

# BIODIVERSITY RISK \*

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## Abstract

We explore the effects of physical and regulatory risks related to biodiversity loss on asset values. We first develop a news-based measure of aggregate biodiversity risk and analyze how it varies over time. We also construct and publicly release several firm- and industry-level measures of exposure to biodiversity risk, based on textual analyses of firms' 10-K statements; the holdings of biodiversity-related funds; firms' responses to a questionnaire fielded by CDP; and a large survey of finance professionals, regulators, and academics. Exposures to biodiversity risk vary substantially across industries in a way that is economically sensible and distinct from exposures to climate risk. We find evidence that biodiversity risks already affect equity prices: returns of portfolios that are sorted on our measures of biodiversity risk exposure covary positively with innovations in aggregate biodiversity risk. However, our survey indicates that market participants do not perceive the current pricing of biodiversity risks in equity markets to be adequate.

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Over the past decade, policymakers, investors, and researchers have increasingly focused on better understanding and managing the complex relationships between the modern economy and the health of our planet. For example, a series of treaties have codified commitments to reduce carbon emissions and slow global warming, and there have been numerous efforts from the business and finance communities to address the various risks from climate change. On the academic side, the field of climate finance has rapidly developed into an active area of research (see [Giglio et al., 2021b](#); [Stroebel and Wurgler, 2021](#); [Hong et al., 2020](#), for recent reviews). Yet, climate change is only one important dimension of the interaction between economic activity and the health of our planet. In this paper, we study a distinct but equally important dimension: the economic risks associated with *biodiversity loss*.

Throughout history, humans have relied on biodiversity—often defined as the sum total of genes, species, and ecosystems—to survive and thrive. At the same time, human activity has led to a rapid decline in the amount of biodiversity over the past decades. For example, the 2019 *Global Assessment* of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services summarized a large literature demonstrating that the global rate of species extinction was at least 10-100 times larger than the base rate over the past 10 million years, and found that this extinction rate had recently been accelerating ([IPBES, 2019](#)).

Such biodiversity loss can have large negative consequences for the economy, as was recently highlighted by [Giglio et al. \(2024\)](#). A key reason is that biodiversity plays a fundamental role in the provision of *ecosystem services*, an important (though often ignored) factor of production alongside other factors like capital and labor (see, e.g., [Daily et al., 1997, 2000](#); [Chichilnisky and Heal, 1998](#); [Heal, 2000](#); [Dasgupta et al., 2013](#)). Crucially, ecosystem services are complementary to these other factors: the effect on output from a loss of ecosystem services is difficult to replace by increasing capital or labor ([Dietz and Neumayer, 2007](#); [Ekins et al., 2003](#)). As a result, early estimates of the annual economic value provided by ecosystem services are in the tens of trillions of dollars ([Costanza et al., 1997](#)).

In addition to these physical risks from biodiversity loss, transition risks from regulatory and other responses to biodiversity loss—such as those resulting from policy commitments made at the recent COP15 conference in Montreal—can also have substantial effects on economic activity and asset values, especially for industries with activities that directly interact with the natural environment (like utilities and energy companies).

While there is recent work on understanding the theoretical mechanisms through which biodiversity loss affects the economy, less work has been done to quantify these physical and regulatory biodiversity risks. The goal of this paper is to make progress towards such measurement, and to assess whether these risks already affect asset prices. We first propose a systematic way to measure economy-wide *aggregate biodiversity risk*. We then develop and publicly release several measures of the *exposures* of firms and industries to biodiversity risks. Our exposure measures generally line up with investors' views about biodiversity risks as elicited through surveys and as reflected in asset prices. Our analysis identifies biodiversity risk as an important new dimension of risk that is distinct from climate risk, and we conclude that academic research should increasingly focus on the role that financial markets can play in managing biodiversity-related economic risks.

To motivate our analysis, we conduct a broad survey of the perceptions of biodiversity risks among finance academics, professionals, public sector regulators, and policy economists from around the world. We received a total of 668 survey responses. The survey shows broad and substantial concerns about the economic effects from biodiversity loss over relatively near-term horizons. Around 70% of respondents perceive physical and transition biodiversity risks to have at least moderate financial materiality for firms in the United States, with private sector respondents reporting the highest perceived financial materiality of these risks.

We next move to quantify the aggregate amount of biodiversity risk over time. A key issue with measuring risks such as those related to biodiversity loss is that they often unfold slowly over long horizons, making it hard to quantify risk and risk exposures using standard statistical tools. To overcome these challenges, we follow the approach developed in [Engle et al. \(2020\)](#) and build a biodiversity risk index using *news* about such risks extracted from newspaper coverage of topics associated with biodiversity loss.

Specifically, we construct a biodiversity news index by analyzing articles in the New York Times (NYT). We first develop a biodiversity dictionary containing a list of relevant terms such as “ecosystem” and “deforestation” that is used to identify articles in the NYT that cover biodiversity risks. We classify the sentiment of these articles using the Bidirectional Encoder Representations from Transformers, or BERT, a standard model from the natural language processing literature. The article-level sentiment is aggregated to compute a daily “NYT-Biodiversity News Index.” We validate the index by showing that it spikes around important events regarding biodiversity risk (e.g., during ecosystem disasters or new regulations to limit biodiversity loss). This high-frequency measure allows us to quantify the immediate impacts of changes in expectations about damages and regulations related to biodiversity loss, even if they might only materialize in the future.

To assess whether this type of biodiversity risk is already priced in asset markets, we start from the observation that the impacts of biodiversity risks are heterogeneous across firms and industries. For example, diverse ecosystems are key to the production of food and nature-based materials such as timber ([Duarte et al., 2009](#); [Liang et al., 2016](#); [Paul et al., 2020](#); [Porto et al., 2020](#); [Steffan-Dewenter et al., 2007](#)), making those industries particularly exposed to physical biodiversity risks. In addition, many medicines, including antibiotics and cancer drugs, are derived from natural compounds found in plants, animals, and microorganisms, so that the pharmaceutical industry is also exposed to this risk. Similarly, utility firms with large footprints in environmentally sensitive areas—including firms operating wind and solar farms—may be disproportionately affected by biodiversity transition risks.

However, while it is intuitive to expect biodiversity risk exposures to be heterogeneous across firms, the absence of standardized disclosure frameworks for physical and transition biodiversity risks makes it hard to quantify these exposures. We thus propose and compare several new ways to measure firms’ biodiversity risk exposures, using four different data sources: firms’ 10-K statements; the opinions elicited in our survey of financial professionals, academics, and regulators; the portfolio holdings of funds focused on biodiversity; and firms’ responses to the CDP Climate Change Questionnaire. We release our measures of biodiversity risk exposures at [www.biodiversityrisk.org](http://www.biodiversityrisk.org).

Our first set of measures of biodiversity risk exposures, available at the firm level, is based on textual analysis of firms' 10-K statements to identify discussions of biodiversity-related risks. The second measure is created at the industry level from our survey of academics and professionals. The survey asked respondents to select the industries most negatively affected by biodiversity loss, distinguishing explicitly between both physical and transition risks. Our third measure of biodiversity risk exposures is based on the holdings of five biodiversity-related funds. It is calculated by comparing the weight of an industry in the market portfolio to its weight in the biodiversity funds' portfolios, based on the assumption that industries that are underweighted relative to the market are negatively exposed to biodiversity risks. The last measure is derived from firms' responses to the CDP Climate Change Questionnaire, where firms disclose whether their activities impact biodiversity-sensitive areas. All these measures are substantially correlated in the cross-section: industries ranked high on biodiversity risk exposure on one measure generally also rank high on the other measures. The sectors with the highest average biodiversity risk exposures include Energy, Utilities, Food, and Pharmaceutical, while firms in the Communication Services, Software, and Technology sectors have minimal direct exposures to biodiversity risks.

To better understand the economic mechanisms driving our estimated risk exposures, we study the 10-K statements of firms in industries that are differentially exposed to biodiversity risks. Both physical and transition risks are frequently mentioned. For example, we find that firms in the energy sector are exposed to biodiversity transition risks because of their exploration, drilling, and refining activities, which can affect the ecosystem and are potentially a target for future regulations. Similarly, utility firms, including those producing solar and wind energy, face regulations on species and habitat protection that can limit their operations, and the real estate industry faces restrictions on developments in areas with high biodiversity. Firms also report facing a variety of physical biodiversity risks. For example, firms in the pharmaceutical sector report relying on biodiversity for drug discovery, and food sector firms depend on water for production.

We then use our measures of news about aggregate biodiversity risk as well as our firm- and industry-level risk exposures to explore the extent to which biodiversity risks are currently incorporated into equity prices. To do so, we form equity portfolios of industries sorted by their biodiversity risk exposures. The portfolios hold long positions in industries with low biodiversity risk exposures and short positions in industries with high biodiversity risk exposures. If biodiversity risk is priced, the return of these biodiversity-risk-sorted portfolios should covary with the aggregate biodiversity news index, effectively behaving like a hedging portfolio for biodiversity risk. We find that the correlations between the returns of our biodiversity hedging portfolios and the biodiversity risk index are positive, with magnitudes as large as 0.2. These correlations are comparable to those obtained by climate hedging portfolios when evaluated against aggregate climate news (see [Engle et al., 2020](#); [Alekseev et al., 2024](#)), and, more generally, to the hedging performance of portfolios built to hedge other macro risks such as consumption or GDP (see [Giglio and Xiu, 2021](#)).

To investigate whether our measures of biodiversity risk exposure are simply recasting information from other firm characteristics, we compare the hedge performance of our biodiver-

sity risk measures with that of hedge portfolios constructed using other firm characteristics—specifically, the 212 characteristics in the “factor zoo” of [Chen and Zimmermann \(2022\)](#)—and find that our measures of biodiversity exposure perform significantly better than this universe of characteristics in hedging aggregate biodiversity risk. Overall, the evidence suggests that biodiversity risk has been at least partly priced in the cross-section of equities over the last decade.

We conclude by reviewing evidence from our survey on market participants’ perceptions of whether biodiversity risks are *adequately* priced in financial markets. About half of the respondents believe that these risks are not sufficiently priced across stock, commodity, sovereign debt, and real estate markets, while 14%-19% of respondents believe that they are correctly priced. Only a handful of respondents believe that biodiversity risks are overpriced in these asset markets (while about 35% of respondents had no opinion).

In additional analyses, we attempt to distinguish between transition risk and physical risk by exploiting the most recent large language models (ChatGPT) to parse the text of the NYT as well as that of the 10Ks. Distinguishing the two risks is both hard in theory (for example, because policymakers respond to changes in physical risks, thereby creating transition risk) and in practice (because automatically parsing the nuances of this difference in text data is difficult). Because of this, in the main paper we make limited use of this distinction, relying only on the experts’ survey to distinguish the two types of risk exposures across industries. In the Appendix, we further explore using ChatGPT to distinguish the two with text data, and document encouraging results.

Throughout the paper, we explore the relationship between biodiversity risks and climate risks. The two risks are conceptually distinct, as biodiversity risk focuses on the threats to the variety of life on Earth and its consequences, while climate risk relates to the potential negative consequences of a change in the climate. As discussed in [Giglio et al. \(2024\)](#), the effects on aggregate output of these two types of risk realizations can be quite different. Despite this conceptual distinction, the two risks are interconnected in that climate change can exacerbate biodiversity loss, and biodiversity loss can drive climate change, for example through the destruction of carbon sinks. Given the recent academic and policy interest in climate change and its economic implications, it is important to distinguish the two types of risk not only qualitatively, but also quantitatively. We do so in several ways. First, we show that the aggregate biodiversity news index behaves differently from analogously constructed climate news index; second, we document that climate risk exposures and biodiversity risk exposures are only weakly related in the cross-section of industries; and finally, we show that portfolios built for hedging biodiversity risk do not perform well at hedging climate risk.

Our work contributes to a growing literature that studies the interaction between financial markets, asset prices, and the health of our planet. Much recent research has studied the physical and transition risks relating to climate change (e.g., [Alekseev et al., 2024](#); [Engle et al., 2020](#); [Giglio et al., 2023](#); [Pástor et al., 2021](#); [Sautner et al., 2023b](#); [Ilhan et al., 2021](#); [Bolton and Kacperczyk, 2021b, 2020, 2023, 2021a](#); [Ilhan et al., 2023](#); [Bolton et al., 2020](#); [Grippa et al., 2019](#); [Bolton and Kacperczyk, 2022](#); [Pástor et al., 2021, 2022](#); [Choi et al., 2020](#); [Giglio et al., 2021b](#); [Bernstein et al., 2019](#); [Baldauf et al., 2020](#); [de Boyrie and Pavlova,](#)

2020; van Bentham et al., 2022; Acharya et al., 2023).

Much less work has been done to understand the effect of biodiversity risks on asset values. For example, our paper is one of the first, to our knowledge, to provide quantitative measures of aggregate biodiversity risk and to study how it is priced in the cross-section of equity markets. By addressing this research gap, we respond to the call for more research in Karolyi and Tobin-de la Puente (2022) and provide publicly available data sources to spur follow-up work on biodiversity risks at [www.biodiversityrisk.org](http://www.biodiversityrisk.org). Among the most related papers studying financial or economic aspects of biodiversity loss is contemporaneous work by Garel et al. (2023), who use the Corporate Biodiversity Footprint (CBF) developed by Iceberg Data Lab to measure firms' impact on biodiversity. They observe that biodiversity risk begins to be reflected in equity pricing after COP15. Similarly, Coqueret and Giroux (2023) employ the CBF data and disentangle carbon risk and biodiversity risk. Their findings indicate that the CBF biodiversity score encompasses carbon considerations along with other nature-related factors and that dimensions related to carbon risk, such as air pollution, are priced significantly more than other nature-related dimensions like land use. In a related study, Xin et al. (2023) use an alternative measure of biodiversity risk derived from MSCI's biodiversity components of ESG rating and conclude that biodiversity ratings do not predict stock returns. In the fixed-income market, Cherief et al. (2022) examine the impact of acute biodiversity events on corporate bond spreads through an event study involving Australian and Brazilian companies between 2019 and 2022.

In addition to the literature on the pricing of biodiversity risk, Giglio et al. (2024) develop an ecologically-founded model to assess the economic effects of biodiversity loss by focusing on the interaction between species and their roles in providing ecosystem services, which enter economic production functions (also see Dasgupta, 2021). Flammer et al. (2023) focus on the financing of biodiversity conservation projects. Several central banks have conducted biodiversity stress tests, including Calice et al. (2023); De Nederlandsche Bank (2020); Banque de France (2021). We contribute to this literature by constructing biodiversity exposure measures and news-based aggregate biodiversity risk index using publicly accessible data.

Our approach also relates to recent literature that employs textual analysis to quantify firm-level risk (e.g., Hassan et al., 2019, 2023, 2024), and aggregate risk over time (Bybee et al., 2021; Chen et al., 2022; Bybee, 2023), particularly in the context of climate risk (e.g., Sautner et al., 2023a; Li et al., 2024; Bingler et al., 2022).

## 1 Biodiversity Risks: Perception and Measurement

The economic and financial risks relating to biodiversity can be broadly divided into physical risks from the actual loss of biodiversity and transition risks from responses by regulators and consumers to reduce biodiversity loss (see OECD, 2019; IFC, 2019; BCG, 2021).

Physical risks encompass the financial and economic effects of the loss of biodiversity and ecosystem services. These services include the supply of raw materials like food, fiber, and fuel; the regulation of climate, water, soil, and air quality; and the support of pollination,

nutrient cycling, and soil formation. For example, firms relying on specific natural resources, such as timber, may face scarcity or quality issues due to deforestation or habitat loss. This can lead to increased raw material costs and deteriorating supply chains. Similarly, biodiversity loss can negatively affect the R&D process in the pharma and biotech sectors. In addition to such direct effects, biodiversity loss can raise the likelihood of the emergence of various diseases, by disrupting the balance of the ecosystem, and increase vulnerability to damages from climate change, for instance by reducing carbon sequestration capacity.

Besides the physical risks associated with biodiversity loss, firms may also be affected by risks from an increased focus of regulators and consumers on the protection of biodiversity. For example, policies aimed at protecting biodiversity, such as land-use regulations and sustainable forestry requirements, may result in changes to asset values across a range of industries. Biodiversity transition risks also come from changing consumer preferences, such as shifts away from palm oil by consumers concerned about its effect on deforestation. In addition, legal and reputational biodiversity risks affect firms by increasing the cost of causing ecological disasters such as oil spills.

In this section, we aim to better understand the importance and evolution of biodiversity risks from an aggregate perspective. We first discuss findings from a survey of academics, financial professionals, and regulators about the relative importance of various biodiversity risks over different time horizons. We then describe a new measure of aggregate biodiversity risk over time, and highlight that the time-series movement of biodiversity risk is distinct from that of climate risk, which has been studied extensively in the academic literature.

## 1.1 Perceptions of the Importance of Biodiversity Risks

To measure perceptions about the importance of biodiversity risks, we surveyed finance researchers, professionals, and public sector employees in Q1 2023. To reach academics, we collected email addresses of about 4,500 faculty at the top 100 finance departments.<sup>1</sup> To reach practitioners, we contacted about 7,000 NYU Stern and Yale SOM graduates working in finance. To reach those involved in policy, we invited about 3,000 researchers or policy-makers working in the finance-related groups of about 35 relevant public sector institutions to participate in our survey (see Appendix A.4 for the full list of these institutions).

In total, we received 668 complete responses for an overall response rate of about 4.5%.<sup>2</sup> 48% of responses were from academic researchers, 34% from financial professionals, and 18% from financial regulators or public-sector researchers. Our respondents' locations tilt toward North America (62%) and Europe (23%), with respondents from Asia and the Rest of the World making up 9% and 5% respectively. Appendix Table A.1 contains summary statistics and cross-tabulations of the demographic information reported by respondents.

Appendix A.1 shows the flow of the survey. The first question asked respondents about

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<sup>1</sup>We used the ranking maintained at [ASU](#) based on the total number of articles published in the Journal of Finance, Journal of Financial Economics, and Review of Financial Studies from 2010 through 2023.

<sup>2</sup>This response rate is comparable to that in other surveys used by finance researchers, such as 7.5% in [Stroebel and Wurgler \(2021\)](#) and 2.5-4% in [Giglio et al. \(2021a\)](#)

how worried they were about both ecosystem diversity loss and species diversity loss. The level of concern about both types of biodiversity loss is high, with about 70% expressing substantial personal concerns. To investigate perceptions of the financial and economic implications of biodiversity risks, we ask survey participants to rate the financial materiality of physical and transition biodiversity risks for U.S. firms. We also ask respondents over what time horizon they expected these risks to materialize. Table 1 presents the responses for different groups of respondents.

Both physical and transition biodiversity risks are generally perceived to be material, in particular by respondents in the private sector as well as by respondents located in Africa, South America, and Australia. While about 20% of respondents believe that physical and transition biodiversity risks are already materializing today, transition risks are generally believed to be somewhat more likely to matter over the coming five years.

Appendix Table A.2 shows several responses to an open-ended question asking if there were any particular ways in which biodiversity risks are important in participants' professional lives. Respondents mentioned both physical risks ("I co-run an investment fund in farmland and timberland, which are directly affected by these risks") and transition risks ("Regulatory risk related to biodiversity are a chief driver of long-term uncertainty in the energy markets in which I work"). Many survey participants discussed mechanisms through which biodiversity loss affects the economy, for example through the exposures of specific industries (as in the examples above), or at the aggregate level (as in the following responses: "Biodiversity risks are a serious threat to financial stability and the resilience of financial companies"; "Loss of biodiversity and area for animals to move closer to cities, causing a great chance for diseases to spread to humans, which may cause another pandemic"). Overall, the survey shows that biodiversity loss is a growing concern among ESG analysts, fund managers, VCs, and management consultants, especially those working with the energy, materials, and construction sectors, as well as among academics and public sector employees.

## 1.2 Measuring Aggregate Biodiversity Risk

Table 1 suggests a substantial degree of concern about biodiversity risks across respondents with a wide range of backgrounds. In this section, we construct a new index that allows us to measure attention and concern related to biodiversity risks over time.

While biodiversity loss can have substantial economic costs, it is relatively slow-moving, with many of the worst possible outcomes materializing over decades (see [Magurran, 2021](#)). This complicates the quantification of the risk and of different assets' exposure to that risk. To address this issue, we build on insights of [Engle et al. \(2020\)](#), who suggest that in the presence of a slow-moving long-term risk such as climate change or biodiversity loss, risk exposures can be studied by obtaining higher-frequency measures of *news* about future damages arising from the risk (see [Ardia et al., 2023](#); [Stecula and Merkley, 2019](#), for further examples of news-based measures of climate risk built on this insight). Based on this idea, we construct an index of biodiversity *news* as reported in the New York Times (NYT).

**Table 1:** Biodiversity Risk Perceptions

	Pooled	Role			Location				Biodiversity Concern			
		Academic Institution	Private Sector	Public Sector	North America	Europe	Asia	ROW	Very High	High	Low	No Concern
<b>Physical Risk Importance (%)</b>												
Not at all important	8	9	9	5	9	6	9	6	1	3	9	100
Slightly important	24	26	23	20	26	20	26	14	6	27	91	0
Moderately important	35	37	28	40	34	36	38	26	19	69	0	0
Very important	34	28	40	35	31	38	28	54	73	0	0	0
<b>Transition Risk Importance (%)</b>												
Not at all important	7	7	6	11	8	6	7	9	1	1	9	100
Slightly important	20	22	19	18	22	19	19	11	8	17	91	0
Moderately important	42	46	34	46	40	50	36	40	26	82	0	0
Very important	30	25	41	25	30	25	38	40	66	0	0	0
<b>Physical Risk Materialization (%)</b>												
Already today	23	18	29	24	24	18	19	29	32	15	12	13
1 to 5 years	10	8	10	14	9	9	5	23	11	9	8	7
5 to 30 years	46	51	43	41	45	52	43	43	45	57	36	7
More than 30 years	17	18	14	19	17	17	22	3	10	17	35	30
Never	5	6	4	1	4	4	10	3	1	2	9	43
<b>Transition Risk Materialization (%)</b>												
Already today	20	16	27	17	23	14	16	23	27	14	15	10
1 to 5 years	26	28	25	24	25	29	22	34	33	23	15	7
5 to 30 years	41	44	34	47	40	44	43	34	33	54	41	13
More than 30 years	8	7	10	7	9	7	9	3	4	7	20	27
Never	5	5	4	6	3	7	10	6	2	2	9	43

**Note:** For the first two blocks, participants were asked: “Biodiversity risks for investors and firms are often divided into (i) physical risks coming from actual changes in biodiversity (e.g., reduced pollinators, freshwater scarcity) and (ii) transition risks coming from changes in the regulatory environment to combat biodiversity loss (e.g., the Clean Water Act). Please rate the financial materiality of these risks for corporations in the United States. 1- Physical Risk; 2- Transition Risk”. For the last two blocks, participants were are: “Over what time horizon, if any, do you expect these biodiversity risks to materialize?”, where biodiversity risk is either the physical risk or transition risk. The percentage breakdowns in the table are to be read in columns within blocks.

**The NYT Biodiversity News Index.** The first step to building our measure of biodiversity news is to identify news articles that cover biodiversity. To do so, we build a Biodiversity Dictionary that contains 100 words, reported in Appendix Table A.3. These words were selected based on their cosine similarity to the term “biodiversity” in Google’s *word2vec*<sup>3</sup> implementation. Using this dictionary, we identify a sentence as biodiversity-related if it contains at least one of these terms, excluding instances of unrelated combinations such as “software ecosystem” (see Appendix A.4 for details) and excluding the word “climate change” to allow us to capture biodiversity news separate from climate news.<sup>4</sup> We identify articles containing at least two biodiversity sentences as covering biodiversity.

News about biodiversity loss can either be positive or negative; for example, an article can report that biodiversity loss is progressing faster or slower than previously anticipated. To separately identify such news stories, we adopt the Bidirectional Encoder Representations from Transformers (BERT) model to classify each of the selected biodiversity sentences to determine whether it expresses a positive or negative sentiment (Devlin et al., 2018). Sentences with positive sentiment get assigned a score of “+1”, negative sentences get assigned a score of “-1”, and neutral sentences get assigned a score of “0”. For example, the following sentence gets classified as having a positive sentiment: *“Populations soon rebounded, improving water quality and bringing more whales, sharks, rays, seals, dolphins and other animals closer to the beach than they’ve been since the middle of the last century.”* In contrast, a negative sentiment is assigned to *“Environmental problems remain, including overfishing and the erosion and deforestation left from earlier eras.”* Appendix Table A.7 presents further examples of biodiversity related sentences alongside their BERT sentiment classifications. We assign an article to have positive (negative) sentiment if the average sentence sentiment score for all biodiversity sentences in the article is positive (negative). About 8.4% of articles get classified as positive, 72.0% as neutral, and 19.6% as negative.

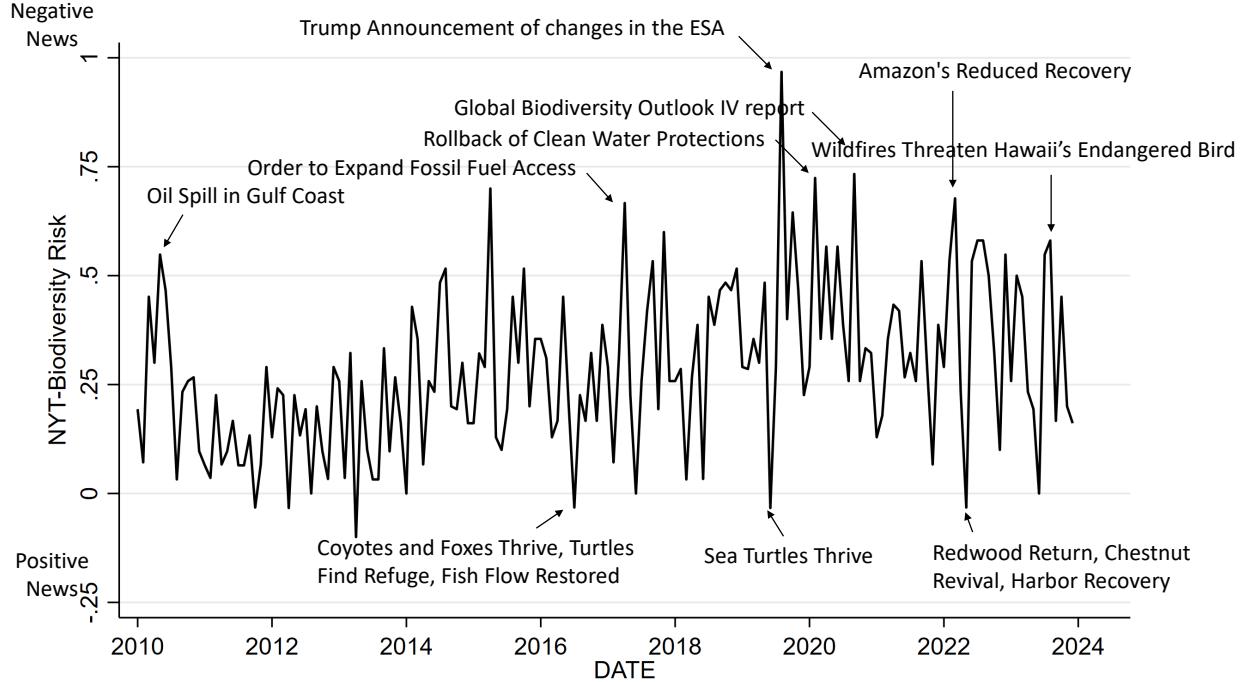
To measure the overall sentiment of biodiversity news on a given day, we construct the NYT-Biodiversity News Index as the number of negative biodiversity articles minus the number of positive biodiversity articles on that day. Therefore, higher values of the NYT-Biodiversity News Index correspond to more negative news about biodiversity risks. Since news related to biodiversity risk is relatively infrequent, we generally aggregate this daily measure of biodiversity news to the monthly levels by averaging daily values over the month. Figure 1 plots the monthly NYT-Biodiversity News Index and adds labels to events relevant to biodiversity. The index spikes around salient biodiversity-related events, such as changes

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<sup>3</sup>We use the pre-trained vectors trained on part of Google News dataset (about 100 billion words). The model contains 300-dimensional vectors for 3 million words and phrases.

<sup>4</sup>We test the robustness of the index by constructing three additional indices: one using all 100 terms from the Biodiversity Dictionary, one using terms from the Biodiversity Dictionary excluding those in the Climate Dictionary (Appendix Table A.4), and one excluding terms in the Climate Change Dictionary (Appendix Table A.5). Terms in red are the common terms that are related to both biodiversity and climate/climate change. Appendix Table A.6 presents the monthly correlations across these indices. The index using all terms is highly correlated with climate risk measures due to its focus on ‘climate change’, whereas the indices excluding climate-related terms show lower correlations with climate risk. This highlights the importance of removing words related to ‘climate change’ from the biodiversity dictionary. The high correlation among the three indices that do such removals indicates the robustness to the exact keywords that are excluded.

**Figure 1:** NYT-Biodiversity News Index



**Note:** Monthly NYT-Biodiversity News Index from 2010 to 2023, annotated with biodiversity-relevant news announcements. ESA: Endangered Species Act. Higher values correspond to more negative news.

to the Endangered Species Act (ESA) in 2019 and the release of biodiversity-related reports. There are also events with positive news about biodiversity risks, leading to a negative biodiversity news index; these include articles on the thriving of coyotes, foxes, and sea turtles. We have explored other ways of constructing our biodiversity news index, for example by measuring an article’s sentiment as the average sentiment of all biodiversity-related sentences in that article, and by measuring the per-period overall biodiversity sentiment as the average sentiment of all biodiversity-related articles. The patterns described in this paper are robust to such variations in constructing our biodiversity risk news series.

### 1.3 Biodiversity Risk vs. Climate Risk

As discussed above, climate and biodiversity risk are related but distinct concepts. In this section, we explore the relationship between the two risks quantitatively, by comparing our biodiversity risk series with a corresponding climate risk series.

To do this, we first build a new climate news series, the NYT-Climate News Index, by applying the methodology described in Section 1.2, identifying climate-related sentences with the terms “climate change” and “global warming.” As alternatives to our own climate news series, we also consider four of Faccini et al. (2023)’s climate news indices: international climate summits, global warming, natural disasters, and the climate policy index. These indices are designed to capture news about the respective topics, which correspond to dif-

ferent aspects of climate risk. These measures, which cover news about both physical and transition climate risks, are available at a daily frequency between January 2000 and June 2023. We aggregate them to the monthly frequency by taking the average of the daily series.

Table 2 shows the pairwise correlation across these various news indices using monthly data from 2010 to 2023. The first column is the NYT-Biodiversity News Index, the next column is the NYT-Climate News Index and the last four columns are the [Faccini et al. \(2023\)](#) indices. The correlation between the biodiversity news index and the five climate news indices ranges between -0.11 and 0.43. These results suggest that while climate risk and biodiversity news are related to some extent, they are not the same.

**Table 2:** Correlation Across Measures of Aggregate Risk

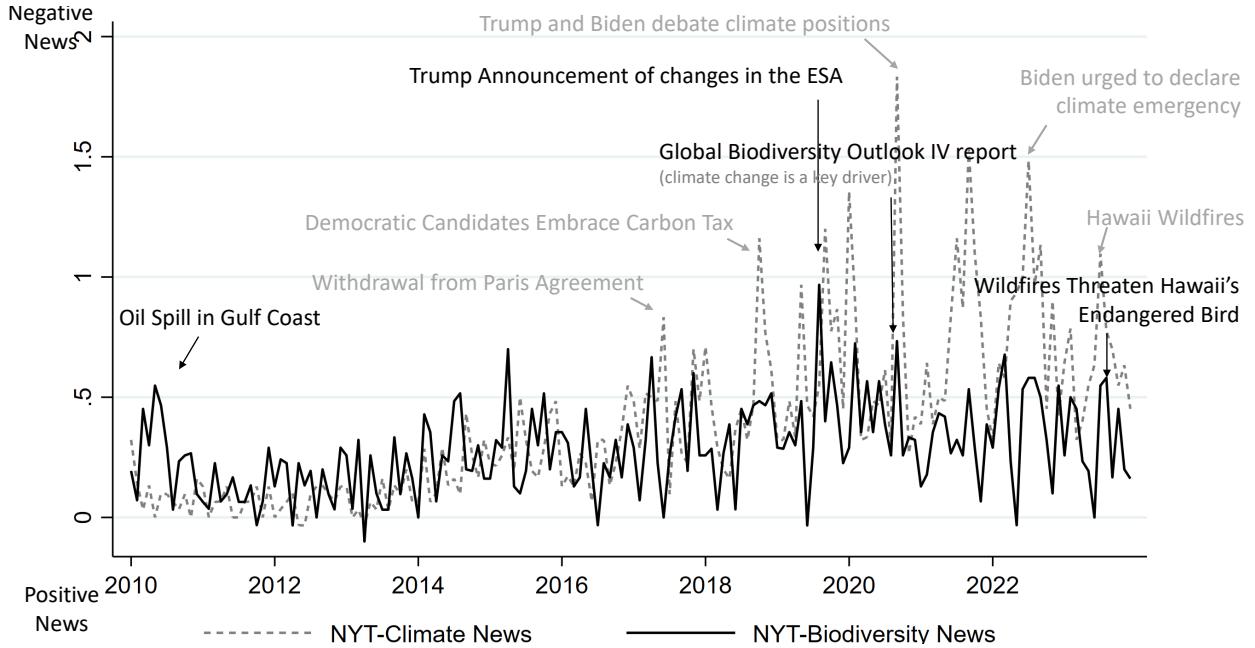
	(1)	(2)	(3)	(4)	(5)	(6)
<b>Biodiversity Risk Measures</b>						
(1) NYT-Biodiversity News	1.00					
<b>Climate Risk Measures</b>						
(2) NYT-Climate News	0.43	1.00				
(3) Faccini et al (2023): Int Summit	-0.11	-0.14	1.00			
(4) Faccini et al (2023): Global Warming	0.10	0.51	0.21	1.00		
(5) Faccini et al (2023): Natural Disaster	0.21	0.64	-0.06	0.41	1.00	
(6) Faccini et al (2023): Climate Policy	0.20	0.50	0.11	0.76	0.41	1.00

**Note:** Pairwise monthly correlation across biodiversity and climate risk measures. NYT-Biodiversity News and NYT-Climate News use data from January 2010 to December 2023, while Faccini et al (2023) indices span from January 2010 to June 2023.

Figure 2 illustrates the differences between the biodiversity and climate news series. The solid black line and black annotations correspond to the NYT-Biodiversity News Index and related biodiversity risk events, while the dotted grey line and grey annotations correspond to the NYT-Climate News Index. Note that both series are generated with the same method and based on the same data: articles published in the New York Times; they differ only in the keywords used to select the articles.

Months with negative biodiversity-related news do not necessarily correspond to months with negative climate news. For example, in August 2019, the Trump administration announced that it would change the way the Endangered Species Act was applied, making it easier to remove a species from the endangered list and weakening protections for threatened species. This led to substantial negative newspaper coverage of biodiversity-related topics, and thus a sharp increase in the NYT-Biodiversity News Index, while the NYT-Climate News Index stayed relatively stable. Similar events include the 2010 Gulf Coast oil spill, which increased risks to various ecosystems. Conversely, climate-related events, such as the withdrawal from the Paris Agreement and discussion on carbon tax did not result in spikes in the biodiversity news index. Finally, some natural disasters were followed by both negative climate and negative biodiversity news: for example, the 2023 Hawaii Wildfires were connected to climate change but also caused habitat and species loss. Similarly, the release of the Global Biodiversity Outlook report, highlighting climate change as a driver of biodiversity loss, resulted in spikes in both climate change and biodiversity news.

**Figure 2:** NYT-Biodiversity News vs NYT-Climate News



**Note:** Monthly NYT-Climate News Index from 2010 to 2023, overlaid against the NYT-Biodiversity News Index and annotated with relevant news announcements. Higher values correspond to more negative news.

## 2 Firm-Level Measures of Biodiversity Risk Exposures

Beyond quantifying aggregate biodiversity risk, we are also interested in exploring how biodiversity risk exposures vary across different firms and industries. For instance, the [World Economic Forum \(2022\)](#) states that the three sectors most reliant on natural capital are construction, agriculture, and food & beverages. Based on this assessment, firms in those sectors would be most substantially exposed to physical biodiversity risks. Similarly, sectors with substantial land use, such as the energy sector, might be particularly impacted by biodiversity transition risks. To improve our understanding of the effects of biodiversity risk on the economy, we need a systematic way to quantify these cross-sectional risk exposures.

A number of data vendors provide measures of firms' physical and transition *climate* risk exposures, though there are substantial doubts about the quality of these measures (see, for example, [Billio et al., 2021](#)). Similar data for firms' biodiversity risk exposures are not broadly available,<sup>5</sup> and standardized disclosure frameworks for biodiversity risk are still under development ([Taskforce on Nature-related Financial Disclosures, 2022](#)). In this section, we therefore propose and compare several new ways to measure firms' biodiversity risk exposures, using different data sources: (i) firms' 10-K statements; (ii) the opinions

<sup>5</sup>Some data providers have some information on firms' activities with respect to biodiversity protection. For example, Refinitiv provides a score that measures whether a "company reports on initiatives to protect, restore or reduce its impact on native ecosystems and species, biodiversity, protected and sensitive areas." However, such measures are, at best, a rather imperfect proxy for firms' biodiversity risk exposures.

elicited in our survey of financial professionals, academics, and regulators; (iii) the portfolio holdings of funds focused on biodiversity; and (iv) firms' responses to the CDP Climate Change Questionnaire, which recently added a survey component focused on biodiversity risks. The first measure is available at the firm level, the others only at the industry level. We publicly release our measures of biodiversity risk exposure at [www.biodiversityrisk.org](http://www.biodiversityrisk.org).

## 2.1 Measures of Biodiversity Risk Exposure

**10K-Biodiversity-Count Score.** Our first firm-level measure of biodiversity risk exposure is based on textual analysis of firms' 10-K statements.<sup>6</sup> We identify biodiversity-related sentences in 10-K statements using regular expression searches for the same biodiversity dictionary used to construct the NYT-Biodiversity News Index, again excluding sentences with unrelated terms. If a 10-K statement contains at least two sentences related to biodiversity, we assign a 10K-Biodiversity-Count Score of "1" to this company in that year; if there is no mention of biodiversity-related terms, we assign a score of "0". We find that about 4.2% of all 10-K statements mention biodiversity between 2015 to 2023. The following are two examples of biodiversity-related sentences from 10-K statements, the first referencing transition risk exposures, and the second referencing physical risk exposures.

In addition, future regulation of, or litigation concerning, the use of timberlands, the protection of endangered species, the promotion of forest biodiversity, and the response to and prevention of wildfires, as well as litigation, campaigns, or other measures advanced by environmental activist groups, could also reduce the availability of the raw materials required for our operations. [[Enviva Partners LP, 2017 10-K filing](#)]

If this infrastructure were to become damaged due to natural or other disasters such as the oil spill that resulted from the Deepwater Horizon incident in 2010, then it is possible that environmental damages to the area and ecosystem could result. If these environmental damages occurred, they could have a material adverse effect on the Company's business, results of operation, and financial condition. [[Omega Protein, 2015 10-K filing](#)]

**10K-Biodiversity-Negative Score.** The 10K-Biodiversity-Count Score combines mentions of biodiversity as both a risk and an opportunity for firms. To separate such mentions, we construct a second measure of biodiversity risk exposure, the 10K-Biodiversity-Negative Score, based on sentiment analysis of the 10-K sentences mentioning biodiversity-related terms. Specifically, we use the BERT model to classify each biodiversity-related sentence

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<sup>6</sup>A 10-K statement is a comprehensive report filed annually by publicly listed companies with the U.S. Securities and Exchange Commission (SEC). It provides a detailed overview of a company's performance, including both structured financial metrics and unstructured textual information, such as management's discussion and analysis, business overview, and risk factors. We collect firms' 10K statements from 2001 to 2023 through the SEC's EDGAR database.

into positive, neutral, and negative sentiments. The two previous 10-K excerpts are assessed to have a negative sentiment by BERT; the following are two examples of a biodiversity-related 10-K mention that received a positive sentiment classification from BERT (Appendix Table A.8 presents further examples).

We believe that the growth of hemp could significantly reduce deforestation by providing the same products that trees are able to supply. [[Celexus Inc, 2019 10-K filing](#)]

The Company follows Sustainable Forestry Initiative ('SFI') Standards that promote sustainable forest management in North America through the use of core principles, objectives, performance measures and indicators to protect water quality, biodiversity, wildlife habitat, species at risk, and forests which have exceptional conservation value. [[DELTIC TIMBER CORP, 2017 10-K filing](#)]

About 5.4% of biodiversity-related sentences are classified as positive, 19.4% as negative, and the remaining as neutral. For each firm-year, we count the number of positive and negative sentences and compute the firm 10K-Biodiversity-Negative Score as the number of negative biodiversity sentences minus the number of positive sentences (firms that do not mention biodiversity-related topics in their 10-K statement and firms that only include neutral sentences are assigned a score of 0). Between 2015 and 2023, among 10-K statements mentioning biodiversity-related issues, 27.6% do so in a predominantly negative way and 5.6% in a predominantly positive way.

**10K-Biodiversity-Regulation Score.** When firms mention biodiversity in their 10-K statements, some explicitly express their concerns about the biodiversity risks stemming from stricter regulations. To directly measure these regulation biodiversity risks faced by firms, we construct a third 10K-based measure that selects biodiversity risk sentences that also contain at least one of the following terms: law(s), regulation, Act, ESA, discharge, or restriction. Appendix Table A.8 shows several examples of such sentences. We assign a 10K-Biodiversity-Regulation Score of "1" if the 10-K statement of a company contains at least two biodiversity risk sentences and at least one of them is a biodiversity regulation risk sentence. Between 2015 and 2023, about 3.2% of all 10-K reports (and 75.5% of all 10-K reports discussing biodiversity) discuss biodiversity-related regulation risks.

**Survey-Based Measures of Biodiversity Risk Exposures.** We construct another measure of biodiversity risk exposures—this time at the industry level—based on responses received in our survey of finance academics, professionals, and regulators. The survey asked participants to select the industries that they believe to be most negatively affected by (i) physical risks arising from biodiversity loss, and (ii) biodiversity-related transition risks (see Appendix Figure A.4). We provided 15 possible industry options to choose from, created

by combining several of the 24 4-digit GICS industries.<sup>7</sup> We quantify an industry's physical and transition biodiversity risk exposure as the share of survey respondents who select each industry as being particularly affected by the risk.

**Holding-Based Measure of Biodiversity Risk Exposures.** In response to growing concerns about the economic effects of biodiversity loss, some asset managers have introduced investment vehicles designed to help investors mitigate biodiversity risks in their portfolios. Our next approach to measuring biodiversity risk exposures builds on information about the holdings of these funds. To construct the Holding-based Biodiversity score, we explore five biodiversity-related funds: [HSBC World ESG Biodiversity Screened Equity ETF](#), [AXA IM ACT Biodiversity Equity ETF](#), [Ossiam Food for Biodiversity ETF](#), [Xtrackers World Biodiversity Focus SRI UCITS ETF](#), and [Xtrackers USA Biodiversity Focus SRI UCITS ETF](#). These biodiversity ETFs were designed to hold companies that are acting positively for biodiversity by reducing or limiting the negative impact of human activities on biodiversity.

We obtain the portfolio holdings from Bloomberg and focus on North American common stocks. We obtain prices from CRSP and GICS industry codes from Compustat by merging the stocks on their CUSIP identifiers. We define the holding-based biodiversity score of fund  $f$  for industry  $I$  as:

$$HoldingScore_{t,f}^I = \frac{w_{I,t,M} - w_{I,t,f}}{w_{I,t,M}} \quad (1)$$

where  $w_{I,t,M}$  is the weight of industry  $I$  in the market portfolio at time  $t$  and  $w_{I,t,f}$  is the weight of industry  $I$  in the fund's portfolio (i.e., based on the industry's market capitalization). When a fund underweights an industry relative to the market, the score will be positive: we interpret this as the industry being negatively exposed to biodiversity risk. We compute this score for each fund and then average across funds to get the industry-level holding-based score (the average pairwise correlation of  $HoldingScore_{t,f}^I$  across different funds is 0.31). Since these ETFs were set up relatively recently, we only use data from December 2023.

**CDP-Based Measure of Biodiversity Risk Exposures.** The last measure of biodiversity risk exposure relies on responses obtained from the CDP Climate Change Questionnaire. CDP's Climate Change Questionnaire, initiated in 2002, has evolved to address emerging climate challenges. Starting in 2022, it includes biodiversity concerns in its 2021-2025 strategy, aligning with IUCN guidelines for comprehensive environmental reporting. Questions

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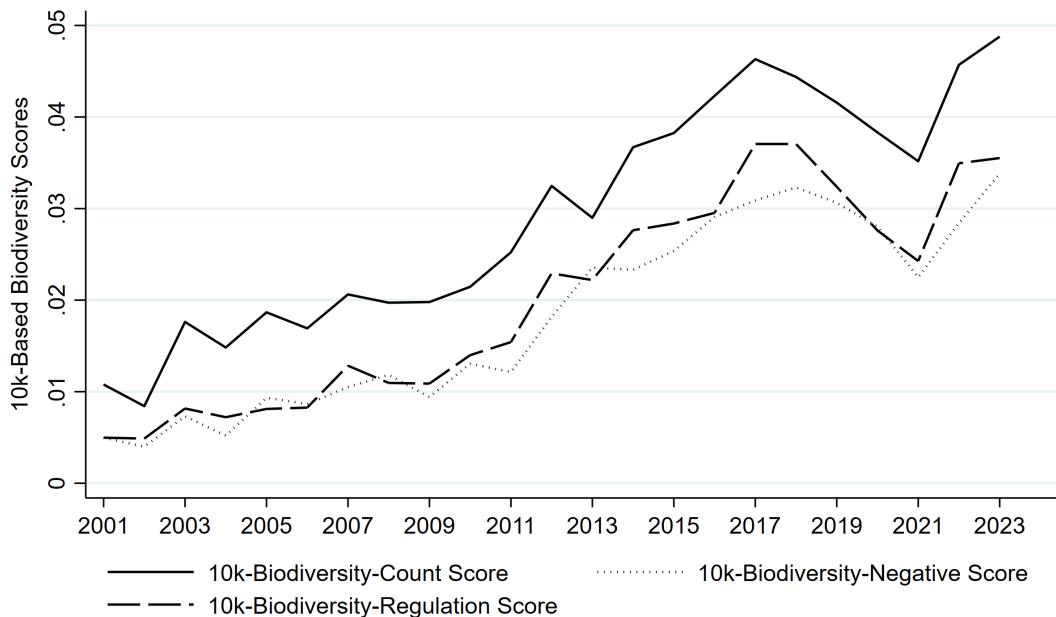
<sup>7</sup>Specifically, Automobiles & Components (GICS code 2510), Consumer Durables & Apparel (GICS code 2520), and Household & Personal Products (GICS code 3030) are pooled into “Auto, Durables and Household Products”. Consumer Services (GICS code 2530), Retailing (GICS code 2550), and Food & Staples Retailing (GICS code 3010) are pooled into “Consumer Services and Retailing”. Banks (GICS code 4010) and Diversified Financials (GICS code 4020) are pooled into “Banks and Diversified Financials”. Software & Services (GICS code 4510), Technology Hardware & Equipment (GICS code 4520), Semiconductors & Semiconductor Equipment (GICS code 4530), Telecommunication Services (GICS code 5010), and Media & Entertainment (GICS code 5020) are pooled into “IT and Communication Services.” We decided to consolidate the 24 GICS industries to keep the survey interface manageable, in particular on mobile devices.

related to biodiversity are shown in Appendix Figure A.7. To quantify a firm's exposure to biodiversity risks, we assign a score of "1" if the firm has activities in or near biodiversity-sensitive areas and the activity could negatively affect biodiversity, otherwise, we assign a score of "0". We focus on the responses of US firms operating in the United States. A total of 633 firms participated in the biodiversity module, with 4.9% of these firms having activities with negative impact located in or near biodiversity-sensitive areas. We aggregate the firm-level exposure measures to the industry level by calculating the value-weighted average of the firm-level scores.

## 2.2 Biodiversity Risk Exposures Over Time

While we can only construct the survey-, holdings-, and CDP-based measures of biodiversity risk exposures at one point in time, the availability of historical 10-K statements allows us to construct a time series of firms' self-reported exposures to biodiversity risks.

**Figure 3:** 10K-Based Biodiversity Scores Over Time



**Note:** Average 10K-Biodiversity-Count Score (solid line), 10K-Biodiversity-Negative Score (dot line), and 10K-Biodiversity-Regulation Score (dash line) over 2001 to 2023. The average scores are computed as the simple average of scores for all firms in each period.

Figure 3 shows our three 10K-based biodiversity risk exposure measures between 2001 and 2023, averaged across all firms in each period. Across all firms, self-reported biodiversity risk exposures have generally been growing over time, from about 1% of firms mentioning biodiversity-related terms in the early 2000s, to a peak of almost 5% of firms in 2023. This increase is largely driven by a corresponding increase in the number of mentions of biodiversity regulation risks. Consistent with this, the sentiment with which firms discuss biodiversity-related issues has declined over time.

## 2.3 Biodiversity Risk Exposures Across Industries

In this section, we compare the biodiversity risk exposures of different industries across our various measures. For this analysis, we aggregate the 10K-based firm-level exposure measures to the industry level by calculating the value-weighted average of the firm-level scores. Table 3 reports the cross-industry correlations of biodiversity exposures according to the different measures. We use 10-K statements from 2015 to 2023 to do the cross-sectional comparison. The Table highlights that our industry-level measures of biodiversity risk exposures are substantially correlated: industries that are assessed to have high biodiversity risk exposures on one measure also have high exposures using the other measures.

**Table 3:** Industry-level Correlations of Biodiversity Scores

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
<b>10k-based Scores</b>									
(1) 10k: Negative	1.00								
(2) 10k: Count	0.70	1.00							
(3) 10k: Regulation	0.80	0.96	1.00						
<b>Survey-based Scores</b>									
(4) Survey: Transition	0.53	0.42	0.42	1.00					
(5) Survey: Physical	0.26	0.20	0.18	0.82	1.00				
(6) Survey: Average	0.41	0.32	0.31	0.95	0.96	1.00			
<b>Holding-based Score</b>									
(7) Holding	0.42	0.10	0.26	0.26	0.02	0.14	1.00		
<b>CDP-based Score</b>									
(8) CDP	0.89	0.87	0.91	0.58	0.30	0.46	0.33	1.00	
<b>Climate Exposure Score</b>									
(9) Quantity-based	0.05	0.01	0.05	-0.15	0.16	0.01	-0.07	-0.10	1.00

**Note:** Industry-level Pearson correlations of 10K-based, Survey-based, Holding-based, CDP-based Biodiversity Scores, and Quantity-based Climate Score. The 10K-based Biodiversity Scores are averaged from 2015 to 2023. Survey-based Scores are from Q1 2023. Holding-based Score is from Q4 2023. CDP-based Score uses data from 2023. The Quantity-based Climate Score is estimated with data from 2010 to 2019 inclusive, and is taken from [Alekseev et al. \(2024\)](#).

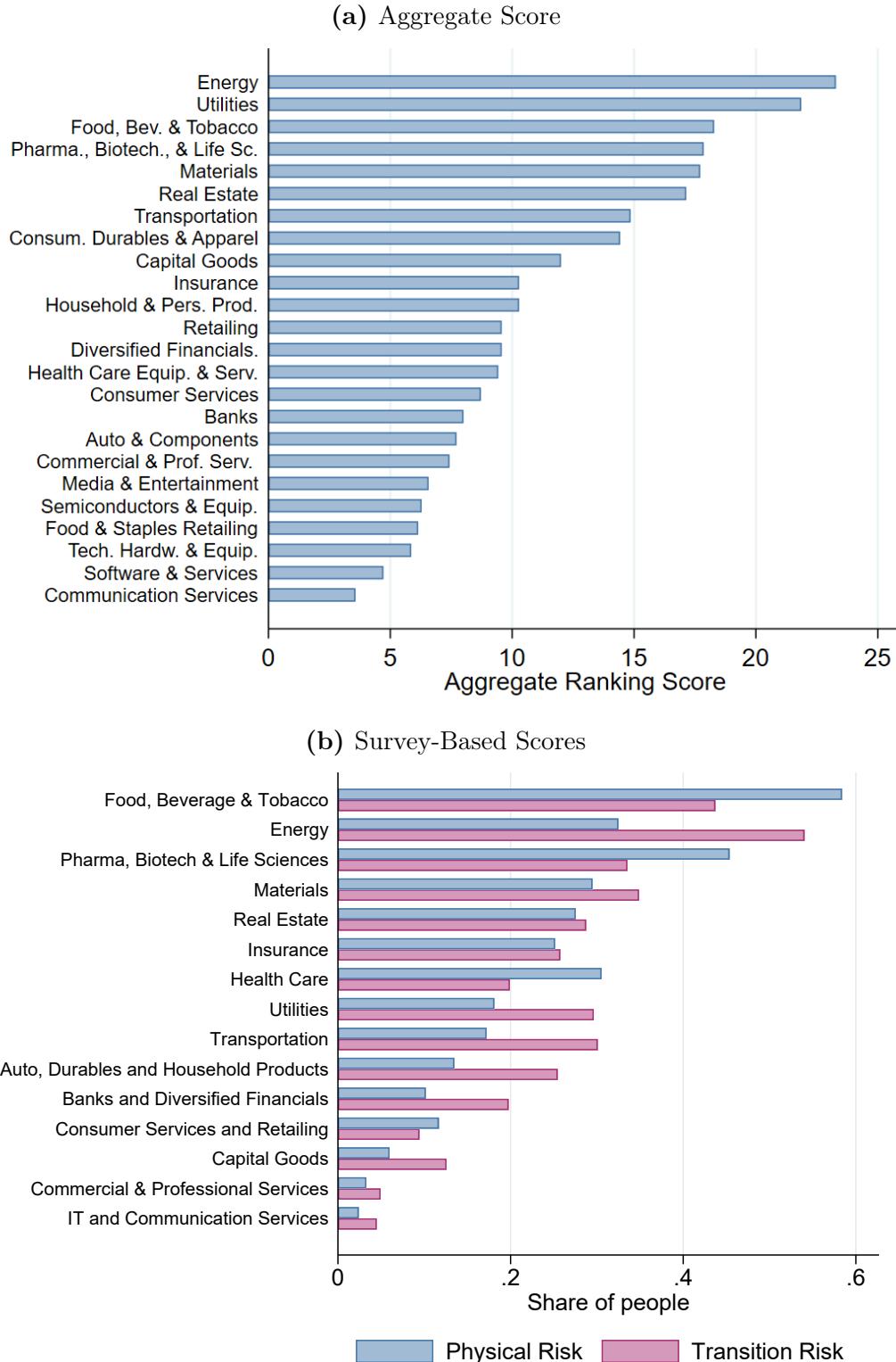
Panel (a) of Figure 4 shows biodiversity risk exposures of different industries. To construct this figure, we first rank each industry from least exposed (rank = 1) to most exposed (rank = 24) and then average the ranks across our measures.<sup>8</sup> The sectors with the highest average biodiversity risk exposures are Energy, Utilities, Food, Beverage & Tobacco, and Pharmaceutical, Biotechnology & Life Sciences, while firms in the Communication Services, Software, and Technology sectors are least exposed to biodiversity risks.

Panel (b) of Figure 4 separately shows physical and transition risk exposures across industries as elicited in our survey.<sup>9</sup> Our survey participants perceive distinct heterogeneities among industries in terms of their biodiversity risk exposures: industries that are perceived

<sup>8</sup>Appendix Figures A.6 show the industry-level exposure measures separately for each of our various measures. Appendix Table A.9 reports the industry rankings for each measure. The industries are sorted by their average ranking across the seven measures. Industries at the top are most exposed to biodiversity risk, while those at the bottom have the lowest exposure to biodiversity risk.

<sup>9</sup>Appendix Table A.10 shows the correlations of average industry rankings across different groups of

**Figure 4:** Industry-Level Biodiversity Risk Exposure



**Note:** Panel (a) shows the average industry exposure ranking based on the simple average of all biodiversity risk measures. The 10K-based Biodiversity Scores are averaged from 2015 to 2023. Survey-based Scores are from Q1 2023. Holding-based Score is from Q4 2023. CDP-based Score uses data from 2023. Panel (b) presents physical and transition risk exposures measured by survey responses. The blue bars represent survey-based physical risk, while the red bars indicate survey-based transition risk. Industries are sorted by the average of these two survey-based measures.

to be exposed to physical biodiversity risks are not necessarily the same as industries that are perceived to be exposed to transition biodiversity risks, though the two measures are substantially correlated. For example, our respondents perceive the "Food, Beverage & Tobacco" sector to be most exposed to physical biodiversity risks, and the "Energy" sector most exposed to transition biodiversity risks.

To better understand the observed variation in biodiversity risk exposures across industries, we next consider the top industries in terms of average risk exposures and discuss the ways in which biodiversity risks affect those industries. To help with these interpretations, Appendix Figure A.8 provides word clouds with the terms that are most frequently mentioned in biodiversity-related sentences extracted from 10-K statements for each industry, with term sizes proportional to their frequency.<sup>10</sup> Appendix Figure A.9 shows the biodiversity risk exposure disaggregated to 6-digit GICS industry codes.

**Energy Sector.** Our survey respondents assessed firms in the energy sector to have the highest biodiversity transition risk due to the potential impact of energy firms' operations on biodiversity. For instance, oil spills and habitat destruction during drilling activities can lead to the loss of species and ecosystems, and entail substantial reputational and legal risks. The industry also faces regulatory risks, as governments introduce stricter environmental regulations and guidelines to prevent further biodiversity loss. Examples of firms in the energy sector describing such biodiversity risk exposures in their 10-K statements include:

If one of our LNG terminals or pipelines may adversely affect a protected species or its habitat, we may be required to develop and follow a plan to avoid those impacts. [[CHENIERE ENERGY INC](#)]

A critical habitat designation could result in further material restrictions on federal land use or on private land use and could delay or prohibit land access or development. [[EARTHSTONE ENERGY INC](#)]

**Utilities.** Firms in the utility sector are affected by both physical and transition risks. Physical risks matter, for example, when the degradation of watersheds affects water quality and availability, which in turn impacts water utilities. On the transition risk side, regulations and laws on species and habitat protection may limit utility firms' operations. In addition, regulations on waste discharges, such as the Clean Water Act, elevate utility firms' costs, especially those in water utilities.

Interestingly, firms producing renewable electricity, which are often considered to be clean and potential winners of a climate transition, have the most substantial negative biodiversity risk exposure among firms in the utilities sector, as shown in Appendix Figure A.9.

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survey respondents. The rankings are similar across subgroups, with the correlation ranging from 0.82 to 0.99. For example, the pairwise correlations between industry rankings reported by academics, private-sector employees, and public-sector employees are above 0.95.

<sup>10</sup>To plot the word cloud, we extract biodiversity sentences using the same Biodiversity Dictionary for companies within each sector and aggregate these sentences into a "Biodiversity Vocabulary", which amounts to the list of unique terms and the associated frequency with which each term appears.

This is because the construction of their wind and solar power generation facilities requires substantial land and thus is subject to various land-use regulations to protect biodiversity. In addition, various regulations affect specific renewable energy sources: regulations on the protection of fish influences the development of hydropower projects, while regulations on the unintentional killing of migratory birds affect the development of wind farms.

Our ability to meet the existing and future water demands of our customers depends on an adequate supply of water. Drought, governmental restrictions, overuse of sources of water, the protection of threatened species or habitats or other factors may limit the availability of ground and surface water. [[American Water Works Company, Inc.](#)]

The Company is also subject to laws regarding the protection of wildlife, including migratory birds, eagles, threatened and endangered species. Federal and state environmental laws have historically become more stringent over time, although this trend could change in the future. [[Clearway Energy, Inc.](#)]

**Food, Beverage, and Tobacco.** The food industry faces significant physical biodiversity risks due to its dependence on biodiversity for essential raw materials. According to [World Economic Forum \(2022\)](#), the food and beverage sector ranks among the top three industries highly reliant on nature. Biodiversity loss adversely affects water availability, quality, and overall ecosystem health, hence endangering food production, distribution, and security.

Physical risks include the increasing frequency of extreme weather events and natural disasters and effects on water availability and quality and biodiversity loss. These impacts increase risks to the global food production and distribution system and to the safety and resilience of the communities where we live, work and source our ingredients, and could further decrease food security for communities around the world. [[Mondelez International, Inc., 2022](#)]

Climate change, agricultural and other factors, such as wildfires, disease, pests, extreme weather conditions, water scarcity, biodiversity loss and competing land use, impact the quality and quantity of grapes available to us for the production of wine from year to year. Our vineyards and properties, as well as other sources from which we purchase grapes, are affected by these factors. [[VINTAGE WINE ESTATES, INC., 2023](#)]

**Pharma and Biotech.** The Pharmaceuticals, Biotechnology & Life Sciences sector is exposed to substantial physical biodiversity risks. For example, in the last 40 years, about 60% of all new chemical entities in the field of antibacterials were based on or derived from natural products ([Newman and Cragg, 2020](#)). Biotechnology companies establish natural product libraries of microorganisms retrieved from soil, plant, and marine sources for drug discovery. Biodiversity loss therefore reduces potential pharmaceutical development options. Examples of firms in this sector describing their biodiversity risk exposures include:

Other potential physical impacts due to climate change include reduced access to high-quality water in certain regions and the loss of biodiversity, which could impact future product development. These risks could disrupt our operations and its supply chain, which may result in increased costs. [IOVANCE BIOTHERAPEUTICS, INC.]

We focus on the use of biodiversity as a means of natural product drug discovery, while also using traditional chemical discovery and development techniques. [CUBIST PHARMACEUTICALS INC]

**Materials.** Materials industries, such as mining, timber, and construction, face a variety of biodiversity risks. Appendix Figure A.9 shows that the Paper & Forest Products, Construction Materials and Metal Mining subsectors have particularly high biodiversity risks. Physical risks can impact the availability and quality of raw materials, such as timber from deforestation. In addition, regulations and legal and reputation risks represent additional exposures for this industry. Examples of firms in the materials sector describing their biodiversity risk exposures include:

Federal and state requirements to protect habitat for threatened and endangered species have imposed restrictions on timber harvest on some of our timberlands, and these protections may be expanded in ways that further affect our operations. These actions may increase our operating costs; further restrict timber harvests or reduce available acres; and adversely affect supply and demand more broadly across our markets. [POPE RESOURCES LTD PARTNERSHIP]

In addition, the Company's existing mining operations may become subject to additional environmental control and mitigation requirements if applicable federal, state and local laws and regulations governing environmental protection, land use and species protection are amended or become more stringent in the future. [STILLWATER MINING CO]

**Real Estate.** The real estate industry is exposed to biodiversity risks in various ways. For example, developments in areas with high biodiversity might face restrictions or require mitigation measures to minimize habitat destruction, adding costs and delays to projects.

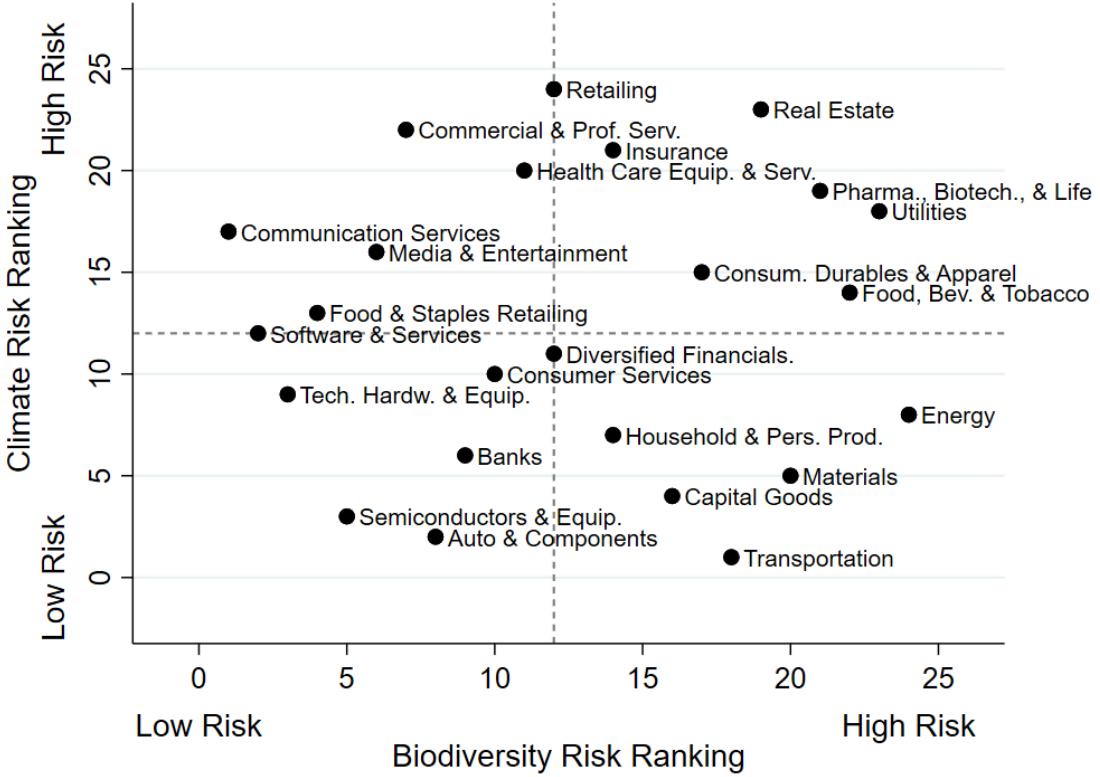
The sale or development of properties may also be restricted due to environmental concerns, the protection of endangered species, or the protection of wetlands. [ST JOE CO]

## 2.4 Climate Risk Exposures vs. Biodiversity Risk Exposures

Just like aggregate biodiversity news is distinct from aggregate climate news (see Section 1.3), firm- and industry-level exposures to biodiversity risk are distinct from climate risk

exposures. The bottom row of Table 3 shows that our measures of biodiversity risk exposure at the industry level are related to the “quantity-based climate exposure” measure developed in Alekseev et al. (2024). This measure identifies industries that investors buy (lower score) and sell (higher score) in response to changes in their beliefs about climate change, and Alekseev et al. (2024) show that long-short portfolios based on this exposure characteristic have the ability to hedge news about climate risks. Figure 5 shows a corresponding scatter plot, where biodiversity risk exposure is measured by the average ranking across our seven biodiversity risk measures. A higher ranking indicates higher risk.

**Figure 5:** Industry Ranking by Biodiversity Risk and Climate Risk



**Note:** Scatterplot of industry biodiversity risk ranking and climate risk ranking. The biodiversity risk exposure is measured by the average ranking across the seven biodiversity risks, and the climate risk exposure is measured by the climate quantity betas estimated based on pooled data from 2010 to 2019 inclusive, and is taken from Alekseev et al. (2024).

Industries with high biodiversity risk exposures are broadly distinct from industries with high climate risk exposures. There are several reasons for this. First, an industry may be highly exposed to biodiversity risk because its operations are dependent on particular ecosystems or species that are not necessarily affected by climate change. Second, from a regulatory perspective, some industries might have a more significant direct impact on ecosystems and habitats rather than contributing to climate change. As a result, they would be more affected by biodiversity regulation than climate regulation. For example, as described above, biodiversity regulation provides challenges for renewable energy firms,

while climate regulation provides many opportunities.

### 3 The Pricing of Biodiversity Risk

A recent body of research in economics and finance has documented that for the last decade—starting around 2010—various measures of firm-level exposures to climate risk have been priced in asset markets (e.g., [Bolton and Kacperczyk, 2023](#); [Engle et al., 2020](#); [Alekseev et al., 2024](#); [Acharya et al., 2022](#)). In this section, we explore whether biodiversity risk—a category of risk that has also attracted the attention of market participants—appears to affect prices in equity markets. To do this, we combine our quantitative measures of aggregate news about biodiversity risk with our industry-level measures of biodiversity risk exposures to ask whether biodiversity risks are currently incorporated into equity prices.

**Empirical Approach.** We begin by forming portfolios of industries sorted by their biodiversity risk exposures. If biodiversity risk is priced—and if our measures of exposure to this risk are correct—we would expect the price of these portfolios to move with the arrival of (aggregate) news about biodiversity risks. For example, when negative biodiversity news arrives, the valuations of highly exposed industries should drop, while the valuations of less exposed industries should drop by less (or even increase). Put differently, if biodiversity risks are priced, we should expect the return to a biodiversity risk-sorted portfolio to covary with the aggregate biodiversity risk news series: it should behave like a *hedging portfolio*.

Note that researchers sometimes refer to the presence of risk premia when asking whether a risk is “priced.” That language refers to the compensation for risk required by investors, which has as a necessary (but not sufficient) condition that prices reflect risk exposures. We focus on the latter pattern—asking whether asset prices display a beta with respect to biodiversity risk—because estimating risk premia would require a much longer time series.

To implement our test, we measure innovations in biodiversity news,  $BiodiversityNews_t$ , by averaging the daily values of our aggregate NYT-Biodiversity News Index within each month and then computing values of  $BiodiversityNews_t$  as residuals from a monthly AR(1) model. We then construct portfolios that go long firms with low biodiversity risk exposures—i.e., firms that are not affected or might even benefit from realizations of biodiversity risks—and short firms with high biodiversity risk exposures, those firms negatively affected by biodiversity risk realizations.<sup>11</sup> We construct eight such portfolios using the three 10K-based biodiversity scores, the three survey-based scores, the fund holding-based score, and the CDP-based score. We construct all portfolios using exposure measures at the industry level, aggregating the firm-level 10K-based scores to the industry level by taking the value-weighted average of the firm-level values.

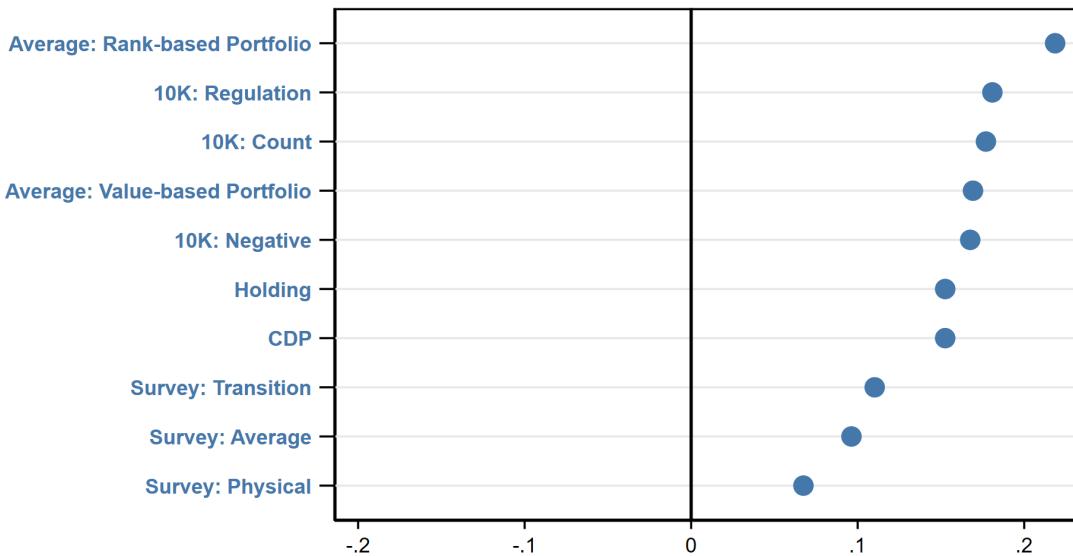
To determine the portfolio weight of each industry, we take two approaches. In our main rankings-based approach, the portfolio’s position in each industry is the industry’s biodiver-

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<sup>11</sup>Since all exposure measures were designed such that higher values are associated with higher biodiversity risk exposures, the portfolios would go long industries with low scores and short industries with high scores.

sity score percentile in the industry distribution, minus 50. For example, the portfolios take a long position of 50 in the industry with the lowest biodiversity score and short a position of -50 in the industry with the highest biodiversity score. The industry with the median biodiversity score is not held, and half of the industries are in a long position and half are in a short position.<sup>12</sup> We show that our findings are robust to a second approach that holds positions in each industry as the cross-sectionally demeaned biodiversity scores in that year, taking long positions for industries with below-average scores (and risk exposures), and short positions for industries with above-average scores. In each period, we compute excess returns of each portfolio by subtracting the risk-free rate from the value-weighted industry returns.

**Figure 6:** Biodiversity Hedge Performance of Various Portfolios



**Note:** Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of NYT-Biodiversity News index using data from 2010 to 2023.

Figure 6 reports the correlations between the various portfolios and innovations of the NYT-Biodiversity News index. We include individual rank-based portfolios for our various industry exposure measures, as well as a portfolio that averages across the industry ranks in the different exposure measures before forming portfolios. We also include a portfolio that uses the average values of the alternative approach to creating industry weights described in the previous paragraph. We focus on the period after 2010, since we do not expect markets to price biodiversity risk before that time (see the discussion in Alekseev et al., 2024; Acharya et al., 2022). All the correlations are positive, with magnitudes from around 0.07 to 0.22. The left column in Table 4 reports these correlations together with bootstrap standard errors. It highlights that, despite substantial noise in both stock prices and our measures of

<sup>12</sup>When ranking the industries, equal observations are assigned the same rank, calculated as 1 plus the number of values lower than those equal observations.

biodiversity risk and risk exposures, most of these correlations are statistically significant. The largest correlation is achieved by the portfolio sorted on the average across our various biodiversity risk exposure rankings. Quantitatively, the observed correlations are comparable to those obtained by climate hedging portfolios when evaluated against aggregate climate news (Engle et al., 2020; Alekseev et al., 2024), and to the hedging performance of portfolios built to hedge other macro risks such as consumption or GDP (see Giglio and Xiu, 2021).

**Table 4:** Biodiversity and Climate Hedge Performance of Various Portfolios

	Hedge Target	
	NYT-Biodiversity News	NYT-Climate News
Average: Rank-based Portfolio	0.22*** (0.08)	0.01 (0.10)
10K: Regulation	0.18** (0.08)	0.09 (0.08)
10K: Count	0.18** (0.07)	0.12 (0.08)
Average: Value-based Portfolio	0.17** (0.07)	0.06 (0.09)
10K: Negative	0.17** (0.07)	0.09 (0.08)
Holding	0.15* (0.08)	0.06 (0.09)
CDP	0.15* (0.08)	0.08 (0.09)
Survey: Transition	0.11 (0.07)	-0.02 (0.08)
Survey: Average	0.10 (0.07)	-0.03 (0.08)
Survey: Physical	0.07 (0.07)	-0.02 (0.08)
Average	0.15*** (0.05)	0.04 (0.06)

**Note:** Monthly correlations for various biodiversity hedge portfolios' returns with biodiversity and climate news series AR(1) innovations using data from 2010 to 2023. Each row represents a hedge portfolio, whereas each column corresponds to a hedge target. The last row shows the simple average of correlations with hedge targets for all portfolios. All news series are coded such that high numbers indicate negative news. Therefore, positive correlation coefficients indicate successful hedges. Significance levels: \*\*\*  $p < 0.01$ ; \*\*  $p < 0.05$ ; \*  $p < 0.1$ . P-values are calculated using a bootstrap of 1000 iterations. Bootstrap standard errors are in parentheses.

A natural question is whether our measures of biodiversity risk exposure are simply recasting information from other firm characteristics. To study this, we investigate whether using other characteristics would yield similarly good hedging portfolios for aggregate news as the ones based on our measures of biodiversity risk exposure.

In comparing our measures of exposures with other characteristics, one important consideration is that, in general, we do not have a clear prior on whether the various characteristics (e.g., firm size, book to market, etc.) should be associated with a high or low exposure to biodiversity risk. For example, we do not know ex-ante if a portfolio that goes

long value companies and short growth companies (HML) should covary positively or negatively with biodiversity risk. Building a hedging portfolio using alternative characteristics therefore requires estimating the sign of the relationship between the biodiversity news and the characteristic—the biodiversity beta—using a mimicking portfolio approach (as in [Engle et al., 2020](#); [Alekseev et al., 2024](#)). The mimicking portfolio approach uses historical data to combine a set of assets into a portfolio that is maximally correlated with a given biodiversity shock. To obtain the mimicking portfolios, we estimate the following regression:

$$BiodiversityNews_t = wR_t + \epsilon_{c,t}, \quad (2)$$

where  $BiodiversityNews_t$  denotes the (mean zero) biodiversity hedge target in month  $t$ ,  $w$  is a vector of  $N$  portfolio weights, and  $R_t$  is a vector of demeaned excess returns. The portfolio weights are estimated each month using a five-year rolling window. When the vector  $R_t$  contains one characteristic-sorted return only (e.g., HML), the weight  $w$  represents the relation between that characteristic and the biodiversity beta. For example, if we build a hedging portfolio using HML and estimate  $w > 0$ , then we expect value stocks to hedge biodiversity risk going forward; if  $w < 0$ , we expect growth stocks to hedge this risk.

Panel (a) of Figure 7 shows a histogram of the out-of-sample correlations of mimicking portfolios built using the 212 characteristics obtained from [Chen and Zimmermann \(2022\)](#) individually. The red bar represents the "Average: Rank-based Portfolio". Of course, there is a large amount of sampling variation, so among the many mimicking portfolios, some correlate more and some less with biodiversity news; but none performs as well as our economically-motivated measure.<sup>13</sup>

Panel (b) of Figure 7 shows the monthly out-of-sample return correlations for the portfolios built using the average biodiversity risk measure, and four mimicking portfolios built with the Fama French Three Factors (Market, SMB, and HML), the Fama French Five Factors (Market, SMB, HML, RMW, and CMA), and with all 212 characteristics and all 24 industries, each selected by LASSO to avoid over-fitting. The portfolio built on the average biodiversity exposure measure has by far the highest correlation with innovations in the NYT-Biodiversity News Index.

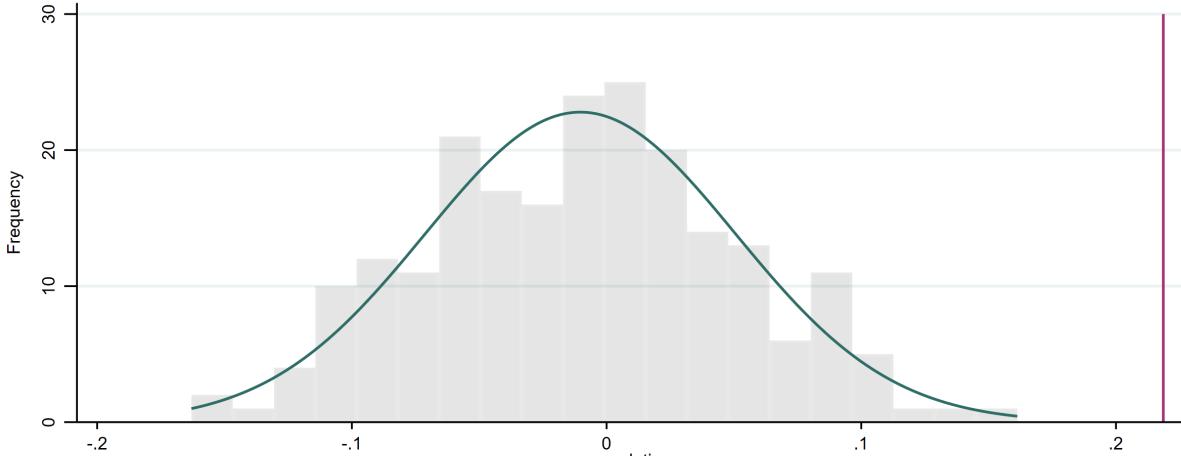
Overall, we find that the returns of portfolios sorted on various measures of biodiversity risk exposure covary positively with realizations of biodiversity news. These correlations are generally statistically significant and larger than correlations achievable using alternative characteristics. These findings suggest that our measures of both risk and exposure are reasonable, and that biodiversity risks are already priced in equity markets.

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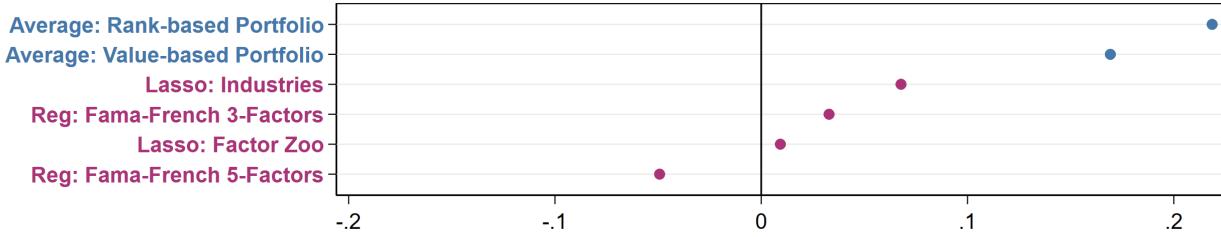
<sup>13</sup>In Appendix A.4.3 we statistically compare the hedging performance of our biodiversity exposure measures, which are motivated a priori, with that of the 212 stock characteristics. The test explicitly takes into account the multiple testing problem associated with the 212 characteristics, which are not economically motivated—i.e., the fact that among the “characteristics zoo”, we would expect some to be correlated with biodiversity risk well just by chance. To adjust for multiple testing, we use the method of [Benjamini and Hochberg \(1995\)](#). We find that the good hedging performance of some of the 212 characteristics is indeed due to chance: none of them is significant after adjusting for the multiple testing problem.

**Figure 7:** Hedging Biodiversity Risk Using the Factor Zoo

(a) Correlation Distribution



(b) Hedging Performance



**Note:** Panel (a) shows the histogram of the out-of-sample correlations for mimicking portfolios with AR(1) innovations of the NYT-Biodiversity News Index using data from 2010 to 2023. The grey bars represent mimicking portfolios built using each of the 212 characteristics. The red bar is the "Average: Rank-based Portfolio". Panel (b) shows the dot plot of monthly out-of-sample return correlations for various hedge portfolios with AR(1) innovations of the NYT-Biodiversity News Index using data from 2010 to 2023. Each dot represents one correlation coefficient. The portfolios with blue labels are built based on the average of all biodiversity risk measures, using ranking-based and value-based approaches. The portfolios with red labels are the mimicking portfolios constructed with 24 industries, 212 characteristics, Fama-French Five Factors, and Fama-French Three Factors, and estimated each month using a five-year rolling window.

**Hedging Biodiversity Risk vs. Climate Risk.** To further explore the similarities and differences between climate and biodiversity risk, we also compute the monthly correlations of biodiversity hedge portfolios against climate risk realizations. Column 2 of Table 4 reports the correlations between the various biodiversity hedge portfolio returns and innovations in the NYT-Climate News index introduced in Section 1. While our various biodiversity hedge portfolios perform well in terms of hedging biodiversity risk they have, on average, close-to-zero correlations with realizations of news about climate risk. This is consistent with our finding of distinct realizations of aggregate climate and biodiversity risks, and the fact that climate and biodiversity risk exposures are not strongly correlated at the industry level.

### 3.1 Robustness and Additional Analyses.

We conduct a number of additional analyses to confirm the robustness of our baseline results and to extend them further.

While our baseline hedge portfolios are constructed using biodiversity risk exposures aggregated at the GICS 4-digit industry level, the underlying risk exposures based on 10-K, CDP, and biodiversity ETF holdings are, in principle, available at the firm level. To examine the impact of asset granularity on our results, Appendix Figure A.10 presents the hedging performance of portfolios constructed with 72 GICS 6-digit industries and 175 GICS 8-digit industries. These portfolios are based on the average rankings across the 10-K, CDP, and holding-based measures. While the hedge portfolios continue to perform well with finer aggregation levels, their performance diminishes somewhat as more assets are included, highlighting the tradeoff between the noise in exposure estimation and the ability to capture true differences in exposures within industries.

We also explore the hedging performance of our procedure when varying the dictionaries used to filter the textual data used to construct the aggregate biodiversity news series, as described in footnote 4. The results, shown in Appendix Figure A.11, highlight that the hedging ability of our portfolios remains similar when the dictionary is changed, though they weaken somewhat when climate change words are included (because the news series will then be more informative about climate events and less about biodiversity events).

In an extension to our baseline results, we show in Appendix Figure A.12 that in the period 2000-2009, the hedging ability of the various portfolios is substantially weaker. This finding is in line with the observation in other work that financial markets paid little attention to climate and nature-related risks prior to 2010 (see the discussions in Acharya et al., 2022; Alekseev et al., 2024). As a result, we would not have expected news realizations to lead to price movements of exposed firms.

We also explore, in Appendix A.3, whether using the recent advances in large language modeling can help us make progress in distinguishing physical and transition biodiversity risk. As discussed above, this distinction is quite subtle and hard to detect using textual data: for example, when policymakers act to reduce physical risks, they often create transition risk. The Appendix uses ChatGPT to try and disentangle the two types of risk both for the aggregate news series and the firm-level exposures. The results, while encouraging, are somewhat mixed, suggesting that these tools need to be further refined before being able to consistently distinguish physical and transition risks.

### 3.2 Survey Evidence on the Adequacy of Biodiversity Risk Pricing

While the previous section suggested that biodiversity risks are at least somewhat reflected in equity prices, it is much less clear whether or not the current pricing of these risks is adequate to reflect the true underlying risks. Answering this question is particularly challenging, and would require taking a precise view of the exact nature of the risks and the ways they would affect the cash flows of different firms.

**Table 5:** Current pricing of biodiversity risks in asset markets

	Pooled	Role			Location				Biodiversity Concern			
		Academic Institution	Private Sector	Public Sector	North America	Europe	Asia	ROW	Very High	High	Low	No Concern
<b>Stock Market (%)</b>												
Not enough	48	43	53	61	45	53	60	69	71	53	30	6
Correct	17	23	11	15	18	17	13	23	11	26	33	23
Too much	3	3	5	3	5	1	2	0	2	2	8	29
No opinion	32	31	32	21	33	28	25	9	16	19	29	42
<b>Commodity Market (%)</b>												
Not enough	43	39	46	55	39	47	57	63	65	45	24	3
Correct	19	25	14	17	20	21	15	20	13	29	39	23
Too much	3	2	5	5	5	1	0	6	1	2	8	29
No opinion	35	35	35	22	36	30	28	11	20	24	29	45
<b>Sovereign Debt Market (%)</b>												
Not enough	43	39	44	58	41	48	50	60	65	45	29	3
Correct	14	20	10	8	16	13	12	9	6	23	33	19
Too much	2	2	2	4	2	1	2	6	0	2	3	26
No opinion	41	39	44	30	41	38	37	26	29	30	35	52
<b>Real Estate Market (%)</b>												
Not enough	46	42	48	61	45	51	53	54	66	51	32	3
Correct	16	22	12	9	17	15	13	20	10	23	32	29
Too much	2	1	3	3	2	2	0	3	0	1	5	26
No opinion	37	35	38	27	37	32	33	23	24	25	32	42

**Note:** Participants were asked: “To what extent do you think that physical or transition biodiversity risks are currently priced in the following asset markets?”, where asset markets are either stock markets, real estate markets, commodity markets, or sovereign debt markets.

To provide some initial insights into this important question, we asked the respondents to our survey whether they believed that prices across a range of asset classes appropriately reflected biodiversity risks. Table 5 highlights that about half of all survey respondents believed that asset markets underpriced biodiversity risks across equity markets, commodity markets, sovereign debt markets, and real estate markets (in addition, about 35% of respondents had no particular views on the pricing of these risks, while fewer than 5% of respondents believed that these risks were overpriced). These responses are consistent across respondents from different institutions and locations. We also find that people who are worried about biodiversity are more likely to believe that asset markets have not yet priced biodiversity risks appropriately, while people with no concern think it is overpriced.

## 4 Conclusion

Ecosystem services play a fundamental role in the economy and risks stemming from biodiversity loss can affect firms through many channels. Yet, those risks can be difficult to quantify and study systematically. The goal of this paper is to introduce measures of aggregate biodiversity risk as well as measures of firms' and industries' exposures to these risks; to connect and validate these two; to study the pricing of biodiversity risks in financial markets; and to publicly release our biodiversity exposure measures at [www.biodiversityrisk.org](http://www.biodiversityrisk.org) to facilitate more research on this important topic.

Given the complexity of biodiversity risk, our paper blends a number of different data sources: textual information, cross-sectional pricing information, and survey data. We employ a variety of methods that allow us to combine these different data sources and construct quantitative series that can be studied together. In addition, the measures we produce can be related to other ones explored in the previous literature, like the long list of firm anomalies, and the vast literature on climate risks.

We view our work as providing a starting point for quantitative analyses of biodiversity risk. Many extensions and refinements could be pursued, including an integrated study of the pricing of biodiversity risk across asset classes; a refinement of the different types of biodiversity risk (e.g., species vs. ecosystem diversity); a more sophisticated distinction between the effects and pricing of transition and physical risks; and a more fundamental understanding of the interactions between biodiversity risk and climate risk.

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## A.1 Screenshots of Survey Flow

**Figure A.1:** Survey Introduction

We invite you to participate in a survey exploring your views on the importance of various biodiversity risks for investors and firms. This study aims to learn more about perceptions of biodiversity risk among academics and professionals. The survey is being conducted by Professor Stefano Giglio of Yale SOM, Professor Johannes Stroebel, Professor Theresa Kuchler and Xuran Zeng of NYU Stern.

If you agree to participate in this study, you will be asked to fill out a brief survey. Participation in this study will take about 5 minutes. There are no known risks associated with your participation in this research.

Since we are not collecting any personally identifiable information, the confidentiality of your responses will be maintained. Participation in this study is voluntary. You may refuse to participate or withdraw at any time without penalty. You have the right not to answer any questions you prefer not to answer.

If there is anything about the study or your participation that is unclear or that you do not understand, or if you have questions or wish to report a research-related problem, you may contact Xuran Zeng at [xz4183@stern.nyu.edu](mailto:xz4183@stern.nyu.edu).

For questions about your rights as a research participant, you may contact the Committee on Activities involving Human Subjects (UCAIHS), New York University, 665 Broadway, Suite 804, New York, New York 10012, at [ask.humansubjects@nyu.edu](mailto:ask.humansubjects@nyu.edu) or (212)998-4808. Please reference the study # (IRB-FY2023-7423) when contacting the IRB (UCAIHS).

Thank you very much for your participation.

Stefano Giglio, Theresa Kuchler, Johannes Stroebel and Xuran Zeng  
Yale SOM & NYU Stern

I consent to participate in this study

### **Figure A.2:** General Information

How is the institution at which you work best described?

Academic Institution

Public Sector

Private Sector

Where are you located?

North America

Europe

Asia

Rest of the World

What is your graduation year?

Before 2000

Between 2000 and 2009

After 2010



**Figure A.3:** Importance of Biodiversity Risk

How worried are you about the following aspects of biodiversity loss?

	Not at all worried	Not very worried	Somewhat worried	Very worried
Ecosystems Diversity Loss	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Species Diversity Loss	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Biodiversity risks for investors and firms are often divided into (i) physical risks coming from actual changes in biodiversity (e.g., reduced pollinators, freshwater scarcity) and (ii) transition risks coming from changes in the regulatory environment to combat biodiversity loss (e.g., the Clean Water Act). Please rate the financial materiality of these risks for corporations in the United States.

	Not at all important	Slightly important	Moderately important	Very important
Physical Biodiversity Risks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Transition Biodiversity Risks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Over what time horizon, if any, do you expect these biodiversity risks to materialize?

	Already today	1 to 5 years	5 to 30 years	More than 30 years	Never
Physical Biodiversity Risks	<input type="radio"/>				
Transition Biodiversity Risks	<input type="radio"/>				

**Figure A.4:** Importance of Biodiversity Risk (Industry Exposure)

Select the industries that you believe are most negatively affected by physical risks from biodiversity loss.

<input type="checkbox"/> Energy	<input type="checkbox"/> Pharmaceuticals, Biotech & Life Sciences
<input type="checkbox"/> Materials	<input type="checkbox"/> Banks and Diversified Financials
<input type="checkbox"/> Capital Goods	<input type="checkbox"/> Insurance
<input type="checkbox"/> Commercial & Professional Services	<input type="checkbox"/> IT and Communication Services
<input type="checkbox"/> Transportation	<input type="checkbox"/> Consumer Services and Retailing
<input type="checkbox"/> Automobiles, Consumer Durables and Household Products	<input type="checkbox"/> Utilities
<input type="checkbox"/> Food, Beverage & Tobacco	<input type="checkbox"/> Real Estate
<input type="checkbox"/> Health Care	

Select the industries that you believe are most negatively affected by biodiversity transition risks.

<input type="checkbox"/> Energy	<input type="checkbox"/> Pharmaceuticals, Biotech & Life Sciences
<input type="checkbox"/> Materials	<input type="checkbox"/> Banks and Diversified Financials
<input type="checkbox"/> Capital Goods	<input type="checkbox"/> Insurance
<input type="checkbox"/> Commercial & Professional Services	<input type="checkbox"/> IT and Communication Services
<input type="checkbox"/> Transportation	<input type="checkbox"/> Consumer Services and Retailing
<input type="checkbox"/> Automobiles, Consumer Durables and Household Products	<input type="checkbox"/> Utilities
<input type="checkbox"/> Food, Beverage & Tobacco	<input type="checkbox"/> Real Estate
<input type="checkbox"/> Health Care	



### **Figure A.5:** Pricing of Biodiversity Risks

To what extent do you think that physical or transition biodiversity risks are currently priced in the following asset markets?

	Not enough	Correct	Too much	No opinion
Stock Markets	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Commodity Markets	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sovereign Debt Markets	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Real Estate Markets	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

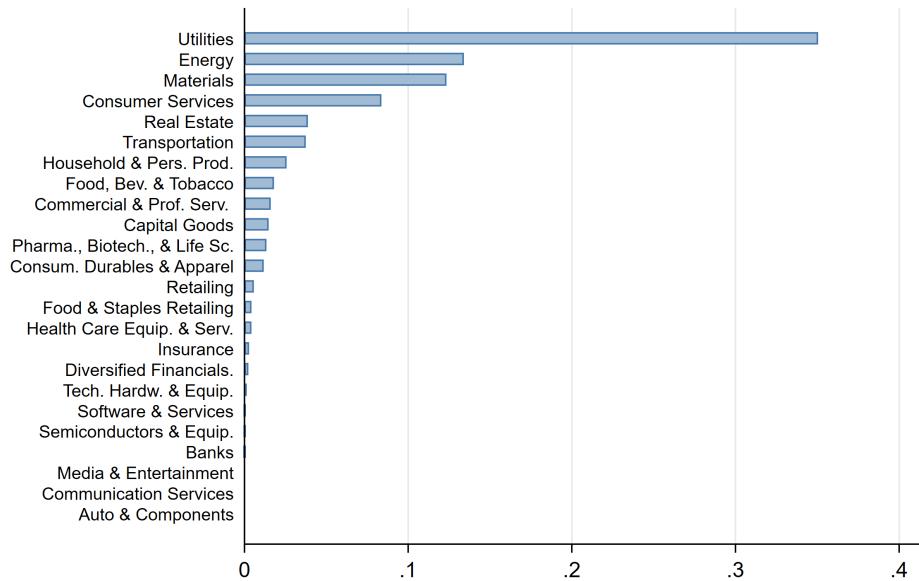
Are there any particular ways in which biodiversity risks are important in your professional life?



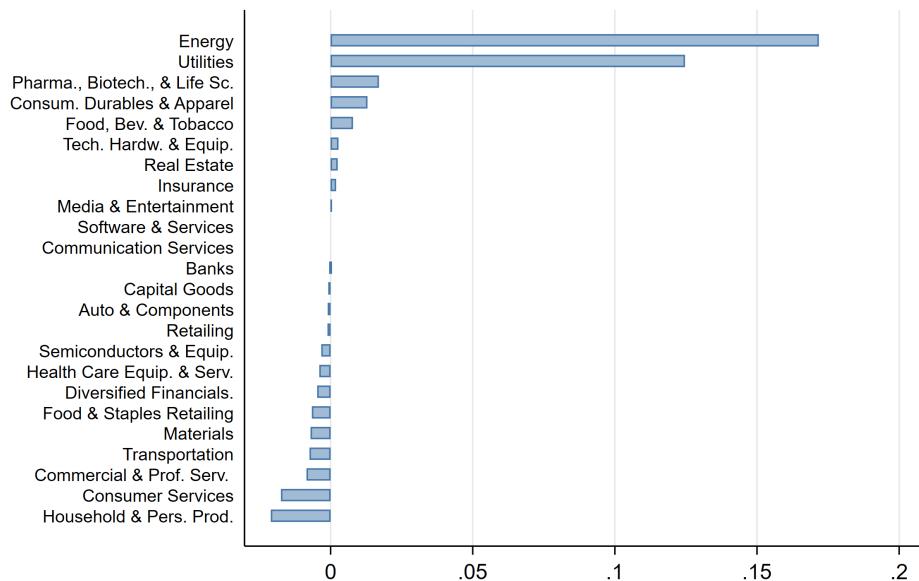
## A.2 Appendix Figures and Tables

**Figure A.6:** Industry Rankings with Biodiversity Measures

(a) 10K-Biodiversity-Count Score

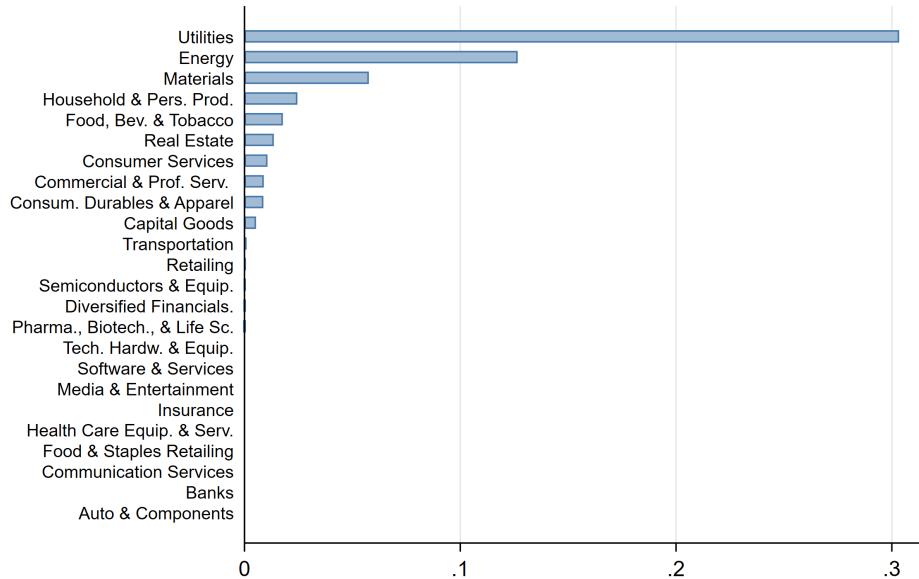


(b) 10K-Biodiversity-Negative Score



**Figure A.6:** Industry Rankings with Biodiversity Measures (Cont.)

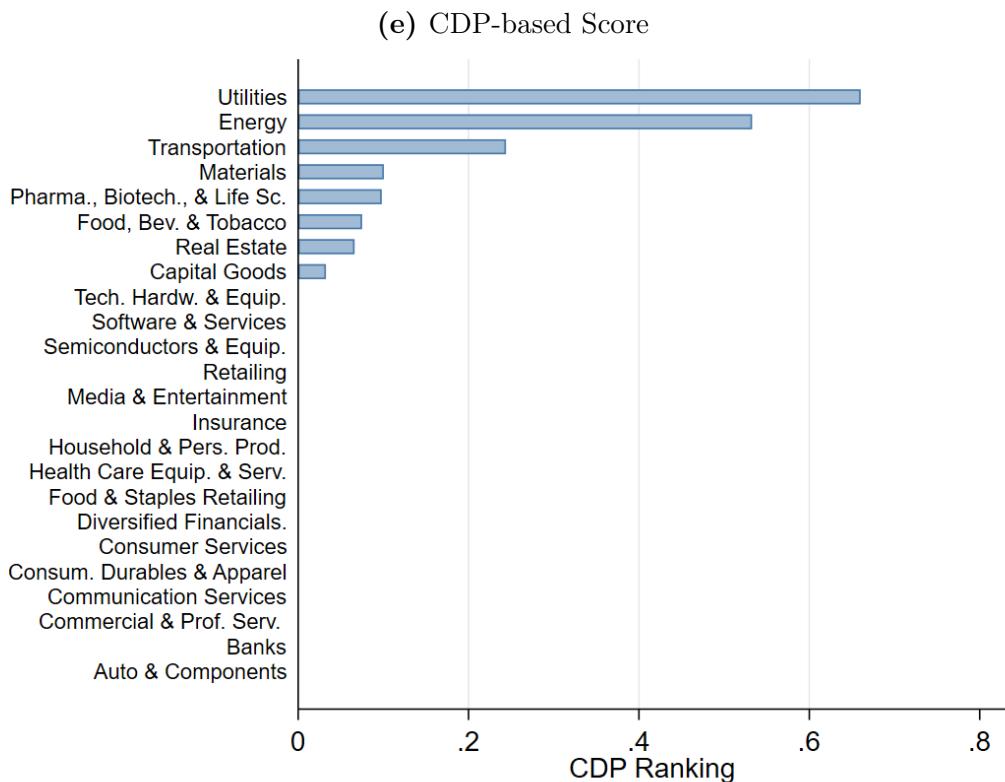
(c) 10K-Biodiversity-Regulation Score



(d) Holding-based Score



**Figure A.6:** Industry Rankings with Biodiversity Measures (Cont.)



**Note:** Panels (a), (b), and (c) display industry rankings based on the 10-K Biodiversity Count Score, 10-K Biodiversity Negative Score, and 10-K Biodiversity Regulation Score, averaged from 2010 to 2023. Panel (d) presents the Holding-based Score using data from December 2023. Panel (e) shows the CDP-based Score using data from 2023.

**Figure A.7:** Biodiversity Questions in the CDP Climate Change Questionnaire

(C15.4) Does your organization have activities located in or near to biodiversity-sensitive areas in the reporting year?

**Change from last year**

New question

**Connection to other frameworks**

*SDG*

Goal 15: Life on Land

**Response options**

Select one of the following options:

- Yes
- No
- Not assessed

(C15.4a) Provide details of your organization's activities in the reporting year located in or near to biodiversity-sensitive areas.

**Question dependencies**

This question only appears if you select "Yes" in C15.4.

**Change from last year**

New question

**Connection to other frameworks**

*SDG*

Goal 15: Life on Land

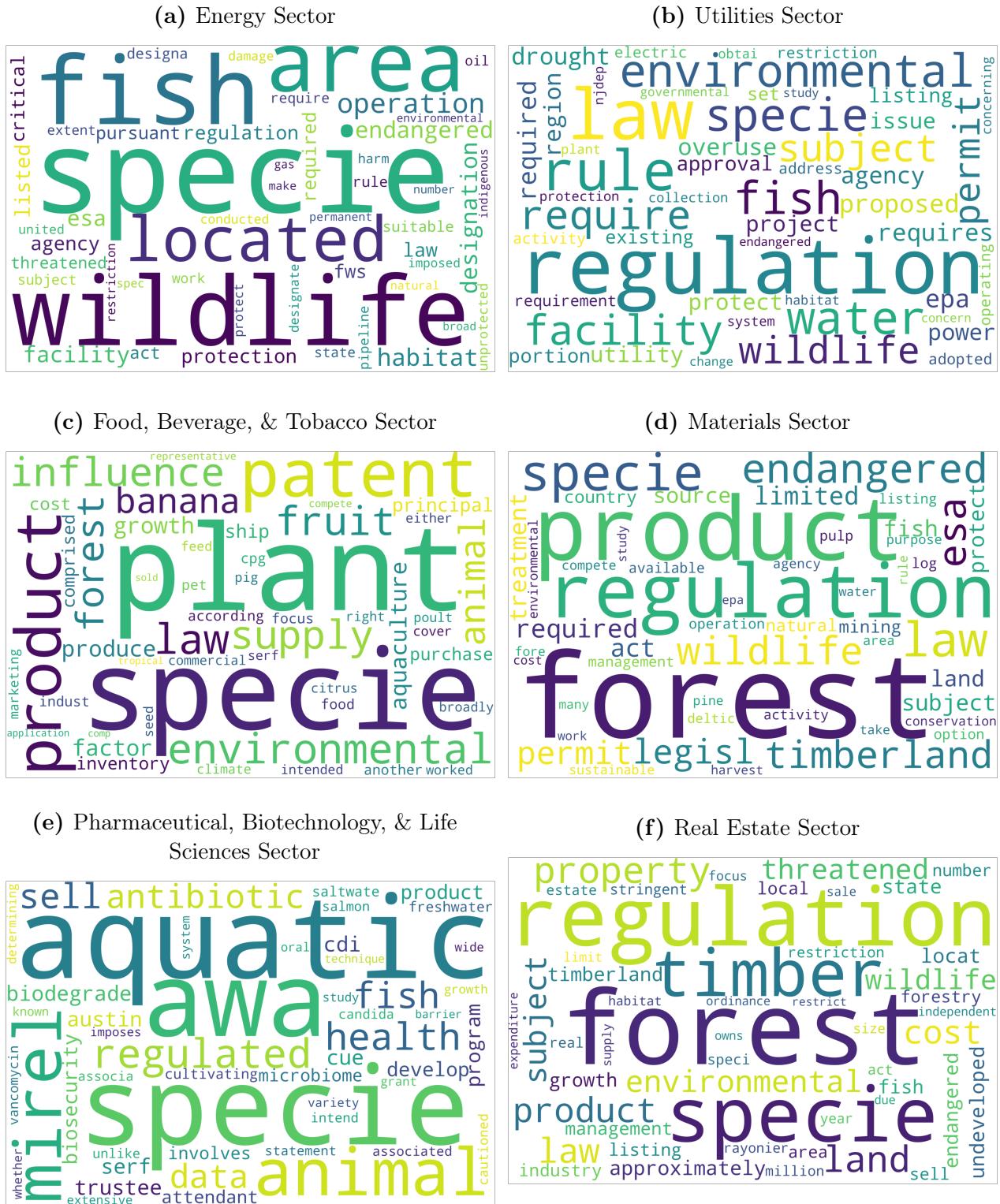
**Response options**

Please complete the following table. \*Column/row appearance is dependent on selections in this or other questions.

1	2	3	4	5
Classification of biodiversity-sensitive area	Country/area	Name of the biodiversity-sensitive area	Proximity	Briefly describe your organization's activities in the reporting year located in or near to the selected area
Select from: • Natura 2000 network of protected areas • UNESCO World Heritage site • Key Biodiversity Area (KBAs) • Other biodiversity sensitive area, please specify	Select from: [List of countries/areas]	Text field [maximum 500 characters]	Select from: • Overlap • Adjacent • Up to 5 km • Up to 10 km • Up to 25 km • Up to 50 km • Up to 70 km • Data not available	Text field [maximum 2,500 characters]
6		7	8	
Indicate whether any of your organization's activities located in or near to the selected area could negatively affect biodiversity		Mitigation measures implemented within the selected area*	Explain how your organization's activities located in or near to the selected area could negatively affect biodiversity, how this was assessed, and describe any mitigation measures implemented*	
Select from: • Yes, but mitigation measures have been implemented • Yes, and no mitigation measures have been implemented • No • Not assessed		Select all that apply: • Site selection • Project design • Scheduling • Physical controls • Operational controls • Abatement controls • Restoration • Biodiversity offsets • Other, please specify	Text field [maximum 3,000 characters]	

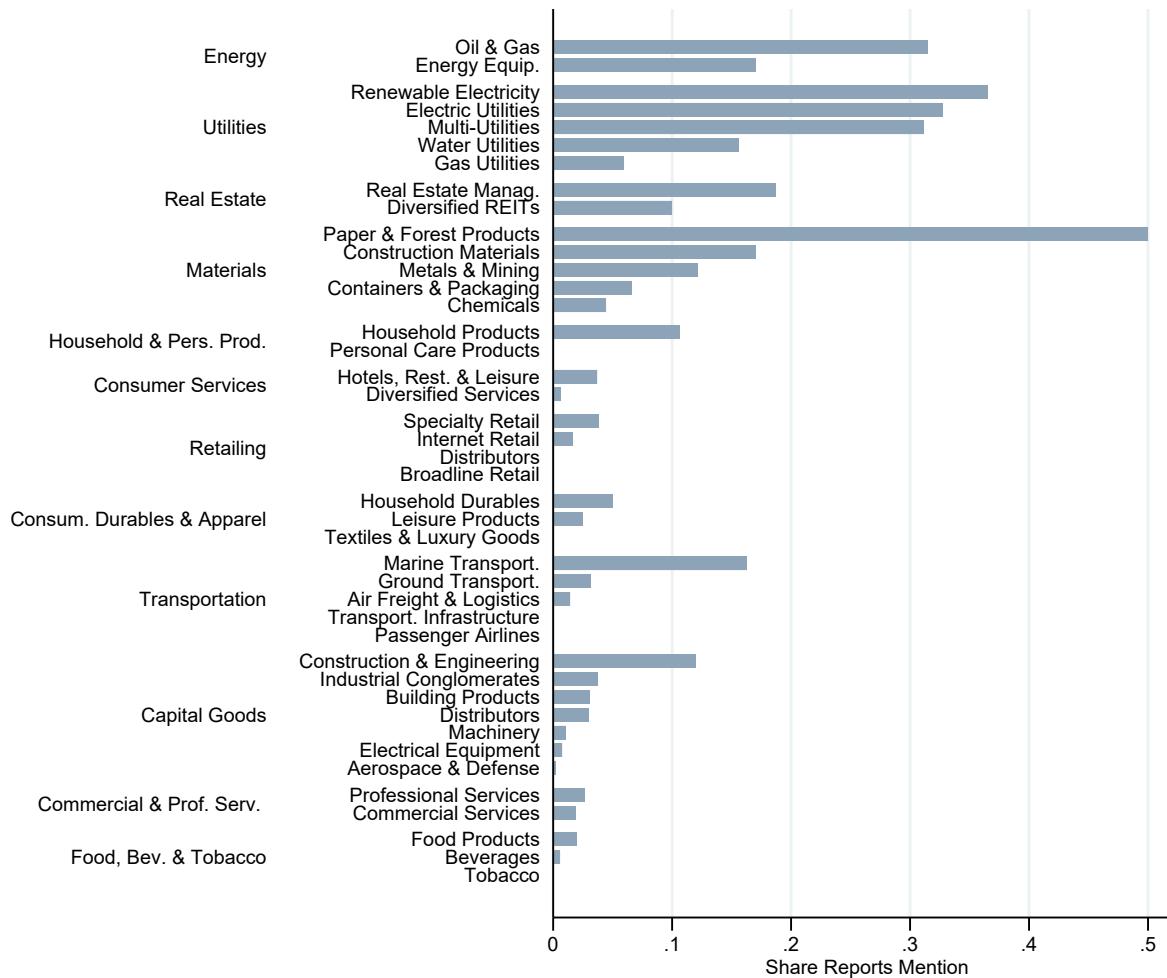
**Note:** Figure shows the questions on biodiversity in the CDP Climate Change Questionnaire.

**Figure A.8:** Word Cloud: Biodiversity Vocabulary by Sector



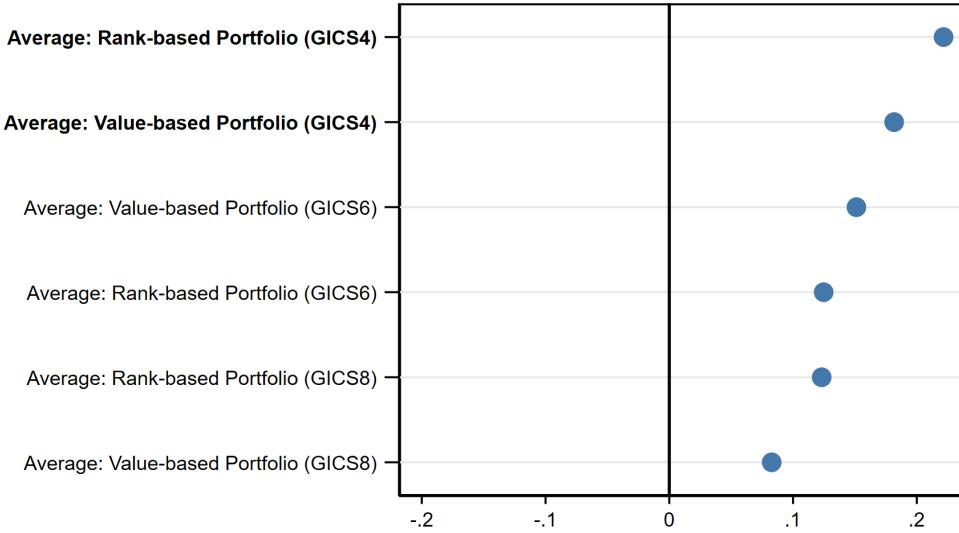
**Note:** Word cloud summary of vocabulary from biodiversity sentences mentioned in firms' 10K statement. Term sizes are proportional to their frequency in the corpus.

**Figure A.9:** Industry and Subindustry Rankings with Biodiversity Measures



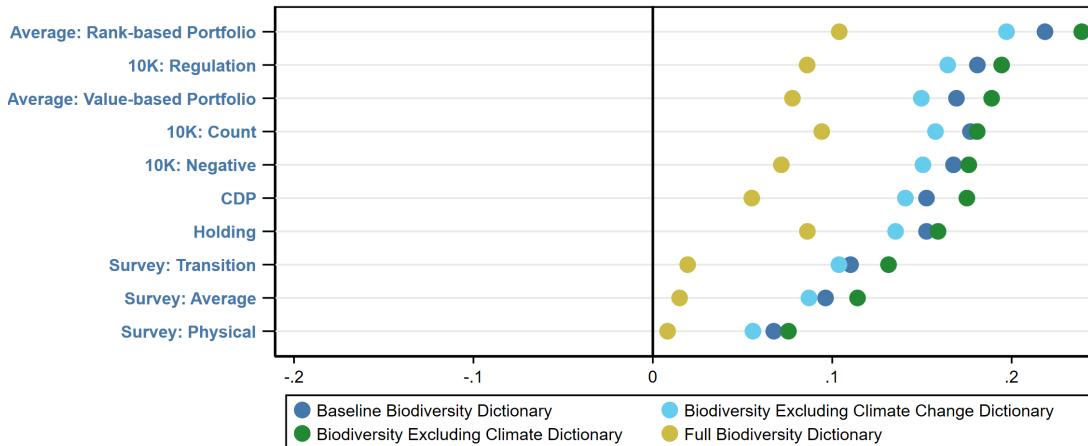
**Note:** The figure displays the ranking of industry biodiversity risk exposure, sorted by both 4-digit and 6-digit GICS industry codes. This exposure is measured by the proportion of 10-K statements that mention biodiversity in the corresponding 6-digit sector, averaged from 2010 to 2023. We keep the 4-digit industries only when at least 1% of the firms have a mention and drop the rest, including Automobiles & Components, Banks, Communication Services, Diversified Financials, Food & Staples Retailing, Health Care Equipment & Services, Insurance, Media & Entertainment, Pharmaceutical, Biotechnology & Equipment, Semiconductors & Semiconductor Equipment, Software & Services, and Technology, Hardware & Equipment.

**Figure A.10:** Biodiversity Hedge Performance of Various Granular Portfolios



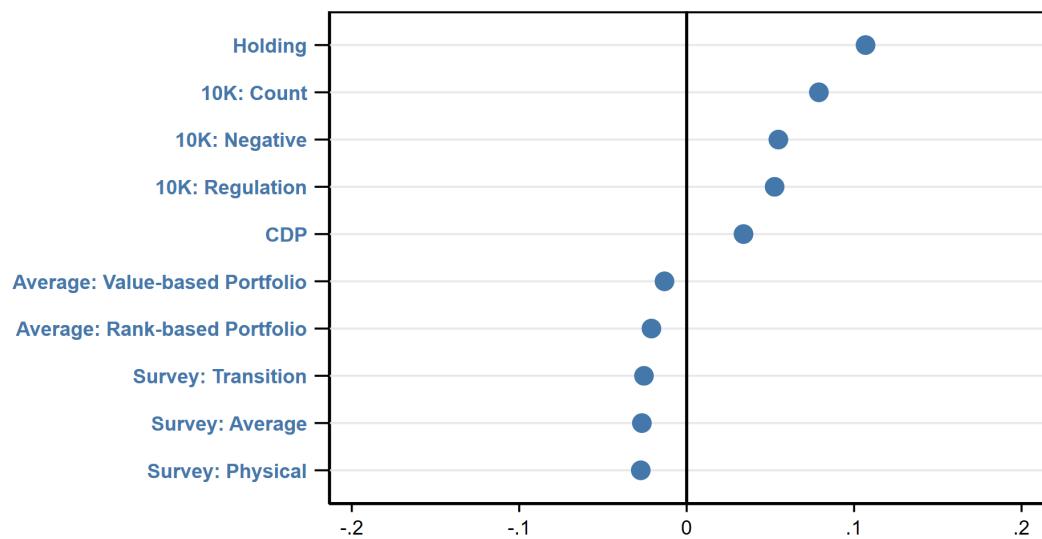
**Note:** Dot plot of monthly return correlations for various biodiversity hedge portfolios based on the average ranking across the 10K-, CDP-, and holding-based exposures with AR(1) innovations of NYT-Biodiversity News Index using data from 2010 to 2023. Each row corresponds to a different level of aggregation used to measure industry-level biodiversity risk exposure. Each dot represents one correlation coefficient.

**Figure A.11:** Biodiversity Hedge Performance with Alternative Hedge Targets



**Note:** Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of NYT-Biodiversity News Index, as well as alternative biodiversity news series built with different dictionaries to filter the textual data, using data from 2010 to 2023. “Baseline Biodiversity Dictionary” is constructed using all terms in the Biodiversity Dictionary except “climate change”; “Biodiversity Excluding Climate Change Dictionary” includes terms in the Biodiversity Dictionary that are not in the Climate Change Dictionary; “Biodiversity Excluding Climate Dictionary” uses terms in the Biodiversity Dictionary that are not in the Climate Dictionary; and “Full Biodiversity Dictionary” includes all terms in the Biodiversity Dictionary; The Biodiversity Dictionary (Appendix Table A.3) lists the top 100 words closest to “biodiversity”; the Climate Dictionary (Appendix Table A.4) lists those closest to “climate”; and the Climate Change Dictionary (Appendix Table A.5) lists those closest to “climate change”.

**Figure A.12:** Biodiversity Hedge Performance of Various Portfolios Before 2010



**Note:** Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of NYT-Biodiversity News Index using data from 2000 to 2009. Each dot represents one correlation coefficient.

**Table A.1:** Composition of Survey Respondents

	Pooled	Role			Location				Biodiversity Concern			
		Academic Institution	Private Sector	Public Sector	North America	Europe	Asia	ROW	Very High	High	Low	No Concern
<b>Role (%)</b>												
Academic Institution	48	100	0	0	46	53	52	43	43	56	53	52
Private Sector	34	0	100	0	42	15	35	26	39	23	36	35
Public Sector	18	0	0	100	13	31	13	31	18	20	11	13
<b>Location (%)</b>												
North America	62	59	76	43	100	0	0	0	58	60	71	70
Europe	23	26	10	41	0	100	0	0	23	27	15	13
Asia	9	10	10	7	0	0	100	0	11	9	11	13
Rest of the World	5	5	4	9	0	0	0	100	9	4	3	3
<b>Ecosystem Diversity Loss Concern (%)</b>												
Not at all important	8	9	9	5	9	6	9	6	1	3	9	100
Slightly important	24	26	23	20	26	20	26	14	6	27	91	0
Moderately important	35	37	28	40	34	36	38	26	19	69	0	0
Very important	34	28	40	35	31	38	28	54	73	0	0	0
<b>Species Diversity Loss Concern (%)</b>												
Not at all important	7	7	6	11	8	6	7	9	1	1	9	100
Slightly important	20	22	19	18	22	19	19	11	8	17	91	0
Moderately important	42	46	34	46	40	50	36	40	26	82	0	0
Very important	30	25	41	25	30	25	38	40	66	0	0	0
<b>Graduation Year (%)</b>												
Before 2000	30	29	35	24	33	27	13	35	30	32	20	32
Between 2000 and 2009	30	28	32	30	27	35	33	29	30	26	41	39
After 2010	40	44	33	46	40	38	53	35	40	41	39	29

**Note:** The percentage breakdowns in the table are to be read in columns within blocks. For example, the share of finance academics in North America is 46%, while the share of North American respondents among finance academics is 59%. The total number of respondents is 668. The table shows the distribution among respondents who answered the question of interest. The level of Biodiversity Concern shown in the column is determined by the maximum value between Ecosystem Diversity Loss Concern and Species Diversity Loss Concern.

**Table A.2:** Example Answers From Open Text Survey Question

Role	Answer
Private Sector	I invest in early-stage climate tech companies, so I am constantly thinking about biodiversity risks and companies that are addressing those risks.
Private Sector	I co-run an investment fund in farmland and timberland, which are directly affected by these risks.
Private Sector	loss of key ecosystem services for agriculture and manufacturing.
Private Sector	Assessing project risks properly given biodiversity risks bring greater uncertainties that we have less foresight in factoring them into the overall viability of infrastructure projects.
Private Sector	I cover part of the energy sector so the physical risk is something we look at.
Private Sector	Yes, as a real estate investor.
Private Sector	Yes as a ESG stock analyst we are seeing an increased focus on biodiversity risk and policy action
Private Sector	More demand for consulting services on the matter
Private Sector	There are insufficient risk disclosures by borrowers and a lack of standard disclosures from which capital markets can appropriately assess and price risk.
Private Sector	Yes I work in Climate Risk for A Bank and biodiversity is something we are looking at now. While biodiversity risk is important to manage it should be done in consideration of economic challenges such as inflation & recession risk and we are in favor or a just transition especially as we operate in developing markets
Private Sector	Yes, companies are now considering biodiversity risks and asking for my expertise in this field more which is very encouraging, while helping companies change their practices with nature.
Private Sector	Regulatory risks related to biodiversity are chief drivers of long-term uncertainty in the energy markets in which I work.
Private Sector	There are insufficient risk disclosures by borrowers and a lack of standard disclosures from which capital markets can appropriately assess and price risk.
Private Sector	As working in the buy side, we are focusing more on impact investment to address ESG issues, including to moderate biodiversity risk
Private Sector	It definitely informs the kind of companies I negatively screen. We don't have an active biodiversity risk strategy; but I tend to negatively view companies that will cause harm to our environment from a long-term business sustainability perspective (as a VC)

**Note:** Participants were asked: Are there any particular ways in which biodiversity risks are important in your professional life?

**Table A.2:** Example Answers From Open Text Survey Question (Cont.)

Role	Answer
Private Sector	Risk gets re-priced when recognition of those risks becomes generally understood. This raises the cost of capital for businesses which tends to be negative for capital assets in general, especially if it's a "shock." This, combined with a re-pricing of negative externalities associated with activities leading to biodiversity loss creates uncertainty that investors and companies eventually need to confront. The confrontation can result in innovation or decline or both. All of this makes investment decisions much more difficult.
Private Sector	I am a hedge fund investor and find that companies well suited to address changes are overpriced, especially global stocks. The point is that there are private sector companies that I may not know about.
Public Sector	I live in a tropical country with an economy that still heavily dominated by commodities export the sustainability of biodiversity in the environment becomes very important.
Public Sector	The influence of transition related measures such as tariffs, offsets and financial market instruments leading to suboptimal conservation behavior.
Public Sector	Biodiversity risks may affect the economy and thereby price stability.
Public Sector	Biodiversity risks are a serious threat to financial stability and the resilience of financial companies. As such, they have a strong impact on my professional life.
Public Sector	Potential regulatory developments.
Public Sector	Looking for ways to modernize economic thinking that humans are part of nature and human capital is a component of natural capital. Good, robust natural capital depends on biodiversity.
Public Sector	Absolutely. Loss of biodiversity and area for animals to move closer to cities, causing a great chance for diseases to spread to humans, which may cause another pandemic. There's dozens of other examples I could also list.
Academic Institution	Impacts the food and beverage industry with whom I work closely.
Academic Institution	Yes, research on the link between human rights and climate - biodiversity protection.
Academic Institution	As a researcher, it is an imperative that scholars support corporates and other organizations in mitigation and adaptation to limit biodiversity loss risk.
Academic Institution	it is a main issue of assessing the value of natural capital.
Academic Institution	I think biodiversity risks are important for non-financial aspects of utility such as tourism and leisure. They may combine with other changes underway to create a worse planet. I am not sure if they would be paramount to financial economics, other than perhaps via impact on health, pharma, medicine, etc., where biodiversity serves a useful purpose as an essential input to innovative solutions to problems pertinent to common man (who is not much in finance!).

**Note:** Participants were asked: Are there any particular ways in which biodiversity risks are important in your professional life?

**Table A.3:** List of Top 100 Words Similar to ‘biodiversity’

Word	Distance	Word	Distance	Word	Distance	Word	Distance
bio_diversity	0.7953	coral_reefs	0.6151	rainforest	0.5661	wetlands	0.5492
Biodiversity	0.7261	aquatic_ecosystems	0.6132	overexploitation	0.5657	UneP	0.5489
biodiversity_conservation	0.7226	marine_ecosystem	0.6078	insect_pollinators	0.5652	Biological_Diversity_CBD	0.5473
ecosystems	0.7113	tropical_rainforests	0.6058	biosphere_reserves	0.5650	extinctions	0.5464
marine_biodiversity	0.7011	species	0.6046	transboundary	0.5641	amphibian_populations	0.5461
deforestation	0.6494	species_extinctions	0.6029	aquatic_habitats	0.5624	ecological_degradation	0.5459
ecological	0.6492	biodiverse	0.5995	wildlife	0.5618	habitat_fragmentation	0.5451
ecology	0.6430	combating_desertification	0.5959	wetland_habitats	0.5618	wetland_ecosystem	0.5424
habitats	0.6428	seagrasses	0.5938	sea_turtle_populations	0.5585	amphibian_species	0.5424
fauna	0.6407	desertification	0.5936	coral_reef_ecosystems	0.5581	tropical_rainforest	0.5423
conserving_biodiversity	0.6394	avifauna	0.5909	coral_reef_ecosystem	0.5578	IPBES	0.5402
marine_ecosystems	0.6389	tropical_forest	0.5890	IUCN	0.5573	migratory_bird_populations	0.5401
freshwater_ecosystems	0.6365	ocean_ecosystems	0.5878	coral_ecosystems	0.5573	genetic_diversity	0.5393
forest_ecosystems	0.6356	conservation	0.5875	grassland_birds	0.5562	ecotourism	0.5383
tropical_forests	0.6354	tropical_deforestation	0.5841	wetland	0.5546	seagrass_meadows	0.5382
wetland_ecosystems	0.6281	soil_fertility	0.5795	wildlife_habitat	0.5544	pollinating_insects	0.5380
flora	0.6271	forests	0.5768	mangrove_forests	0.5537	peat_lands	0.5378
conserve_biodiversity	0.6270	climate_change	0.5760	environmental_degradation	0.5535	Biodiversity_Strategy	0.5374
biodiversity_hotspot	0.6254	birdlife	0.5758	endemism	0.5529	Wet_Tropics	0.5362
rainforests	0.6243	drylands	0.5741	riparian_zones	0.5524	Coral_Triangle	0.5361
coastal_ecosystems	0.6199	biosphere	0.5725	genebanks	0.5505	peatland	0.5359
biodiversity_hotspots	0.6170	aquatic_ecosystem	0.5722	Protected_Areas	0.5501	fragile_ecosystems	0.5354
habitat	0.6166	native_flora	0.5722	delicate_ecosystems	0.5499	freshwater_habitats	0.5353
carbon_sinks	0.6157	degraded_ecosystems	0.5678	Desertification	0.5496	Biodiversity_Conservation	0.5346
wildlife_habitats	0.6155	terrestrial_ecosystems	0.5668	soil_erosion	0.5494	fisheries	0.5333

**Note:** This table shows the list of top 100 words based on their cosine similarity to “biodiversity” in Google’s word2vec implementation. IUCN: International Union for Conservation of Nature; UNEP: United Nations Environment Programme; IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; Biological\_Diversity\_CBD: The Convention on Biological Diversity (CBD). Terms in red are the common terms in Appendix Table A.3, Appendix Table A.4, and Appendix Table A.5, i.e., terms related to both biodiversity and climate/climate change.

**Table A.4:** List of Top 100 Words Similar to ‘climate’

Word	Distance	Word	Distance	Word	Distance	Word	Distance
climate_change	0.6570	Bjørn_Lomborg	0.4524	Stefan_Rahmstorf	0.4293	warmer_wetter	0.4174
Climate	0.6231	greenhouse_gases	0.4510	CO2_concentrations	0.4278	radiative_forcing	0.4171
climates	0.6195	wetter_winters	0.4507	hydrologic_cycle	0.4278	subterranean_swelter	0.4171
global_warming	0.6047	greenhouse_gas_concentrations	0.4495	El_Nino_La_Nina	0.4268	Climategate_scandal	0.4166
environment	0.6010	anthropogenic_warming	0.4491	Ice_Ages	0.4267	biodiversity	0.4157
climatic	0.5555	microclimate	0.4479	paleoclimatologist	0.4263	Bjorn_Lomborg	0.4149
climatic_conditions	0.5207	hotter_summers	0.4465	balmier	0.4259	paleoclimatology	0.4145
Global_warming	0.5049	Global_Warming	0.4444	warmists	0.4237	atmospheric_circulation	0.4143
Climate_Change	0.4956	global_warming_alarmists	0.4444	ozone_depletion	0.4236	reducing_carbon_emissions	0.4133
anthropogenic_climate	0.4938	climatic_variations	0.4434	paleoclimate	0.4233	coastal_ecosystems	0.4132
weather	0.4833	Nielsen_Gammon	0.4431	conditions	0.4230	planetary_warming	0.4109
CLIMATE	0.4830	greenhouse_gas	0.4376	Veerabhadran_Ramanathan	0.4230	Eileen_Claussen_president	0.4106
hotter_drier	0.4771	climate_modelers	0.4374	climatology	0.4221	warming	0.4102
solar_irradiance	0.4764	carbon_emissions	0.4368	ecosystems	0.4213	atmospheric_CO2_concentrations	0.4098
greenhouse_warming	0.4683	biogeochemical_cycles	0.4354	thermohaline_circulation	0.4208	emitting_greenhouse_gases	0.4097
warnings	0.4666	climatologically	0.4351	Polar_Regions	0.4204	atmospheric	0.4097
oceanic_circulation	0.4655	Climatologist	0.4344	warmer_drier	0.4201	cooler_wetter_weather	0.4088
climatically	0.4654	ozone_layer_depletion	0.4343	Pielke	0.4200	Roger_Pielke_Jr.	0.4087
climatological	0.4626	anthropogenic	0.4329	Warming	0.4198	atmospheric_CO2	0.4084
forcings	0.4619	El_Nino_periodic	0.4316	carbon_emission	0.4196	mankind_global_warming	0.4079
climate_atmosphere	0.4598	climatechange	0.4311	Copenhagen_Climate	0.4189	anthropogenic_emissions	0.4078
climatic_variability	0.4595	Schellnhuber	0.4299	cooler_wetter	0.4184	atmospheric_carbon_dioxide	0.4075
economic	0.4587	greenhouse_gas_emissions	0.4296	anthropogenic_global_warming	0.4183	emissions	0.4071
Climatic	0.4576	biosphere	0.4295	curbing_carbon_emissions	0.4175	warmer	0.4062
colder_wetter	0.4525	aridity	0.4294	climatologists	0.4175	clime	0.4054

**Note:** This table shows the list of top 100 words based on their cosine similarity to “Climate” in Google’s word2vec implementation. Terms in red are the common terms in Appendix Table A.3, Appendix Table A.4, and Appendix Table A.5, i.e., terms related to both biodiversity and climate/climate change.

**Table A.5:** List of Top 100 Words Similar to ‘climate change’

Word	Distance	Word	Distance	Word	Distance	Word	Distance
global_warming	0.8896	climatechange	0.5673	species_extinctions	0.5250	melting_polar	0.5056
Climate_Change	0.7148	reduce_carbon_emissions	0.5671	emission_reduction	0.5242	decarbonisation	0.5054
Climate	0.6954	curbing_greenhouse_gases	0.5631	Hans_Verolme	0.5197	coastal_erosion	0.5052
Global_warming	0.6611	Climate_Change_IPCC	0.5620	greenhouse_gas_concentrations	0.5197	climatic	0.5048
climate	0.6570	melting_icecaps	0.5577	Schellnhuber	0.5180	IAASTD	0.5048
greenhouse_gas_emissions	0.6449	curbing_carbon_emissions	0.5519	carbon	0.5167	melting_glaciers	0.5041
greenhouse_gases	0.6433	Bjørn_Lomborg	0.5517	Worldwatch	0.5160	CLIMATE	0.5034
carbon_emissions	0.6395	greenhouse_warming	0.5502	CO2_emissions	0.5158	halting_deforestation	0.5030
Global_Warming	0.6282	greenhouse_gas_emission	0.5442	Steven_Guilbeault	0.5149	greenhouse_gas_GHG_emissions	0.5025
reducing_carbon_emissions	0.6227	ocean_acidification	0.5441	climatic_variability	0.5148	GHGs	0.5024
greenhouse_emissions	0.6146	combatting_global_warming	0.5438	GHG_emissions	0.5144	environmentalism	0.5019
combating_global_warming	0.6045	Al_Gore_Inconvenient_Truth	0.5437	Bjorn_Lomborg	0.5142	Eaarth	0.5018
greenhouse_gasses	0.6019	Lomborg	0.5407	greenhouses_gases	0.5140	conserving_biodiversity	0.5007
tropical_deforestation	0.5970	manmade_global_warming	0.5397	environmental	0.5124	greenhouse_gas_emission_reductions	0.5002
anthropogenic_climate	0.5918	emissions	0.5379	Climate_Change_Secretariat	0.5122	reduce_greenhouse_gas	0.5001
deforestation	0.5914	greenhouse_gas_emitters	0.5372	ozone_depletion	0.5112	fossil_fuels	0.4997
greenhouse_gas	0.5857	anthropogenic_global_warming	0.5369	Environment_Programme_UneP	0.5110	UNFCCC_Executive	0.4996
carbon_emission	0.5765	environmental_degradation	0.5343	UNFCCC	0.5107	pollution	0.4992
biodiversity	0.5760	UneP	0.5338	Di_Aping	0.5098	greenhouse_gases_GHGs	0.4990
greenhouse_emission	0.5738	global_warming_alarmists	0.5332	anthropogenic	0.5096	atmospheric_carbon_dioxide	0.4984
desertification	0.5708	carbon_sinks	0.5326	reducing_greenhouse_gas	0.5093	glacial_melting	0.4984
carbon_dioxide_emissions	0.5688	planetary_warming	0.5299	carbon_sequestration	0.5085	TEEB	0.4982
Climate_Change_UNFCC	0.5686	floods_droughts	0.5288	Pachauri	0.5080	Ocean_Acidification	0.4982
resource_depletion	0.5680	Copenhagen_Climate	0.5263	GLOBAL_warming	0.5069	COP	0.4980
ozone_layer_depletion	0.5676	Climatic_Change	0.5258	G8_+5	0.5064	warmists	0.4974

**Note:** This table shows the list of top 100 words based on their cosine similarity to “Climate Change” in Google’s word2vec implementation. UNFCC: United Nations Framework Convention on Climate Change; IPCC: Intergovernmental Panel on Climate Change. Terms in red are the common terms in Appendix Table A.3, Appendix Table A.4, and Appendix Table A.5, i.e., terms related to both biodiversity and climate/climate change.

**Table A.6:** Correlation Across Measures of Aggregate Risk - Alternative News Indices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
<b>Biodiversity Risk Measures</b>									
(1) NYT-Biodiversity News (Baseline)	1.00								
(2) NYT-Biodiversity News (All 100 terms)	0.73	1.00							
(3) NYT-Biodiversity News (Excluding Climate Dictionary)	0.98	0.73	1.00						
(4) NYT-Biodiversity News (Excluding CC Dictionary)	0.97	0.69	0.96	1.00					
<b>Climate Risk Measures</b>									
(5) NYT-Climate News	0.43	0.85	0.43	0.38	1.00				
(6) Faccini et al (2023): Climate Policy	0.20	0.46	0.18	0.16	0.50	1.00			
(7) Faccini et al (2023): Internat. Summit	-0.11	-0.17	-0.12	-0.09	-0.14	0.11	1.00		
(8) Faccini et al (2023): Global Warming	0.10	0.44	0.07	0.06	0.51	0.76	0.21	1.00	
(9) Faccini et al (2023): Natural Disaster	0.21	0.49	0.19	0.15	0.64	0.41	-0.06	0.41	1.00

**Note:** Pairwise monthly correlation across biodiversity and climate risk measures. NYT-Biodiversity News and NYT-Climate News use data from January 2010 to December 2023, while Faccini et al (2023) indices span January 2010 to June 2023. (1) NYT-Biodiversity News (Baseline) is constructed using all terms in the Biodiversity Dictionary except "climate change"; (2) NYT-Biodiversity News (All 100 Terms) includes all terms in the Biodiversity Dictionary; (3) NYT-Biodiversity News (Excluding Climate Dictionary) uses terms in the Biodiversity Dictionary that are not in the Climate Dictionary; (4) NYT-Biodiversity News (Excluding Climate Change Dictionary) includes terms in the Biodiversity Dictionary that are not in the Climate Change Dictionary. The Biodiversity Dictionary (Appendix Table A.3) lists the top 100 words closest to "biodiversity"; the Climate Dictionary (Appendix Table A.4) lists those closest to "climate"; and the Climate Change Dictionary (Appendix Table A.5) lists those closest to "climate change".

**Table A.7:** BERT classification examples: NYT

---

*Panel A: Negative Sentences*

biodiversity	It is hard to believe that the Trump administration and the current Senate will be any more enthusiastic about preserving <b>biodiversity</b> than the Senate was then.
deforestation	Environmental problems remain, including overfishing and the erosion and <b>deforestation</b> left from earlier eras.
habitat	The antelope's numbers, once in the millions, have been severely depleted by illegal hunting, <b>habitat</b> loss and competition for food.
marine	There is concern, too, about the effect of broken-down plastic on <b>marine</b> life.
species	Even so, in August, the United States Fish and <b>Wildlife</b> Service withdrew its proposal to list the animal as a "threatened" species under the Endangered <b>Species</b> Act.

---

*Panel B: Positive Sentences*

biodiversity	These organic seed sellers share a passion for the unusual and a mission to preserve <b>biodiversity</b> .
species	It highlights where endangered wild lands are being preserved, threatened <b>species</b> are being protected, historical wrongs are being acknowledged and fragile communities are being bolstered.
desertification	In the mid-2000s, African leaders envisioned creating a huge swath of green that could help combat <b>desertification</b> and land degradation.
habitat	In cities, trees cool hot streets, absorb pollution, improve air quality, limit storm water runoff, prevent erosion, enhance the physical and mental health of human beings, and provide desperately needed <b>habitat</b> for wildlife.

---

**Note:** Sentences classified as positive are assigned a score of 1, and sentences classified as negative are assigned a score of -1.

**Table A.8:** BERT classification examples: 10-K

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*Panel A: Negative Sentences*

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Materials	Long-term, higher average global temperatures could result in induced changes in natural resources, growing seasons, precipitation patterns, weather patterns, species distributions, water availability, sea levels, and <b>biodiversity</b> .
Energy	If our access to materials under <b>biodiversity</b> access agreements or other arrangements is reduced or terminates, it could harm our internal and our collaborative research and development efforts.
Consumer Services	These risks include the increased public focus, including by governmental and nongovernmental organizations, on these and other environmental sustainability matters, such as packaging and waste, animal health and welfare, <b>deforestation</b> and land use.
Pharma., Biotech., & Life Sc.	The natural oils and fats route can lead to concerns of <b>deforestation</b> due to the rapid expansion of palm oil plantations to meet growing demand.
Energy	If one of our LNG terminals or pipelines adversely affects a protected species or its <b>habitat</b> , we may be required to develop and follow a plan to avoid those impacts.

---

*Panel B: Positive Sentences*

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Semi. & Equip.	We leverage our expertise to develop new solutions to help restore natural resources, regenerate the quality of our <b>biosphere</b> and reduce carbon emissions.
Pharma., Biotech., & Life Sc.	We believe that growth of hemp could significantly reduce <b>deforestation</b> by providing the same products that trees are able to supply.
Materials	The Company follows Sustainable Forestry Initiative ('SFI') Standards that promote sustainable forest management in North America through the use of core principles, objectives, performance measures and indicators to protect water quality, <b>biodiversity</b> , wildlife habitat, species at risk, and forests which have exceptional conservation value.
Real Estate	Such forest practices include planting 300 to 600 seedlings on each acre, thinning <b>forest</b> stands to give remaining trees more room to grow, pruning selected trees to produce knot-free wood, fertilizing stands to supplement natural nutrient levels, and harvesting at sustainable rates—approximately 2 percent of our forestlands each year in the West and 3 percent in the South where the growing cycle is faster.
Materials	Our efforts to advance sustainable <b>forest</b> management and restore <b>forest</b> landscapes are an important lever for mitigating climate change through carbon storage in forests.

---

**Note:** Sentences classified as positive are assigned a score of 1, and sentences classified as negative are assigned a score of -1. Panel A shows the sentences that are classified as negative by BERT, while Panel B presents the positive sentences.

**Table A.8:** BERT classification examples: 10-K (Cont.)

---

<i>Panel C: Neutral Sentences</i>	
Food, Bev. & Tobacco	The Company continues to own the property and continues to conduct its long-term water dispersement program and <b>wildlife</b> management programs.
Energy	Fish and Wildlife Service (the 'FWS') announced a series of changes to the rules implementing the ESA, including revisions to the regulations governing interagency cooperation, listing species and delisting critical <b>habitat</b> , and prohibitions related to threatened wildlife and plants.
Materials	The U.S. EPA alleges the original <b>wetland</b> area has been partially filled by various waste handling and disposal activities which started as early as the 1940's.
Retailing	In fiscal 2018, we published an updated wood sourcing policy to ensure that all wood products sold in our stores originate from well-managed, non-endangered <b>forests</b> and committed to achieve 100 percent Forest Stewardship Council (FSC) certification for all wood products sourced from identified regions at risk by 2020.
Capital Goods	If endangered <b>species</b> or their <b>habitats</b> are identified, ESA requirements for protection, mitigation or avoidance apply.

---

<i>Panel D: Transition Sentences</i>	
Energy	A critical <b>habitat</b> or suitable habitat designation could result in further material <b>restrictions</b> to federal land use and may materially delay or prohibit access to protected areas for natural gas and oil development.
Consum. Durables & Apparel	Recent regulatory action involving the listing of a certain <b>species</b> of gopher as 'threatened' under the federal Endangered Species Act may adversely affect this project, for example by imposing new <b>restrictions</b> and requirements on our activities there and possibly delaying, halting or limiting, our development activities.
Materials	In addition, future domestic or foreign legislation or <b>regulation</b> , litigation advanced by Aboriginal groups and litigation concerning the use of timberlands, forest management practices, the protection of endangered <b>species</b> , the promotion of <b>forest biodiversity</b> and the response to and prevention of catastrophic wildfires could also affect timber supplies.
Real Estate	Federal, state and local <b>laws</b> and regulations, as well as those of other countries, which are intended to protect threatened and endangered <b>species</b> , as well as waterways and wetlands, limit and may prevent timber harvesting, road building and other activities on our timberlands.

---

**Note:** Panel C shows the neutral sentences identified by BERT. Panel D presents examples of sentences marked as biodiversity transition risk sentences.

**Table A.9:** Biodiversity Scores Rankings

GICS	Description	Avg.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1010	Energy	23.3	23	24	23	24	22	24	23
5510	Utilities	21.9	24	23	24	19	17	22	24
3020	Food, Bev. & Tobacco	18.3	17	20	20	23	24	5	19
3520	Pharma., Biotech., & Life Sc.	17.9	15	22	10	21	23	14	20
1510	Materials	17.7	22	2	22	22	20	15	21
6010	Real Estate	17.1	20	19	19	18	19	7	18
2030	Transportation	14.9	19	5	14	20	16	8	22
2520	Consum. Durables & Apparel	14.4	14	21	17	14	13	21	1
2010	Capital Goods	12.0	13	9	15	10	7	13	17
4030	Insurance	10.3	11	14	1	17	18	10	1
3030	Household & Pers. Prod.	10.3	18	1	21	14	13	4	1
4020	Diversified Financials.	9.6	9	6	12	11	8	20	1
2550	Retailing	9.6	10	10	13	7	10	16	1
3510	Health Care Equip. & Serv.	9.4	12	7	1	13	21	11	1
2530	Consumer Services	8.7	21	3	18	7	10	1	1
4010	Banks	8.0	5	13	1	11	8	17	1
2510	Auto & Components	7.7	1	12	1	14	13	12	1
2020	Commercial & Prof. Serv.	7.4	16	4	16	6	6	3	1
5020	Media & Entertainment	6.6	1	18	1	1	1	23	1
4530	Semiconductors & Equip.	6.3	4	8	11	1	1	18	1
3010	Food & Staples Retailing	6.1	8	14	1	7	10	2	1
4520	Tech. Hardw. & Equip.	5.9	7	11	1	1	1	19	1
4510	Software & Services	4.7	6	14	1	1	1	9	1
5010	Communication Services	3.6	1	14	1	1	1	6	1

**Note:** Industry biodiversity scores measured by (1) 10K-Biodiversity-Count, (2) 10K-Biodiversity-Negative, (3) 10K-Biodiversity-Regulation Score, (4) Survey-Transition Score, (5) Survey-Physical Score, (6) Holding-based score, and (7) CDP-Biodiversity Score. The 10K-based Biodiversity Scores are averaged from 2015 to 2023. Survey-based Scores are from Q1 2023. Holding-based Score is from Q4 2023. CDP-based Score uses data from 2023. The industries are sorted by the average score across the seven measures.

**Table A.10:** Correlation of Survey-based Average Industry Rankings Across Subgroups

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
<b>Role</b>											
(1) Academic	1.00										
(2) Private Sector	0.97	1.00									
(3) Public Sector	0.98	0.95	1.00								
<b>Location</b>											
(4) Asia	0.97	0.98	0.98	1.00							
(5) Europe	0.98	0.93	0.99	0.97	1.00						
(6) North America	0.99	0.99	0.97	0.98	0.95	1.00					
(7) ROW	0.96	0.91	0.93	0.90	0.94	0.94	1.00				
<b>Concern</b>											
(8) Very High	0.99	0.95	0.98	0.98	0.97	0.99	0.94	1.00			
(9) High	0.98	0.98	0.97	0.97	0.96	0.99	0.94	0.97	1.00		
(10) Low	0.98	0.99	0.96	0.97	0.94	0.99	0.94	0.97	0.98	1.00	
(11) No Concern	0.89	0.82	0.87	0.86	0.91	0.85	0.83	0.89	0.82	0.84	1.00

**Note:** Correlation of average industry rankings across different groups of survey respondents. The average survey score is computed as the average value of the transition score and physical score.

### A.3 Separating Physical and Transition Biodiversity Risks

Beyond quantifying general biodiversity risk, we are also interested in separately exploring physical and transition risks. As discussed in Section 2, industries reliant on natural capital are most exposed to physical biodiversity risk, while sectors with substantial land use are particularly impacted by biodiversity transition risks. These industries are affected differently by the rising risks from the physical and transition sides. Therefore, we need a systematic method to quantify physical and transition risks over time and across industries.

Several studies provide measures of physical and transition *climate* indices (e.g., Faccini et al., 2023), and firm-level climate physical and transition risk exposures (e.g., Sautner et al., 2023a). Most of these measures are based on textual analysis including machine learning keyword discovery algorithms or Latent Dirichlet Allocation (LDA). In this section, we employ the state-of-the-art large language model ChatGPT, to identify and quantify physical and transition risks. Since its release, ChatGPT has been extensively applied in finance literature to study firms’ disclosure reports (e.g., Li et al., 2023) and to measure risks and market sentiments from news articles (e.g., Bybee, 2023; Chen et al., 2022).

In this section, we propose measures of physical and transition risks over time using NYT articles. Then, we describe new measures of firms’ physical and transition risk exposures using firms’ 10-K statements. Finally, we explore how the returns on portfolios sorted by physical and transition risks covary with the physical and transition risk news series.

**Measuring Aggregate Biodiversity Risks.** The first step is to identify biodiversity-related articles in the NYT using regular expression searches based on the biodiversity dictionary (Appendix Table A.3). These identified articles are then provided to OpenAI’s GPT-4.0, which is prompted to classify each article by category (physical vs. transition), direction (increase, decrease, neutral), and strength (extremely important, very important, moderately important, slightly important, not at all important). The prompt used to query GPT is detailed in Appendix Code 1. Each query to GPT includes the headline and the full text of the article. In response, GPT generates a string of text according to the requested format in the prompt. For instance, when presented with a news article about the significant weakening of the Endangered Species Act by the U.S., ChatGPT identifies it as a significant decrease in biodiversity transition risk, likely increasing biodiversity physical risk. Similarly, when presented with an article about Biden’s voiding of a Trump-era deal to open an Alaskan wildlife area, ChatGPT identifies it as an increase in biodiversity transition risk and a decrease in biodiversity physical risk. Appendix Table A.13 provides further examples of headlines, leads, and related explanations, demonstrating the reasoning behind GPT’s responses.

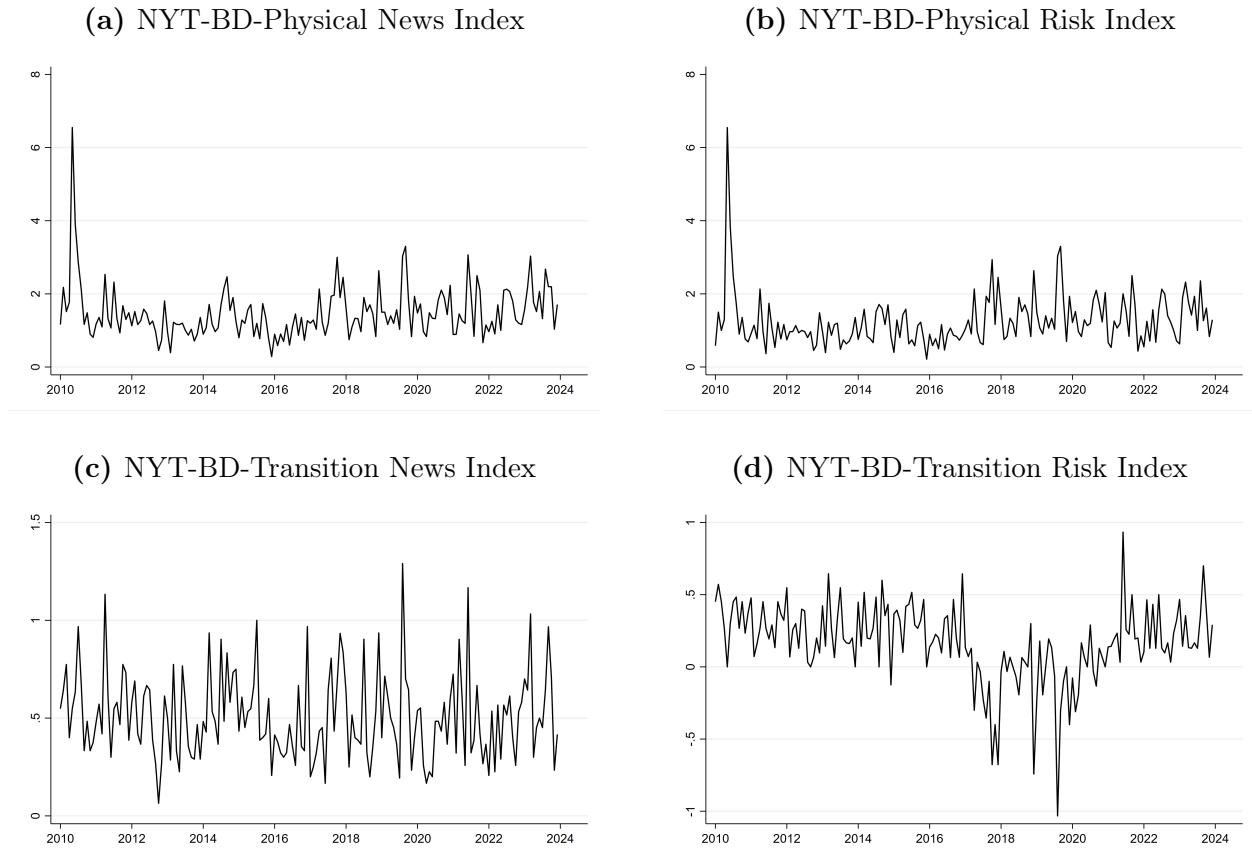
We then aggregate these article-level responses into a daily measure to form a time series of physical and transition risks. We compute two types of article-level scores: one for news mentions and one for risk level. Articles mentioning physical or transition risks receive a mention score of 1, while those not mentioning these risks receive a score of 0. This mention score is multiplied by the strength (4 for extremely important to 0 for not at all important)

to calculate the NYT-BD-Physical News Index and NYT-BD-Transition News Index.

For the NYT-BD-Physical Risk Index and NYT-BD-Transition Risk Index, we use the direction of risk (+1 for increasing, 0 for neutral, and -1 for decreasing) and multiply it by the strength. A score of +4 represents the highest level of increasing risk, while a score of -4 indicates the highest level of decreasing risk. We then sum all article-level scores within a day to obtain the daily risk score.

These daily measures can be easily aggregated to weekly or monthly levels by taking the average of the daily series. Appendix Figure A.13 plots the monthly indices. Physical risks are generally increasing, while transition biodiversity risks were generally decreasing during the years of the Trump administration (2017-2021).

**Figure A.13:** Biodiversity Physical and Transition Risks



**Note:** Monthly NYT-Biodiversity Risks indices between 2010 to 2023.

Appendix Table A.11 shows the pairwise correlation across these various news indices using monthly data from 2010 to 2023. The first column is the baseline NYT-Biodiversity News Index, while the remaining four columns display the disaggregated indices. The correlation between the NYT-BD-Physical News Index and the NYT-BD-Physical Risk Index is 0.95, indicating that discussions about physical risk in newspapers are closely aligned with concerns about biodiversity loss. In contrast, the correlation between the NYT-BD-Transition

News Index and the NYT-BD-Transition Risk Index is lower (0.12), suggesting that coverage of biodiversity-related policies in the news is inconsistent and reflects varying degrees of policy tightening and loosening. The correlations represented in column (1) suggest that our baseline NYT-Biodiversity News Index captures physical biodiversity risk news more frequently than transition risk news.

**Table A.11:** Correlation Across Measures of Aggregate and Disaggregate Risk

	(1)	(2)	(3)	(4)	(5)
<b>Aggregate Measures</b>					
(1) NYT-Biodiversity News Index	1.00				
<b>Disaggregate Measures</b>					
(2) NYT-BD-Physical News Index	0.34	1.00			
(3) NYT-BD-Physical Risk Index	0.40	0.95	1.00		
(4) NYT-BD-Transition News Index	0.15	0.49	0.39	1.00	
(5) NYT-BD-Transition Risk Index	-0.32	-0.15	-0.28	0.12	1.00

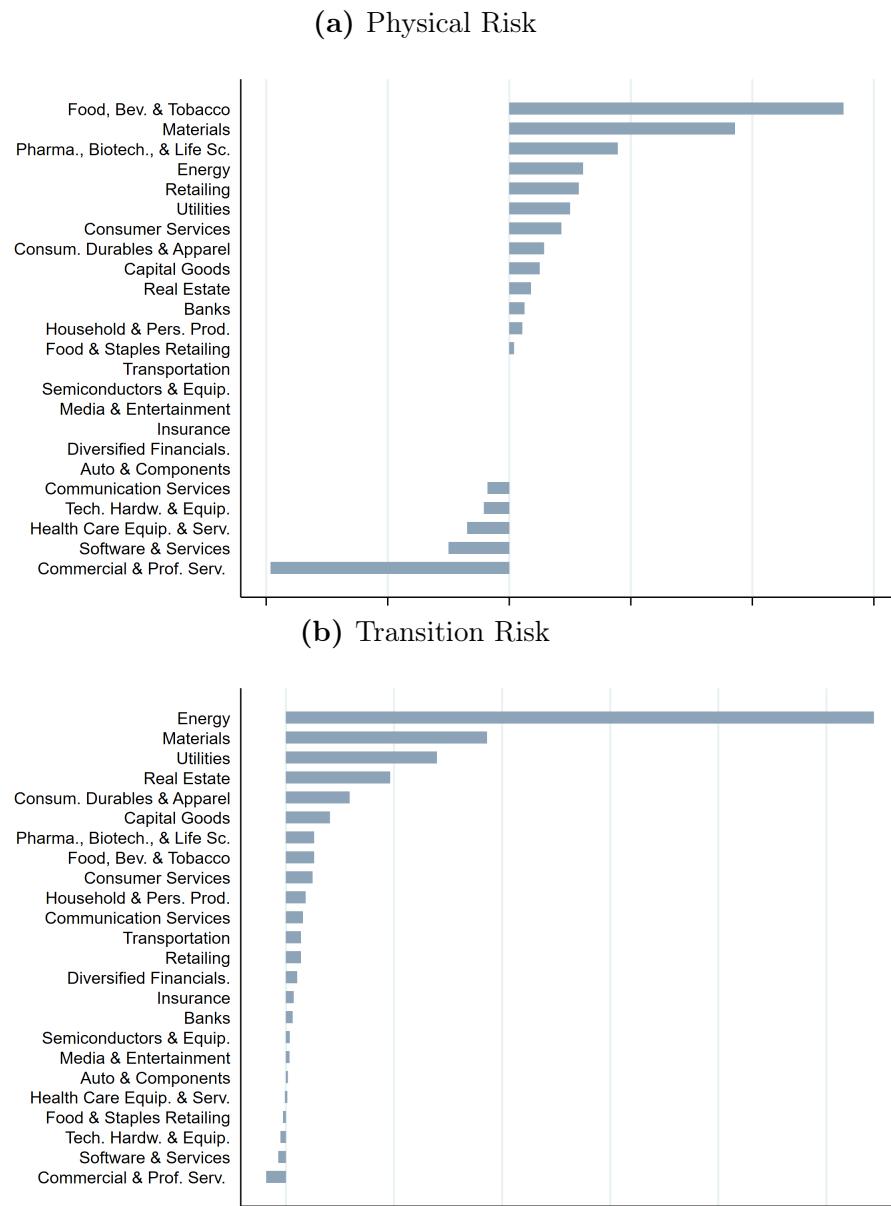
**Note:** Pairwise monthly correlation across biodiversity risk measures from 2010 to 2023.

**Firm-level Measures of Biodiversity Risk Exposures.** Our firm-level measures of physical and transition biodiversity risk exposures are based on textual analysis of firms' 10-K statements. We identify biodiversity-related mentions using regular expression searches for the biodiversity dictionary in Appendix Table A.3. We focus on discussion in item 1 (Business), item 1A (Risk Factors), and item 2 (Properties), retaining the sentences that mention the keywords as well as the two preceding and two following sentences.

For each sentence with context, we ask ChatGPT to assess whether the direct consequences of biodiversity and ecosystem services loss (physical biodiversity risk) pose potential advantages or risks to the firm's operations and financial outlook. Similarly, we inquire whether increased regulatory stringency in nature preservation and biodiversity conservation (transition biodiversity risk) creates potential advantages or risks. The prompt used to query GPT is detailed in Appendix Code 2. We assign a 10K-Biodiversity-Physical Score or 10K-Biodiversity-Transition Score of "+1" if ChatGPT identifies the discussion as a risk and "-1" if ChatGPT identifies it as an advantage. Appendix Table A.14 provides examples of 10-K discussion and GPT responses.

To compare biodiversity risk exposures across industries using our various measures, we aggregate the firm-level scores to the industry level by summing the 10K-Biodiversity-Physical Score (10K-Biodiversity-Transition Score) for all firms within each industry. Appendix Figure A.14 shows the industry ranking based on physical and transition risks. The sectors with the highest biodiversity physical risk exposures are Food, Beverage & Tobacco, Materials, and Pharmaceutical, Biotechnology & Life Science, while the sectors most exposed to transition risk are Energy, Materials, and Utilities.

**Figure A.14:** Industry Ranking based on 10K Biodiversity Risk Exposure



**Note:** Panel (a) shows the industry ranking based on the average 10K-Biodiversity-Physical Score from 2010 to 2023. Panel (b) presents the industry ranking based on the average 10K-Biodiversity-Transition Score over the same period.

Appendix Table A.12 reports the cross-industry correlations of biodiversity exposures across different measures. The table highlights that our industry-level measures of biodiversity risk exposures are highly correlated. Specifically, both 10-K-based and survey-based measures show strong correlations for physical and transition risks.

**Table A.12:** Industry-level Correlations of Biodiversity Scores

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<b>Survey-based Scores</b>								
(1) Survey: Physical	1.00							
(2) Survey: Transition	0.82	1.00						
(3) Survey: Average	0.96	0.95	1.00					
<b>10K-based Scores</b>								
(4) 10K: Physical	0.75	0.65	0.74	1.00				
(5) 10K: Transition	0.33	0.66	0.52	0.34	1.00			
(6) 10K: Average	0.38	0.69	0.55	0.41	1.00	1.00		
<b>CDP-based Score</b>								
(7) CDP	0.30	0.58	0.46	0.32	0.72	0.73	1.00	
<b>Holding-based Score</b>								
(8) Holding	0.02	0.26	0.14	0.11	0.32	0.32	0.33	1.00

**Note:** Industry-level Pearson correlations of Survey-based, 10K-based Biodiversity Scores, CDP Biodiversity Scores, and Holding-based Score. The 10-K based scores are averaged across 2015 to 2023. Survey-based Scores use data in Q1 2023. Holding-based Score uses data from Q4 2023. CDP-based Score uses data from 2023.

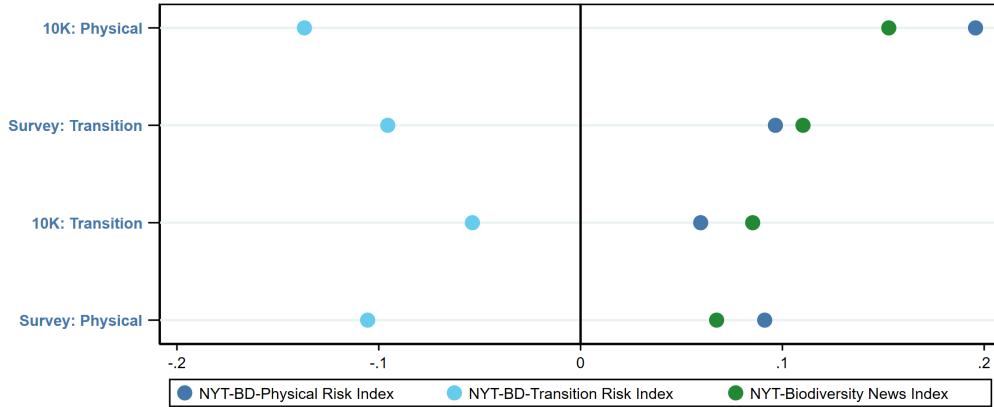
**Hedge Performance** Appendix Figure A.15 presents the monthly correlations of various hedge portfolios with AR(1) innovations in biodiversity news and risk indices. Panel (a) displays the hedging performance of biodiversity portfolios against biodiversity news indices. Overall, biodiversity hedging portfolios perform well with respect to the NYT series they are designed to target. Physical risk portfolios formed using 10-K and survey responses, perform well in hedging biodiversity physical risk, whereas transition risk portfolios generally hedge transition risk well.

**Figure A.15:** Biodiversity Hedge Performance of Various Portfolios

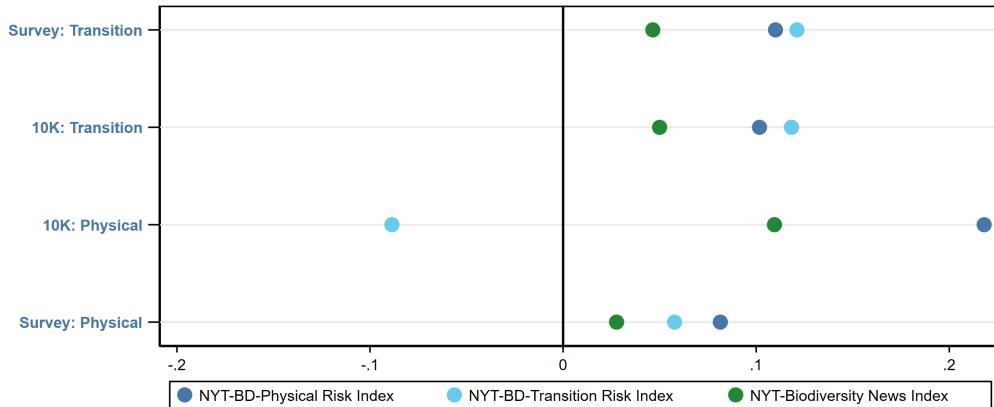
(a) Biodiversity News Indices



(b) Biodiversity Risk Indices



(c) Biodiversity Risk Indices (dropping 2017 to 2020 inclusive)



**Note:** Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of biodiversity indices. Panel (a) and (b) show the correlation with NYT-BD News indices and NYT-BD Risk indices respectively using data from 2010 to 2023. Panel (c) shows the correlations with NYT-BD Risk indices from 2010 to 2023, dropping the years 2017 to 2020 inclusive.

Panel (b) shows the correlations with biodiversity risk indices—recall that the difference

to the biodiversity news indices is the attempt to separate whether a particular news article corresponds to being ‘good news’ or ‘bad news.’ While correlations with the NYT-BD-Physical Risk Index are generally positive, correlations with the NYT-BD-Transition Risk Index are negative. This might be explained by difficulties in interpreting the ‘sign’ of the transition news, in particular during the years of the Trump presidency, when there were frequent instances interpreted as ‘good news’ from a biodiversity transition risk perspective. For instance, reports of biodiversity policy relaxation can be followed by discussions of opposition, legal challenges, or potential policy reversals, as highlighted in the NYT article *"Trump's Environmental Rollbacks Were Fast. It Could Get Messy in Court."*

In Panel (c), we exclude the years 2017 to 2020, during which the NYT-BD-Transition Risk Index fluctuated remarkably, moving from positive to negative and back to positive. Compared to Panel (b), portfolios show better hedging performance with respect to the NYT series they target. While the results are promising, they are somewhat mixed, suggesting that further extensions and refinements could be explored.

### **Example Responses**

*Panel A: Physical Risk Increases*

*Fight Against an Invasive Fish Threatens a Fragile Unity in the Great Lakes (2010-01-03)*

The State of Michigan is suing Illinois to close Chicago-area waterways that could allow Asian carp, a nonnative species that consumes the food of other fish, to reach Lake Michigan.

The Asian carp invasion threat in the Great Lakes underscores a significant risk to U.S. biodiversity, leading to legal actions and regional cooperation to prevent ecological and economic damage.

*The Global Extinction Crisis (2021-09-29)*

More than 20 species on the U.S. endangered list are now gone forever, officials said Wednesday. A million more are at risk.

The extinction of over 20 species in the U.S. underscores a significant national biodiversity crisis, with a million species at risk.

*Mapping California's 'Zombie' Forests (2023-03-08)*

A warming climate has left a fifth of the conifer forests that blanket California's Sierra Nevada stranded in habitats that no longer suit them, according to a study published last week by researchers at Stanford University.

California's Sierra Nevada faces a biodiversity crisis with 'zombie forests' indicating a severe risk to ecosystem services in the U.S.

*Panel B: Physical Risk Decreases*

*Biden Administration Sets a Mining Ban in Boundary Waters Wilderness (2023-01-26)*

A 20-year moratorium on new mining activity for more than 225,000 acres of federal land in Minnesota could deal a fatal blow to a proposed Twin Metals copper-nickel mine.

The decision to establish a 20-year moratorium on mining in Minnesota, as discussed in the article, specifically addresses the conservation of the Boundary Waters Canoe Area Wilderness. This action directly impacts the United States by protecting a significant natural area, thereby reducing the risk of biodiversity loss and ecosystem service degradation within the country.

*How California's Elephant Seals Made a Remarkable Recovery (2023-03-16)*

Hunted nearly to extinction, northern elephant seals, native to the waters off the West Coast, now number more than 175,000.

Conservation measures in the United States have effectively increased the northern elephant seal population, indicating a positive impact on biodiversity.

*Uptick Seen in Red Knots on Jersey Shore (2023-06-15)*

An annual spring count instilled hope among biologists that the threatened shorebird may be recovering from recent declines. Crab harvesting bans were partly credited for the rise.

The focus on the recovery of shorebirds and horseshoe crabs in the United States, due to regulatory actions, indicates a declining risk of losing biodiversity and ecosystem services nationally.

**Note:** Panel A shows the articles classified by ChatGPT as indicating increasing physical risk, while Panel B presents those indicating decreasing physical risk. Column 1 shows the headline and date, column 2 contains the lead sentences of the NYT news article, and column 3 presents the output of ChatGPT Prompt 1.

**Table A.13:** ChatGPT classification examples: NYT (Cont.)

*Panel C: Transition Risk Increases*

*White House Aims to Reflect the Environment in Economic Data (2023-01-20)*

The Biden administration has set out to measure the economic value of ecosystems, offering new statistics to weigh in policy decisions.

The article discusses incorporating natural capital into economic calculations, a move towards recognizing and potentially enhancing biodiversity policy. The Biden administration's effort suggests a tightening of policy, very likely influencing operational strategies of companies, especially those reliant on natural resources.

*Biden Voids Trump-Era Deal to Open Alaskan Wildlife Area (2023-03-14)*

The administration canceled a plan that would have allowed road construction in Izembek National Wildlife Refuge.

The article discusses the Biden administration's decision to withdraw a land swap deal, protecting Izembek National Wildlife Refuge, indicating a tightening of biodiversity policy.

*A 24-Armed Hunter, Threatened With Extinction, Is Set to Get Protection (2023-03-15)*

Sunflower sea stars, huge starfish that until recently thrived in waters up and down the west coast of North America, are threatened with extinction and should be protected under the Endangered Species Act, federal officials said Wednesday.

The article discusses the proposal to list sunflower sea stars as threatened under the Endangered Species Act, indicating a tightening of biodiversity policy.

*Panel D: Transition Risk Decreases*

*U.S. Significantly Weakens Endangered Species Act (2019-08-12)*

The Trump administration on Monday announced that it would change the way the Endangered Species Act is applied, significantly weakening the nation's bedrock conservation law and making it harder to protect wildlife from the multiple threats posed by climate change.

The article discusses weakening biodiversity policy by making it harder to protect wildlife, especially from climate change.

*Trump Drilling Plan Threatens 9 Million Acres of Sage Grouse Habitat (2018-12-06)*

The Trump administration on Thursday detailed its plan to open nine million acres to drilling and mining by stripping away protections for the sage grouse, an imperiled ground-nesting bird that oil companies have long considered an obstacle to some of the richest deposits in the American West.

The article discusses reducing protections for the sage grouse, indicating a loosening of biodiversity policy.

*Trump Administration Loosens Sage Grouse Protections, Benefiting Oil Companies (2019-03-15)*

The Trump administration on Friday finalized its plan to loosen Obama-era protections on the habitat of the sage grouse, an imperiled ground-nesting bird that roams across 10 oil-rich Western states.

The article discusses loosening protections for sage grouse, impacting biodiversity policy.

**Note:** Panel C shows the articles classified by ChatGPT as indicating increasing transition risk, while Panel D presents those indicating decreasing transition risk. Column 1 shows the headline and date, column 2 contains the lead sentences of the NYT news article, and column 3 presents the output of ChatGPT Prompt 1.

**Table A.14:** ChatGPT classification examples: 10-K

*Panel A: Biodiversity Physical Risk*

Food, Bev. & Tobacco	Water is a main ingredient in substantially all of our products, production of the agricultural ingredients and is needed in our manufacturing process. It also is critical to the prosperity of the communities we serve and the ecosystems in which we operate. Water is facing unprecedented challenges from overexploitation, increasing pollution and emerging awareness of potential contaminants.	The report directly links biodiversity loss (water scarcity and quality) to potential risks for operations and finances.
Pharma., Biotech., & Life Sc.	Other potential physical impacts include reduced access to high-quality water and the loss of biodiversity, which could impact future product development. These risks could disrupt our operations and supply chain, which may result in increased costs.	The report directly mentions risks related to biodiversity loss impacting operations and R&D.
Materials	Our operations and those of our suppliers are subject to climate change variations which can impact the productivity of forests, the abundance of species, harvest levels and fiber supply.	The report directly links biodiversity loss to potential risks like reduced fiber supply, impacting the firm's operations and finances.
Energy	Companys largest refinery is located about 10 miles southeast of New Orleans. The gradual loss of coastal wetlands in southeast Louisiana increases the risk of future flooding should storms such as Katrina recur.	The report directly links biodiversity loss (coastal wetlands) to increased flooding risk, affecting the firm's operations and finances.

*Panel B: Biodiversity Physical Advantage*

Commercial & Prof. Serv.	We work with our customer to manage and comply with the nation's most important environmental laws, including the Endangered Species Act and the Marine Mammal Protection Act. We also provide ocean and coastal environmental planning, biological surveys and monitoring, habitat restoration and invasive species management.	The firm benefits directly from biodiversity loss through increased demand for its environmental compliance and sustainability services.
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**Note:** Sentences classified as risk are assigned a score of 1, and sentences classified as an advantage are assigned a score of -1. Panel A shows the sentences that are classified as risk by ChatGPT, while Panel B presents the advantage sentences. Column 1 shows the industry, column 2 contains the sentences in the 10-K report discussing biodiversity risk, and column 3 presents the output of ChatGPT Prompt 2.

**Table A.14:** ChatGPT classification examples: 10-K (Cont.)

*Panel C: Biodiversity Transition Risk*

Energy	Regulations related to the protection of wildlife could adversely affect our ability to conduct drilling activities in some of the areas where we operate. Our operations can be adversely affected by regulations designed to protect various wildlife, including threatened and endangered species and their critical habitat.	The report highlights risks from increased regulatory stringency on nature preservation, affecting operations and finances due to constraints on exploration and production activities.
Materials	The Company's activities are subject to extensive laws and regulations governing the protection of the environment, natural resources and human health. These laws address protection of natural resources, fisheries and wildlife protection, endangered species and reclamation of lands disturbed by mining operations.	The report indicates potential risks from increased regulatory stringency on nature preservation and biodiversity, affecting costs and operations.
Utilities	The Companies are subject to extensive and evolving federal, state and local environmental laws, regulations and permit requirements relating to air and water quality, protected natural resources (such as wetlands, endangered species and other protected wildlife) and health and safety.	The report highlights risks from environmental regulations.
Real Estate	Threatened and endangered species restrictions apply to activities that would adversely impact a protected species or significantly degrade its habitat. A number of species on our timberlands have been, and in the future may be, protected under these laws.	The report highlights risks from regulatory changes on biodiversity conservation.

*Panel D: Biodiversity Transition Advantage*

Commercial & Prof. Serv.	Our teams test and analyze air, water and soil to determine concentrations of contaminants, as well as the toxicological impact of contaminants on flora, fauna and human health.	Increased regulatory stringency on nature preservation likely boosts demand for the firm's environmental testing and analysis services.
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**Note:** Sentences classified as risk are assigned a score of 1, and sentences classified as an advantage are assigned a score of -1. Panel C shows the sentences that are classified as risk by ChatGPT, while Panel D presents the advantage sentences. Column 1 shows the industry, column 2 contains the sentences in the 10-K report discussing biodiversity risk, and column 3 presents the output of ChatGPT Prompt 2.

## ChatGPT Prompts

### Code Listing 1: Prompts for NYT Biodiversity News Index

---

```
prompt_sys = """
    You are ChatGPT, an AI assistant from OpenAI, based on the GPT-4 large language model
    architecture, released 2023, using pretrained knowledge up to April 2023.
"""

prompt = """
    Here is a news article:

    "%s"

    Please answer the following questions and return JSON:

    {'Q1': '(choice id)'};
    {'Q2': '(choice id)'};
    {'Q3': Answer Q3 (less than 80 words)};

    Q1: Based on the article, how would you summarize the news about the risk of losing biodiversity and
        ecosystem services in the United States?
    (a) Increase — The article suggests a rising risk of losing biodiversity and ecosystem services in the
        United States.
    (b) Decrease — The article suggests a declining risk of losing biodiversity and ecosystem services in the
        United States.
    (c) Neutral — The article includes a discussion of the risk of losing biodiversity and ecosystem
        services in the United States, but the direction is neutral or unclear.
    (d) No information — The article does not discuss the risk of losing biodiversity and ecosystem services
        in the United States.

    Q2: How important is this news in helping an analyst understand the risk of losing biodiversity and
        ecosystem services in the United States? Assign greater signal strength to nationally relevant
        information and lower signal strength to information about regional and local levels .
    (a) Extremely important
    (b) Very important
    (c) Moderately important
    (d) Slightly important
    (e) Not at all important

    Q3: Provide detailed explanations on Q1 and Q2.

    Biodiversity policy refers to the set of laws, regulations, guidelines, and practices designed to
    conserve and manage biodiversity. This includes the protection of species, habitats, and ecosystems
    to ensure their sustainability and resilience . Please exclude assessments of indirect elements, such
    as climate change policy.

    Please answer the following questions about biodiversity policy and return JSON:

    {'Q4': '(choice id)'};
    {'Q5': '(choice id)'};
    {'Q6': '(choice id)'};
    {'Q7': Answer Q7};

    Q4: Does this article explicitly discuss biodiversity policy, or factors related to biodiversity policy?
    (a) Yes
    (b) No

    Q5: Does this article indicate a tightening or loosening biodiversity policy?
    (a) Tightening
    (b) Loosening
```

(c) Neutral – The article does not provide specific details or evidence regarding changes in biodiversity policy.

Q6: How important do you anticipate the impact of this news about biodiversity policy will be on the market prices and operational strategies of exposed companies?

- (a) Extremely important
- (b) Very important
- (c) Moderately important
- (d) Slightly important
- (e) Not at all important

Q7: Provide detailed explanations on Q4 to Q6, identifying specific parts of the article or exact policies discussed that contribute to this score. The explanation should be concise and precise, directly relating to the aspects mentioned in the article. (less than 50 words);  
"""

---

## Code Listing 2: Prompts for 10k-based Biodiversity Scores

```
prompt_sys = """
You are ChatGPT, an AI assistant from OpenAI, based on the GPT-4 large language model architecture,
released 2023, using pretrained knowledge up to April 2023.
"""
```

```
prompt = """
Please read through this passage from a firm's 10-k report and analyze the firm's risk and opportunity
regarding biodiversity loss.
```

Here is an excerpt from a firm's 10-k report:

```
<article>
%
</article>
```

Please answer all the questions and return JSON.

```
{'Q1a': '(choice id)'};
{'Q1b': '(choice id)'};
{'Q2': Answer Q3};

{'Q3a': '(choice id)'};
{'Q3b': '(choice id)'};
{'Q4': Answer Q6};
```

Q1a: Based on the 10-k report, do the direct consequences of biodiversity and ecosystem services loss create potential advantages for the firm's operations and financial outlook, such as an upsurge in demand for the company's products and services?

Exclude assessments of indirect elements, such as environmental regulations linked to the firm's effects on biodiversity and ecosystems.

- (a) Yes
- (b) No information

Q1b: Based on the 10-k report, do the direct consequences of biodiversity and ecosystem services loss pose potential risks for the firm's operations and financial outlook, such as declining availability of raw materials, potential supply chain disruption, and diminished sources for R&D?

Exclude assessments of indirect elements, such as environmental regulations linked to the firm's effects on biodiversity and ecosystems.

- (a) Yes
- (b) No information

Q2: Provide detailed explanations on Q1a and Q1b.

The explanation should be concise and precise, directly relating to the aspects mentioned in the 10-k report. Please summarize the essential details in a single bullet point of fewer than 50 words.

Q3a: Based on the 10-k report, impact of increased nature preservation and biodiversity conservation regulatory stringency creates potential advantages for the firm's operations and financial outlook?

- (a) Yes
- (b) No information

Q3b: Based on the 10-k report, impact of increased nature preservation and biodiversity conservation regulatory stringency poses potential risks for the firm's operations and financial outlook?

- (a) Yes
- (b) No information

Q4: Provide detailed explanations on Q3a and Q3b.

The explanation should be concise and precise, directly relating to the aspects mentioned in the 10-k report. Please summarize the essential details in a single bullet point of fewer than 50 words.

\*\*\*

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## A.4 Additional Data Details

### A.4.1 Surveyed Public Sectors

We gathered email addresses from a range of institutions that make researcher emails accessible on their institutional websites. The institutions are Banco Central de Chile, Banco Central de Reserva del Perú, Banco Central do Brasil, Banco de España, Banco de la república Colombia, Banco de México, Bangko Sentral ng Pilipinas, Bank for International Settlements, Bank Negara Malaysia, Bank of Canada, Bank of England, Bank of Finland, Bank of Israel, Bank of Japan, Bank of Korea, Banque de France, Central Bank of Malta, Central Bank of Thailand, Danmarks Nationalbank, De Nederlandsche Bank, Deutsche Bundesbank, European Central Bank, Federal Reserve Banks of Boston, Federal Reserve Banks of Chicago, Federal Reserve Banks of Dallas, Federal Reserve Banks of Minneapolis, Federal Reserve Banks of New York, Federal Reserve Banks of Philadelphia, Federal Reserve Banks of Richmond, Hongkong Monetary Authority, International Monetary Fund, National Bank of Georgia, Norges Bank, Reserve Bank of Australia, Reserve Bank of India, Reserve Bank of South Africa, United Nations, World Bank, World Economic Forum.

### A.4.2 Biodiversity Sentences

We define the Biodiversity Dictionary in Appendix Table A.3. While certain unigrams, such as deforestation, effectively identify biodiversity sentences, others are not as precise due to their broad connotations. For example, the word “ecosystem” can also be used in the context of describing “software ecosystems”, as illustrated in the following example: “Our products primarily compete based on performance, energy efficiency, integration, ease-of-use, innovative design, features, price, quality, reliability, security features, **software ecosystem** and developer support, time-to-market, brand recognition, customer support and customization, and availability.”

To avoid selecting sentences that are irrelevant to biodiversity, we employ other terms to narrow down the sentences for these particular words. A sentence will be classified as being related to biodiversity only if it contains both the specific biodiversity vocabulary and one of the following terms simultaneously. For example, a sentence will be selected if it contains both “ecosystem” and “climate”: “We understand the adverse effects of human behavior and **climate change** on **ecosystems** and the animals who call them home; therefore, we are constantly working to minimize the footprint of our operations.”

- **Ecosystem(s):** climate, coast, forest, micro, natur, public health, sustaina, water
- **Species:** aquatic, biodiversity, bird, endanger, environment, fish, habitat, invasive, list, marine, protect, threat, ESA, EPA

### A.4.3 p-value Adjustment for Multiple Testing

In this section, we apply the Benjamini-Hochberg method ([Benjamini and Hochberg \(1995\)](#), BH) to study the statistical significance of the correlation between hedging portfolios sorted

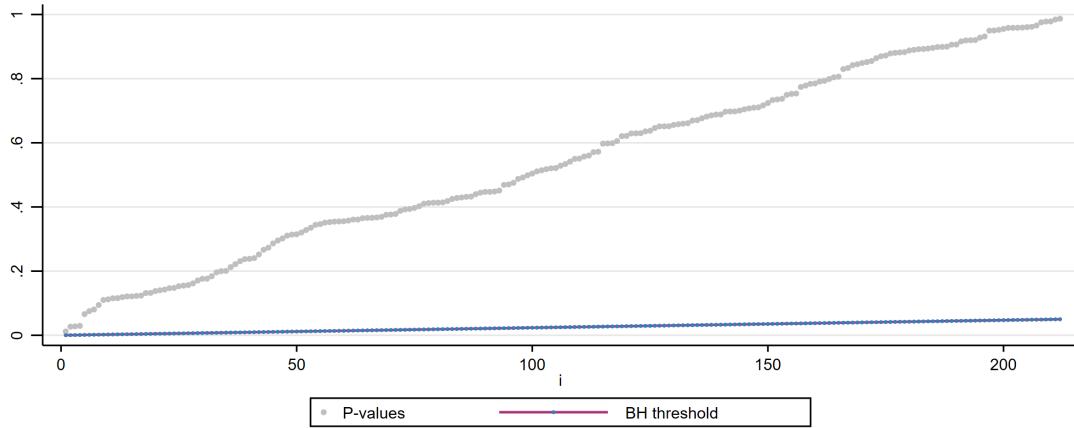
on the 212 stock characteristics and biodiversity risk innovations. The key idea of BH is to adjust the statistical significance threshold in a way that guarantees a “false discovery rate” control. That is, having chosen a threshold  $\tau$ , the adjustment guarantees that in expectation, at most a fraction  $\tau$  of the tests that are deemed significant by the test are in fact false positives (for more details, see [Giglio et al., 2021c](#)).

To apply the BH procedure, we proceed as follows. First, we compute the (univariate) correlation between each of the hedging portfolios sorted on the 212 stock characteristics and the innovation of the NYT Biodiversity Risk Index over the period of 2010 to 2023 and get the standard p-values for the statistical test that these correlations are not zero. Then we sort all the p-values in ascending order, denoted as  $p_{(1)} \leq \dots \leq p_{(N)}$ . The BH procedure recommends rejecting the null hypothesis that the correlation is zero, for each  $i = 1, \dots, N$ , if  $p_i \leq p_{(\hat{k})}$ , where  $\hat{k} = \max \{i \leq N : p_{(i)} \leq \tau i/n\}$ . In this test,  $N$  is 212 and we set  $\tau$  to be 0.05 (the false discovery rate). We find that *none* of the 212 characteristics has a correlation lower than the cutoff, suggesting that the good hedging performance observed for some measures is the product of random chance.

To visualize these results, we plot the p-value ( $p_{(i)}$ ) for each for each correlation  $i$  and the corresponding threshold ( $\tau i/n$ ), where  $i$  is the position in the ordering. Appendix Figure [A.16](#) illustrates that none of these p-values is below the threshold. Meanwhile, the p-value of the portfolio built using our average biodiversity risk measure is 0.005, below the 0.05 threshold. We do not adjust this p-value since our measures are economically motivated a priori.

This test suggests that none of these common factors in the factor zoo captures biodiversity risks and has a significantly non-zero correlation with innovations in the biodiversity risk index. In contrast, our economically motivated biodiversity measure shows significant hedging performance.

**Figure A.16:** Adjusted P-values Distribution



**Note:** The gray dots illustrate the p-values of the 212 characteristics using data from 2010 to 2023. The red line represents the corresponding threshold for each correlation.