.02168	0.00683	0.03593

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	(0.02408)	(0.01791)	(0.04586)	(0.02934)	(0.02337)	(0.02282)	(0.02817)
Observations	1,347	1,347	1,347	1,347	1,347	1,347	1,347

, **, and * represent 10%, 5%, and 1% levels of significance, respectively. Standard error in parentheses.*

A similar pattern emerges for resource utilization. The interaction between resource-utilization growth and institutional quality becomes negative and statistically significant toward the upper quantiles, suggesting that the marginal contribution of additional resource utilization becomes weaker as institutional quality improves. This may indicate reduced dependence on resource expansion as a source of net-output growth in stronger institutional environments, although the total conditional effect depends on the combined main and interaction coefficients.

In contrast, the interaction between pollution and institutional quality is positive and statistically significant from the 25th quantile onward. Given the negative direct coefficient of pollution, the positive interaction indicates that stronger institutional quality attenuates the adverse association between pollution and net-output growth. This finding is consistent with the argument that effective institutional environments strengthen the capacity to manage the economic consequences of environmental pressures.

Overall, the results suggest that institutional quality does not operate uniformly across the mechanisms underlying net-output growth. While institutions directly promote innovation, as established in Eq. (14), the extended specification indicates that they also condition the growth returns associated with innovation, resource utilization, and pollution.

4.5 Conditional Marginal Effects

To facilitate interpretation of the interaction terms in Eq. (15), Table 7 reports the marginal effects of innovation, resource-utilization growth, and pollution evaluated at low and high levels of institutional quality. The results reveal distinct patterns of institutional moderation across the three channels.

Table 7: Conditional Marginal Effects of Innovation, Resource Utilization, and Pollution at Low and High Institutional Quality

Channel	IQ Level	Q10	Q25	Q50	Q75	Q90
Innovation ($g_{A_{it}}$)	Low IQ	0.0028**	0.0022**	0.0018**	0.0015**	0.0011
		(0.0014)	(0.0009)	(0.0007)	(0.0007)	(0.0009)
	High IQ	0.001	−0.0003	−0.0011**	−0.0019***	−0.0027***
		(0.0011)	(0.0007)	(0.0005)	(0.0005)	(0.0007)
Resource utilization ($g_{R_{it}}$)	Low IQ	0.0012	0.0028**	0.0037***	0.0047***	0.0056***
		(0.002)	(0.0013)	(0.001)	(0.001)	(0.0012)

	High IQ	0.0032**	0.0026***	0.0022***	0.0018***	0.0015*
		(0.0013)	(0.0008)	(0.0007)	(0.0006)	(0.0008)
Pollution (P_{it})	Low IQ	−0.0015**	−0.0015***	−0.0014***	−0.0014***	−0.0014***
		(0.0007)	(0.0005)	(0.0004)	(0.0004)	(0.0004)
	High IQ	−0.0008**	−0.0007***	−0.0006***	−0.0005***	−0.0004*
		(0.0004)	(0.0002)	(0.0002)	(0.0002)	(0.0002)

, **, and * represent 10%, 5%, and 1% levels of significance, respectively. Standard error in parentheses.*

For innovation, the marginal effect on net-output growth is positive under low institutional quality from Q10 to Q75, although its magnitude declines across the distribution and becomes statistically insignificant at Q90. Under high institutional quality, the marginal effect is insignificant at the lower quantiles but becomes negative and statistically significant from the median onward, with the negative magnitude increasing toward Q90. Importantly, this result should not be interpreted as indicating that stronger institutions are associated with lower innovation: Eq. (14) shows a positive and statistically significant association between institutional quality and innovation across all quantiles. Rather, Eq. (15) indicates that the marginal net-output-growth return associated with additional innovation diminishes with institutional quality and, at the upper part of the conditional distribution, becomes negative.

The resource-utilization channel exhibits attenuation toward the upper quantiles rather than a general sign reversal. Resource-utilization growth retains a positive marginal effect under both low and high institutional quality. However, the association becomes progressively stronger across quantiles under low institutional quality and progressively weaker under high institutional quality. Consequently, particularly toward the upper part of the distribution, resource-utilization growth is more weakly associated with net-output growth under high institutional quality than under low institutional quality. This pattern is consistent with lower reliance on additional resource utilization at higher levels of institutional quality, although it should not be interpreted causally.

Finally, pollution retains a negative marginal effect under both low and high institutional quality. However, the magnitude of this negative effect is consistently smaller under high institutional quality. Thus, the positive pollution–institution interaction identified in Eq. (15) reflects a mitigation of the adverse association between pollution and net-output growth rather than a reversal of its sign. Overall, the marginal-effects results show that institutional quality is associated with different patterns across the three mechanisms: under high institutional quality, the innovation–growth association weakens and becomes negative from the median onward; the positive association between resource-utilization growth and net-output growth becomes weaker toward the upper quantiles; and the negative association between pollution and net-output growth is attenuated.

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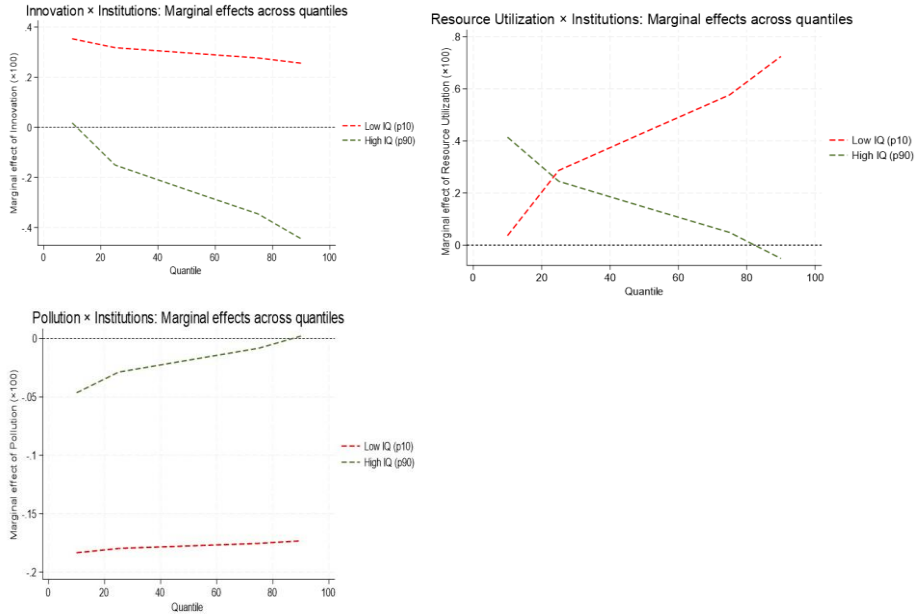

Figure 1: Marginal Plot of Interaction Terms.

The marginal-effect plots in Figure 1 reveal distinct patterns of institutional moderation across the three channels. Under low institutional quality, innovation is positively associated with net-output growth, although this association weakens across the quantiles. Under high institutional quality, the association is negative at the upper quantiles, indicating a diminishing marginal effect of additional innovation. The positive association between resource-utilization growth and net-output growth becomes stronger across the quantiles under low institutional quality but progressively weaker under high institutional quality. This pattern is consistent with lower reliance on additional resource utilization at higher levels of institutional quality, particularly toward the upper part of the net-output-growth distribution. Finally, pollution remains negatively associated with net-output growth under both low and high institutional quality, but the magnitude of this negative association becomes progressively smaller particularly under high institutional quality. Thus, higher institutional quality appears to be associated with an attenuation of the negative relationship between pollution and net-output growth.

4.6 Robustness analysis

To ensure our results are not dependent on the quantile-based model specification, we test the sensitivity of the findings using the panel feasible generalized least squares. This technique improves the efficiency of the estimated coefficients by controlling for spatial correlation and addressing cross sectional dependence, which is common in unbalanced panel datasets (Soberon et al., 2022; Bai et al., 2021).

Table 8: PGLS Estimates of the Extended Model

Variable	(1) g_{it}
$g_{A_{it}}$	0.01405***
	(0.00352)
$g_{R_{it}}$	0.00918**
	(0.00418)
P_{it}	-0.00505***
	(0.00162)
IQ_{it}	0.00068**
	(0.00031)
$g_{A_{it}} \times IQ_{it}$	-0.00021***
	(0.00005)
$g_{R_{it}} \times IQ_{it}$	-0.00010
	(0.00006)
$P_{it} \times IQ_{it}$	0.00006***
	(0.00002)
Trade openness	0.00015***
	(0.00004)
Population density	0.00000
	(0.00000)
Ethnic fractionalization	-0.01071*
	(0.00550)
Constant	-0.02645
	(0.01977)
Observations	1,223

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Panels are homoscedastic. Correlation: No autocorrelation.

The PGLS results are consistent with those obtained from the method of moments quantile regression and support the validity of the estimates presented in Table 8 above.

5. Conclusions

The paper has important implications for the debate on sustainability transitions by providing further insights into the role that institutions play in the context of the transition towards sustainable growth. As has been extensively argued in the literature (see for example, North, 1991; Acemoglu & Johnson, 2005), the role that institutions play in the context of governance and economic progress cannot be overstated. However, our findings suggest that environmental and innovation objectives can be achieved simultaneously only when certain conditions are fulfilled, for instance, the effectiveness of the institutional arrangements that support these policies exceeds the rate of resource depletion. This ensures the stability of the growth-environment system and prevents sustainability efforts from being undermined by ecological pressures.

The major implication that can be drawn from our findings is that institutional capacity is not important in isolation, but in conjunction with organizational and economic

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structures. As Blind (2012) and Aghion et al. (2023) have pointed out in their research, environmental regulation can have positive effects on the environment, but can also create organizational incentives that may not favor innovation. The major extension that our research makes to this argument is that this is not necessarily the case, depending on the presence of innovation capacity in organizations and the enforcement capacity of regulatory institutions, as in the absence of these, regulatory interventions may actually crowd out innovation, or may not be sufficient in reducing resource depletion. This explains the divergent outcomes from similar regulatory frameworks in different countries and organizational contexts.

Through the integration of institutional quality into an endogenous growth model, we contribute to a more refined understanding of the role of institutions in influencing organizational behavior within ecological constraints. Our model views institutions as governance structures that shape organizational resource allocation and behavior. Institutions affect sustainability outcomes through three closely linked channels: innovation incentives, resource efficiency, and pollution mitigation, but the strength of these channels is not automatic. This result is consistent with organizational views that highlight the importance of coordination, enforcement, and incentive alignment among organizational actors in determining sustainability outcomes (Aguilera et al., 2007; Delmas & Toffel, 2008).

The empirical analysis provides further support for this argument. By employing the method of moments quantile regression (Machado & Silva, 2019), we show that the relationships between innovation, resource utilization, pollution, and net-output growth vary systematically across the conditional distribution of net-output growth and with the level of institutional quality. The conditional marginal effects make this heterogeneity particularly clear. Under relatively low institutional quality, innovation is positively associated with net-output growth from Q10 to Q75, with the estimated marginal effect declining from approximately 0.0028 to 0.0015. Under high institutional quality, by contrast, the association becomes negative and statistically significant from the median onward, reaching approximately −0.0027 at Q90. Resource-utilization growth remains positively associated with net-output growth under both institutional regimes, but its contribution becomes progressively weaker under high institutional quality toward the upper quantiles. Similarly, pollution remains negatively associated with net-output growth, although the magnitude of this adverse association is consistently smaller under high institutional quality. These patterns demonstrate that institutional conditions shape the relationships between innovation, resource use, environmental pressures, and net-output growth in ways that would be obscured by conventional mean-based estimators (Koenker, 2004; Machado & Silva, 2019).

From a policy and governance perspective, these results caution against one-size-fits-all institutional reforms. The appropriate policy emphasis depends both on institutional quality and on a country's position in the conditional net-output-growth distribution. In relatively weaker institutional environments, where innovation is positively associated with net-output growth across most quantiles, strengthening innovation capacity together with institutional implementation may be particularly relevant. In stronger institutional environments, however, the declining and eventually negative marginal effect of additional innovation suggests that expanding innovation alone may not

translate into higher environmentally adjusted growth; greater emphasis may instead be needed on the environmental orientation and resource efficiency of innovation. The resource-utilization results similarly suggest that stronger institutional environments are less dependent on additional resource use as a source of net-output growth, while the pollution results indicate that stronger institutions attenuate, but do not eliminate, the adverse association between pollution and net-output growth. Policy priorities should therefore reflect differences in institutional capacity, regulatory effectiveness, and existing net-output-growth conditions rather than assuming uniform benefits from institutional strengthening alone.

More broadly, the paper also contributes to the literature on the challenges of governing sustainability in a disrupted world. As the pressure on the environment continues to build and the capacity of the institutional system is stretched to the limit, the capacity of organizations and the system of rules to adapt, coordinate, and implement those rules becomes a more central issue (Ansell & Trondal, 2018; Ferraro et al., 2015). Our research indicates that sustainability is not simply a function of the ambition of the rules, but also the degree to which regulatory effectiveness, organizational capacity, and resources intersect.

Future research can build on the channels identified here by examining how sector-specific institutional arrangements shape organizational responses and by extending the macro-institutional analysis to firm-level behavior. Alternative governance indicators that distinguish more clearly between institutional capacity and regulatory effectiveness would also help assess the robustness of the institutional mechanisms proposed in our theoretical model. Finally, stronger causal identification strategies and dynamic research designs could examine how enforcement capacity and innovation capabilities interact over time in shaping sustainability outcomes.

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