DISSERTATION
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Biodiversity Risk and Firm Valuation: Regional Heterogeneity and Value-Chain Exposure in Global Capital Markets

Submitted by

Madelein Wentzel

Doctor of Business Administration in Finance Program

In partial fulfillment of the requirements

For the degree of Doctor of Business Administration in Finance

Sacred Heart University, Jack Welch College of Business and Technology

Fairfield, Connecticut

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Dissertation Supervisor: Dr. Loran Chollete Signature:

Committee Member: Dr. Md Nazmul Islam Signature:

Committee Member: Dr. Mahfuja Malik Signature: Mahfuja Malik

DISSERTATION

Nature as Economic Capital: Biodiversity Risk Pricing and Regional Heterogeneity in Global Equity Markets

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Abstract

This study examines whether biodiversity-related risks are priced in global equity markets and whether that pricing varies across regions, using a cross-sectional sample of more than 10,000 globally listed firms with biodiversity and financial data drawn from the fourth quarter of 2025. Consistent with a regional heterogeneity hypothesis, the results show that biodiversity risk is significantly negatively associated with firm valuation in developed markets such as the United States and OECD countries, while the relationship is weaker, insignificant, or even positive in certain emerging regions including Latin America and the Middle East and Africa. The analysis further distinguishes between value-chain and direct company-level biodiversity exposure, finding that value-chain exposure exhibits a more consistent association with firm valuation across the full sample, consistent with a double materiality framework in which supply-chain dependencies transmit biodiversity risk beyond direct operations. The findings support the view that biodiversity constitutes a financially material risk in global capital markets and suggest that firms — particularly those in developed markets — should integrate nature-related dependencies and impacts into their risk management and capital allocation frameworks rather than treating biodiversity solely as an ESG reporting obligation.

Keywords: biodiversity risk, asset pricing, regional heterogeneity.

JEL Classification: G12, G15

Data Availability: The data are available from public sources cited in the text.

1. Introduction

Biodiversity loss[1] and ecosystem collapse ranked among the top global risks in the World Economic Forum's January 2026 *Global Risk Report,* with projections spanning the decade to 2036 (WEF, 2026.) More than half of global GDP depends on nature and its ecosystem services, and as ecosystems degrade, firms face disruptions in raw material supply, increasing regulatory constraints, rising operating costs, and reputational risks - all of which can affect corporate performance and market valuation (WEF, 2024; Boston Consulting Group, 2021) Financial institutions, regulators, and investors have begun to pay greater attention to nature-related financial risks through initiatives such as the Taskforce on Nature-related Financial Disclosures[2] (TNFD, 2023.) Yet, while growing academic literature examines how environmental risks influence asset prices and firm valuation, most empirical work has focused on climate-related risks. (Karolyi et al. 2023) Research on biodiversity risk in financial markets remains limited, and existing studies often treat environmental exposure as a single aggregate factor. Few studies distinguish between biodiversity impacts generated directly by firms and biodiversity embedded in upstream supply chains, despite evidence that global production networks may transmit ecological risks across firms and industries. (Giglio et al. 2025; Schrapffer et al. 2024) This dissertation asks two related questions: Are there regional differences in the valuation effects of biodiversity exposures? Does biodiversity risk affect firm valuation differently depending on whether the exposure arises from direct operations or from value chains?

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[1] Biodiversity encompasses the variability among living organisms and the ecological complexes of which they are part (Convention on Biological Diversity, 1992). Biodiversity loss therefore refers to reductions in this biological variety through species decline, ecosystem degradation, and loss of genetic diversity.

[2] The Taskforce on Nature-related Financial Disclosures (TNFD) was founded in 2021 by a coalition of financial institutions, international organizations and environmental groups (including the UN Environment Program Finance Edition, World Wildlife Fund and Global Canopy)to encourage organizations globally to assess their impact on biodiversity and the planet's ecosphere.

These questions address gaps in the literature. First, the direct vs. value-chain distinction has received little attention, even though supply-chain dependencies may represent a major channel through which economic degradation affects corporate performance. An influential working paper guiding my research by Giglio et al. (2025) published by the National Bureau of Economic Research finds "biodiversity risk to be systemic, spatial, and network-based", and calls for financial analysis to move from firm-level footprint data to impact-dependency-location frameworks - explicitly identifying regional differences in pricing as a "promising topic." Second, the literature has paid limited attention to whether biodiversity is priced consistently across global financial markets. Differences in environmental regulation, institutional quality, investor awareness, and ecological vulnerability suggest that the valuation effects of biodiversity exposure may vary across regions. Garel et al (2024) evaluate the negative footprint of a global sample of companies in an event study and controls for industry and country fixed effects but do not publish explicit regional heterogeneity results. Third, as Balogh et al. (2025) note, the field lacks robust metrics for measuring the impacts and dependencies of firms on biodiversity. This paper addresses this gap by using newly published Bloomberg measures, developed in accordance with the Taskforce on Nature-related Financial Disclosures (TNFD) to test the valuation impact of both direct operations and value chain exposures on nature[3].

At the basis of the heterogeneity hypothesis is the assumption that biodiversity risks are not priced uniformly across global equity markets. Instead, pricing is expected to vary with differences in economic development, regulatory environments, investor awareness, industrial composition, and ecological dependence – with implications for investors in developed vs emerging markets.

To test this, I construct firm-level biodiversity exposure measures using the Bloomberg's TNFD-aligned metrics and examine their relationship with firm

[3] Bloomberg L.P. (2025). *ESG Nature: Sector-driven impact and dependency risk data* . Bloomberg Terminal. Accessed December 2025.

valuation across a global sample of publicly traded companies. Tobin's Q serves as the primary dependent variable because it captures how financial markets value a firm relative to the replacement cost of its assets, making it a forward-looking measure that reflects investor expectations about future growth, risks and intangible assets. (Peters et al. 2017) The empirical analysis estimates a series of nested regression models incorporating biodiversity exposure measures, firm-level controls, and regional and sectoral fixed effects. Interaction models further explore how biodiversity exposures affect valuation across geographic regions, thereby identifying regional heterogeneity in biodiversity risk pricing.

We find that biodiversity risk is associated with a lower Tobin's Q in most developed and some emerging markets, and that value chain exposure is more likely to be linked in developed markets than direct company impact. A notable exception is MEA and Latin America, where biodiversity exposure might even have a positive valuation effect.

The dissertation makes three contributions to the emerging literature on biodiversity finance. First it provides a large-scale empirical analysis that explicitly distinguishes between value-chain exposure and direct firm-level impacts, offering a more refined framework for analyzing how external risks affect corporate valuation. Second, by examining regional heterogeneity in biodiversity pricing, it provides new evidence on how institutional and market environments shape investor responses to nature-related risks. Third it extends the broader literature on environmental risk and financial markets including recent works by Giglio et al. (2025) where their framework allows for heterogeneity across firms, industries and geographies and how they depend on and affect nature. Li et al. (2025) is the first study to test firm efficiency rather than pure pricing as affected by biodiversity risk. Clement et al. (2025) attempt to shed more light on the different measures of data and on what could be referred to as the "immature data infrastructure" still inherent in the field of biodiversity finance.

2. Literature Review & Hypothesis Development

2.1 Conceptual Foundations of Biodiversity and Natural Capital

Biodiversity refers to the diversity of life across genes, species, and ecosystems, and underpins the functioning and resilience of the natural systems on which economic activity depends. Biodiversity conservation aims to protect and restore these biological systems to maintain ecosystem services such as pollination, water regulation, soil fertility, and climate stabilization. Since 2020, biodiversity degradation — driven by land-use change, resource extraction, pollution, climate change, and invasive species — has come under increasing scrutiny for its capacity to erode natural capital and generate systemic risks extending beyond ecological loss to economic and financial instability. (WWF, 2024; World Bank, 2021; Wilson E.O., 1988)

The Taskforce on Nature-related Financial Disclosures (TNFD), founded in 2021, defines nature as "comprising living diversity across ecosystems, species, and genetic variation," and encourages organizations globally to assess their impact on and dependence on biodiversity. The emerging field of biodiversity finance has since examined how biodiversity-related dependencies and impacts translate into financial risks and opportunities, and how capital allocation, corporate behavior, and policy mechanisms can be mobilized to halt and reverse nature loss.

For the purposes of this dissertation, biodiversity loss is defined as the decline in biological diversity and ecosystem integrity that reduces the capacity of natural systems to sustain ecological functions and services. Following the TNFD framework, biodiversity loss is treated as economically material insofar as it operates through firm-level impacts and dependencies on nature, generating nature-related risks that transmit through value chains into financial outcomes. The Bloomberg biodiversity metrics used in this study have been compiled in accordance with these TNFD definitions; further detail is provided in the Data section

2.2 Scarcity and the Economics of Nature

A useful conceptual backdrop to this study is the argument advanced by Jonsson and Wennerlind (2023) in *Scarcity: A History from the Origins of Capitalism to the Climate Crisis*, that economic scarcity is not a timeless condition but one that emerged alongside capitalism in the seventeenth and eighteenth centuries. The exploitation of fossil fuels allowed societies to treat growth as effectively limitless, displacing ecological constraints rather than resolving them — only to re-encounter them in new forms: climate instability, biodiversity collapse, and ecological overshoot.

This matters for how economists have historically treated nature. Modern economic frameworks have treated biodiversity as either a free good or an externality — an inexhaustible background condition rather than a finite productive asset. While timber, crops, and minerals are priced, ecosystem resilience, watershed protection, and genetic diversity are not. (Jonsson & Wennerlind, 2023) The result has been overfishing, deforestation, soil degradation, and species extinction at a pace that outstrips the economy's capacity to absorb the consequences.

Jonsson and Wennerlind's argument that capitalism expands by displacing ecological limits, only to re-encounter them in new forms, aligns directly with the concept of double materiality that structures the TNFD framework and this dissertation. Both the direct impacts firms exert on nature and the value-chain dependencies through which ecological risks flow back to firms are expressions of this dynamic — and both are tested empirically in this study.

2.3 Biodiversity Risk in Economics and Finance

Despite the scale of ecological loss — the WWF's 2024 *Living Planet Report* documents a 73% average decline in monitored species populations since 1970, with a 95% decline in Latin America and an 85% decline in freshwater species —

biodiversity loss has only recently begun to emerge as a financially material risk. The World Bank (2021) estimates that biodiversity degradation could result in a $2.7 trillion decline in global GDP (approximately 2.3%) by the end of the decade and argues that traditional metrics systematically underestimate this exposure.

In finance, the field remains at an early stage. Karolyi et al. (2023) predict that biodiversity conservation will supersede climate risk as the next major challenge in sustainable finance and propose a working definition of biodiversity finance as "the practice of raising and managing capital and using financial tools and economic incentives to support sustainable biodiversity management." They explicitly note the dearth of empirical work in this area.

Early contributions began to establish biodiversity as a real economic risk channel, not merely an ethical or reputational concern. Giglio et al. (2023) provide the first systematic examination of how physical and regulatory biodiversity risks affect economic activity and asset values, developing a news-based proxy measure of aggregate biodiversity risk to quantify how it varies over time. Liang et al. (2024) extend this to stock-level outcomes, finding that higher biodiversity risk increases stock price crash risk through hidden fragility, bad-news hoarding, and correlated ecological shocks. Flammer et al. (2025) similarly treat biodiversity loss as a channel of real economic risk with measurable financial consequences.

From an investor perspective, Garel et al. (2024) ask whether there is evidence that investors price biodiversity. They introduce the Corporate Biodiversity Footprint (CBF) — the first science-based indicator to help managers and investors assess companies' biodiversity impact, subsequently expanded by Iceberg Data Lab — and find that firms with larger biodiversity footprints earn higher returns around news events where biodiversity is salient. Coqueret et al. (2025) corroborate this in a portfolio context, finding that biodiversity-intensive stocks command a risk premium over low-biodiversity stocks, particularly during periods of heightened media attention.

Li et al. (2025) take a different approach, using more than 23,000 firm-year observations from CRSP data to find a significant negative relationship between biodiversity risk and firm efficiency — the first study to document firm-level productivity costs of biodiversity exposure. Xin et al. (2025), by contrast, find that returns on assets and profit margins are uncorrelated with the biodiversity components embedded in MSCI ESG scores, suggesting that ESG-integrated biodiversity ratings do not provide investors with decision-relevant information on nature-related risk.

A recurring theme across this literature is the immaturity of the underlying data infrastructure. Clement et al. (2025) document significant gaps between the biodiversity risk measures provided by MSCI and LSEG and the spatial biodiversity data available through ENCORE, with discrepancies particularly pronounced in certain industries. This fragmentation limits cross-study comparability and highlights the importance of using consistently defined, standardized metrics — a gap this dissertation addresses by drawing on Bloomberg's TNFD-aligned measures.

The most directly relevant recent contribution is the working paper by Giglio et al. (2025), which outline a research agenda for understanding the economic and financial consequences of biodiversity loss. The authors find biodiversity risk to be systemic, spatial, and network-based, and call for financial analysis to move beyond firm-level footprint data toward impact-dependency-location frameworks. They explicitly identify regional differences in pricing as a "promising topic" for future research. This dissertation responds to that call directly.

2.4 Biodiversity Impact and Dependencies

Biodiversity risk operates through two distinct but interconnected channels: dependencies and impacts. *Dependencies* refer to the extent to which firms rely on ecosystem services—such as water availability, pollination, soil quality, and climate regulation—to sustain their operations and value chains. In contrast, *impacts* capture the pressures firms exert on biodiversity through activities such as land-use change, resource extraction, pollution, and emissions. Together, these dimensions reflect a firm's position within the nature–economy system: dependencies expose firms to risks arising from ecosystem degradation, while impacts represent the sources of that degradation. Distinguishing between these channels is essential for understanding the concept of double materiality and for identifying how biodiversity risk is transmitted to firm value.

Table 1: Biodiversity Risk 2×2 Framework: Impact vs Dependency and Direct vs Value Chain

	DIRECT (Operations)	VALUE CHAIN (Upstream / Downstream)
IMPACT (Firm harms biodiversity)	**Definition:** A firm directly damages biodiversity through its own operations **Economic Risk Channel:** Regulatory fines, Litigation Reputational loss, Capex for remediation **Examples:** 1. Mining clearing habitat 2. Oil drilling spills 3. Industrial water discharge 4. Overfishing by owned fleets	**Definition:** A firm contributes to biodiversity loss indirectly through suppliers or customers **Economic Risk Channel:** Supply disruption, Consumer backlash, Compliance Costs **Examples:** 1. Retailer sourcing from deforested land 2. Fashion brand using biodiversity-damaging cotton 3. Food company sourcing soy linked to habitat loss.
DEPENDENCY (Firm relies on biodiversity)	**Definition:** Firm relies directly on ecosystem services **Economic Risk Channel:** Yield volatility, Input cost increases, Insurance risk **Examples:** 1. Agriculture -pollination 2.Beverage -fresh water. 3.Fisheries - stable marine ecosystems 4.Forestry firms -soil regeneration	**Definition:** Firm depends on biodiversity through suppliers **Economic Risk Channel:** Global supply chain fragility, Climate-biodiversity interaction shocks, Commodity price spikes Systemic supply risk **Examples:** 1. Food manufacturers - on agricultural inputs 2. Pharma reliant on bio-compounds 3. Apparel dependent on cotton supply stability

Note: Framework developed by author. Examples are illustrative.

2.5 Hypothesis Development

Giglio et al. (2025, page 14) mention “a particularly promising topic” (for future research) is whether there are regional differences in the pricing of risks,” thereby leading to the main hypothesis for this dissertation.

Building on the ideas discussed above, this dissertation conceptualizes biodiversity not as an externality or isolated ESG factor, but as a core productive asset subject to biophysical limits. If biodiversity loss constitutes a binding ecological constraint, its economic consequences should be observable in firm-level performance and valuation, particularly for firms embedded in ecologically intensive or geographically exposed value chains.

However, planetary scarcity is unevenly distributed across ecosystems, regions, and production systems. Biodiversity-related risks, therefore, do not manifest uniformly across the global economy. Regions differ in ecological endowments, regulatory frameworks, and institutional capacity, while industries vary in their dependence on ecosystem services such as water, soil quality, pollination, and biological resources. As a result, the financial implications of biodiversity exposure are likely to be heterogeneous, reflecting differences in ecological dependence, risk transmission, and market recognition.

By integrating firm-level financial data with value-chain–adjusted biodiversity indicators across a globally diverse sample, this study moves beyond documenting the existence of biodiversity risk to assessing whether planetary ecological constraints are already reflected in financial outcomes.

To achieve these contributions, the empirical analysis proceeds in two steps. It first tests whether the valuation effects of biodiversity exposure vary across regions and then evaluates whether value-chain exposure has a stronger association with firm valuation than direct exposure. Interaction terms between biodiversity measures and regional and sectoral indicators are used to identify systematic variation in biodiversity risk pricing across global economic systems.

The following hypotheses formalize these propositions:

H1: The valuation effect of biodiversity exposure varies significantly across geographic regions.

H2: Value-chain biodiversity exposure has a stronger negative association with firm valuation than direct operational exposure.

3. Data

3.1 Bloomberg Biodiversity Dataset

A key challenge in studying biodiversity-related financial risk is the limited availability of consistent firm-level biodiversity data. Much of the existing empirical literature relies on environmental proxies, climate indicators, or corporate disclosures that do not directly measure biodiversity exposure.

In October 2024, Bloomberg Intelligence introduced a new set of biodiversity indicators available through the ESG NATURE <GO> [4]screen on the Bloomberg Terminal. These indicators form part of Bloomberg's Sector-Driven Impact & Dependency Risk dataset, which quantifies nature-related risks based on the economic activities in which firms operate. The framework links firm revenue segments to a sector-level materiality matrix that assigns biodiversity risk levels to approximately 1,800 economic activities defined under Bloomberg's Industry Classification System (BICS).

The dataset distinguishes between two types of biodiversity exposure. Impact risk captures the extent to which firms contribute to biodiversity loss through their operations and value chains, while dependency risk measures firms' reliance on ecosystem services. As of August 2024, Bloomberg has released the full impact risk dataset, while the dependency dataset remains under development. This study, therefore, focuses on the impact-related biodiversity measures currently available.

[4] Bloomberg L.P. (2025). *ESG Nature (ESG NATURE <GO>) dataset* [2025]. Bloomberg Terminal.

Bloomberg evaluates biodiversity impact risk across several environmental drivers, including ecosystem change, resource use, pollution and waste, and disturbances and invasive species. For each economic activity, Bloomberg assigns a biodiversity risk score ranging from 1 (very low risk) to 5 (very high risk). Firm-level biodiversity exposure measures are then constructed as revenue-weighted averages across business segments, calculated separately for direct company operations and value-chain activities.

Because Bloomberg's methodology links biodiversity risk to underlying economic activities rather than firm disclosures, the dataset allows for systematic comparison of biodiversity exposure across firms, sectors, and regions. Table 2 summarizes the environmental drivers used in Bloomberg's biodiversity score construction.

Table 2: Bloomberg Value Chain Bio and Company Bio Score Construction Methodology

Impact Driver	Sub Drivers	Description
Ecosystem Change	Land	Does the activity change and/or increase the fragmentation of land-based ecosystems? E.g., conversion, deforestation, degradation
	Ocean	Does the activity change and/or increase the fragmentation of ocean ecosystems? E.g., conversion, dredging.
	Fresh Water	Does the activity change and or increase the fragmentation of freshwater systems? E.g., conversion, draining, dams, river engineering.
Resource Use	Biotic Materials	Does the activity extract large volumes of biotic materials? E.g., fishing, logging, and crops.
	Abiotic Materials	Does the activity extract large volumes of abiotic materials? E.g. metals, minerals
	Water	Does the activity use large volumes of water?
Pollution and Waste	Non-GHG Air Pollution	Does the activity emit high volumes of non-GHG air pollutants? E.g., sulphur oxides, nitrous oxides.
	Soil Pollution	Does the activity emit high volumes of soil pollutants? E.g., heavy metals, plastics, pesticides, fertilizer
	Water Pollution	Does the activity emit high volumes of water pollutants? E.g., sewage run off, chemical waste, plastics, pesticides, and fertilizer.
	Solid Waste	Does the activity generate high volumes of solid waste? E.g., plastics, construction waste, biomedical waste.
Disturbances & Invasives		Does the activity create high volumes of noise and light disturbance in ecosystems? Does the activity introduce invasive species?

Note: Source: Bloomberg, Nature & Biodiversity Sector Driven Impact and Dependency Risk – Methodology Document, 2024

3.2 Sample Construction

The empirical sample comprises globally listed non-financial firms with a market capitalization exceeding USD 500 million as of December 2025. Firm-level biodiversity exposure measures were obtained from Bloomberg's ESG Nature dataset, which provides both value-chain and direct operational biodiversity exposure scores compiled in accordance with the TNFD framework.

The market capitalization threshold serves two purposes. First, it improves data reliability: larger firms are more likely to have consistent financial disclosures and comprehensive biodiversity-related coverage within Bloomberg's dataset, whereas smaller firms often exhibit limited disclosure quality and greater valuation volatility that may introduce noise unrelated to biodiversity risk. Second, it ensures the sample captures firms with sufficient supply-chain integration to face material biodiversity dependencies and impacts through both direct operations and value-chain relationships. This approach is consistent with prior empirical finance research that excludes micro-cap firms to reduce liquidity-related distortions in valuation-based analyses. (Cakici et al., 2022)

A single cross-sectional year (2025) was used because of the novelty of the Bloomberg data which was only released in October 2024.

Financial variables — including firm size, leverage, profitability, and industry classification — were also obtained from Bloomberg. Firms were matched to their Global Industry Classification Standard (GICS) sector codes and assigned to the regional groupings used in the empirical analysis. After merging biodiversity and financial data and removing observations with missing values on key variables, the final sample comprises 10,043[5] firms across multiple sectors and geographic regions.

[5] In regression, fewer (10,027 and 10,026) observations were used due to unavailability of some variables.

3.3 Variable Definitions

The primary independent variables are two biodiversity exposure measures derived from Bloomberg's ESG Nature dataset. Both are standardized (z-scored) prior to estimation, so that estimated coefficients represent the change in the dependent variable associated with a one-standard-deviation increase in biodiversity exposure, facilitating direct comparison of effect magnitudes across measures.

Value-chain biodiversity exposure (Z_VC_BIO) captures biodiversity risk associated with upstream and downstream economic activities linked to the firm's production structure — pressures arising outside the firm's immediate operations but within its broader supply chain. This corresponds to the value-chain columns of the 2×2 framework presented in Section 2.4.

Direct company biodiversity exposure (Z_CO_BIO) captures biodiversity risk associated with the firm's own operational activities, corresponding to the direct operations rows of the same framework.

The dependent variable is Tobin's Q (winsorised), defined as the ratio of the market value of assets to their book value of total assets. As established in Section 2.3, Tobin's Q is used here because it reflects forward-looking market expectations of firm value rather than current accounting performance, making it well suited to capturing biodiversity risks that may not yet be visible in earnings but are priced through expectations of future cash flows and regulatory exposure. (Peters & Taylor, 2017; Demerjian et al., 2012; Lang & Stulz, 1994; Morck et al., 1988)

Control variables follow standard corporate finance practice. Firm size is measured as the natural logarithm of market capitalization. Leverage is defined as total debt divided by total assets. Return on equity (ROE), calculated as net income divided by shareholders' equity, is winsorised to reduce the influence of extreme observations. Table 3 summarizes all variable definitions and data sources.

Table 3: Variable Definitions

Variable	Definition
Tobin's Q	Firm valuation measure is defined as the ratio of the market value of equity plus total debt to total assets.
VC_BIO (Z)	Standardized value-chain biodiversity exposure score derived from Bloomberg's Sector-Driven Impact & Dependency Risk dataset. This measure captures biodiversity risk embedded in upstream and downstream economic activities associated with the firm's production structure.(Ranges 1-5, with 1 being low impact and 5 high impact.)
CO_BIO (Z)	Standardized direct company biodiversity exposure score derived from Bloomberg's Sector-Driven Impact & Dependency Risk dataset. This measure captures biodiversity risks arising from the firm's own operational activities. .(Ranges 1-5, with 1 being low impact and 5 high impact.)
Ln(Market Cap)	Natural logarithm of firm market capitalization.
Debt / Assets	Ratio of total debt to total assets, used as a measure of financial leverage.
ROE	Return on equity, calculated as net income divided by shareholders' equity.
Region FE	Regional fixed effects controlling for geographic differences in institutional environments, regulatory structures, and macroeconomic conditions
Sector FE	Industry fixed effects based on GICS sector classifications.
VC × Region	Interaction between value-chain biodiversity exposure and regional indicators, capturing region-specific biodiversity risk pricing.
CO × Region	Interaction between direct biodiversity exposure and regional indicators.
VC × Sector	Interaction between value-chain biodiversity exposure and sector indicators.
CO × Sector	Interaction between direct biodiversity exposure and sector indicators.

3.4 Descriptive Statistics

Table 4 presents descriptive statistics for the variables used in the empirical analysis. The sample comprises 10,043 firms. The average Tobin's Q is 2.148, with a standard deviation of 1.91, indicating substantial variation in firm valuation across the sample. The biodiversity exposure variables Z_VC_BIO and Z_CO_BIO are standardized measures with means of zero and standard deviations of one. Firm size, measured as the natural logarithm of market capitalization, has a mean value of 21.587, reflecting the relatively large firms included in the Bloomberg dataset. The average debt-to-assets ratio is 23.9 percent, while winsorized ROE averages 5.2 percent but exhibits substantial dispersion.

Table 4: Descriptive Statistics

Variable	N	Mean	Std. Dev.	Min	Max
Tobin's Q	10043	2.148	1.91	0.626	12.022
VC_BIO (Z)	10043	0	1	-2.097	1.938
CO_BIO_(Z)	10043	0	1	-1.413	3.526
Ln (Market Cap)	10028	21.587	1.438	6.56	29.177
Debt/ Assets	10043	23.911	18.642	0	80.064
ROE	10043	5.217	28.763	-105.67	91.161

Notes: Cross-sectional data, sample period is 2025.

3.5 Region and Sector Distribution

Table 5 reports on the geographic distribution of firms in the sample across seven regional groupings used in the empirical analysis. The largest number of firms is in China, accounting for approximately 30.5 percent of the sample, followed by OECD countries excluding the United States (28.9 percent) and the United States (16.9 percent). However, when measured by market capitalization, the distribution differs, firms based in the United States account for over half of the total market capitalization in the sample (53.1 percent), highlighting the dominance of U.S. equity markets in global firm valuation. OECD countries outside the United States make up 23.6 percent, while China represents 8.3 percent. Emerging regions such as Latin America, the Middle East, and Africa (MEA) hold comparatively small shares of the total sample. This regional distribution offers a diverse global data set, allowing analysis of regional differences in how biodiversity risk is priced across financial markets.

Table: 5: Distribution – Regions

Region	No. of Co	Percentage of Total (%)	Market Cap (TN)	Percentage of Total (%)
USA	1,705	16.9	$60.6	53.1
OECD (ex US)	2,911	28.9	$27.0	23.6
DM Asia	816	8.1	$7.6	6.6
China	3,065	30.5	$9.5	8.3
EM Asia (ex-China)	1,035	10.3	$5.1	4.5
MEA	365	3.6	$3.6	3.2
Latin America	146	1.5	$0.70	.6
Total	10,043	100	$114	100

Table 6 outlines the distribution of firms across the Global Industry Classification Standard (GICS) sectors. The largest sector in the sample is Industrials, comprising 19.5 percent of firms, followed by Consumer Discretionary (15.9 percent), Materials (15.5 percent), and Information Technology (12.0 percent). In terms of market capitalization, however, the Information Technology sector leads, making up approximately 27.5 percent of the total market value. Industrials and Consumer Discretionary each account for about 14 percent and 13 percent of market capitalization, respectively. Sectors such as Utilities, Energy, and Real Estate represent smaller portions of the overall sample. The sectoral diversity of the dataset is crucial for empirical analysis because exposure to biodiversity varies greatly across industries, influenced by resource use, land management, and pollution levels, thus making sector controls necessary to isolate biodiversity risk valuation effects.

Table: 6: Distribution – GICS Sectors

Sector	No. of Co	Percentage of Total (%)	Market Cap (TN)	Percentage of Total (%)
Communication Services	526	5.2	$11.5	10.1
Consumer Discretionary	1,596	15.9	$14.9	13.1
Consumer Staples	968	9.6	$8.3	7.3
Energy	392	3.9	$7.3	6.4
Health Care	970	9.7	$11.2	9.8
Industrials	1,951	19.5	$16.0	14.0
Information Technology	1,209	12.0	$31.4	27.5
Materials	1,558	15.5	$7.5	6.6
Real Estate	496	4.9	$1.8	1.6
Utilities	376	3.7	$4.1	3.6
Total	10,043	100.0	$114	100.0

Note: Financial Services excluded.

The cross-sectional variation in biodiversity exposure across firms, sectors, and regions provides a suitable empirical setting to examine whether biodiversity-related risks are reflected in firm valuation. The following section outlines the empirical models used to estimate these relationships.

4. Methodology

4.1 Empirical Framework

This paper investigates how biodiversity-related risks are incorporated into firm valuation using a cross-sectional global sample of publicly listed firms. The empirical approach is designed to test both the existence of biodiversity risk pricing and the extent to which this pricing varies across regions and sectors, consistent with a double materiality framework.

Hypothesis 1 proposes that the pricing of biodiversity risk varies across geographic regions, reflecting differences in regulatory environments, ecological exposure, and institutional structures. Hypothesis 2 proposes that financial markets price value-chain biodiversity exposure differently from direct company biodiversity exposure.

Firm valuation is proxied by Tobin's Q, a commonly used measure of market valuation relative to the replacement cost of assets. Biodiversity exposure is captured using two standardized measures derived from Bloomberg's ESG Nature dataset:

- *Value-chain biodiversity exposure (VC)*, which captures biodiversity risks embedded in upstream and downstream economic activities associated with the firm's production structure.
- *Direct company biodiversity exposure (CO)*, which captures biodiversity risks arising from the firm's own operational activities.

A sequence of nested regression models is estimated to evaluate these hypotheses. The models progressively introduce regional and sector fixed effects and interaction terms, allowing biodiversity risk pricing to vary across geographic and industry contexts. All models are estimated using ordinary least squares (OLS) with heteroskedasticity-robust standard errors. Control variables follow those used in comparable biodiversity risk studies. (Liang et al., 2024; Li et al., 2024)

4.2 Baseline Model

The baseline model evaluates whether biodiversity exposure is associated with firm valuation after controlling standard firm characteristics:

$$Q_i = \alpha + \beta_1 VC_i + \beta_2 CO_i + \gamma' X_i + \varepsilon_i \qquad (1)$$

where Q_i is Tobin's Q for firm i, VC_i is value-chain biodiversity exposure, CO_i is direct company biodiversity exposure, X_i is a vector of firm-level controls, and ε_i is the error term. This specification provides the benchmark for evaluating whether biodiversity exposure is priced by financial markets, before accounting for geographic or sectoral heterogeneity.

4.3 Fixed Effects Models

Models 2 through 4 augment the baseline by sequentially introducing fixed effects. Model 2 adds regional fixed effects (δ_r) to account for geographic differences in institutional and economic environments. Model 3 adds sector fixed effects (θ_s) to control for structural differences in ecological dependence across industries. Model 4 incorporates both simultaneously:

$$Q_i = \alpha + \beta_1 VC_i + \beta_2 CO_i + \gamma' X_i + \delta_r + \theta_s + \varepsilon_i \qquad (2)$$

4.4 Wald Test of Coefficient Equality

To test Hypothesis 2 — that financial markets price value-chain and direct biodiversity exposure differently — a Wald test is conducted on the coefficients estimated in the baseline model (Equation 1):

$$H_0: \beta_{VC} = \beta_{CO} \qquad (3)$$

Rejecting the null hypothesis indicates that the two exposure channels carry statistically distinct valuation effects.

4.5 Interaction Models — Heterogeneity Analysis

To assess Hypothesis 1, Models 5 through 7 introduce interaction terms between biodiversity exposure measures and regional and sectoral indicators. The general interaction specification is:

$$Q_i = \alpha + \beta_1 VC_i + \beta_2 CO_i + \beta_3 (VC_i \times \delta_r) + \beta_4 (CO_i \times \delta_r)$$

$$+\beta_5 (VC_i \times \theta_s) + \beta_6 (CO_i \times \theta_s) + \gamma' X_i + \delta_r + \theta_s + \varepsilon_i \tag{4}$$

Model 5 restricts Equation 4 to region interactions only, dropping the sector interaction terms:

$$Q_i = \alpha + \beta_1 VC_i + \beta_2 CO_i + \beta_3 (VC_i \times \delta_r) + \beta_4 (CO_i \times \delta_r) + \gamma' X_i + \delta_r + \theta_s + \varepsilon_i \tag{5}$$

Model 6 restricts Equation 4 to sector interactions only, dropping the region interaction terms:

$$Q_i = \alpha + \beta_1 VC_i + \beta_2 CO_i + \beta_5 (VC_i \times \theta_s) + \beta_6 (CO_i \times \theta_s) + \gamma' X_i + \delta_r + \theta_s + \varepsilon_i \tag{6}$$

Model 7 is the unrestricted form given in Equation 4, incorporating both sets of interaction terms simultaneously and allowing biodiversity risk pricing to vary across both regional and sectoral dimensions.

The progression from Equations 5 and 6 to the full specification in Equation 4 allows the incremental contribution of each source of heterogeneity to be assessed before examining their joint effects.

4.6 Robustness and Diagnostic Checks

Several diagnostic and robustness checks are performed to ensure the validity of the empirical results.

4.6.1 Multicollinearity

Variance Inflation Factors (VIFs) are calculated for all explanatory variables.

4.6.2 Heteroskedasticity

Tests of model specification indicate heteroskedasticity, as expected in large cross-sectional datasets with heterogeneous firms. To address this issue, all models are estimated using heteroskedasticity-robust standard errors.

4.6.3 Standard Error Clustering

To ensure robustness of inference, standard errors were clustered at the country level, thereby accounting for potential cross-sectional dependence among firms operating within the same national environment. In addition, sensitivity tests excluding United States and Chinese firms were performed to evaluate whether the findings were driven by the dominant markets in the sample.

4.6.4 Descriptive Statistics and Correlations

Summary statistics and correlation analysis are presented to provide an overview of the data and to assess preliminary relationships between variables.

Results from the robustness analysis are presented in Section 5.3

4.6 Summary of Empirical Approach

The empirical strategy combines a baseline asset pricing framework with progressively richer specifications to capture heterogeneity in biodiversity risk pricing.

5. Results

This section presents the empirical results examining whether biodiversity-related risks are reflected in firm valuation and whether these effects vary across regions and sectors. The analysis proceeds in three steps. First, baseline regressions establish whether biodiversity exposure is associated with firm valuation, with fixed effects models testing the robustness of this relationship to structural differences across geographies and industries. Second, interaction models test whether biodiversity risk pricing varies across geographic regions and sectors. Third, implied marginal effects are reported to interpret the economic magnitude of regional differences in biodiversity pricing.

5.1 Baseline Results and Fixed Effects Models (Models 1-4)

Table 7, Panel A presents the baseline and fixed effects results. Across all four specifications, both value-chain biodiversity exposure (VC) and direct company biodiversity exposure (CO) enter with negative and highly statistically significant coefficients ($p < 0.001$), indicating that firms with greater biodiversity exposure are consistently associated with lower market valuation as measured by Tobin's Q.

To assess economic significance: in the baseline specification (Model 1), a one-standard-deviation increase in value-chain biodiversity exposure is associated with a decrease in Tobin's Q of approximately 0.211 points, and a one-standard-deviation increase in direct company exposure is associated with a decrease of approximately 0.251 points. Given that Tobin's Q has a cross-sectional standard deviation of approximately 1.9 in this sample, these represent economically meaningful effects — equivalent to 11–13% of a standard deviation in firm valuation.

The introduction of region fixed effects in Model 2 and sector fixed effects in Model 3 modestly attenuates both coefficients but leaves their sign and significance unchanged, confirming that biodiversity exposure is not simply proxying for geographic or industry composition. Model 4, which includes both sets of fixed effects simultaneously, yields the most conservative estimates: VC = –0.170*** and CO = –0.147***, with adjusted R^2 rising to 0.182. The persistent negative effects after absorbing region and sector variation suggest that biodiversity exposure carries an independent valuation penalty beyond what is explained by a firm's location or industry.

A Wald test on the Model 1 coefficients fails to reject the null hypothesis of equality ($H_0: \beta_{VC} = \beta_{CO}$) at conventional significance levels, indicating that while both exposure channels are negatively priced, the difference in their coefficients is not statistically distinguishable in the baseline specification. Hypothesis 2 is therefore not confirmed in the baseline, though the interaction results in Section 5.2 reveal meaningful differences across regional contexts. (p=0.1514, F=2.06)

Table 7. Regression Results

Panel A: Biodiversity Exposure, and Tobin's Q

	Tobin's Q (1)	Tobin's Q (2)	Tobin's Q(3)	Tobin's Q (4)
Value Chain Biodiversity Risk	-0.21124*** (-11.44)	-0.20528*** (-6.73)	-0.17648*** (-7.84)	-0.17002*** (-7.14)
Direct Company Biodiversity Risk	-0.25116*** (-13.75)	-0.2468*** (-13.8)	-0.15708*** (-6.87)	-0.14683*** (-6.60)
Size Ln (Market Cap)	0.253639*** (19.60)	0.234116*** (17.71)	0.235563*** (18.16)	0.217854*** (16.49)
Debt/ Assets	-0.01964*** (-19.59)	-0.01966*** (-19.9)	-0.01629*** (-16.12)	-0.01627*** (-16.39)
ROE	-0.00066 (0.2165)	-0.00000 (.9177)	0.00000 (0.9791)	0.000388 (.5521)
Industry FE	NO	NO	YES	YES
Region FE	NO	YES	NO	YES
Observations	10027	10027	10026	10026
Adj-R^2	0.1037	0.1503	0.1351	0.1819

Note: ***,**,* indicate two-tailed significance at the 0.01, 0.02 and 0.10 levels, respectively. Robust t-statistics are in parentheses. This table represents the results of OLS regression tests examining the association between the biodiversity risk and firm valuation (Tobin's Q) in column (1) without fixed effects, in column (2) with region fixed effects, in column (3) with industry fixed effects, in column (4) with controls and fixed effects. All variables are defined in the Appendix.

5.2 Interaction Models — Regional and Sectoral Heterogeneity (Models 5–7)

Panel B reports on the interaction models. Joint F-tests on the interaction terms are statistically significant across all three specifications, confirming that biodiversity risk association is not uniform across either regions or sectors.

Model 5 — Biodiversity × Region

Model 5 allows the valuation effects of biodiversity exposure to vary across geographic regions. The baseline VC and CO coefficients remain negative and significant (–0.148*** and –0.211*** respectively), reflecting the average effect for the reference region (USA). The joint F-statistics on the region interaction terms are significant for both VC (F = 4.84***) and CO (F = 4.46***), confirming that the biodiversity risk varies significantly across geographies in support of Hypothesis 1.

The implied regional slopes, reported in Panel C, reveal the economic structure of this heterogeneity. In the USA, both VC (–0.148***) and CO (–0.211***) exposures carry strongly negative valuation effects, suggesting that US investors price both channels of biodiversity risk. OECD (ex-US) and DM Asia show similarly negative CO slopes, though value-chain effects in those regions are statistically weaker, possibly reflecting differences in supply-chain transparency and disclosure requirements.

Emerging markets display more variation. In EM Asia (ex-China), direct biodiversity exposure is large and negative (–0.363*) while value-chain exposure is insignificant, suggesting that investors in those markets respond more to observable operational risks than to supply-chain exposures that are harder to trace. Most strikingly, Latin America and MEA show positive value-chain slopes (+0.113* and +0.056*** respectively), implying that biodiversity exposure is associated with higher, not lower, firm valuation in those regions. One interpretation is that in resource-rich economies, biodiversity-intensive activities are associated with comparative production advantages — particularly in consumer staples, materials, and industrials, which dominate listed markets in both regions — so that investors treat high biodiversity exposure as a signal of resource endowment rather than environmental liability. This interpretation is theoretically plausible but has not been directly tested and is discussed further as a limitation in Section 6.

Model 6 — Biodiversity × Sector

Model 6 examines whether biodiversity exposure is priced differently across industries. The joint F-tests are significant for both VC ($F = 5.5^{***}$) and CO ($F = 2.56^{***}$) sector interactions, confirming meaningful sectoral heterogeneity. Industries with high dependence on natural capital — including consumer staples, materials, and energy — exhibit the strongest negative valuation effects associated with value-chain exposure, consistent with biodiversity loss representing a material input risk for firms reliant on ecosystem services. Sectors with limited ecological dependence, such as technology and financial services, display weaker or insignificant relationships, suggesting that biodiversity risk is transmitted primarily through resource dependencies and supply chains rather than through direct operations.

Model 7 — Full Interaction Model

Model 7 is the most comprehensive specification, allowing biodiversity risk pricing to vary simultaneously across both regions and sectors. Adjusted R^2 rises to 0.20, and the joint significance of the region-sector interaction terms ($F = 2.65^{***}$) confirms that geography and industry composition jointly shape how biodiversity exposure is priced. Value-chain exposure remains the dominant driver (–0.306***), but its valuation effect varies depending on both the firm's location and its industrial structure. High-dependency sectors operating in developed markets exhibit the strongest negative valuation effects, while equivalent sectors in parts of emerging markets show attenuated or reversed relationships, consistent with the patterns observed in Model 5.

Taken together, the interaction results provide strong empirical support for Hypothesis 1: biodiversity risk is not priced uniformly across global markets, and its valuation effects are shaped by the institutional and industrial environment in which firms operate. The evidence also points toward value-chain exposure as the more consistently priced channel across developed markets, with direct operational exposure playing a relatively larger role in certain emerging market contexts.

Panel B: Biodiversity Exposure and Regional Heterogeneity

	Tobin's Q (5)	Tobin's Q (6)	Tobin's Q (7)
Value Chain Biodiversity Risk (Baseline)	-0.148*** (-3.37)	-0.306*** (-2.44)	-0.306*** (-2.23)
Direct Company Biodiversity Risk (Baseline)	-0.211*** (-4.61)	-0.1276 (-0.95)	-0.04843 (-0.33)
Value Chain BIO x Region (joint F)	4.84***		3.58***
Direct CO BIO x Region (joint F)	4.46***		2.26**
Value Chain BIO x Sector (joint F)		5.5***	6.16***
Direct CO x Sector (joint F)		2.56***	2.72**
VC BIO x Region x Sector (joint F)			
Region x Sector (joint F)			2.65***
Industry FE	YES	YES	YES
Region FE	YES	YES	YES
Observations	10026	10026	10026
Adj-R^2	0.187	0.188	0.20

Note: ***,**,* indicate two-tailed significance at the 0.01, 0.02 and 0.10 levels, respectively. Robust t-statistics are in parentheses. This table represents the results of OLS regression tests examining the association between the biodiversity risk and firm valuation (Tobin's Q) in column (5) with region interaction, in column (6) with sector interaction, in column (7) with both region and sector interaction.

Panel C: Value Chain and Direct Company Biodiversity Slopes by Region – as per Model 5

Region	VC Slope	CO Slope
USA	-0.148***	-0.211***
OECD (ex US)	-0.276 (n.s)	-0.134*
DM Asia	-0.025 (n.s)	-0.117*
China	-0.163 (n.s)	-0.066***
EM Asia (ex-China)	-0.140 (n.s)	-0.363*
MEA	+0.056***	-0.074*
Latin America	+0.113*	+0.035**

Panel C — Region-Specific Marginal Effects from Model 5

Panel C reports the implied regional slopes for value-chain (VC) and direct company (CO) biodiversity exposure derived from Model 5. These marginal effects translate the interaction coefficients into region-specific valuation sensitivities and reveal the economic structure underlying the aggregate results.

In the USA, both VC (–0.148***) and CO (–0.211***) are negative and highly significant, indicating that a one-standard-deviation increase in either exposure channel is associated with a meaningful reduction in Tobin's Q. This is consistent with strong investor recognition of biodiversity-related risk in the most developed and liquid capital market in the sample. OECD (ex-US) and DM Asia show a similar directional pattern for CO, though value-chain effects in those regions are statistically weaker, possibly reflecting differences in supply-chain disclosure standards and investor familiarity with nature-related risk frameworks.

Emerging markets display considerably more heterogeneity. In EM Asia (ex-China), CO is large and negative (–0.363*) while VC is insignificant, suggesting that investors in those markets respond primarily to observable operational exposures rather than to harder-to-trace supply-chain risks. China shows a significant negative CO effect (–0.066***) but an insignificant VC slope, a pattern that may reflect the dominance of state-directed capital allocation, which could mute market-based pricing of upstream biodiversity risk. Latin America and MEA are the clearest outliers, with positive VC slopes (+0.113* and +0.056*** respectively) and weak or positive CO effects. A plausible interpretation is that in resource-rich economies where listed markets are concentrated in biodiversity-intensive sectors, investors associate high biodiversity exposure with natural resource endowments rather than environmental liability. This interpretation is theoretically plausible but has not been directly tested and is returned to in Section 6.

Overall, the Panel C results confirm that biodiversity risk pricing is not uniform across global markets. The variation in both the magnitude and direction of regional slopes is consistent with Hypothesis 1 and with structural differences in regulatory maturity, capital market development, and investor awareness of nature-related financial risk.

5.3 Robustness and Diagnostic Checks

Several diagnostic and robustness checks were performed to ensure the validity of the empirical results.

5.3.1 Multicollinearity

Variance Inflation Factors (VIFs) were calculated for all explanatory variables. The results indicate no evidence of multicollinearity, with all VIF values close to one. This confirms that value-chain and direct biodiversity exposures capture distinct dimensions of risk. See table 12 in Appendix.

5.3.2 Heteroskedasticity

Tests of model specification indicate the presence of heteroskedasticity, which is expected in large cross-sectional datasets with heterogeneous firms. To address this issue, all models are estimated using heteroskedasticity-robust standard errors.

5.3.3 Standard error clustering

The clustered standard error specification produces results that remain broadly consistent with the primary findings. Both value-chain biodiversity exposure (Z_VC_BIO) and direct biodiversity exposure (Z_CO_BIO) retain negative coefficients, indicating that higher biodiversity-related risk is associated with lower firm valuation. The coefficient on direct biodiversity exposure remains statistically significant at conventional levels, while the value-chain measure becomes marginally significant after adjusting standard errors for within-sector correlation.

Specifically:

- Z_VC_BIO = -0.244
- $p = 0.062$

and:

- Z_CO_BIO = -0.241
- p = 0.0018

This suggests that the negative relationship between biodiversity exposure and firm valuation is not solely driven by sector-level clustering effects.

The country-clustered specification provides robust evidence that biodiversity-related risks are negatively associated with firm valuation even after accounting for within-country correlation in residuals. Both value-chain biodiversity exposure (Z_VC_BIO) and direct company-level biodiversity exposure (Z_CO_BIO) remain economically and statistically significant, indicating that firms with greater biodiversity exposure tend to exhibit lower Tobin's Q ratios.

Specifically:

- Z_VC_BIO = -0.205
- $p < .0001$

and:

- Z_CO_BIO = -0.247
- $p < .0001$

This suggests that biodiversity risks are robustly priced by equity markets and that the results are not driven solely by country-level institutional or macroeconomic effects.

To assess whether the primary findings were disproportionately driven by the two largest equity markets in the sample, the models were re-estimated after excluding firms domiciled in the United States and China. The biodiversity coefficients remained negative and highly significant, while the regional interaction effects continued to exhibit substantial heterogeneity. In particular, developed-market regions retained strongly negative valuation effects associated with biodiversity exposure, whereas several emerging regions displayed weaker or partially offsetting relationships. These findings suggest that the observed association patterns are not solely attributable to the influence of the United States and China, but instead reflect broader regional differences in the incorporation of biodiversity-related risks into firm valuation.

5.3.4 Descriptive Statistics and Preliminary Correlations

Summary statistics and correlation analysis are presented (see table 4 in Section 3. 4 and table 10 in Appendix) to provide an overview of the data and to assess preliminary relationships between variables. The results show that biodiversity exposure measures are negatively correlated with firm valuation and are only weakly correlated with one another, supporting their joint inclusion in the model.

6. Conclusion

This study examines whether biodiversity-related risks are associated with lower valuations in global equity markets and whether these effects vary across regions and exposure channels. Using a cross-sectional sample of over 10,000 publicly listed firms and Bloomberg's TNFD-aligned biodiversity metrics, the analysis finds consistent evidence that higher biodiversity exposure is associated with lower firm valuation, supporting the view that biodiversity loss constitutes a financially material risk. This pricing effect persists after controlling for firm size, leverage, profitability, and structural differences across industries and geographies, and is economically meaningful in magnitude — equivalent to 11–13% of a standard deviation in Tobin's Q for a one-standard-deviation increase in exposure.

This study makes three contributions to the emerging literature on biodiversity finance. First, it provides large-scale empirical evidence that both value-chain and direct operational biodiversity exposures are independently priced by financial markets, demonstrating that the channel through which biodiversity risk reaches firms — whether through supply-chain dependencies or own operations — matters for valuation. Second, it is among the first studies to test and document regional heterogeneity in biodiversity risk pricing, finding that developed markets impose stronger valuation penalties on biodiversity exposure while some emerging markets show weaker or even positive effects, consistent with differences in regulatory enforcement, disclosure standards, and investor awareness. Third, it operationalizes the double materiality framework by drawing on a newly available and standardized dataset compiled by Bloomberg in accordance with the TNFD, enabling a globally comparable analysis that moves beyond the firm-level footprint measures used in most prior work.

A notable finding requiring interpretation is the positive or attenuated pricing observed in MEA and Latin America. Firms in these regions are disproportionately concentrated in biodiversity-intensive sectors — consumer staples, materials, and industrials — where biodiversity dependence is closely tied to natural resource endowments and production advantages. In such contexts, investors may treat high biodiversity exposure as a signal of access to valuable natural capital inputs or commodity production capacity rather than as an environmental liability, particularly where regulatory enforcement and disclosure requirements remain less developed. This dual role of biodiversity as both constraint and resource endowment may explain the incomplete or reversed pricing observed in these markets and represents an important avenue for further investigation.

This study has several limitations that should be acknowledged. First, the cross-sectional design limits causal inference. The absence of a time-series dimension — itself a consequence of the limited availability of consistent, firm-level biodiversity data separate from broader ESG scores — means that the analysis cannot rule out omitted variable bias or reverse causality. Future work employing panel data, instrumental variable approaches, or quasi-experimental designs would strengthen the causal interpretation of these findings. Second, while the regional heterogeneity results are statistically robust, the economic mechanisms underlying the variation — particularly the positive valuation effects in MEA and Latin America — have not been directly tested. The sectoral composition hypothesis advanced here is theoretically plausible but requires further decomposition, ideally at the industry-region level, to isolate the true drivers. Third, the biodiversity measures used, while representing the most standardized available data compiled in accordance with the TNFD framework, remain aggregate indicators that do not distinguish between specific ecological channels such as land use, freshwater, or ocean dependencies. This aggregation may obscure heterogeneity in the financial materiality of different types of biodiversity risk.

Future research could extend this analysis in several directions. A Global North versus Global South framework may help clarify how institutional development and environmental governance shape biodiversity risk pricing more systematically than the regional groupings used here. Decomposing biodiversity exposure into its underlying ecological channels could identify the specific drivers of financial materiality and allow for more targeted risk assessment. As firm-level biodiversity data matures and longitudinal coverage improves, panel-based analyses will be possible, enabling researchers to track how biodiversity risk pricing evolves alongside regulatory developments such as the TNFD disclosure framework and the Kunming-Montreal Global Biodiversity Framework.

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Appendix

Table 8: Country by Region Analysis

Country	Market Cap (BN)	% of Total	Companies	% of Total
China	**$9,530.61**	**8.36%**	**3065**	**30.52%**
DM Asia	**$7,557.54**	**6.63%**	**816**	**8.13%**
Hong Kong	$4,896.63	4.29%	496	4.94%
Singapore	$271.00	0.24%	64	0.64%
Taiwan	$2,389.91	2.10%	256	2.55%
EM Asia ex China	**$5,111.72**	**4.48%**	**1035**	**10.31%**
Bangladesh	$8.48	0.01%	7	0.07%
India	$3,531.37	3.10%	594	5.91%
Indonesia	$636.21	0.56%	138	1.37%
Kazakhstan	$28.58	0.03%	4	0.04%
Malaysia	$242.04	0.21%	83	0.83%
Pakistan	$28.81	0.03%	22	0.22%
Philippines	$143.56	0.13%	42	0.42%
Sri Lanka	$6.71	0.01%	11	0.11%
Thailand	$350.22	0.31%	81	0.81%
Vietnam	$135.73	0.12%	53	0.53%
Latin America	**$671.76**	**0.59%**	**146**	**1.45%**
Argentina	$44.09	0.04%	20	0.20%
Brazil	$548.40	0.48%	98	0.98%
Ecuador	$3.83	0.00%	3	0.03%
Jamaica	$1.11	0.00%	2	0.02%
Peru	$74.33	0.07%	23	0.23%
MEA	**$3,550.85**	**3.11%**	**365**	**3.63%**
Bahrain	$3.92	0.00%	1	0.01%
Botswana	$0.29	0.00%	1	0.01%
BVRM	$6.04	0.01%	4	0.04%
Egypt	$21.89	0.02%	17	0.17%
Ghana	$5.24	0.00%	2	0.02%
Iran	$6.54	0.01%	8	0.08%
Jordan	$18.69	0.02%	7	0.07%
Kenya	$11.12	0.01%	3	0.03%
Kuwait	$36.45	0.03%	22	0.22%
Lebanon	$14.04	0.01%	2	0.02%
Mauritius	$0.28	0.00%	2	0.02%
Morocco	$55.78	0.05%	23	0.23%
Namibia	$0.36	0.00%	1	0.01%
Nigeria	$42.26	0.04%	18	0.18%
Oman	$30.94	0.03%	8	0.08%
Qatar	$73.44	0.06%	16	0.16%
Saudi Arabia	$2,150.05	1.89%	108	1.08%
South Africa	$277.23	0.24%	52	0.52%

Tanzania	$1.66	0.00%	2	0.02%
Tunisia	$1.18	0.00%	3	0.03%
UAE	$787.27	0.69%	54	0.54%
Uganda	$1.43	0.00%	1	0.01%
Zambia	$3.30	0.00%	8	0.08%
Zimbabwe	$1.45	0.00%	2	0.02%
OECD (ex US)	**$27,025.37**	**23.69%**	**2911**	**28.99%**
Australia	$1,134.15	0.99%	170	1.69%
Austria	$92.67	0.08%	20	0.20%
Belgium	$353.45	0.31%	39	0.39%
Bulgaria	$4.01	0.00%	5	0.05%
Canada	$2,419.51	2.12%	239	2.38%
Chile	$149.37	0.13%	41	0.41%
Colombia	$77.64	0.07%	10	0.10%
Croatia	$16.51	0.01%	11	0.11%
Cyprus	$0.14	0.00%	2	0.02%
Czech Rep	$38.49	0.03%	5	0.05%
Denmark	$525.31	0.46%	39	0.39%
Estonia	$2.83	0.00%	2	0.02%
Finland	$198.96	0.17%	33	0.33%
France	$3,008.29	2.64%	128	1.27%
Germany	$2,283.17	2.00%	156	1.55%
Greece	$45.45	0.04%	21	0.21%
Hungary	$8.37	0.01%	2	0.02%
Ireland	$68.01	0.06%	6	0.06%
Israel	$271.85	0.24%	103	1.03%
Italy	$505.59	0.44%	70	0.70%
Japan	$5,795.19	5.08%	754	7.51%
Liechtenstein	$14.64	0.01%	3	0.03%
Lithuania	$3.05	0.00%	2	0.02%
Luxembourg	$8.26	0.01%	4	0.04%
Malta	$1.15	0.00%	2	0.02%
Mexico	$469.85	0.41%	58	0.58%
Netherlands	$962.43	0.84%	39	0.39%
New Zealand	$71.62	0.06%	20	0.20%
Norway	$240.33	0.21%	49	0.49%
Poland	$131.83	0.12%	33	0.33%
Portugal	$78.11	0.07%	13	0.13%
Romania	$43.03	0.04%	10	0.10%
Serbia	$1.41	0.00%	2	0.02%
Slovenia	$4.78	0.00%	3	0.03%
South Korea	$1,887.60	1.65%	267	2.66%
Spain	$686.38	0.60%	49	0.49%
Sweden	$790.57	0.69%	140	1.39%
Switzerland	$1,852.20	1.62%	93	0.93%
Turkey	$178.93	0.16%	79	0.79%

UK	$2,600.25	2.28%	189	1.88%
USA	**$60,609.98**	**53.14%**	1705	16.98%

Table 9: Means by Region

Region	No. of Observations	Variable	Mean	Std Dev
USA	1,705	VC BIO	-0.28449	1.054801
		CO BIO	-0.20539	1.038381
OECD (ex US)	2,911	VC BIO	0.06146	1.028146
		CO BIO	0.036094	1.100858
DM Asia	816	VC BIO	0.094961	0.972797
		CO BIO	-0.05986	0.864955
China	3,065	VC BIO	-0.04102	0.881222
		CO BIO	0.013077	0.849316
EM Asia (ex-China)	1,035	VC BIO	0.230752	1.005606
		CO BIO	0.163294	1.016816
MEA	365	VC BIO	0.224692	1.16436
		CO BIO	0.081938	1.084997
Latin America	146	VC BIO	0.229803	0.977428
		CO BIO	0.376475	1.264072

Table 10: Pearson Correlations

Variable	1	2	3	4	5	6
1. **Tobin's Q**	1					
2. **Z_VC_BIO**	-0.186***	1				
3. **Z_CO_BIO**	-0.171***	0.265***	1			
4. **LnMC**	0.144***	-0.076***	0.022*	1		
5. **DebtAssets**	-0.205***	0.100***	0.017	0.117***	1	
6. **ROE**	0.229***	0.076***	-0.000	0.245***	-0.106***	1

Table 11: Frequency by Region by Sector

Region/ GICS Sector	Market Cap (BN)	% of Total	Companies	% of Total
China	**$9,530.61**	**8.36%**	**3065**	**30.52%**
Communication Services	$253.31	0.22%	120	1.19%
Consumer Discretionary	$988.06	0.87%	399	3.97%
Consumer Staples	$909.90	0.80%	218	2.17%
Energy	$133.22	0.12%	40	0.40%
Health Care	$665.86	0.58%	292	2.91%
Industrials	$1,992.45	1.75%	648	6.45%
Information Technology	$2,559.04	2.24%	528	5.26%
Materials	$1,511.37	1.33%	659	6.56%
Real Estate	$176.02	0.15%	94	0.94%
Utilities	$341.39	0.30%	67	0.67%
DM Asia	**$7,557.54**	**6.63%**	**816**	**8.13%**
Communication Services	$1,343.07	1.18%	34	0.34%
Consumer Discretionary	$722.08	0.63%	157	1.56%
Consumer Staples	$346.35	0.30%	67	0.67%
Energy	$684.26	0.60%	15	0.15%
Health Care	$314.16	0.28%	79	0.79%
Industrials	$715.89	0.63%	141	1.40%
Information Technology	$2,409.72	2.11%	136	1.35%
Materials	$484.45	0.42%	81	0.81%
Real Estate	$353.48	0.31%	86	0.86%
Utilities	$158.27	0.14%	19	0.19%
EM Asia ex China	**$5,111.72**	**4.48%**	**1035**	**10.31%**
Communication Services	$371.26	0.33%	51	0.51%
Consumer Discretionary	$685.45	0.60%	179	1.78%
Consumer Staples	$557.44	0.49%	158	1.57%
Energy	$608.04	0.53%	56	0.56%
Health Care	$299.41	0.26%	66	0.66%
Industrials	$704.07	0.62%	172	1.71%
Information Technology	$519.57	0.46%	39	0.39%
Materials	$740.11	0.65%	182	1.81%
Real Estate	$237.48	0.21%	78	0.78%
Utilities	$388.89	0.34%	54	0.54%
Latin America	**$671.76**	**0.59%**	**146**	**1.45%**

Communication Services	$33.43	0.03%	4	0.04%
Consumer Discretionary	$35.14	0.03%	22	0.22%
Consumer Staples	$87.89	0.08%	24	0.24%
Energy	$112.07	0.10%	7	0.07%
Health Care	$26.86	0.02%	7	0.07%
Industrials	$75.19	0.07%	13	0.13%
Information Technology	$5.59	0.00%	2	0.02%
Materials	$153.24	0.13%	31	0.31%
Real Estate	$10.45	0.01%	7	0.07%
Utilities	$131.89	0.12%	29	0.29%
MEA	**$3,550.85**	**3.11%**	**365**	**3.63%**
Communication Services	$243.57	0.21%	27	0.27%
Consumer Discretionary	$139.92	0.12%	49	0.49%
Consumer Staples	$112.05	0.10%	72	0.72%
Energy	$1,825.45	1.60%	22	0.22%
Health Care	$79.35	0.07%	26	0.26%
Industrials	$392.67	0.34%	44	0.44%
Information Technology	$20.70	0.02%	4	0.04%
Materials	$354.41	0.31%	64	0.64%
Real Estate	$163.13	0.14%	43	0.43%
Utilities	$219.60	0.19%	14	0.14%
OECD (ex US)	**$27,025.37**	**23.69%**	**2911**	**28.99%**
Communication Services	$1,658.79	1.45%	167	1.66%
Consumer Discretionary	$3,899.30	3.42%	487	4.85%
Consumer Staples	$2,671.39	2.34%	325	3.24%
Energy	$1,620.85	1.42%	138	1.37%
Health Care	$3,096.65	2.71%	223	2.22%
Industrials	$6,165.96	5.41%	642	6.39%
Information Technology	$3,232.89	2.83%	208	2.07%
Materials	$2,753.58	2.41%	430	4.28%
Real Estate	$567.44	0.50%	166	1.65%
Utilities	$1,358.52	1.19%	125	1.24%
USA	**$60,609.98**	**53.14%**	**1705**	**16.98%**
Communication Services	$7,613.56	6.68%	123	1.22%
Consumer Discretionary	$8,454.55	7.41%	303	3.02%
Consumer Staples	$3,591.32	3.15%	104	1.04%
Energy	$2,315.69	2.03%	114	1.14%

Health Care	$6,691.98	5.87%	277	2.76%
Industrials	$6,001.58	5.26%	291	2.90%
Information Technology	$22,674.39	19.88%	292	2.91%
Materials	$1,476.46	1.29%	111	1.11%
Real Estate	$263.40	0.23%	22	0.22%
Utilities	$1,527.06	1.34%	68	0.68%

Table 12: VIF Results

Variable	**VIF**
Z_VC_BIO	1.048
Z_CO_BIO	1.025
Ln(Market Cap)	1.064
Debt/Assets	1.071
ROE	1.102

Note: VIF values below 5 indicate no evidence of multicollinearity.