Biodiversity Physical and Transition Risks: Evidence from Financial Performance of US Firms

Abstract

Biodiversity loss is increasingly recognized as a material financial risk, yet firm-level evidence remains limited. This study examines how biodiversity physical risks, measured by firms' dependencies on ecosystem services, and transition risks, measured by firms' pressures on nature, affect corporate financial performance. Using 24,753 firm-year observations of U.S. exchange-listed firms from 2000 to 2023, we combine textual-based biodiversity risk measures with ENCORE dependency and pressure ratings for this analysis. The result shows a negative relationship between biodiversity risk and financial performance. This effect is more pronounced among firms with high pressure ratings and it is transmitted through higher production cost and burden from adoption of biodiversity policy. Further analysis reveals that the negative relationship is more pronounced for firms highly dependent on regulating and maintenance ecosystem services, as well as for smaller firms and high-growth firms, highlighting the uneven distribution of biodiversity risk across businesses. The results are robust to alternative specifications and sensitivity analyses. Overall, the findings suggest that although firms are incentivized to reduce pressure on biodiversity in response to negative financial impact of biodiversity transition risk, biodiversity physical risk should not be overlooked as this risk is systemic in nature, and breaches of planetary boundaries could accelerate ecosystem degradation, generate simultaneous shocks across firms and industries, posing risks to macro financial stability.

Keywords: Biodiversity Finance, Biodiversity Risk, Biodiversity Physical Risk, Biodiversity Transition Risk, Ecosystem Dependencies, Ecosystem Pressures, Corporate Financial Performance

JEL: G24, G32, G35, G39, H41, Q51, Q57

1. Introduction

Biodiversity was first coined by American entomologist E.O. Wilson (Wilson et al., 1988) referring to biological diversity, the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, this includes diversity within species, between species and of ecosystems. (UN, 1992). Building on biodiversity, ecosystem services provide essential inputs to economic activity by supporting production processes, regulating environmental conditions and sustaining natural capital. Recent evidence suggests that biodiversity loss could have economical material impact on business and the consequence could be the disruption to production process, supply chain, and asset value (Dasgupta, 2021; Karolyi & Tobin-de la Puente, 2023; Garel et al., 2024; Giglio et al., 2026).

However, biodiversity and ecosystem services are increasingly threatened by human activities such as habitat destruction, pollution, overexploitation of resources and spread of invasive species. As a result, biodiversity loss has shifted from an ecological concern to an issue with clear economical and financial relevance. According to the World Economic Forum, biodiversity loss is identified as one of the top five risks to the global economy, with nearly half of global GDP was estimated either moderately or highly dependent on nature and ecosystem services it provides (World Economic Forum, 2020; World Economic Forum & PwC, 2020). The Network for Greening the Financial System has further identified biodiversity risk as a potential systemic risk in the coming years (NGFS, 2021). From micro perspective, biodiversity risk already showed implications for firms and financial markets. A global survey shows that 48% of surveyed companies considers nature risks which include biodiversity degradation, are financially material to them. And risks are perceived urgent by many surveyed companies (Gjerde et al., 2026). In Europe, presence of biodiversity risk gets highly sensitive positive reaction from stock market in developed European market thanks to strict regulatory environment. (Hongjun et al., 2025).

These concerns gather the significant policy attention. In December 2022, the Kunming-Montreal Global Biodiversity Framework (GBF) was adopted at COP15 [1], establishing a landmark global initiative to halt and reverse biodiversity loss through the coordinated efforts for conservation, restoration and sustainable use of ecosystems (CBD, 2022). Building on this momentum, the Taskforce on Nature-related Financial Disclosure (TNFD) was officially launched in 2023. This disclosure framework equips business and financial institutions with the tools to assess, manage and disclose nature related financial risks (TNFD, 2023), thereby complementing Kunming-Montreal Global Biodiversity Framework.

As biodiversity loss emerges as a major global concern following climate change (WEF, 2020), businesses that depend on ecosystem services or exert pressure on biodiversity face increasing levels of risks (Giglio et al., 2023). These risks, refer to as biodiversity risk, can be categorized into two forms: First, physical risk affects firms reliant on ecosystem services; it arises from disruptions to these services, which may result in operational instability, higher costs, or even business failure. Second, transition risk applies to firms that place pressure on biodiversity; it stems from regulatory changes, shifting investor preferences, and evolving social expectations as economies transition toward sustainability. Both types of risk are likely to materialize as regulatory pressures intensify, and biodiversity loss accelerates.

The connection between dependency and physical risk, as well as pressure and transition risk, can be examined through the lens of double materiality. A firm's operations depend on ecosystem services; therefore, the degradation of these services may result in physical shocks to the business, translating into financial materiality (Carvalho et al., 2023). At the same time, a firm's operations can exert pressures on biodiversity, creating negative environmental impacts that are vulnerable to transition shocks and constitute impact materiality. Analyzing dependency on nature and the impact of economic activities on nature can be the first step of identifying the source of physical and transition risks (NGFS, 2024). This framework reveals the main channels of risk transmission to firms'

[1] 15th Conference of the Parties to the UN Convention on Biological Diversity

financial performance, therefore bringing up a further question of how these risks being reflected in real market settings. Figure 1 illustrates this relationship.

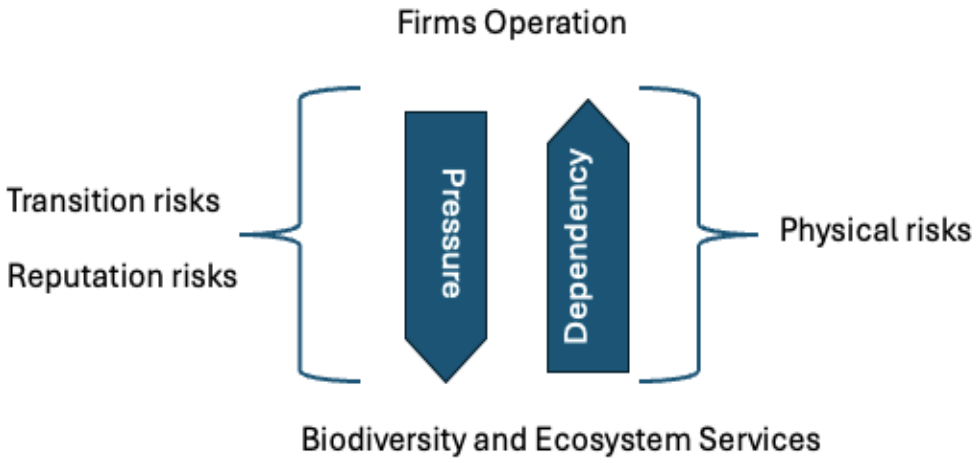


Figure 1. Double materiality approach to biodiversity risk: The connection between dependency and biodiversity physical risks, pressure and biodiversity transition risks

Against this background, we examine the financial impact of biodiversity-related physical risk and transition risk for U.S. exchange listed firms. The U.S. capital market provides ideal setting for multiple reasons. First, although ESG pushback from recent U.S. administration, biodiversity related regulation is present throughout and even much more beyond the sample period in American history. This includes a longstanding federal framework "Endangered Species Act of 1973", which aims at conserving endangered species and ecosystems both domestically and abroad. This act has been in place since the 1970s and continue to shape regulatory expectations of firms which operate in or affect sensitive areas (ESA, 1973). Apart from ESA, the environmental law such as National Environmental Policy Act (NEPA) requires federal agencies to assess and disclose environmental impact of major actions, this includes the actions that impact on ecosystems and biodiversity (NEPA, 1969). The Clean Water Act (CWA), which aims to address water quality issues, also regulates firms' negative impact on aquatic ecosystems (EPA,2023). Those regulations can remain constraints and compliance for firms during the ESG backlash from federal government. On the other hand, the U.S. regulatory environment is heterogeneous across the states, some "blue" states continue the support

for sustainability initiative, while some other states hold more skeptical stance towards ESG. This provides good setting where biodiversity related transition risk can vary a lot across firms and over the time. Second, U.S. capital market is highly globalized, this is the destination for most of global capital flow. Especially European investors are among one of them, they are facing the stricter environmental regulations such as the Sustainable Finance Disclosure Regulation (SFDR), which to some extent shapes the behaviors of the firms they invest into (European Commission, 2025). As a result, transition risk for U.S. exchange listed firms not only result from the domestically regulatory environment, but also from the regulatory abroad. Third, many U.S. exchange listed firms operate globally and generate big portion of revenue abroad (Chintha et al., 2024), this implies that their biodiversity related physical risks may arise from different regions with different level of ecosystem fragility, therefore offering more variability to examine actual impact of biodiversity related physical risks. At last, U.S. has the most developed capital market with incomparable depth and liquidity. Prior evidence shows that liquidity is highly linked to the price discovery (Frijns et al., 2018). Accordingly, investors' belief in biodiversity related physical and transition risks could be more efficiently incorporated into market pricing, which in turn generating financial impact on the firms' operation. Taken together, the co-existence of biodiversity related regulation, heterogeneous transition pressures, broad reach of global investments, multinational operations, and the highly developed capital market make U.S. exchange listed firms a well-suited sample for studying the financial implications of biodiversity related physical and transition risks.

Table 1. Major biodiversity related regulation framework in the United States

Regulation	Year Enacted	Description
Endangered Species Act (ESA)	1973	Protecting threatened and endangered species and ecosystems upon they depend. Restricting activities that may result in the "take" of listed species and adverse impact on critical habitats.
National Environmental Policy Act (NEPA)	1969	Requires federal agencies to assess and disclose the environmental impacts of major actions, including impacts on biodiversity and ecosystems.

Clean Water Act (CWA)	1972	Regulating discharges into water to protect aquatic ecosystems and water quality.

Against this institutional and market backdrop. This research primarily seeks to answer the question: “What is the relationship between firms’ financial performance and biodiversity-related physical and transition risk?” The mechanisms through which biodiversity loss affects business operations are supported by several theories. The resource-based view theory (Barney, 1991) suggests that firms build competitive advantage through rare, valuable and non-substitutable resources. Biodiversity degradation undermines firm’s ability to access such resources, thereby increasing costs and impairing profitability. The stakeholder theory (Freeman, 1984) argues that businesses must consider the interests of all parties involved in or affected by their activities, challenging the shareholder theory that prioritizes maximizing shareholder value as the sole responsibility. Stakeholders – including regulators, investors and consumers – may impose reputational and regulatory consequences on companies that fail to manage their impact on biodiversity, thereby undermining investor confidence and financial performance.

The contribution of this research is multifold: First, prior studies have often proxied biodiversity risk using self-reported biodiversity word count (Bach et al., 2025). In contrast, this study replaces simple word count with the ratio of sentiment sentences as a proxy for general biodiversity risk. Furthermore, we incorporate the ENCORE dependency and pressure ratings to separately examine the effects of biodiversity-related physical and transition risks. This approach allows us to assess biodiversity risk through the lens of the double materiality standard, thereby enabling a more granular and precise examination of the relationship between biodiversity risk and financial performance.

Second, this research combines biodiversity dependency and pressure rating from Encore with biodiversity risk dataset developed by Giglio et al. (2023) and firms’ financial data from LESG Workspace. This integration of datasets has not been employed in prior research.

Third, this research offers important practical implication. For policymakers, it explicitly examines the effects of biodiversity-related physical and transition risks on financial performance, providing a clearer understanding of this nexus. Such insights can justify the implementation of stricter environmental regulations and policies for biodiversity conservation. For companies, the findings contribute evidence to further enhance existing frameworks, such as the TNFD, by better integrating biodiversity considerations into corporate disclosure. For investors, this research establishes a more explicit link between biodiversity risk and financial performance, enabling more informed investment decisions that account for biodiversity impacts.

The remainder of this research is organized as follows. Section 2 is the literature review and hypothesis development; Section 3 introduces the data and methodology; Section 4 presents the results; Section 5 is the discussion and conclusion.

2. Literature review and hypothesis development

Biodiversity finance research has garnered increasing attention from finance researchers since Karolyi & Tobin-de la Puente (2023) coined the term biodiversity finance. Since then, biodiversity risk related to firms has been gaining interest in financial literature. Building on this momentum, Flammer et al. (2023) advances the field by analyzing a real transaction deal involving biodiversity conservation projects. Subsequent research has gradually shaped the biodiversity finance literature into two distinct streams.

The first stream of research primarily seeks to understand whether biodiversity risk is priced in financial markets. Giglio et al. (2023) adopt a *text as data* approach, using textual analysis of financial reports to extract firm's biodiversity exposure. Their regression results with stock returns suggest that investors have already priced in biodiversity risk, although the pricing remains insufficient. Similarly, Garel et al. (2024), using proprietary firm-level biodiversity footprint data provided by Iceberg Data Lab, find in an event study that investors began demanding a biodiversity premium following several influential global biodiversity conservation events. Beyond equity markets, evidence also emerges from fixed-income markets. Soylemezgil and Uzmanoglu (2024) find a positive association between biodiversity risk exposure and yield spreads, indicating that biodiversity loss is perceived as a long-term risk.

The second stream of research focuses on the association between biodiversity risk, biodiversity disclosure, and broader corporate finance issues. Regarding biodiversity risk, most studies rely on textual analysis as a proxy for biodiversity exposure, both in the US market (Giglio et al., 2023) and in the Chinese market (He et al., 2024). In the US market, research finds that there is significant negative association between biodiversity risk and firm efficiency, through the channel of higher cost of capital and external financing needs, indicating the economic cost brought by biodiversity risk (Li et al., 2025). This effect is further supported by evidence showing a negative relationship between biodiversity risk and firm's financial performance (Bach et al., 2024) and by findings that firms with higher biodiversity risk are more likely to engage in seasoned equity offering (Liu et al., 2025). Additionally, Steindl et al. (2025) reveal that auditors charge higher audit fees to firms with elevated biodiversity risk. In the Chinese market, Yang and Li (2025) find that firms with higher biodiversity risk are more likely to use short term debt for long use, reflecting lower risk-taking capacity and asset turnover. Similarly, Zhou et al. (2025) report a negative relationship between biodiversity risk and dividend payout, primarily due to financing constraints and resource reallocation. In terms of the impact factor of biodiversity performance, there is evidence that managerial myopia negatively impacts on corporate biodiversity performance (Zhao et al., 2025).

In terms of biodiversity disclosure, a global analysis shows that the presence of institutional investors is positively associated with biodiversity disclosure, with this effect being more pronounced for investors with long-term horizon (Ali et al., 2024). Another multi-country analysis finds a positive association between biodiversity conservation disclosure and board gender diversity, with this relationship moderated by eco-innovation, resource usage and CSR award (Issa et al., 2023). In the Chinese market, He et al. (2025) demonstrate that higher levels of biodiversity disclosure reduce the likelihood of corporate greenwashing. Lublóy et al. (2025) provide a typology of firm-level greenwashing and measures.

Regarding the nexus between biodiversity risk and financial performance, Bach et al. (2024) employ firm-level regulation related biodiversity scores, following the textual analysis methodology of Giglio et al. (2023), to examine the impact of biodiversity risk on

financial performance in the US market. Their findings reveal a negative relationship between biodiversity risk and firm financial performance. However, the biodiversity risk measure applied in this study doesn't capture firms' sentiment toward biodiversity risk, making it a less optimal proxy. Moreover, this study only considers overall biodiversity risk, despite its two distinct dimensions: physical risk and transition risk. Carvalho et al. (2023) highlight the importance of distinguishing between these two dimensions. They find companies in sectors with material impact on biodiversity are more likely to adopt biodiversity policy, whereas firms in sectors with material dependency risk are less likely to do so. Building on the connection between physical risk and dependency levels, as well as between transition risk and pressure levels, the following hypotheses are proposed:

H1: Biodiversity physical risk is negatively associated with firm's financial performance

H2: Biodiversity transition risk is negatively associated with firm's financial performance

According to resource-view theory, company would experience reduction in profitability through increasing production costs due to losing access strategic resources. An OECD report suggests that losing access to ecosystem services leads to the disruption in companies' production process, which can translate to the increasing production costs for the business (OECD, 2023). A study on French insurers shows that physical shock from biodiversity loss could slow or stop insured firms' production process due to loss of ecosystem services, and transition shocks from change of regulations can cause losses through penalty, sanctions and reputation damage, both shocks can lead to the further increase of the costs (ACPR, 2024). Therefore, we examine increase of production costs as the channel of negative nexus of biodiversity physical and transition risk with financial performance by raising these two hypotheses:

H3: Biodiversity physical risk is positively associated with production costs

H4: Biodiversity transition risk is positively associated with production costs

Stakeholder theory posits that firms must consider interests of all parties affected by their activities (Freeman, 1984). Accordingly, external pressures from stakeholders serves as an important supervisory force when firms operate at the expense of biodiversity loss. In the context of climate risk, Yu and Ramanathan (2015) find that stakeholder engagement significantly increases the likelihood of firms adopting green operation practices, though these pressures also impose burdens by requiring investments in new capabilities and processes. Similarly, an article by Impact Investors (2021) highlights that financial institutions and investors are increasingly pressuring firms to address biodiversity loss within their operations and supply chains. We argue that firms facing greater biodiversity risks will be more likely to respond to such pressure by adopting biodiversity-related management practices. These responses, while potentially improving legitimacy and stakeholder relations, can also increase operational burdens and thereby affect financial performance. We therefore propose policy adoption – that may result from stakeholder engagement as a second transmission mechanism. Hence, we formalize the following hypothesis:

H5: Biodiversity physical risk is positively associated with firm's biodiversity policy adoption

H6: Biodiversity transition risk is positively associated with biodiversity policy adoption

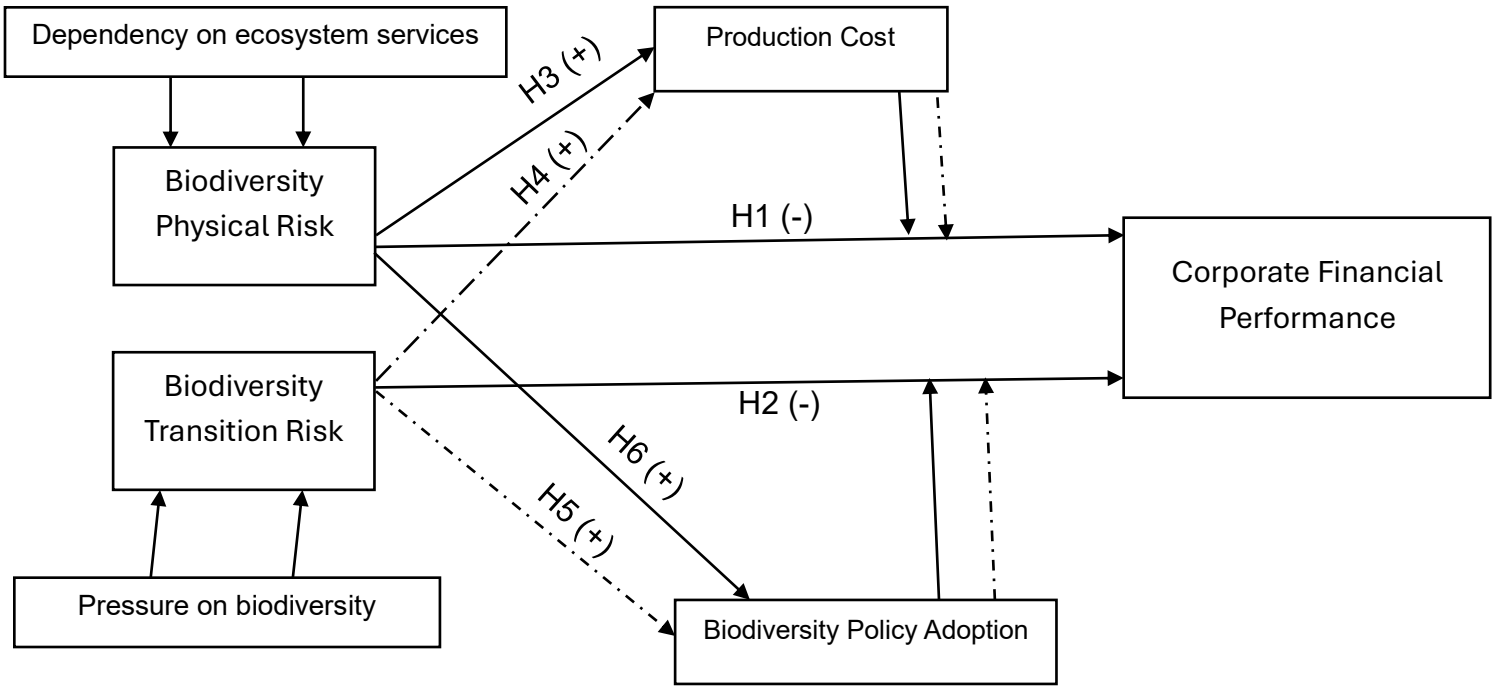


Figure 2. Theoretical research framework

We contribute to the ongoing discussion on biodiversity finance by presenting the first empirical analysis of the relationship between biodiversity-related physical and transition risk and firm's financial performance. In addition, we examine how these risks affect financial performance through the channels of rising production costs and policy adoption.

3. Research design

3.1 Data

3.1.1 Biodiversity risk exposure and firm financial data

This study examines US publicly listed companies over the period from 2000 to 2023. Financial and firm-specific data are sourced from LESG Workspace, while firm level biodiversity risk is proxied by biodiversity negative score, following the methodology of Giglio et al. (2023). This score reflects firm's negative sentiment towards biodiversity exposure and serves as a better gauge of the biodiversity risk they face. Companies in the financial and utility sectors are excluded from the analysis. Continuous variables are winsorized at the 1st and 99th percentiles to mitigate the influence of outliers. The final dataset comprises of 24,753 firm-year observations.

3.1.2 Biodiversity dependency and pressure rating from ENCORE

ENCORE, which stands for *Exploring Natural Capital Opportunities, Risks, and Exposure*, was first developed in 2018 through a collaboration between Global Canopy, UNEP FI[2], and UNEP-WCMC[3]. This database is designed to identify nature-related risks and provide insights to help organizations to better understand their dependencies on ecosystem services and the pressures they exerted on nature.

The industry-level ecosystem dependency score is classified into five categories: Very High (VH), High (H), Medium (M), Low (L), and Very Low (VL). These categories correspond to quantitative materiality scores ranging from 2 to 6, with higher scores indicating greater dependency on ecosystem services (ES). Similarly, the industry-level pressure materiality score applies the same VL-to-VH scale. The pressure score is calculated using a weighted approach that assigns three times more weight to the magnitude of the pressure than to the scale of economic activity. The absolute scores for each rating range from 4 to 12, with higher scores indicating more significant

[2] United Nations Environment Programme Finance Initiative (UNEP FI)
[3] The UN Environment Programme World Conservation Monitoring Center (UNEP-WCMC)

environmental pressures. Table 1 demonstrates the ecosystem service types and pressure types.

Table 2
Type of ecosystem services and pressures

Ecosystem services	Pressures
Provisioning services: Biomass provisioning services; Genetic material services; Water supply; Other provisioning services – Animal-based energy **Regulating and maintenance services**: Global climate regulation services; Rainfall pattern regulation services; Local (micro and meso) climate regulation services; Air filtration services; Soil quality regulation services; Soil and sediment retention services; Solid waste remediation; Water purification services; Water flow regulation services; Flood mitigation services; Storm mitigation services; Noise attenuation services; Pollination services; Biological control services; Nursery population and habitat maintenance services; Other regulating and maintenance service – Dilution by atmosphere and ecosystem; Other regulating and maintenance service – Mediation of sensory impacts **Cultural services**: Recreation-related services; Visual amenity services; Education, scientific and research services; Spiritual, artistic and symbolic services	Emission of GHGs Emission of non-GHG air pollutants Other biotic resource extraction (e.g. fish, timber) Other abiotic resource extraction Generation and release of solid waste Area of land use Volume of water use Disturbances (e.g. noise, light) Area of freshwater use Area of seabed use Emissions of toxic pollutants to water and soil Emissions of nutrient pollutants to water and soil Introduction of invasive species

Source: Explanatory note on the updated ENCORE knowledge base outlining business dependencies and impacts on nature, UNEP-WCMC, June 2024

Table 3
Variable definitions and sources

Variable	Definition	Source
1. Biodiversity Risk Exposure (10-K based)		
BRE	10K biodiversity count score, assign 1 when a firms' 10-K filing includes at least two sentences related to biodiversity; assign 0 the otherwise	**Giglio et al. (2023)**
BRE_N	10K biodiversity negative score, number of negative biodiversity related sentence minus number of positive biodiversity related sentence in 10-K filing; assign 0 to neutral or not mention	
BRE_R	10K biodiversity regulation score, assign 1 when there are at least two biodiversity related sentences, and at least one biodiversity regulation related sentence in 10-K filing; assign 0 the otherwise	
2. Biodiversity dependency and pressure rating		
HP	Dummy variable that equals 1 if firms are in GICS sub industries with High or Very High ENCORE pressure rating; assign 0 the otherwise	**Encore**
HD	Dummy variable that equals 1 if firms are in GICS sub industries with High or Very High ENCORE dependency rating; assign 0 the otherwise	
HPROV	Dummy variable that equals 1 if firms are in GICS sub industries with High or Very High ENCORE provisioning services dependency rating; assign 0 the otherwise	
HREG	Dummy variable that equals 1 if firms are in GICS sub industries with High or Very High ENCORE regulating	

	and maintenance services dependency rating; assign 0 the otherwise	
HCUL	Dummy variable that equals 1 if firms are in GICS sub industries with High or Very High ENCORE cultural services dependency rating; assign 0 the otherwise	
3. Firm Characteristic		
ROA	Net income divided by total assets	
ROE	Net income divided by total equity of common shares	
BM	Book-to-market ratio	
CF	Operating cash flow scaled by total assets	
CCE	Cash and cash equivalents scaled by total assets	
SIZE	Natural logarithm of firm total assets	
LEV	Liabilities divided by total assets	
TAN	Tangibility, fixed assets over total assets	**LSEG Workspace**
RG	Revenue growth, percentage of year over year change for revenue	
BIG_4	Dummy variable equals to 1 if auditor of the firm is a big for auditor; assign 0 otherwise	
IRP	Dummy variable equals to 1 if firm has biodiversity impact reduction policy; assign 0 the otherwise	
COGS	Cost of goods sold scaled by total sale	
CITY	Variable calculated as average biodiversity risk of other surrounding firms in the same three-digit zip code.	

3.2 Methodology

Using a panel data regression model with two-way fixed effects, we first examine the relationship between financial performance and general biodiversity risk, proxied by

negative score. We then incorporate dependency and pressure ratings into the model to assess the effects of biodiversity-related physical and transition risk on financial performance. The baseline regression models are specified as follows:

$$ROA_{i,t} = \beta_0 + \alpha_1 BiodiversityRisk_{it} + \alpha_2 Cintrol_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

$$ROA_{i,t} = \beta_0 + \alpha_1 (BiodiversityRisk_{it} * HighDependencyDummy_{it}) + \alpha_2 Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

$$ROA_{i,t} = \beta_0 + \alpha_1 (BiodiversityRisk_{it} * HighPressureDummy_{it}) + \alpha_2 Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

The dependent variable is the financial performance of firm *i* in year *t*, proxied by return on assets (ROA). Biodiversity risk exposure follows methodology of Giglio et al. (2023) and is measured by negative score. Biodiversity dependency and pressure rating are sourced from ENCORE database. The high dependency dummy equals 1 for firms with high or very high ecosystem service dependency ratings and 0 the otherwise; The high pressure dummy equals 1 for firms with high or very high biodiversity pressure ratings and 0 the otherwise. The high dependency dummy and high pressure dummy are the proxy for the presence of biodiversity physical risk and biodiversity transition risk respectively. $Control_{it}$ represents control variables. Specifically, consistent with prior literatures (Titman & Wessels, 1988; Rajan & Zingales, 1995; Becker et al., 1998; Opler et al., 1999; Bhagat et al., 2008), We control for firm size (*SIZE*), Leverage (*LEV*), Tangibility (*TAN*), Book to market ratio (*BM*), Operating cash flow (*CF*), Cash and cash equivalent (*CCE*) and Big 4 auditing dummy (*Big_4*). μ_i represents firm fixed effect, δ_t represents year fixed effect. The disturbance term ε_{it} captures idiosyncratic, time varying firm level shocks and other unobservable factors that may affect financial performance but are not specified in the model. Detailed descriptions and sources of the independent variables, control variables and interaction terms are provided in Table 2.

4. Results

4.1 Baseline regression

Table 5 presents the baseline regression results on the relationship between general biodiversity risk and financial performance using the full sample. A significant negative relationship between financial performance and biodiversity risk is observed across all four model specifications. After controlling for firm and year fixed effect, a one standard deviation increase in biodiversity risk reduces return on asset by 0.06%. The magnitude of biodiversity risk coefficients shows little variation across the four models. This negative relationship is consistent with expectations, suggesting that accelerating biodiversity loss translates into higher costs for firms, thereby weakening the profitability. In the subsequent baseline regression, we incorporate Encore dependency and pressure rating to further disentangle biodiversity risk and examine the relationship between biodiversity-related physical and transition risk and firm's financial performance.

Table 6 shows the results. the coefficient of the interaction term between the high biodiversity pressure dummy and biodiversity risk is negative and significant at the 10 % level. This indicates that the negative relationship between biodiversity risk and financial performance is more pronounced for firms in high-pressure sub-industries, where return on assets is reduced by an additional 0.8% compared to firms outside these industries. By contrast, no significant difference is observed for firms in high-dependency sub-industries; the coefficient magnitude is also extremely close to zero. This outcome can be explained by the distinction between the two measures: dependency ratings capture physical risks, whereas pressure ratings reflect transition risks. Transition risks impose more immediate pressure on businesses due to recent developments in biodiversity regulation, while physical risks take much longer to materialize. As a result, the profitability reduction effect has not yet emerged for firms operating in high-dependency sub-industries.

Table 4
Descriptive statistics

	Obs	Mean	SD	Min	Max
ROA	35785	0.018	0.154	-0.741	0.265
BRE_N	47261	0.014	0.209	-6.000	5.000
SIZE	40800	20.907	1.728	17.061	25.412
LEV	40579	0.528	0.265	0.051	1.336
BM	28234	0.464	0.455	-0.309	2.803
TAN	38381	0.377	0.232	0.013	0.942
CF	40649	0.060	0.148	-0.614	0.348
CCE	40605	0.147	0.168	0.001	0.833
BIG_4	47261	0.736	0.441	0.000	1.000

Notes: All continuous variables are winsorized at the 1st and 99th percentiles. Obs, Mean, SD, Min, and Max stand for number of observations, average value, standard deviation, minimum value and maximum value respectively

Table 5
Correlation table

	ROA	BRE_N	SIZE	LEV	BM	TAN	CF	CCE	BIG_4
ROA	1.00								
BRE_N	0.02*	1.00							
SIZE	0.34***	0.03***	1.00						
LEV	0.07***	-0.01*	0.40***	1.00					
BM	-0.04***	0.07***	0.03***	-0.19***	1.00				
TAN	0.21***	0.13***	0.33***	0.26***	0.14***	1.00			
CF	0.87***	0.04***	0.31***	0.09***	-0.05***	0.28***	1.00		
CCE	-0.38***	-0.05***	-0.41***	-0.28***	-0.16***	-0.46***	-0.34***	1.00	
BIG_4	0.03***	-0.00	0.30***	0.15***	-0.03***	0.04***	0.04***	-0.10***	1.00

,and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

Table 6
The effect of biodiversity risk on firm financial performance

VARIABLES	(1) ROA	(2) ROA	(3) ROA	(4) ROA
BRE_N	-0.007**	-0.007***	-0.007**	-0.006***
	(0.003)	(0.002)	(0.003)	(0.002)
SIZE	0.008***	0.020***	0.008***	0.019***
	(0.001)	(0.001)	(0.001)	(0.002)
LEV	-0.033***	-0.071***	-0.033***	-0.071***
	(0.004)	(0.006)	(0.004)	(0.006)
TAN	-0.066***	-0.037***	-0.066***	-0.033***
	(0.004)	(0.008)	(0.004)	(0.008)
BM	-0.007***	-0.028***	-0.006***	-0.028***
	(0.002)	(0.002)	(0.002)	(0.002)
CF	0.889***	0.652***	0.894***	0.657***
	(0.010)	(0.017)	(0.010)	(0.017)
CCE	-0.119***	-0.050***	-0.119***	-0.044***
	(0.007)	(0.008)	(0.007)	(0.008)
BIG_4	-0.012***	-0.005	-0.010***	-0.005
	(0.003)	(0.004)	(0.003)	(0.004)
Constant	-0.135***	-0.364***	-0.128***	-0.344***
	(0.012)	(0.023)	(0.012)	(0.035)
Observations	24,753	24,753	24,753	24,753
R-squared	0.787	0.506	0.790	0.516
Firm FE	NO	YES	NO	YES
Year FE	NO	NO	YES	YES

*This table presents the effect of general biodiversity risk on financial performance. The models control for key financial variables and include or exclude two-way fixed effect as robust check. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

Table 7
The effect of biodiversity related physical and transition risk on financial performance

VARIABLES	(1) ROA	(2) ROA
HD * BRE_N	0.000	
	(0.007)	
HP * BRE_N		-0.008*
		(0.004)
BRE_N	-0.006***	0.001
	(0.002)	(0.003)
SIZE	0.019***	0.019***
	(0.002)	(0.002)
LEV	-0.071***	-0.071***
	(0.006)	(0.006)
TAN	-0.033***	-0.033***
	(0.008)	(0.008)
BM	-0.028***	-0.028***
	(0.002)	(0.002)
CF	0.657***	0.657***
	(0.017)	(0.017)
CCE	-0.044***	-0.044***
	(0.008)	(0.008)
BIG_4	-0.005	-0.005
	(0.004)	(0.004)
Constant	-0.344***	-0.344***
	(0.035)	(0.035)
Observations	24,753	24,753
R-squared	0.516	0.516
Firm FE	YES	YES
Year FE	YES	YES

*This table shows the effect of biodiversity related physical and transition risk on financial performance. BRE_N interacts with HD and HP dummy, showcasing extra impact brought by physical risk and transition risk. The model controls for key financial variables and include two way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

Overall, no significant effect of biodiversity-related physical risk on financial performance is observed. According to the SEEA EA report (United Nations, 2021), ecosystem services can be categorized into three groups: provisioning services, regulating and maintenance services, and cultural services. Each type of service provides businesses with distinct functionalities. For example, water supply is a provisioning service, pollination falls under regulating and maintenance services, and recreation-related activities are classified as cultural services. To further disentangle the impact of biodiversity-related physical risk, we use dependency ratings for these three ecosystem services and interact them with biodiversity risk separately. The results show that firms exposed to regulating and maintenance services experience a greater reduction in profitability when biodiversity risk is present, with the effect significant at the 10% level. The effect of exposure to provisioning services is also negative, though not statistically significant. By contrast, the coefficient for cultural services is positive, but it is not statistically or economically significant. The regression results are presented in Table 7.

Table 8

The effect of biodiversity dependency sub-group on financial performance

VARIABLES	(1) ROA	(2) ROA	(3) ROA
HPROV * BRE_N	-0.008		
	(0.006)		
HREG * BRE_N		-0.014*	
		(0.008)	
HCUL * BRE_N			0.010
			(0.007)
BRE_N	-0.002	-0.002	-0.005*
	(0.002)	(0.002)	(0.003)
SIZE	0.026***	0.026***	0.026***
	(0.002)	(0.002)	(0.002)
LEV	-0.069***	-0.069***	-0.069***
	(0.007)	(0.007)	(0.007)
TAN	-0.015	-0.015	-0.015
	(0.011)	(0.011)	(0.011)
BM	-0.024***	-0.024***	-0.024***
	(0.003)	(0.003)	(0.003)
CF	0.646***	0.647***	0.646***
	(0.020)	(0.020)	(0.020)
CCE	-0.033***	-0.033***	-0.033***
	(0.011)	(0.011)	(0.011)
BIG_4	-0.001	-0.001	-0.001
	(0.006)	(0.006)	(0.006)
Constant	-0.514***	-0.513***	-0.514***
	(0.048)	(0.048)	(0.048)
Observations	13,520	13,520	13,520
R-squared	0.550	0.550	0.550
Firm FE	YES	YES	YES
Year FE	YES	YES	YES

*This table presents separate effects of ecosystem services dependencies on financial performance. HPROV is 1 if companies are in sub industries with high or very high provisioning ecosystem service dependency rating, 0 the otherwise; HREG is 1 if companies are in sub industries with high or very high regulating and maintenance ecosystem services dependency rating, 0 the otherwise; HCUL is 1 if companies are in sub industries with high or very high cultural ecosystem services dependency rating, 0 the otherwise; The model controls for key financial variables and include two way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

4.2 Heterogeneity analysis

This section investigates how the relationship between biodiversity-related physical and transition risks and financial performance varies across different firm characteristic. We focus on firm size and revenue growth as the key characteristics for this analysis. Firm size matters because larger firms typically have greater access to critical resources when risks arise, while revenue growth is important because firms at different growth stages differ in their capacity to address risks.

The first heterogeneity analysis focuses on firm size. Firm size is an important characteristic that influences firms in many ways, including risk-adjusted returns, agency costs, governance structures, and credit constraints (Meckling & Jensen, 1976; Banz, 1981; Beck et al., 2008). Larger firms control more resources, typically have well-established governance structures, and face less credit constraints, making them more resilient when risks arise. By contrast, smaller firms are more vulnerable due to their disadvantaged positioning in these respects. Table 8 shows that the impact of biodiversity risk on financial performance is not significant for large firms, whereas it is significant for small firms, with an additional negative effect for small firms exposed to biodiversity-related transition risk.

Table 9
Heterogeneity analysis by firm size

VARIABLES	Big Size			Small Size		
	ROA	ROA	ROA	ROA	ROA	ROA
BRE_N	-0.003	-0.003*	0.001	-0.013*	-0.015**	0.006
	(0.002)	(0.002)	(0.005)	(0.007)	(0.008)	(0.005)
HD * BRE_N		0.001			0.008	
		(0.006)			(0.015)	
HP * BRE_N			-0.005			-0.032***
			(0.005)			(0.010)
SIZE	0.005***	0.005***	0.005***	0.030***	0.030***	0.030***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
LEV	-0.053***	-0.053***	-0.053***	-0.088***	-0.088***	-0.088***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
TAN	-0.042***	-0.042***	-0.042***	-0.029**	-0.029**	-0.029**
	(0.009)	(0.009)	(0.009)	(0.012)	(0.012)	(0.012)
BM	-0.025***	-0.025***	-0.025***	-0.037***	-0.037***	-0.037***
	(0.003)	(0.003)	(0.003)	(0.005)	(0.005)	(0.005)
CF	0.459***	0.459***	0.459***	0.701***	0.701***	0.701***
	(0.028)	(0.028)	(0.028)	(0.019)	(0.019)	(0.019)
CCE	-0.046***	-0.046***	-0.046***	-0.038***	-0.038***	-0.038***
	(0.017)	(0.017)	(0.017)	(0.010)	(0.010)	(0.010)
BIG_4	-0.003	-0.003	-0.003	-0.004	-0.003	-0.004
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
Constant	-0.039	-0.039	-0.039	-0.539***	-0.539***	-0.538***
	(0.044)	(0.044)	(0.044)	(0.058)	(0.058)	(0.058)
Observations	13,704	13,704	13,704	11,049	11,049	11,049
R-squared	0.375	0.375	0.375	0.556	0.556	0.556
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

*This table presents the impact of biodiversity-related physical and transition risk on financial performance across firms of different size. The sample is divided into two groups (big size and small size) based on firm size. The model controls for key financial variables and include two-way fixed effect. Robust standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

The second heterogeneity analysis is based on firm growth, proxied by the revenue growth rate. Growth reflects a firm's potential for scaling and profitability (Cho & Pucik, 2005; Sounder & Shaver, 2010). High-growth firms often hold more working capital, which can strain profitability (Deloof, 2003), whereas low-growth firms are typically at a more mature stage and thus have more resources at their disposal. Table 9 presents the

differences between high-growth and low-growth firms in the relationship between biodiversity risk and financial performance. For high-growth firms, biodiversity-related transition risk shows a significant negative relationship with financial performance, while no significant effect is observed for low-growth firms.

Table 10

Heterogeneity analysis by firm growth

VARIABLES	High Growth			Low Growth		
	ROA	ROA	ROA	ROA	ROA	ROA
BRE_N	-0.004**	-0.005**	0.005	-0.003	-0.004	0.001
	(0.002)	(0.002)	(0.006)	(0.003)	(0.002)	(0.003)
HD * BRE_N		0.006			0.001	
		(0.005)			(0.008)	
HP * BRE_N			-0.011*			-0.006
			(0.006)			(0.004)
SIZE	0.020***	0.020***	0.020***	0.010***	0.010***	0.010***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
LEV	-0.071***	-0.071***	-0.071***	-0.056***	-0.056***	-0.056***
	(0.007)	(0.007)	(0.007)	(0.009)	(0.009)	(0.009)
TAN	-0.034***	-0.034***	-0.035***	-0.033***	-0.033***	-0.033***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
BM	-0.023***	-0.023***	-0.023***	-0.022***	-0.022***	-0.022***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
CF	0.693***	0.693***	0.693***	0.520***	0.520***	0.520***
	(0.019)	(0.019)	(0.019)	(0.027)	(0.027)	(0.027)
CCE	-0.047***	-0.047***	-0.047***	-0.031**	-0.031**	-0.031**
	(0.010)	(0.010)	(0.010)	(0.015)	(0.015)	(0.015)
BIG_4	-0.007	-0.007	-0.007	-0.005	-0.005	-0.005
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Constant	-0.369***	-0.369***	-0.369***	-0.191***	-0.191***	-0.190***
	(0.042)	(0.042)	(0.042)	(0.054)	(0.054)	(0.054)
Observations	15,100	15,100	15,100	9,653	9,653	9,653
R-squared	0.552	0.552	0.552	0.403	0.403	0.403
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

*This table presents the impact of biodiversity-related physical and transition risk on financial performance across firms of different revenue growth. The sample is divided into two groups (high growth and low growth) based on revenue growth rate. The model controls for key financial variables and include two-way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

4.3 Mechanism analysis

In this section, we further explore how biodiversity-related physical and transition risks impact financial performance by examining two potential mechanisms. The first mechanism is the policy adoption channel, reflecting firms' management responses to biodiversity risks. This is proxied by the presence of a biodiversity impact reduction policy, which indicates whether a firm has formally committed to mitigating its biodiversity impacts. The second mechanism is the production cost channel, captured by the cost of goods sold (COGS) relative to sales, which reflects how biodiversity risks may translate into higher operational costs.

Table 11
Mechanism analysis: Biodiversity impact reduction policy adoption

VARIABLES	(1) IRP	(2) IRP
HD	-0.014	
	(0.177)	
HP		1.222***
		(0.161)
SIZE	0.754***	0.731***
	(0.057)	(0.057)
LEV	-0.774**	-0.375
	(0.318)	(0.320)
TAN	2.511***	2.185***
	(0.350)	(0.326)
BM	0.104	0.003
	(0.152)	(0.154)
CF	2.014***	2.115***
	(0.666)	(0.686)
CCE	0.154	0.015
	(0.664)	(0.717)
BIG_4	0.007	0.019
	(0.267)	(0.249)
Constant	-22.041***	-22.192***
	(1.276)	(1.294)
Observations	15,820	15,820
Pseudo R^2	0.234	0.273
Year FE	YES	YES

*This table presents the likelihood of having biodiversity impact reduction policy for firms in high dependency and high pressure GICS sub industries. The models control for key financial variables and include year fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at 10%, 5% and 1% level, respectively.*

Literature findings suggest that ESG disclosure is associated with stakeholder engagement through goal compatibility and resource dependency (Liu et al., 2022). The presence of a biodiversity impact reduction policy may well be the result of stakeholder engagement activities (Treepongkaruna, 2024). As shown in Table 10, we use the adoption of a biodiversity impact reduction policy as the indicator to proxy policy adoption. Results of the logistic regression show that firms in GICS sub-industries that have high

pressure ratings are more likely to adopt such policies, whereas no significant effect is observed for firms in sub-industries with high dependency ratings. This finding implies that firms facing high transition risk are more likely to adopt policies, possibly resulting from stakeholder engagement activities, which places additional burdens on firm operations, ultimately lowering profits.

Table 12
Mechanism analysis: Cost of goods sold

	(1)	(2)
VARIABLES	COGS	COGS
HD	-0.232***	
	(0.022)	
HP		0.060***
		(0.022)
SIZE	-0.081***	-0.079***
	(0.007)	(0.007)
LEV	0.088***	0.095***
	(0.019)	(0.019)
TAN	-0.226***	-0.232***
	(0.035)	(0.035)
BM	-0.022***	-0.022***
	(0.008)	(0.008)
CF	0.395***	0.410***
	(0.028)	(0.028)
CCE	-0.267***	-0.275***
	(0.021)	(0.021)
BIG_4	-0.004	-0.006
	(0.021)	(0.021)

Constant	2.359***	2.244***
	(0.145)	(0.144)
Observations	13,858	13,858
R-squared	0.06	0.03
Year FE	YES	YES

*This table presents the production costs impact of the firms in high dependency and pressure GICS sub industry. The models control for key financial variables and include year fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at 10%, 5% and 1% level, respectively.*

The resource-based view theory posits that firms' profitability is reduced by rising production costs resulting from limited access to essential resources. Table 11 examines this channel by analyzing the relationship between cost of goods sold and high biodiversity dependency and pressure. The results indicate that firms in high-dependency industries are likely to have lower costs, whereas firms in high-pressure industries are more likely to experience higher production costs.

The interpretations of the mechanism analysis are as follows. A high-pressure rating, used as a proxy for biodiversity-related transition risk, is positively associated with both mechanisms. This suggests that firms exposed to transition risk face imminent pressure from regulators and customers, as real costs can be incurred over a relatively short horizon. By contrast, a high dependency rating, used as a proxy for biodiversity-related physical risk, is less visible to the public due to limited understanding of how dependency affects firms' long-term operations (ABN AMRO, 2023). Moreover, physical risk itself unfolds gradually, eroding profitability over a longer time horizon (Garel et al., 2025; NGFS, 2024). Therefore, these mechanisms are evident for transition risk but not for physical risk.

4.4 Robustness Test

This study may be subject to statistical issues such as selection bias and endogeneity. To address these concerns, we conduct several robustness tests. In the propensity score matching and entropy balancing tests, firms with high pressure ratings—indicating exposure to high transition risk—are treated as the treatment group. These tests help mitigate potential selection bias. In addition, we employ three-digit zip codes as an instrumental variable to address potential endogeneity concerns.

4.3.1 Propensity score matching and entropy balancing test

Table 13
Propensity score matching test statistics

Variables	Treatment	Control	Difference	P value
Panel A: Pre-matching balancing test				
SIZE	21.346	20.779	-0.567	0.000
LEV	0.506	0.534	0.028	0.000
TAN	0.428	0.361	-0.067	0.000
BM	0.512	0.441	-0.071	0.000
CF	0.078	0.054	-0.024	0.000
CCE	0.127	0.153	0.026	0.000
BIG_4	0.760	0.723	-0.030	0.000
Panel B: After-matching balancing test				
SIZE	21.487	21.371	-0.116	0.000
LEV	0.511	0.516	0.005	0.223
TAN	0.419	0.398	-0.021	0.000
BM	0.500	0.476	-0.025	0.001
CF	0.081	0.076	-0.005	0.011
CCE	0.127	0.137	0.010	0.000
BIG_4	0.873	0.867	-0.006	0.298

Note: Treatment group is those observations with high pressure dummy (HP) as 1, control group is those with high pressure dummy (HP) as 0

Table 14

Entropy balancing test statistics

	Treatment			Control		
	Mean	Variance	Skewness	Mean	Variance	Skewness
Panel A: Pre Entropy Balancing						
SIZE	21.35	3.279	0.090	21.04	2.754	0.294
LEV	0.504	0.055	0.414	0.535	0.070	0.464
TAN	0.424	0.053	0.537	0.362	0.048	0.657
BM	0.509	0.197	2.225	0.429	0.202	2.491
CF	0.079	0.014	-2.217	0.060	0.025	-1.958
CCE	0.128	0.019	2.229	0.158	0.031	1.939
BIG_4	0.858	0.122	-2.053	0.868	0.114	-2.177
Panel B: Post Entropy Balancing						
SIZE	21.35	3.279	0.090	21.34	2.905	0.280
LEV	0.504	0.055	0.414	0.504	0.056	0.288
TAN	0.424	0.053	0.537	0.424	0.055	0.430
BM	0.509	0.197	2.225	0.508	0.252	2.439
CF	0.079	0.014	-2.217	0.078	0.017	-2.086
CCE	0.128	0.019	2.229	0.129	0.022	2.300
BIG_4	0.858	0.122	-2.053	0.858	0.122	-2.054

Note: Treatment group is those observations with high pressure dummy (HP) as 1, control group is those with high pressure dummy (HP) as 0

Propensity score matching is conducted to address potential selection bias. For this purpose, we construct a dummy variable based on the pressure rating, which represents the level of transition risk faced by firms. The dummy equals 1 for observations with a high-pressure rating and 0 otherwise. As shown in Table 12, the variation between the control and treatment groups is significantly reduced after matching. We then re-estimate the baseline regression using the matched sample, and the negative relationship between biodiversity risk and financial performance remains significant at the 1% level. This demonstrates that the effect is not driven by selection bias, thereby supporting our baseline findings.

Propensity score matching relies on exact matching, which substantially reduces the sample size. To retain the sample size, we apply entropy balancing. As in propensity score matching, the treatment group consists of observations with high pressure ratings. Table 13 shows the improvement in covariate balance between the treatment and control groups after entropy balancing. We then re-estimate the baseline regression using the entropy-balanced sample, and the negative relationship remains highly significant, further supporting our findings. The regression results after propensity score matching and entropy balancing are reported in Table 14.

Table 15

Re-estimate baseline regression after propensity score matching and entropy balancing

Propensity scoring matching and entropy score matching regression result

	Propensity Score Matching	Entropy Balancing Method
VARIABLES	ROA	ROA
BRE_N	-0.006***	-0.006***
	(0.002)	(0.002)
SIZE	0.013***	0.017***
	(0.002)	(0.002)
LEV	-0.066***	-0.068***
	(0.009)	(0.008)
TAN	-0.039***	-0.035***
	(0.010)	(0.008)
BM	-0.029***	-0.030***
	(0.003)	(0.003)
CF	0.591***	0.617***
	(0.024)	(0.018)
CCE	-0.054***	-0.049***
	(0.012)	(0.009)
BIG_4	-0.009**	-0.006*
	(0.004)	(0.004)
Constant	-0.213***	-0.301***
	(0.047)	(0.040)
Observations	12,976	24538
R-squared	0.851	0.847
Weighted with PSM	Yes	NO
Firm FE	Yes	Yes
Year FE	Yes	Yes

Clustered SEs	Yes	Yes
Weighted with EPM	NO	Yes

*This table presents the re-estimation of baseline model after propensity score matching and entropy balancing. The models control for key financial variables and include two way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

4.3.2 Instrument variable

A potential endogeneity concern is that biodiversity risk exposure may be a consequence of financial performance. One could argue that firms achieving better financial performance through business expansion may become more exposed to biodiversity risks.

To address the concern of reverse causality, we implement an instrumental variable (IV) approach. Following Safiullah et al. (2021), we use geographical location as the instrument. Two main reasons justify this choice. First, geographical location is captured by U.S. firms' three-digit zip codes, which are exogenous to firm financial performance since they are assigned for postal delivery purposes and are unrelated to firm outcomes. Second, prior evidence shows that a firm's level of corporate social responsibility (CSR) is influenced by the CSR practices of neighboring firms within the same three-digit zip code (Jiraporn et al., 2014).

Accordingly, geographical location is used as an instrumental variable, proxied by the average biodiversity risk of other surrounding firms within the same three-digit zip code. The two-stage least squares regression results are presented in Table 15. In the first stage, the instrumental variable is positively correlated with biodiversity risk, with the coefficient significant at the 1% level. In the second stage, the biodiversity risk estimated in the first stage is used to predict financial performance. Its interaction with the high-pressure dummy is negatively associated with financial performance, and the coefficient is significant at the 1% level. These results reinforce the finding that biodiversity-related transition risk further undermines firms' financial performance.

Table 16
Robustness test: Instrument variables

	First stage	Second stage	
CITY	0.103***		
	(0.0152)		
BRE_N		-0.108*	
		(0.0564)	
BRE_N * HP			-0.066***
			(0.0199)
SIZE	-0.0006	0.007***	0.008***
	(0.00126)	(0.000420)	(0.000399)
LEV	-0.038***	-0.036***	-0.033***
	(0.00763)	(0.00407)	(0.00319)
TAN	0.158***	-0.050***	-0.059***
	(0.00863)	(0.0100)	(0.00397)
BM	0.028***	-0.001	-0.003*
	(0.00413)	(0.00257)	(0.00183)
CF	0.014	0.902***	0.900***
	(0.0128)	(0.00694)	(0.00680)
CCE	0.014	-0.113***	-0.114***
	(0.0125)	(0.00576)	(0.00565)
BIG_4	0.004	-0.010***	-0.010***
	(0.00548)	(0.00208)	(0.00199)
Constant	-0.055**	-0.132***	-0.131***
	(0.0264)	(0.00984)	(0.00938)
Observations	21707	19766	19766
R-square	0.031	0.772	0.792
Year FE	YES	YES	YES
Firm FE	YES	YES	YES

This table presents instrumental variable robustness test for baseline regression. In first stage, instrumental variable is used to predict independent variable in second stage. In second stage, variable estimated in first stage is used to re-examine the effect of biodiversity transition risk on

*financial performance. The models control for key financial variables and include two-way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

4.5 Additional analysis

In the previous analysis, we examined only the individual effects of high biodiversity-related physical risk and transition risk on financial performance. However, physical and transition risks may also jointly affect firms' operations. This joint impact is illustrated in the graph below.

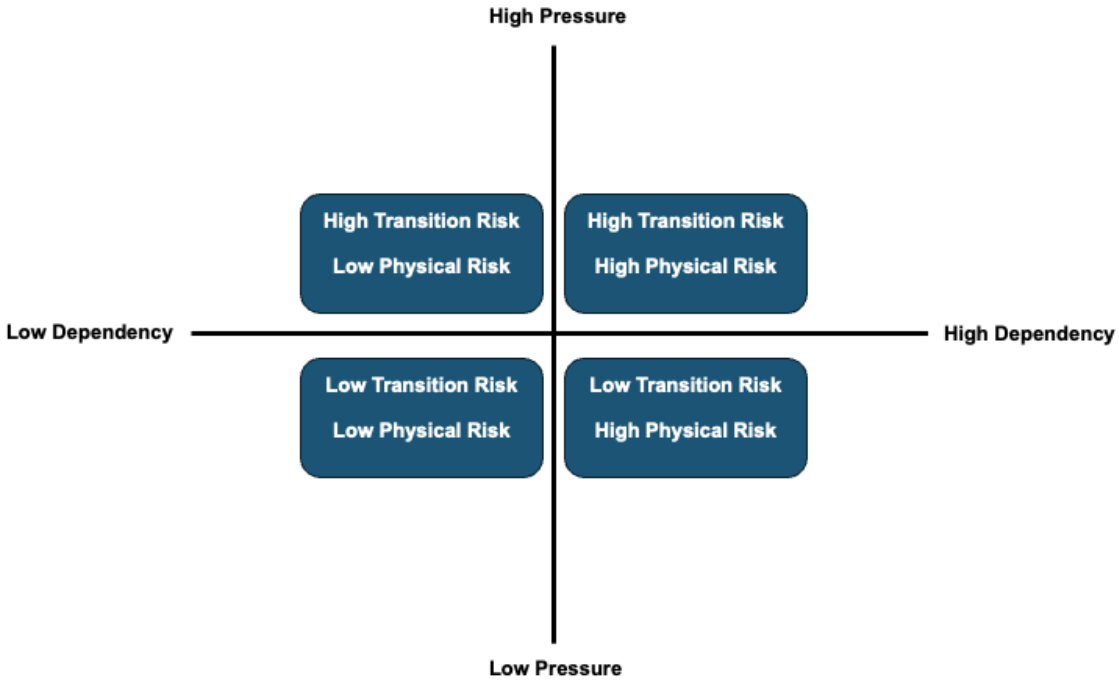


Figure 3. Biodiversity risk matrix

Each quadrant represents a combination of different levels of biodiversity-related physical and transition risks. The combination of high transition risk and high physical risk

may aggravate the negative impact on profitability, whereas the combination of high transition risk and low physical risk may lessen the negative impact of transition risk through the offsetting effect of lower physical risk. The dynamics between these two risk attributes are reflected in the overall biodiversity risk to which firms are exposed. Similarly, Yusifzada et al. (2025) find evidence of trade-offs in ESG scores: firms with high environmental scores but low social scores outperform those with low environmental scores but high social scores by an average return of 0.39% per month. In this analysis, we examine how the impact of biodiversity risk varies across firms with different combinations of risk attributes.

4.5.1 Cross effect of physical risk and transition risk: High vs Low

ENCORE provides five categories of dependency and pressure ratings: Very High, High, Medium, Low, and Very Low. In this study, observations with “Very High” or “High” ratings are classified into the high dependency/pressure group. For firms in the high-dependency group, this implies that disruptions to ecosystem services would at least prevent economic activities or significantly affect their financial viability when adapting to such disruptions. For firms in the high-pressure group, it indicates that their economic activities generate high output and exert severe pressure on nature. Observations with “Low” or “Very Low” ratings are classified into the low dependency/pressure group. For firms in the low-dependency group, this means that ecosystem service disruptions would have only minor effects on economic activities or impose minor adaptation costs. For firms in the low-pressure group, it implies that their economic activities generate low output or cause only limited environmental pressure (ENCORE, 2024).

Table 17
Cross effect of physical and transition risk on financial performance: High vs Low

VARIABLES	(1) ROA	(2) ROA
HD * HP * BRE_N	-0.025***	
	(0.009)	
LD * HP * BRE_N		0.017
		(0.012)
SIZE	0.019***	0.019***
	(0.002)	(0.002)
LEV	-0.070***	-0.070***
	(0.006)	(0.006)
TAN	-0.029***	-0.029***
	(0.008)	(0.008)
BM	-0.028***	-0.027***
	(0.003)	(0.003)
CF	0.657***	0.657***
	(0.018)	(0.018)
CCE	-0.041***	-0.041***
	(0.009)	(0.009)
BIG_4	-0.002	-0.002
	(0.004)	(0.004)
Constant	-0.350***	-0.349***
	(0.036)	(0.036)
Observations	22,641	22,641
R-squared	0.510	0.510
Firm FE	YES	YES
Year FE	YES	YES

*This table presents cross effect of combinations of high or low dependency rating and pressure rating on financial performance. The models control for key financial variable and include two way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

Table 16 presents the cross-effects of high dependency and high pressure, as well as low dependency and high pressure, on financial performance. The other two quadrants—high dependency with low pressure and low dependency with low pressure—are excluded because no observations with these combinations exist in the sample. This also suggests that it is unlikely for firms to simultaneously exhibit high dependency and low pressure, or both low dependency and low pressure, with respect to biodiversity. The

coefficient for the interaction of high dependency and high pressure is –0.025, significant at the 1% level. This effect is larger in magnitude than –0.008, the coefficient observed when only high pressure is present. By contrast, the coefficient for the interaction of low dependency and high pressure is positive but not statistically significant, suggesting a potential offsetting effect of low dependency.

4.5.2 Cross effect of physical risk and transition risk: Medium vs High & Low

Firms with medium dependency and pressure ratings represent a relatively larger proportion of the sample. A medium dependency rating indicates that disruptions to ecosystem services would result in a moderate loss of functionality or impose moderate financial costs on economic activities. A medium pressure rating suggests that the output of economic activities is at a medium level or that the pressure caused by these activities is relatively significant. We therefore examine the cross-effects of medium-level ratings with both low- and high-level ratings on firms' financial performance. Table 17 reports the results. Since no observations exist with both medium dependency and low pressure ratings, this combination is excluded from the analysis.

Table 18

Cross effect of physical and transition risk on financial performance: Medium vs (High & Low)

VARIABLES	(1) ROA	(2) ROA	(3) ROA	(4) ROA
HP * MD * BRE_N	0.003			
	(0.011)			
MP * MD * BRE_N		-0.007		
		(0.010)		
MP * HD * BRE_N			0.026**	
			(0.012)	
MP * LD * BRE_N				-0.025*
				(0.013)
SIZE	0.019***	0.019***	0.019***	0.019***
	(0.002)	(0.002)	(0.002)	(0.002)
LEV	-0.070***	-0.070***	-0.070***	-0.070***
	(0.006)	(0.006)	(0.006)	(0.006)
TAN	-0.029***	-0.029***	-0.029***	-0.029***
	(0.008)	(0.008)	(0.008)	(0.008)
BM	-0.027***	-0.028***	-0.028***	-0.028***
	(0.003)	(0.003)	(0.003)	(0.003)
CF	0.657***	0.657***	0.657***	0.657***
	(0.018)	(0.018)	(0.018)	(0.018)
CCE	-0.041***	-0.041***	-0.041***	-0.041***
	(0.009)	(0.009)	(0.009)	(0.009)
BIG_4	-0.002	-0.002	-0.002	-0.002
	(0.004)	(0.004)	(0.004)	(0.004)
Constant	-0.350***	-0.350***	-0.350***	-0.350***
	(0.036)	(0.036)	(0.036)	(0.036)
Observations	22,641	22,641	22,641	22,641
R-squared	0.510	0.510	0.510	0.510
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

*This table presents cross effect of combination of medium or high & low dependency and pressure rating on financial performance. Models control for key financial variables and include two-way fixed effect. Robustness standard errors are clustered at firm level. *,**and***indicate statistical significance at the 10%, 5% and 1% level, respectively.*

No significant results are found for the combinations of high pressure with medium dependency or medium pressure with medium dependency. Firms with medium pressure ratings and high dependency ratings experience relatively smaller profitability reductions

when biodiversity risk is present, with a coefficient of 0.026, significant at the 5% level. This result supports the baseline finding that physical risk, as a long-term factor, has not yet been fully reflected in firms' performance. By contrast, firms with medium pressure ratings and low dependency ratings experience greater profitability reductions, with a coefficient of –0.025, significant at the 10% level. Comparing these two combinations suggests that physical risk remains only weakly manifested and is not yet priced into financial markets.

5. Discussion and conclusions

As attention to biodiversity loss and its associated risks for firms continue to grow, biodiversity risk assessment can't be confined to textual analysis alone anymore. Instead, more meaningful biodiversity risk measurement requires the incorporation of scientifically grounded indicators, such as ecosystem dependency and pressure ratings provided by ENCORE which are used in this study. At the same time, examining biodiversity risk as a single, undifferentiated concept may obscure important mechanisms. Biodiversity physical risk and transition risk are two main dimensions of biodiversity risk exposure, therefore need to be examined specifically to capture their implications for firm's financial performance. Motivated by those considerations, this study advances biodiversity finance research by integrating text based risk measurement from Giglio et al.(2023) and scientifically grounded dependency and pressure rating from ENCORE to examine effects of biodiversity physical and transition risks on financial performance separately. Our sample consists of U.S. exchange listed firms over the period from 2000 to 2023.

The baseline regression reveals a negative relationship between biodiversity risk and firms' financial performance, consistent with the findings of Bach et al. (2024). Moreover, this negative relationship is more pronounced for firms with high ENCORE pressure ratings, indicating that biodiversity-related transition risk undermines profitability. By contrast, no such effect is observed for firms with ENCORE high dependency ratings, suggesting that physical risk, as a long-term factor, is not yet visibly reflected in reduced profitability. This aligns with previous evidence that firms have responded primarily to biodiversity impact risks, but less so to dependency risks (Carvalho et al., 2022). Further

disaggregation of ecosystem dependencies shows that only firms highly reliant on regulating and maintenance ecosystem services exhibit a more pronounced negative relationship between biodiversity risk and financial performance.

The heterogeneity analysis re-estimates the baseline regression across subgroups defined by firm size and firm growth. In the firm size analysis, a significant negative relationship between biodiversity risk and financial performance is observed, with the effect more pronounced for firms with high pressure ratings in the small size firm group. No significant results are found for large firms, indicating that smaller firms are more vulnerable to biodiversity risks. In the firm growth analysis, the results show that high-growth firms tend to experience greater profitability losses at the same level of biodiversity risk. This can be explained by the fact that high growth firms have fewer resources to buffer risk impacts compared to low growth firms, which are typically at a more mature stage.

The mechanism analysis explores channels through which biodiversity-related risks are associated with financial performance. The first is the policy adoption channel, proxied by a dummy variable indicating whether a firm has adopted a biodiversity impact reduction policy. Logistic regression results show that firms in high-pressure industries are significantly more likely to adopt such policies, suggesting that transition risks are associated with stronger management responses. While this result is consistent with stakeholder engagement and stewardship efforts, it also suggests that policy adoption may impose additional operational and compliance burdens when transition risks are high.

The second channel is production costs channel, proxied by the cost of goods sold (COGS). The results show that firms with high dependency ratings tend to have lower production costs, whereas firms with high pressure ratings are more likely to face higher production costs. This suggests that transition risks reduce profitability through rising production costs, as regulatory pressures and compliance requirements materialize in the short term. By contrast, lower costs among firms with high dependency ratings can be explained by two factors: first, these firms currently benefit from extracting or relying on biodiversity-related resources, with the adverse effects of depletion emerging only over longer horizons; and second, regulatory and market scrutiny has so far focused primarily

on firms' negative impacts on biodiversity, while dependency risks remain less visible to the regulators and insufficiently priced by the market.

The additional analysis examines the interaction of biodiversity physical and transition risks. We consider two sets of cross-effects. The first examines combinations of high or low dependency ratings with all levels of pressure ratings. The results show there are no observations with both high ecosystem services dependency and low biodiversity pressure, or with low ecosystem services dependency and low biodiversity pressure, indicating that such combinations are rare in practice. Firms simultaneously exposed to high ecosystem services dependency and high biodiversity pressure experience significantly greater profitability losses, suggesting that the joint effect of physical and transition risks is more detrimental than the effect of transition risk alone.

The second set of cross-effects examines combinations of medium or low ecosystem services dependency ratings and all levels of biodiversity pressure ratings. The results show that firms with medium biodiversity pressure rating and high ecosystem services dependency rating experience smaller profitability reductions, whereas firms with medium biodiversity pressure rating and low ecosystem services dependency rating experience larger profitability reductions. This contrast implies the muted effect of biodiversity physical risk and strong impact from biodiversity transition risks.

To test the robustness of the results, we conduct propensity score matching, entropy balancing, and instrumental variable tests on the baseline regression. The findings remain consistent across these tests, supporting the robustness of the main analysis.

The implications of this research are multifaceted. First, it suggests that investors should account for firms' biodiversity risk as part of market risk, particularly by demanding a risk premium for firms exposed to biodiversity risk. Furthermore, long-term investors should not overlook the gradual materialization of physical risk shocks to businesses, as our analysis shows that the impact of physical risk has not yet been reflected in firms' financial performance.

Second, our findings suggest that biodiversity risks have important systemic implication. Biodiversity transition risks, captured through firms' pressures on nature, are

already associated with lower profitability, as they are manifested in higher production costs and increased adoption of biodiversity-related policies. Because these effects are observable across firms and industries, they can propagate through supply chains, capital markets, and regulatory channels, thereby creating correlated exposures. Consequently, biodiversity transition risks are the sources of financial instability, as widespread cost shocks and policy adjustments can jointly affect capital allocation and matket valuation.

By contrast, biodiversity physical risks, captured through firms' dependencies on ecosystem services, do not yet show a direct financial effect in our analysis. However, their systemic potential remains substantial. Physical risks are likely to materialize abruptly once planetary boundaries are breached and critical ecosystems are pushed beyond tipping points, leading to irreversible disruptions. Such shocks would not be confined to individual firms but could ripple across sectors, causing simultaneous losses that threaten macro-financial stability. Taken together, our results indicate that while transition risks are already reflected in practice, physical risks remain systemic in potential, underscoring the need for both firms and policymakers to integrate biodiversity risk into forward-looking financial stability assessments. Therefore, we urge regulators to have regulatory oversight on firms that with high adverse impact on nature. At the same time, there is a need for regulators to develop a framework that informs businesses about biodiversity-related physical risks and incorporate the associated unrealized costs into accounting procedures.

Third, for firms, our findings underscore the importance of being transparent about biodiversity risk exposure and adopting proactive biodiversity management strategies. Firms that actively monitor their dependencies and pressures can better anticipate cost increases and stakeholder demands, thereby reducing unexpected shocks to profitability. In practice, this may involve integrating biodiversity considerations into supply chain management, investing in eco-innovation to lower resource intensity, and engaging with stakeholders to build trust and legitimacy. Moreover, transparent disclosure of biodiversity-related risks and mitigation policies not only improves accountability but may also attract long-term investors who are increasingly attentive to nature-related risks. By taking a proactive approach, firms can strengthen their resilience against transition risks,

prepare for tightening regulatory standards, and mitigate the gradual impacts of physical risks.

While this study provides novel insights to the existing literature, several limitations present opportunities for future research. First, our analysis focuses on U.S. exchange listed firms, although this U.S. market setting provides better ground for the examination of our research questions, this may limit generalizable of results to other markets with different market structure, investor bases, and regulatory regimes. Recent studies have begun to construct comparable biodiversity risk measurement for other major economies, including China and India (He et al., 2024; Rao et al., 2024). This opens door for cross country analysis that could assess how biodiversity physical and transition risk transmission varies in different institutional context and lead way to the discoveries of universal mechanisms.

Second, this study relies on ENCORE dependency and pressure rating at GICS sub sector level to proxy biodiversity physical and transition risks. While these ratings provide scientifically grounded biodiversity risk exposure assessment, sector level assessment may mask the heterogeneity across firms in the same industry. As a result, the estimated results should be interpreted properly as average effect at sub sector level rather than firm specific dependency and pressure. Future research could refine these measures by weighting sector ratings with firms' revenues to construct a measurement at more granular level. Improvement on measurement granularity can reflect more cross firms' variation and better capture the financial consequences.

Third, biodiversity risk is inherently spatial and location specific since ecological conditions varies significantly across regions (Adamolekun, 2024). Although this study incorporates scientifically based assessment from ENCORE, it does not take geo location difference into account. Future research could refine biodiversity risk measurement by incorporating geo location attribute, this approach would help distinguish between firms with similar sector profile but different spatial exposure to ecological degradation. More broadly, incorporating geo location factor into biodiversity risk assessment would make us better understand how localized biodiversity risk translate into financial outcomes.

Declaration of generative AI use

During the preparation of this work the authors used ChatGPT 5 in order to polish the Language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Reference

ABN AMRO. (2023, April 24). How exposed are companies and banks to biodiversity risks? https://www.abnamro.com/research/en/our-research/esg-strategist-how-exposed-are-companies-and-banks-to-biodiversity-risks

Adamolekun, G. (2024). Firm biodiversity risk, climate vulnerabilities, and bankruptcy risk. Journal of International Financial Markets, Institutions and Money, 97, 102075.

Ali, R., García-Sánchez, I. M., Aibar-Guzmán, B., & Rehman, R. U. (2024). Is biodiversity disclosure emerging as a key topic on the agenda of institutional investors? Business Strategy and the Environment, 33(3), 2116-2142.

Autorité de contrôle prudentiel et de résolution. (2024). *French insurers facing the risks associated with biodiversity loss: Challenges and lessons learned for the insurance industry and supervisors* (Analyses et synthèses No. 159). ACPR. https://acpr.banque-france.fr/system/files/import/acpr/medias/documents/20240620_analyses_syntheses_biodiv_fr_en.pdf

Banz, R. W. (1981). The relationship between return and market value of common stocks. Journal of Financial Economics, 9(1), 3-18.

Bach, T. N., Hoang, K., & Le, T. (2025). Biodiversity risk and firm performance: Evidence from US firms. Business Strategy and the Environment, 34(1), 1113-1132.

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of management, 17(1), 99-120.

Bastien-Olvera, B. A., & Moore, F. C. (2021). Use and non-use value of nature and the social cost of carbon. *Nature Sustainability*, *4*(2), 101–108. https://doi.org/10.1038/s41893-020-00615-0

Beck, T., Demirgüç-Kunt, A., & Maksimovic, V. (2008). Financing patterns around the world: Are small firms different?. Journal of Financial Economics, 89(3), 467-487.

Becker, C. L., DeFond, M. L., Jiambalvo, J., & Subramanyam, K. R. (1998). The effect of audit quality on earnings management. Contemporary Accounting Research, 15(1), 1-24.

Berlinger, E., Keresztúri, J. L., & Lublóy, Á. (2025). Self-regulation, media pressure, and corporate catastrophes. *Economic Analysis and Policy*, *85*, 1337-1356.

Bhagat, S., & Bolton, B. (2008). Corporate governance and firm performance. Journal of Corporate Finance, 14(3), 257-273.

Bolton, P., & Kacperczyk, M. (2021). Do investors care about carbon risk?. Journal of financial economics, 142(2), 517-549.

Carvajal, M., Nadeem, M., & Zaman, R. (2022). Biodiversity disclosure, sustainable development and environmental initiatives: does board gender diversity matter?. Business Strategy and the Environment, 31(3), 969-987.

Carvalho, S. H. C. D., Cojoianu, T., & Ascui, F. (2023). From impacts to dependencies: A first global assessment of corporate biodiversity risk exposure and responses. Business Strategy and the Environment, 32(5), 2600-2614.

Cho, H. J., & Pucik, V. (2005). Relationship between innovativeness, quality, growth, profitability, and market value. Strategic Management Journal, 26(6), 555-575.

Deloof, M. (2003). Does working capital management affect profitability of Belgian firms?. Journal of Business Finance & Accounting, 30(3-4), 573-588.

El Ouadghiri, I., Kaabia, O., Peillex, J., Platania, F., & Hernandez, C. T. (2025). Attention to biodiversity and stock returns. International Review of Financial Analysis, 97, 103855.

Encore (2024). Encore explain note. ENCORE nature. https://www.encorenature.org/en/data-and-methodology/methodology

Flammer, C., Giroux, T., & Heal, G. M. (2025). Biodiversity finance. Journal of Financial Economics, 164, 103987.

Freeman, R. E., & Phillips, R. A. (2002). Stakeholder theory: A libertarian defense. Business ethics quarterly, 12(3), 331-349.

Garel, A., Romec, A., Sautner, Z., & Wagner, A. F. (2024). Do investors care about biodiversity? Review of Finance, 28(4), 1151-1186.

Garel, A., Romec, A., Sautner, Z., & Wagner, A. F. (2025). Firm-level nature dependence. European Corporate Governance Institute–Finance Working Paper Forthcoming.

Giglio, S., Kuchler, T., Stroebel, J., & Zeng, X. (2023). Biodiversity risk (No. w31137). National bureau of economic research.

He, F., Chen, L., & Lucey, B. M. (2024). Chinese corporate biodiversity exposure. Finance Research Letters, 70, 106275.

He, F., Wei, C., Lucey, B., & Hao, J. (2025). Beyond greenwashing: How does firm-level biodiversity disclosure affect corporate sustainability strategy?. Pacific-Basin Finance Journal, 102787.

Impact Investor. (2021). *Pushing biodiversity up the corporate and investor agenda*. Impact Investor.https://impact-investor.com/pushing-biodiversity-up-the-corporate-and-investor-agenda/

Jiraporn, P., Jiraporn, N., Boeprasert, A., & Chang, K. (2014). Does corporate social responsibility (CSR) improve credit ratings? Evidence from geographic identification. Financial Management, 43(3), 505-531.

Karolyi, G. A., & Tobin-de la Puente, J. (2023). Biodiversity finance: A call for research into financing nature. Financial Management, 52(2), 231-251.

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The importance of climate risks for institutional investors. The Review of Financial Studies, 33(3), 1067-1111.

Li, Y., Liu, X., Canil, J., & Cheong, C. S. (2025). Biodiversity risk and firm efficiency. Finance Research Letters, 71, 106414.

Liu, X., Li, Y., & Krishnamurti, C. (2025). Biodiversity risk and seasoned equity offerings. Economics Letters, 247, 112214.

Liu, Z., Zheng, R., Qiu, Z., & Jiang, X. (2022). Stakeholders and ESG disclosure strategies adoption: The role of goals compatibility and resources dependence. Elementa: Science of the Anthropocene, 10(1), 1-12.

Lublóy, Á., Keresztúri, J.L., Berlinger, E. (2025). Quantifying firm-level greenwashing: A systematic literature review. *Journal of Environmental Management*, 373, 123399. https://doi.org/10.1016/j.jenvman.2024.123399

Meckling, W. H., & Jensen, M. C. (1976). Theory of the Firm. Managerial behavior, agency costs and ownership structure, Journal of Finance Economics, 3(4), 305-360.

Nature for Greening the Financial System. (2024). Nature-related financial risks: a conceptual framework to guide action by central banks and supervisors.

Network for Greening the Financial System. (2024). Nature-related financial risks: A conceptual framework to guide action by central banks and supervisors. https://www.ngfs.net/sites/default/files/medias/documents/ngfs-conceptual-framework-nature-risks.pdf

Organisation for Economic Co-operation and Development. (2023). Assessing biodiversity-related financial risks: Navigating the landscape of existing approaches (OECD Environment Policy Papers No. 36). OECD Publishing. https://doi.org/10.1787/d52137a5-en

Opler, T., Pinkowitz, L., Stulz, R., & Williamson, R. (1999). The determinants and implications of corporate cash holdings. Journal of Financial Economics, 52(1), 3-46.

Painter, M. (2020). An inconvenient cost: The effects of climate change on municipal bonds. Journal of Financial Economics, 135(2), 468-482.

Rajan, R. G., & Zingales, L. (1995). What do we know about capital structure? Some evidence from international data. The Journal of Finance, 50(5), 1421-1460.

Rao, A., Lucey, B. M., & Kumar, S. (2024). Corporate Biodiversity Risk and Concern: Evidence from Indian Firms and Industry-Level Insights. Available at SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4986392

Safiullah, M., Kabir, M. N., & Miah, M. D. (2021). Carbon emissions and credit ratings. Energy Economics, 100, 105330.

Schlenker, W., & Taylor, C. A. (2021). Market expectations of a warming climate. Journal of financial economics, 142(2), 627-640.

Souder, D., & Shaver, J. M. (2010). Constraints and incentives for making long horizon corporate investments. Strategic Management Journal, 31(12), 1316-1336.

Steindl, T., Küster, S., & Hartlieb, S. (2024). Pricing firms' biodiversity risk exposure: Empirical evidence from audit fees. Journal of Industrial Ecology.

Taskforce on Nature-related Financial Disclosures. (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. Taskforce on Nature-related Financial Disclosures.

Titman, S., & Wessels, R. (1988). The determinants of capital structure choice. The Journal of Finance, 43(1), 1-19.

Treepongkaruna, S. (2024). Corporate sustainability and biodiversity reporting: A proactive business strategy to mitigate litigation and reputational risks. Business Strategy and the Environment, 33(7), 6640-6651.

United Nations. (1992). *Convention on Biological Diversity.* https://www.cbd.int/doc/legal/cbd-en.pdf

United Nations. (2021). *System of Environmental Economic Accounting—Ecosystem accounting*. United Nations. https://seea.un.org/ecosystem-accounting

Wilson, E. O. (1988). Biodiversity.

World Economic Forum. (2020). Nature risk rising: why the crisis engulfing nature matters for business and the economy. https://www.weforum.org/publications/nature-risk-rising-why-the-crisis-engulfing-nature-matters-for-business-and-the-economy/?t

World Economic Forum. (2025). *Global risks report 2025: Conflict, environment and disinformation top threats*. World Economic Forum. *https://www.weforum.org/publications/global-risks-report-2025/*

Xue, B., Zhang, Z., & Li, P. (2020). Corporate environmental performance, environmental management and firm risk. *Business Strategy and the Environment*, *29*(3), 1074–1096. https://doi.org/10.1002/bse.2418

Yu, W., & Ramanathan, R. (2015). An empirical examination of stakeholder pressures, green operations practices and environmental performance. International Journal of Production Research, 53(21), 6390-6407.

Zhao, Y., Qu, X., & Lucey, B. (2025). Managerial myopia and biodiversity alignment-evidence from China. International Review of Financial Analysis, 103974.

Zhou, Y., Lucey, B. M., & He, F. (2025). Dividend payouts and biodiversity risk-Chinese evidence. Research in International Business and Finance, 102792.

U.S. Fish and Wildlife Service. (1973). *Endangered Species Act*. https://www.fws.gov/law/endangered-species-act

Council on Environmental Quality. (1969). *National Environmental Policy Act*. https://ceq.doe.gov/index.html

U.S. Environmental Protection Agency. (2023). *Clean Water Act*. https://www.epa.gov/laws-regulations/laws-and-executive-orders

European Commission. (2025). *Sustainability-related disclosure in the financial services sector*.https://finance.ec.europa.eu/sustainable-finance/disclosures/sustainability-related-disclosure-financial-services-sector_en

Chintha, B. R., Jagannathan, R., & Sridhar, S. S. (2024). Globalization and Profitability of US Firms: The Role of Intangibles (No. w32202). National Bureau of Economic Research.

Frijns, B., Indriawan, I., & Tourani-Rad, A. (2018). The interactions between price discovery, liquidity and algorithmic trading for US-Canadian cross-listed shares. *International Review of Financial Analysis*, *56*, 136-152.