





How does biodiversity risk exposure affect corporate regulatory intensity?

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ARTICLE INFO

Keywords:

Biodiversity risk
Institutional quality
Regulatory intensity
Vertical integration

ABSTRACT

This paper investigates the impact of biodiversity risk on corporate regulatory intensity of firms in the United States during 2007-2020. Using text-based measures of biodiversity risk and regulatory intensity extracted from corporate disclosures and public media, we provide empirical evidence of a positive impact of biodiversity risk exposure on corporate regulatory intensity. The finding suggests that more corporate exposure to biodiversity risk increases the regulatory intensity and cost of regulatory compliance. Further empirical analysis suggests that the impact of biodiversity risk exposure on regulatory intensity is less pronounced in firms with headquarters located in states with poorer institutions, and in vertically integrated firms.

1. Introduction

The 2024 World Wildlife Fund's Living Planet Report reveals a catastrophic decline of 73% in wildlife populations over the last 50 years (1970-2020), alarming immense biodiversity risk with severe impacts on ecosystems and economies (Adamolekun, 2024; Carvalho et al., 2023).¹ The escalating biodiversity crisis presents substantial operational and financial risks to firms, including supply chain vulnerabilities, rising costs of inputs (Bach et al., 2025), and increasing regulatory scrutiny that directly influence corporate market competition and operations. As biodiversity loss escalates into a global crisis, regulators are sharpening their focus on firms with significant ecological footprints. The emergence of frameworks such as the Task Force on Nature-related Financial Disclosures (TFND) and the International Sustainability Standards Board (ISSB) exert significant pressure on firms to adapt to new biodiversity risk disclosure requirements and tightening environmental regulations.

The current academic literature on corporate biodiversity risk is embryonic and rapidly-growing. Recent studies investigate the impact of biodiversity risk exposure on stock returns and firm performance (Bach et al., 2025; Garel et al., 2024; Giglio et al., 2024; Kalhoro and Kyaw, 2024; Liang et al., 2024), corporate environmental protection practices and biodiversity risk responses (Carvalho et al., 2023; Panwar et al., 2023; Wagner, 2023), and eco-innovation practices (Tian and Chen, 2025), among others. Most studies in the literature focused on the corporate responses to biodiversity risk from the financial and management perspectives, leaving the regulatory perspective virtually absent. Consequently, this current study seeks to explore: how does biodiversity risk exposure

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¹ See the report for more details: <https://www.arcticwwf.org/newsroom/news/wwf-living-planet-report-2024-a-planet-in-crisis/>

influence corporate regulatory intensity? And what are the underlying mechanisms that moderate this relationship?

As biodiversity risk emerges from the losses of ecosystem services due to environmental and ecological degradation, it presents as another form of environment-related risk. Therefore, biodiversity risk can manifest in both physical impacts (Bach et al., 2025; Li et al., 2025) as well as transitional impacts (Giglio et al., 2024; Hutchinson and Lucey, 2024; Kalhoro and Kyaw, 2024). Previous studies in the literature of environmental-related risk suggest that firms exposing these risk factors generally face more public scrutiny and regulatory pressure under climate transition (Nguyen and Phan, 2020; Kalhoro and Kyaw, 2024) and tightening environmental protection policies (Dincer and Fredriksson, 2018; Cullen-Knox et al., 2019). As biodiversity loss becomes a critical global concern, international agreements (e.g., Kunming-Montreal Global Biodiversity Framework), regional policies (e.g., EU Green Deal, Corporate Sustainability Reporting Directive), and sustainability standards (e.g., TNFD, ISSB) impose increasing regulatory demands on firms. These institutional pressures compel firms exposed to biodiversity risks to enhance compliance and reporting, thereby increasing regulatory intensity. Based on this argument, we hypothesize that firms with higher exposure to biodiversity risk experience greater regulatory intensity, as regulators impose more stringent oversight and compliance requirements on companies whose operations significantly affect or depend on ecosystem services.

We test this hypothesis using data from various sources, including text-based measures of corporate regulatory intensity (Kalmenvitz, 2023), the firm-level biodiversity risk exposure (Giglio et al., 2024), and other firm-level data. Empirical results suggest that at the firm-level, biodiversity risk exposure has a positive impact on regulatory intensity, including the number of active regulations that apply to the firm, the amount of paperwork, and time and dollar costs of regulatory compliance. We confirm robustness of the findings via various tests, for example, using alternative variable measurements and model specifications, an instrumental variable approach and the Heckman selection estimation. Further analysis reveals how the impact varies across different degrees of local institution quality and vertical integration.

This paper contributes to literature in three main ways. Firstly, this is the first study empirically investigating how biodiversity risk exposure drives corporate regulatory intensity, an important argument in the emerging biodiversity risk literature (Bach et al., 2025; Garel et al., 2024; Giglio et al., 2024; Kalhoro and Kyaw, 2024; Karolyi and Tobin-de la Puente, 2023; Panwar et al., 2023) but was not empirically proven. Secondly, we highlight the role of local institution quality in shaping the impact of biodiversity risk on firm regulation intensity. We show that poorer institutional quality, proxied by local corruption, significantly weaken the sensitivity of regulation intensity to biodiversity risk. This adds new insights to the literature on the impact of local institutions in economics and finance from the corporate biodiversity risk perspective. Our findings partially support the argument raised by He et al. (2024) that different policies and institutions can lead to different responses to biodiversity risk. Thirdly, we provide novel evidence of vertical integration strategies to partly mitigate the regulatory burden of firms that are exposed to biodiversity risk, indicating the importance of better control over supply chains and proactively addressing regulatory challenges related to biodiversity and ecosystem protection.

2. Research methodology and data

2.1. Empirical design

We use the following empirical model to investigate the impact of biodiversity risk exposure on regulatory intensity:

$$REGIN_{it} = \alpha + \beta BIODR_{it-1} + \sum CONTROL_{it-1} + \gamma_i + \delta_t + \varepsilon_{it} \quad (1)$$

where $REGIN_{it}$ is the proxy of regulatory intensity of firm i during period t ; $BIODR_{it-1}$ is the measure of biodiversity risk exposure of firm i during period $t-1$; $\sum CONTROL$ is the vector of control variables at $t-1$; γ_i and δ_t stand for the firm- and year-fixed effects; and ε_{it} is the error term.

Following Kalmenvitz (2023), we use a set of firm-specific measures of regulatory intensity, measured via administrative data and machine-learning that capture the cost of compliance with federal regulations at firm-level, including the number of active regulations ($REGIN$), the number of forms and responses for compliance ($REGIN_Res$), the estimated time spent for compliance in hours ($REGIN_Time$), and the estimated dollar cost spent for compliance ($REGIN_USD$). The higher their values are, the heavier the regulatory burden is.

The variable-of-interest is one-year lag of corporate biodiversity risk exposure scored developed by textual analysis (Giglio et al., 2024). The main variable ($BIODR$) is a dummy variable that equals one if the firm mentions biodiversity-related terms in at least two sentences in its 10-K filing during the year, zero otherwise. For robustness check, alternative measures include an indicator variable, $BIODR_R$, that captures biodiversity-related regulation mentionings and $BIODR_S$, a dictionary-based sentiment score capturing the net sentiment of biodiversity-related sentences within a firm's 10-K filing (Giglio et al., 2024). $BIODR_S$ is computed as the number of negative biodiversity sentences minus the number of positive biodiversity sentences in the 10-K filing of the firm in a given year (Giglio et al., 2024). The higher the value of $BIODR_S$ is, the more negative the tone the firm's management use in disclosing biodiversity-related information. Furthermore, we use $BIODR_NYT$, the New York Times Biodiversity News Index (Giglio et al., 2024), as an alternative measurement of biodiversity risk exposure, however, measured at the macro-level via textual analysis.

For control variables, as large firms tend to have heavier regulatory burden than small firms (Kalmenvitz, 2023), we included firm size ($SIZE$), firm growth ($GROWTH$), and market concentration ($MCONCEN$) in the model. We also control corporate exposure to new rule proposals ($R_PROPOSAL$) (Chang et al., 2023) and local institution quality ($INSTQUAL$) proxied by the number of public corruption convictions in the state-year (Smith, 2016). Table 1 explains all variable construction.

Table 1
Variable description.

Variable	Definition	Sources
REGIN	The number of regulations currently applicable to a firm or industry at a given time, data from 10-K filings and other compliance-related paperwork.	Kalmenovitz (2023)
REGIN_Res	The number of required paperwork responses that firms must submit to comply with regulations.	Kalmenovitz (2023)
REGIN_Time	The estimated total hours spent by firms on compliance activities related to regulatory requirements.	Kalmenovitz (2023)
REGIN_USD	The estimated dollar expenditure spent by firms on compliance activities related to regulatory requirements.	Kalmenovitz (2023)
BIODR	Dummy variable that equals one if the firm mentions biodiversity-related terms in at least two sentences in 10-K filling during the year, zero otherwise	Giglio et al. (2024)
BIODR_R	Dummy variable that equals one if the firm mentions biodiversity-related terms in at least two sentences and one of them is about regulation in 10-K filling during the year, zero otherwise.	Giglio et al. (2024)
BIODR_S	The biodiversity sentiment score, calculated by subtracting the number of positive sentiment sentences from the number of negative sentiment sentences regarding biodiversity in the 10-K filling during the year.	Giglio et al. (2024)
BIODR_NYT	The New York Times Biodiversity News Index, computed as the number of negative biodiversity articles minus the number of positive biodiversity articles, counted daily and aggregated to annually.	Giglio et al. (2024)
SIZE	Natural logarithm of total assets	Bloomberg
GROWTH	Sales growth ratio that equals changes in sales scaled by previous sales	Bloomberg
R_PROPOSAL	Firm exposure to regulatory pipeline score developed by machine learning on the regulatory text and corporate disclosure files.	Chang et al. (2023)
MCONCEN	Market concentration score developed by textual analysis from 10-K filing of the firm-year	Hoberg and Phillips (2024)
CCEXPO	Text-based firm-level climate change exposure score by Sautner et al. (2023) constructed from transcripts of earnings conference calls.	Sautner et al. (2023)
RG_CCEXPO	Text-based firm-level regulatory climate change exposure score by Sautner et al. (2023) constructed from transcripts of earnings conference calls.	Sautner et al. (2023)
PH_CCEXPO	Text-based firm-level physical climate change exposure score by Sautner et al. (2023) constructed from transcripts of earnings conference calls.	Sautner et al. (2023)
BOARDSIZE	Number of directors on the board of directors of the firm during the year	Bloomberg
SUS_COMM	Dummy variable that equals one if the firm has a CSR or Sustainability committee, zero otherwise.	Bloomberg
BIG4	Dummy variable that equals one if the firm's auditor is one of the Big Four auditor, zero otherwise.	Bloomberg
SCOPE	Number of product markets the firm is operating in in a particular year. This score is discrete and developed using 10-K filling data.	Hoberg and Phillips (2024)
ENERGY	Dummy variable that equals one if the firm belongs to the Energy sector based on Global Industry Classification Sandard (GICS)	Bloomberg
MATERIALS	Dummy variable that equals one if the firm belongs to the Materials sector based on Global Industry Classification Sandard (GICS)	Bloomberg
INDUSTRIALS	Dummy variable that equals one if the firm belongs to the Industrials sector based on Global Industry Classification Sandard (GICS)	Bloomberg
CONDISC	Dummy variable that equals one if the firm belongs to the Consumer Discretionary sector based on Global Industry Classification Sandard (GICS)	Bloomberg
CONSTAP	Dummy variable that equals one if the firm belongs to the Consumer Staples sector based on Global Industry Classification Sandard (GICS)	Bloomberg
HEALTHCARE	Dummy variable that equals one if the firm belongs to the Health Care sector based on Global Industry Classification Sandard (GICS)	Bloomberg
INFOTECH	Dummy variable that equals one if the firm belongs to the Information Technology sector based on Global Industry Classification Sandard (GICS)	Bloomberg
COMMU	Dummy variable that equals one if the firm belongs to the Communication sector based on Global Industry Classification Sandard (GICS)	Bloomberg
REALES	Dummy variable that equals one if the firm belongs to the Real Estate sector based on Global Industry Classification Sandard (GICS)	Bloomberg
VERTINTEG	Vertical integration score of the firm	Frésard et al. (2020)
INSTQUAL	Natural logarithm of one plus the number of public corruption convictions in the state-year	Department of Justice (DOJ) website, Public Integrity Section

2.2. Data

The data is retrieved from various sources. Text-based firm-level regulatory intensity are from Kalmenovitz (2023). Corporate biodiversity risk exposure data by Giglio et al. (2024) is from <https://www.biodiversityrisk.org/>. Accounting and industry classification data are from Bloomberg. Market concentration and firm scope data are from Hoberg and Phillips (2024). Local corruption data is from the Department of Justice website.² Firm-level vertical integration data is from Frésard et al. (2020). After merging the datasets, we exclude all missing value and winsorized the continuous accounting variables at the 1st and the 99th percentiles to alleviate the

² The data is accessible at: <https://www.justice.gov/criminal/criminal-pin>

Table 2
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
REGIN	12,153	109.459	7.154	21.094	145.625
REGIN_Res	12,153	118.546	16.101	18.971	178.509
REGIN_Time	12,153	114.401	13.999	18.493	182.024
REGIN_USD	12,153	111.189	22.766	22.065	245.846
BIODR	12,153	0.033	0.179	0.000	1.000
BIODR_R	12,153	0.023	0.151	0.000	1.000
BIODR_S	12,153	0.031	0.283	-4.000	5.000
BIODR_NYT	12,153	90.967	32.362	38.000	156.000
SIZE	12,153	7.365	1.585	2.472	12.139
GROWTH	12,153	0.130	0.501	-0.945	8.562
R_PROPOSAL	12,153	1.283	4.218	-27.843	50.867
MCONCEN	12,153	0.297	0.261	0.019	1.000
CCEXPO	12,153	0.001	0.002	0.000	0.036
RG_CCEXPO	12,153	0.000	0.000	0.000	0.008
PH_CCEXPO	12,153	0.000	0.000	0.000	0.007
BOARDSIZE	5,863	9.560	2.146	3.000	21.000
SUS_COMM	5,865	0.343	0.475	0.000	1.000
BIG4	12,153	0.874	0.332	0.000	1.000
SCOPE	12,153	10.756	7.002	1.000	35.000
ENERGY	12,153	0.061	0.239	0.000	1.000
MATERIALS	12,153	0.070	0.255	0.000	1.000
INDUSTRIALS	12,153	0.219	0.413	0.000	1.000
CONDISC	12,153	0.155	0.362	0.000	1.000
CONSTAP	12,153	0.052	0.222	0.000	1.000
HEALTHCARE	12,153	0.151	0.358	0.000	1.000
INFOTECH	12,153	0.224	0.417	0.000	1.000
COMMU	12,153	0.044	0.205	0.000	1.000
REALES	12,153	0.006	0.076	0.000	1.000
VERTINTEG	12,153	0.012	0.011	0.000	0.093
INSTQUAL	12,153	3.339	1.040	0.000	5.118

impact of outliers. The final sample consists of 12,153 firm-year observations of 1,747 U.S. listed firms during 2007-2020.³ Table 2 presents the summary statistics of the variables in our sample. On average, there are approximately 109 different regulations applicable to a firm in our sample. Moreover, a general firm in our sample files 118 responses, spends 114.4 hours and 111,189 USD per year for regulatory compliance.

3. Empirical results and discussion

3.1. Baseline results

Table 3 presents the estimation results of Model (1) using the full and the reduced form specifications.

In Table 3, *BIODR*'s coefficient remains positive and statistically significant in both specifications, suggesting a positive relationship between biodiversity risk exposure and regulatory intensity. Specifically, the full model in Column (1) shows that being exposed to biodiversity risk is associated with 2.27% increase in the number of regulations applicable to the firm, meaning two more regulations compared to the base case (i.e., not exposed to biodiversity risk). The finding supports the notion that exposure to biodiversity risk drives corporate regulatory status (Bassen et al., 2024; Cullen-Knox et al., 2019; Panwar et al., 2023). This impact is attributable to increased scrutiny or compliance requirements related to ecosystem protection, hence, firms exposed to biodiversity risk are generally subject to higher regulation intensity. This relationship highlights the importance of biodiversity considerations in corporate governance and regulatory frameworks.

3.2. Endogeneity diagnostics and robustness tests

Endogeneity is a prevalent issue that arises from simultaneity, measurement errors, and variable omission. Additionally, biases can arise via sample selection as firms can self-select to disclose their cost of regulatory compliance or not. We account for the variable omission concern by including the fixed effects in Model (1). Other than using the lagged term of *BIODR* in the baseline estimation, we further alleviate these empirical concerns by employing the two-step Heckman selection estimator to check if potential sample selection bias can affect our findings, then adopt the Instrumental Variable estimator to address the potential simultaneity issue in our

³ The firm-level regulatory intensity data (Kalmenovitz, 2023), the biodiversity risk exposure data (Giglio et al., 2024), and the firm-level exposure to new rule proposal data (Chang et al., 2023) range from 1999 to 2020, 2000 to 2023, and 2008 to 2021, respectively. The panel is unbalanced.

Table 3
The impact of biodiversity risk on corporate regulatory intensity.

VARIABLES	(1) REGIN	(2) REGIN
L.BIODR	2.494*** (0.424)	0.868** (0.354)
L.SIZE	-0.250 (0.177)	
L.GROWTH	0.499** (0.225)	
L.R_PROPOSAL	-0.006 (0.025)	
L.MCONCEN	-0.187 (0.280)	
L. INSTQUAL	0.109 (0.104)	
Constant	111.418*** (1.348)	105.008*** (0.042)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	12,153	12,153
Adjusted R-squared	0.624	0.644

This table reports the regression results of corporate biodiversity risk (BIODR) on corporate regulatory intensity (REGIN). Variable definitions are in Table 1. Standard errors are clustered by firm and year and are put in parentheses.

*** p<0.01,

** p<0.05, *p<0.1.

model. For the former approach, we model the disclosure choice of firms as a function of the type of industry the firms are in, the state legislation, and firm size, which are relevant to regulatory compliance and disclosure (Kalmenovitz, 2023), then apply the Heckman selection estimation. The regression results are reported in Panel A of Table 4, in which we observe a similar result to the baseline finding above on the positive impact of biodiversity risk exposure on regulatory intensity.

Since it is difficult to find an external instrument for biodiversity risk in its relation to regulatory intensity, we resort to the heteroskedasticity-based instrument approach proposed by Lewbel (2012). This method exploits the presence of heteroskedasticity in the error terms to generate instruments that are uncorrelated with the error but correlated with the endogenous regressors when no external valid instruments are available. It allows identification and consistent estimation in models with endogenous or mismeasured regressors by using higher moments of the data rather than traditional exclusion restrictions. Panel B, Table 4, reports the IV estimation results, which are generally in line with the baseline results, thus further supporting the impact of biodiversity risk exposure on regulatory intensity.

We conduct sensitivity tests to mitigate the concern about measurement errors and examine the variations of the impact of biodiversity risk exposure. Panel A, Table 5, reports the estimation results of Model (1) but using alternative measurements of regulatory intensity (i.e., *REGIN_Res*, *REGIN_Time*, and *REGIN_USD*) and biodiversity risk exposure (i.e., *BIODR_R*, *BIODR_S*, and *BIODR_NYT*). The estimation results in Panel A show that regardless of variable measurement choices for both biodiversity risk exposure and regulatory intensity, we document similar findings compared to the baseline finding. More specifically, firms exposed to biodiversity risk generally have 4.14% more regulatory paperwork (i.e., filing approximately four more responses to regulators), use 1.78% more time, and spend 6.94% more dollar cost for regulatory compliance.

Panel B, Table 5, reports the estimation results of robustness tests using alternative regression specifications, including (i) the Driscoll-Kraay estimation to address potential cross-sectional dependence issues; (ii) the Prais-Winsten estimation to control serial correlation; (iii) the bootstrapping estimation to account for limited sample compared to the population; (iv) estimation with additional controls (i.e., firm-level climate change exposure scores (Sautner et al., 2023), board size, presence of a CSR/Sustainability Committee within the firm, and presence of a Big Four auditor; and (v) estimation with additional controls and Entropy Balancing weights to mitigate omitted variable bias and sample selection issues (Hainmueller, 2012). After conducting these tests, we see that all estimation results support a positive relationship between biodiversity risk exposure and regulatory intensity.

Panel C, Table 5, presents the estimations across different GICS sectors by using interaction terms of *BIODR* and the sector dummies, and with firms that operate in multiple product markets (i.e., firms having larger scopes). The estimations in Panel C indicate that the impact of biodiversity risk seems to have little variation across sectors, except for the cases of three sectors: Energy, Industrials and Materials. This suggests that the impact is more pronounced for firms in the Energy sector, a sector that are typically held responsible for environmental degradation and tightly scrutinized by the public. In contrast, the impact is less pronounced in the Industrials and Materials sectors because these sectors often involve manufacturing and processing, which may not directly engage with biodiversity-sensitive ecosystems as frequently as the other sectors.

Table 4
Endogeneity treatments.

<i>Panel A. Heckman selection estimation</i>			
VARIABLES	(1) REGIN	(2) REGIN_check	(3) /mills
L.BIODR	1.312*** (0.331)		
L.SIZE	-0.152 (0.119)		
L.GROWTH	-0.622** (0.314)		
L.R_PROPOSAL	0.038 (0.028)		
L.MCONCEN	-2.077*** (0.253)		
L. INSTQUAL	0.078 (0.064)		
INDUSTRY		-0.002*** (0.000)	
SIZE		0.149*** (0.002)	
STATE		-0.002*** (0.000)	
Lambda			8.522*** (0.263)
Constant	97.853*** (0.470)	-1.529*** (0.015)	
Observations	88,970	88,970	88,970
<i>Panel B. Instrumental variable estimation using heteroskedasticity-based instruments (Lewbel, 2012)</i>			
VARIABLES	(1) REGIN		
L.BIODR		4.559*** (1.701)	
L.SIZE		-0.034 (0.170)	
L.GROWTH		0.485** (0.209)	
L.R_PROPOSAL		-0.004 (0.035)	
L.MCONCEN		-0.146 (0.373)	
L. INSTQUAL		0.115 (0.122)	
Firm FE		Yes	
Year FE		Yes	
Kleibergen-Paap rk LM statistic		12.301**	
Cragg-Donald Wald F statistic		278.444***	
Hansen-J statistics		4.301	
Observations		12,153	
Adjusted R-squared		0.003	

This table reports the endogeneity treatment tests, including the Heckman selection estimation, and the heteroskedasticity-based instrumental variable estimation. Variable description are presented in Table 1. Numbers in parentheses are standard errors.

*** p<0.01,

** p<0.05, *p<0.1

3.3. Cross-sectional analysis

We further explore the relationship between biodiversity risk exposure and regulatory exposure from two different perspectives: local institutions and firm-level strategy. Local institutions play an important role in corporate decision-making (Smith, 2016; Bou-baker et al., 2025) and can negatively affect the stringency of environmental policies (Dincer and Fredriksson, 2018). Therefore, poorer local institutions may hinder the impact of biodiversity risk exposure on regulatory intensity via lowering the stringency of environmental and biodiversity protection policies.

Nevertheless, firms may proactively manage biodiversity risk exposure to reduce regulatory scrutiny via vertical integration. Vertical integration allows firms to exert direct control over their supply chain (Ersahin et al., 2024), enabling them to better align

Table 5
Sensitivity tests.

Panel A. Alternative variable measurements						
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	REGIN_Res	REGIN_Time	REGIN_USD	REGIN	REGIN	REGIN
L.BIODR	4.974*** (1.053)	2.058*** (0.644)	7.828*** (1.222)			
L.BIODR_R				2.864*** (0.560)		
L.BIODR_S					1.550*** (0.274)	
L.BIODR_NYT						0.200*** (0.010)
L.SIZE	-1.739*** (0.380)	0.027 (0.332)	1.282** (0.515)	-0.254 (0.176)	-0.220 (0.177)	-0.139 (0.186)
L.GROWTH	1.236*** (0.377)	0.861** (0.335)	-0.277 (0.347)	0.501** (0.225)	0.507** (0.225)	0.048 (0.157)
L.R_PROPOSAL	-0.035 (0.040)	-0.037 (0.034)	-0.062 (0.050)	-0.006 (0.025)	-0.005 (0.025)	-0.019 (0.016)
L.MCONCEN	-0.391 (0.654)	-0.027 (0.557)	1.078 (0.953)	-0.185 (0.280)	-0.215 (0.280)	-0.360 (0.281)
L.INSTQUAL	0.408* (0.229)	0.230 (0.197)	0.025 (0.338)	0.108 (0.105)	0.092 (0.104)	-0.103 (0.089)
Constant	131.454*** (2.910)	114.701*** (2.533)	102.902*** (4.025)	111.462*** (1.347)	111.297*** (1.349)	86.409*** (1.198)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,153	12,153	12,153	12,153	12,153	12,153
Adjusted R-squared	0.608	0.626	0.628	0.624	0.624	0.577

This table presents the regression results of robustness tests using alternative variable measurements of corporate biodiversity risk and corporate regulatory intensity. Variable description are presented in Table 1. Standard errors are clustered by firm and year and are put in parentheses. ***p<0.01, **p<0.05, *p<0.1

Panel B. Alternative model specifications and controls					
	(1)	(2)	(3)	(4)	(5)
	Driscoll-Kraay estimator	Prais-Winsten estimator	Bootstrapping (1,000 reps)	Additional controls	Additional controls with Entropy Balancing
VARIABLES	REGIN	REGIN	REGIN	REGIN	REGIN
L.BIODR	2.481*** (0.711)	0.678** (0.283)	2.481*** (0.401)	2.069*** (0.622)	2.136*** (0.719)
L.CCEXPO				-60.994 (144.076)	72.042 (373.883)
L.RG_CCEXPO				-71.381 (514.181)	-2,839.428** (1,433.023)
L.PH_CCEPO				14.835 (550.991)	-459.974 (1,378.274)
L.OP_CCEPO				-10.962	-374.787

(continued on next page)

Table 5 (continued)

Panel B. Alternative model specifications and controls					
	(1)	(2)	(3)	(4)	(5)
	Driscoll-Kraay estimator	Prais-Winsten estimator	Bootstrapping (1,000 reps)	Additional controls	Additional controls with Entropy Balancing
VARIABLES	REGIN	REGIN	REGIN	REGIN	REGIN
L.BOARDSIZE				(228.564)	(547.042)
				-0.073	-0.338**
				(0.084)	(0.158)
L.SUS_COMM				0.246	1.727**
				(0.299)	(0.763)
L.BIG4				-0.928	-11.437**
				(0.691)	(4.507)
L.SIZE	-0.037	-0.044	-0.037	-0.888***	-2.616***
	(0.176)	(0.162)	(0.145)	(0.290)	(0.781)
L.GROWTH	0.489**	-0.057	0.489*	0.218	0.680
	(0.197)	(0.102)	(0.250)	(0.135)	(0.559)
L.R_PROPOSAL	-0.004	0.076***	-0.004	0.099***	0.378***
	(0.009)	(0.011)	(0.028)	(0.030)	(0.104)
L.MCONCEN	-0.166	-0.200	-0.166	-0.198	0.405
	(0.218)	(0.222)	(0.270)	(0.448)	(0.848)
L. INSTQUAL	0.110	0.081	0.110	0.054	0.119
	(0.160)	(0.065)	(0.123)	(0.171)	(0.444)
Constant	107.604***	108.284***	109.565***	117.785***	133.327***
	(0.599)	(0.282)	(0.460)	(2.458)	(7.068)
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	Yes
Bootstrapping	No	No	Yes	No	No
Entropy Balancing	No	No	No	No	Yes
Observations	12,153	12,153	12,153	4,942	3,868
Adjusted R-squared			0.624	0.644	0.654

This table presents the regression results of robustness tests using alternative model and estimation specifications, additional controls and Entropy Balancing weights. Variable description are presented in Table 1. Standard errors are in parentheses. Standard errors are clustered by firm and year in Column (4) and Column (5). ***p<0.01, ** p<0.05, * p<0.1

Panel C. The impact across industries										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN
L.BIODR	2.536***	0.727*	3.192***	2.938***	2.569***	2.452***	2.494***	2.500***	2.494***	2.494***
	(0.713)	(0.420)	(0.501)	(0.491)	(0.438)	(0.443)	(0.424)	(0.439)	(0.424)	(0.424)
L.SCOPE	0.019									
	(0.014)									
L.BIODR × SCOPE	-0.005									
	(0.047)									
L.BIODR × ENERGY		4.029***								
		(0.861)								
L.BIODR × MATERIALS			-3.385***							
			(0.766)							
L.BIODR × INDUSTRIALS				-2.632***						

(continued on next page)

Table 5 (continued)

Panel C. The impact across industries										
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN	REGIN
L.BIODR × CONDISC				(0.784)	-0.824 (1.686)					
L.BIODR × CONSTAP						0.833 (1.118)				
L.BIODR × HEALTHCARE							0.000 (0.000)			
L.BIODR × INFOTECH								-0.137 (1.154)		
L.BIODR × COMMU									0.000 (0.000)	
L.BIODR × REALES										0.000 (0.000)
Constant	111.417*** (1.347)	111.458*** (1.342)	111.414*** (1.346)	111.426*** (1.347)	111.429*** (1.347)	111.423*** (1.348)	111.418*** (1.348)	111.419*** (1.348)	111.418*** (1.348)	111.418*** (1.348)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,153	12,153	12,153	12,153	12,153	12,153	12,153	12,153	12,153	12,153
Adjusted R-squared	0.624	0.625	0.625	0.624	0.624	0.624	0.624	0.624	0.624	0.624

This table reports the regressions results of the baseline model with interaction terms with firm scope and different GICS sector dummies. Variable description are presented in Table 1. Standard errors are clustered by firm and year and are put in parentheses.

*** p<0.01,

** p<0.05,

* p<0.1

Table 6
Mechanism tests.

VARIABLES	(1) REGIN	(2) REGIN
L.BIODR	5.519*** (1.123)	3.980*** (0.749)
L.BIODR × L.INSTQUAL	-0.928*** (0.308)	
L.INSTQUAL	0.149 (0.105)	
L.VERTINTEG		-19.412** (8.845)
L.BIODR × L.VERTINTEG		-105.067*** (38.862)
Constant	111.275*** (1.344)	111.523*** (1.341)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	12,153	12,147
Adjusted R-squared	0.625	0.625

This table reports the regression results of the further analysis into the mechanisms of the relationship between corporate biodiversity risk exposure and corporate regulatory intensity, including local institution quality (INSTQUAL) and vertical integration (VERTINTEG). Variable description are presented in Table 1. Standard errors are clustered by firm and year and are put in parentheses.

*** $p < 0.01$,

** $p < 0.05$, * $p < 0.1$

environmental policies and production activities, which can lead to improved environmental performance and reduced regulatory scrutiny. This strategy might facilitate consistent implementation of sustainable practices and compliance with environmental regulations, thus reducing the external regulatory interventions.

We test these two arguments by alternatively including interaction terms of *BIODR* and the proxies of local institutions and vertical integration. To proxy local institutions, we follow Smith (2016) to use the number of corruption convictions in the federal district courts during the state-year (*INSTQUAL*). The higher the number of corruption convictions, the poorer the local institutions. To proxy firm-level vertical integration, we employ the text-based vertical integration measure proposed by Frésard et al. (2020). The estimation results are reported in Table 6.

In Column (1), Table 6, the coefficient of the interaction term *BIODR* × *INSTQUAL* is negative and significant at 1% level, suggesting that poorer institutional quality hinder regulatory reduces the sensitivity of regulatory intensity to biodiversity risk exposure. Specifically, the *BIODR*'s coefficient is 5.519, whereas *BIODR* × *INSTQUAL*'s coefficient is -0.928. The mean value of *INSTQUAL* is 3.339, hence the overall impact of biodiversity risk exposure on regulatory intensity, both directly and indirectly via institutional quality, is on average a 56.2% decrease in magnitude. Collectively, the moderating effect of institutional quality is economically significant.

Column (2), Table 6, presents the test results of the vertical integration analysis. The coefficient of *BIODR* × *VERTINTEG* is negative and significant, implying a moderating effect of vertical integration that reduce the impact of biodiversity risk on regulatory intensity. In this regression, *BIODR*'s coefficient is 3.501, whereas *BIODR* × *VERTINTEG*'s is -105.067. With the mean value of *VERTINTEG* at 0.012, the overall impact of biodiversity risk exposure on regulatory intensity, both directly and indirectly via vertical integration, is a 36% decrease in magnitude. This finding suggests the crucial role of a vertical integration strategy in moderating the impact of biodiversity risk exposure.

4. Conclusion

By examining the impact of biodiversity risk on regulatory intensity and underlying mechanisms, this study provides insights for businesses, investors, and regulators to navigate the challenges of biodiversity risk management and regulatory compliance. The implications of our findings are profound. For policymakers, improving local institutions can enhance the effectiveness of environmental policies, leading to more stringent biodiversity protection and better regulatory outcomes. For businesses, adopting vertical integration strategies can facilitate the implementation of sustainable practices, reduce regulatory scrutiny, and ultimately lower compliance costs. By understanding these mechanisms, stakeholders can develop targeted strategies to mitigate biodiversity risks and foster a more sustainable business environment.

Despite the merits of this study, we acknowledge two limitations. First, the availability of data used in this study is limited and only covers about fifteen percent of the population of listed firms in the US due to missing values in variables merged from different datasets. Secondly, this study investigates the relationship between biodiversity risk and regulatory intensity in the U.S., hence the findings may only be applicable to other countries with similar contexts, but not for developing countries. Further studies can explore this direction for comparative purposes.

CRediT authorship contribution statement

Thanh Tat Tran: Writing – review & editing, Writing – original draft, Validation, Supervision, Funding acquisition. **Khanh Hoang:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Thanh Ngo:** Writing – review & editing, Writing – original draft, Data curation. **Thang Xuan Nguyen:** Writing – review & editing, Writing – original draft, Investigation. **Hien Thi Thu Tran:** Writing – review & editing, Writing – original draft, Project administration.

Declaration of competing interest

None.

Acknowledgement

This research is funded by National Economics University, Vietnam under grant number 07/HD-CBQT2024.07.

Data availability

The authors do not have permission to share data.

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