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Do investors care about biodiversity?

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Abstract

This article introduces a new measure of a firm's negative impact on biodiversity, the corporate biodiversity footprint (CBF), and studies whether it is priced in an international sample of stocks. On average, the CBF does not explain the cross-section of returns between 2019 and 2022. However, a biodiversity footprint premium (higher returns for firms with larger footprints) began emerging in October 2021 after the Kunming Declaration, which capped the first part of the UN Biodiversity Conference (COP15). Consistent with this finding, stocks with large footprints lost value in the days after the Kunming Declaration. The launch of the Taskforce on Nature-related Financial Disclosures (TNFD) in June 2021 had a similar effect. These results indicate that investors have started to require a risk premium upon the prospect of, and uncertainty about, future regulation or litigation to preserve biodiversity.

Keywords: biodiversity; corporate biodiversity footprint; Kunming Declaration; natural capital; nature; stock returns; Taskforce on Nature-related Financial Disclosures (TNFD)
JEL classifications: G12, G30, Q57

1. Introduction

Biodiversity, the variety of living organisms in all habitats, is deteriorating at an unprecedented and alarming rate. Between 1970 and 2018, the world has seen a 69 percent loss of monitored wildlife (WWF 2022), and biosphere integrity has been identified as one of the overstepped planetary boundaries (Rockström et al. 2009; Steffen et al. 2015). Biodiversity collapse jeopardizes the goods and services humans obtain from all ecosystems, with potentially far-reaching economic implications (World Bank 2020).[1] In addition, biodiversity loss may bring about a new "era of pandemics" (IPBES 2020). While the UN Convention on Biological Diversity (CBD) entered into force in 1993, and several Conferences of the Parties (COPs) to the CBD have adopted plans to protect biodiversity, most goals have not been achieved (CBD Secretariat 2020). Recent globally coordinated steps toward

[1] While "biodiversity" is an ecological term, the economic term "natural capital" is often used to emphasize the role of nature in supporting human economic activity and well-being. Indeed, the World Economic Forum (2020) estimates that half of the world's gross domestic product stems from industries that depend on nature and ecosystem services (e.g., construction, agriculture, and tourism).

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protecting biodiversity include the Kunming Declaration (2021) and the Montreal Agreement (2022).

Given the potentially dramatic financial consequences of the loss of biodiversity, firms, investors, and financial market regulators are increasingly paying attention to the topic. For example, the Taskforce on Nature-related Financial Disclosures (TNFD), modeled after the Taskforce on Climate-related Financial Disclosures (TCFD), was launched in 2021 and released its final disclosure recommendations in September 2023 (TNFD 2023a). Also in September 2023, the Network for Greening the Financial System released NGFS (2023), a framework to help central banks and supervisors identify and assess sources of nature-related transition and physical risks, following its earlier report in NGFS and INSPIRE (2022). However, the link between biodiversity and finance has received little attention by academics. As noted by Karolyi and Tobin-de la Puente (2023), no studies in the top-10 finance journals reference biodiversity.[2] In this article, we take a step toward filling this gap by introducing to the finance literature a science-based measure, the corporate biodiversity footprint (CBF), and exploring whether investors price this footprint.

Developed by Iceberg Data Lab (IDL), the CBF aggregates the biodiversity loss caused by a firm's annual activities related to land use, greenhouse gas (GHG) emissions, water pollution, and air pollution. To quantify this loss, the CBF builds on the concept of Mean Species Abundance (MSA), which measures the relative abundance of native species in ecosystems, compared to their abundance in undisturbed ecosystems. The CBF expresses this loss in terms of km^2.MSA and quantifies not only the direct impact of a firm, but also the biodiversity loss along the entire value chain. Thus, the CBF contains scope 1, 2, and 3 components, whereby scope 1 measures the environmental pressure of the firm's direct activities, such as the area artificialized or occupied due to its business activity; scope 2 measures the pressures induced by the purchase of electricity, heat, and cooling; and scope 3 measures all indirect pressures (i.e., products sold or purchased, or investments made).[3]

Our international sample consists of 2,106 listed firms from 34 countries for which CBF data are available from IDL over the years 2018–2021. While the sample period includes only a few years, the most important global policy developments concerning biodiversity are also quite recent. Retail and Wholesale, Paper and Forest, and Food are the sectors with the largest average CBF, reflecting these sectors' intensive land use or contribution to air pollution.[4] While there is a sizeable industry component to the CBF, there is large heterogeneity within each industry. This heterogeneity is a strength of the metric, as it allows for the exploration of granular within-industry variation. Capturing such variation is important; several institutional investors have recently started negative screening policies, by which they exclude the laggards within certain sectors (e.g., La Banque Postale Asset Management 2022). The CBF reveals that larger firms, understandably, have a more negative impact on biodiversity. The CBF also relates positively to a firm's carbon emissions, which represent one channel through which firms harm biodiversity.

The CBF correlates with whether firms are targeted by the investor coalition Nature Action 100 (NA100), which, in June 2023, released a list of 100 firms to engage with to

[2] By contrast, the economics of biodiversity received early and substantial attention (e.g., Weitzman 1992, 1993; Metrick and Weitzman 1998; Heal 2003, 2004; Dasgupta 2021).

[3] Alternative metrics to MSA exist, e.g., Potentially Disappeared Fraction (PDF) and Species Threat Abatement and Restoration (STAR). We discuss these concepts below. As biodiversity receives more attention, more data options are becoming available. For example, data provider ISS ESG launched in 2022Q3, and MSCI plans to launch in 2024, biodiversity impact measures that build on a combination of MSA and PDF. Since 2023, S&P offers a tool utilizing STAR. To our knowledge, these data providers do not offer (yet) a time-series comparable to that of IDL.

[4] While the biodiversity impact from land use is mostly indirect for Retail and Wholesale (e.g., because of sold food and beverage products), it is direct for Paper and Forest and Food (e.g., because of deforestation and farming). Retail and Wholesale has a high negative air pollution impact because of pollution related to shipping activities in the value chain.

tackle biodiversity and nature loss. Almost 70 percent of NA100 targets are located in the top quintile of the CBF distribution. Using textual analysis, we find that terms related to biodiversity are mentioned in only 5.0 percent of our sample firms' earnings calls. This low number is consistent with Giglio et al. (2023), who find that only 3.8 percent of U.S. firms' 10-K statements mention biodiversity terms. As a result, the correlation between the CBF and the number of biodiversity terms in earnings calls is just 8.8 percent. Notably, many large-CBF firms, including many NA100 targets, do not discuss biodiversity at all in their earnings calls.

How can a firm's CBF be expected to correlate with its stock returns? A first possibility is that large-CBF stocks will earn higher returns, as these firms potentially face higher transition risks. These transition risks may result from legal fines or the costs of compliance with an increasingly demanding regulatory environment regarding biodiversity preservation. The theory by Pástor and Veronesi (2012) implies that uncertainty associated with future regulation or litigation leads investors to require a risk premium for holding large-CBF stocks. Consistent with this prediction, studies show that investors demand compensation for exposure to carbon or pollution risks (Bolton and Kacperczyk 2021, 2023; Hsu, Li, and Tsou 2023).

A second possibility is that large-CBF stocks will earn higher returns due to mispricing, which may originate from unexpected cash flow shocks. A negative biodiversity impact is an externality, and some firms may, therefore, not invest in mitigating or reducing their biodiversity impacts. As a result, they may enjoy unexpectedly higher earnings and returns.

A third possibility is that large-CBF stocks will earn lower returns. Evidence shows that brown (green) stocks had lower (higher) returns, due to unexpected shifts in investors' preferences for green stocks (Pástor, Stambaugh, and Taylor 2022) and as climate attention or concerns increased (Choi, Gao, and Jiang 2020; Engle et al. 2020; Ardia et al. 2023). If growing concerns about biodiversity loss gradually shift investor preferences, then large-CBF stocks will see lower returns.

These channels compete against the null hypothesis that the CBF is unrelated to returns. This result may arise, first, because measuring and disclosing a firm's biodiversity impact is more complex and less well developed than measuring and disclosing the corporate carbon footprint. Second, whereas the personal experience of phenomena attributable to climate change affects investors' perceptions of the problem (Choi, Gao, and Jiang 2020; Di Giuli et al. 2022), such personal experience is less likely for signals of biodiversity loss, presumably leading to lower investor awareness. Third, even if investors have a sense of biodiversity harm, they are unlikely to price the CBF metric if they ignore impact materiality.

We examine the pricing of the CBF by regressing firms' monthly stock returns on their 1-year lagged CBF values (i.e., we relate 2019–2022 returns to 2018–2021 CBF values). We rely on a characteristics-based approach, which has the advantage of not requiring assumptions about the underlying asset pricing model. On average, we find no evidence that the CBF is related to returns between 2019 and 2022. However, we do find a relationship between the CBF and returns following major biodiversity-related policy changes, signifying that the biodiversity footprint had then started to be priced. In October 2021, the first part of the UN Biodiversity Conference (COP15) concluded with the Kunming Declaration (2021). Similar to the Paris Agreement, the Kunming Declaration calls for countries to act urgently to protect biodiversity by aligning financial flows to support its conservation and sustainable use. The event arguably increased both investor awareness about the loss of biodiversity and the prospect of, and uncertainty about, future biodiversity regulation or litigation. Between the Kunming Declaration and December 2022, a one-standard deviation higher log(CBF) value is associated with monthly returns that are 18.5 basis points higher (or 2.2 percent annualized).

We conduct an event study to examine closely whether and how investors revised their valuations of large-CBF stocks around the Kunming Declaration.[5] If the declaration raised investor awareness of biodiversity issues and the prospect of regulation aimed at preserving it, we would expect investors to revise downward their valuation of large-CBF stocks. Indeed, in the 3 days following the declaration, relative to the 3 days before, large-CBF stocks experienced a cumulative stock price decline of 1.14 percent, relative to small-CBF stocks.

The signing of the Kunming Declaration is a salient event, but this does not preclude the possibility that other events had similar effects. In fact, the launch of the TNFD on June 4, 2021 was another salient event that contributed to raising awareness of biodiversity issues and the associated transition risks (though the TNFD is primarily concerned with disclosure, it increases the odds of a firm being targeted by litigation on the basis of its disclosed information). In the 3 days following the TNFD launch, relative to the 3 days before, investors reduced their valuation of large-CBF stocks by 1.5 percent, relative to small-CBF stocks.[6]

How do these results align with the above-mentioned channels through which biodiversity and returns may be related? Our evidence suggests that investors have started to anticipate that new regulations or litigation will target large-CBF firms. The results of our event studies indicate that around relevant events (Kunming, TNFD), the stock prices of such firms were bid down; higher returns of large-CBF firms followed. Thus, consistent with Pástor and Veronesi (2012), the increase in policy uncertainty associated with these events leads to investors demanding a biodiversity footprint premium. To corroborate this interpretation, we demonstrate that the biodiversity footprint premium is larger in countries with low biodiversity protection; firms in such countries face greater transition risks, due to the prospect of future "catch-up" regulations. In sum, the CBF appears to reflect exposure to biodiversity transition risks, and our results reflect the pricing of such risks. Consistent with this interpretation, we demonstrate that large-CBF firms had higher implied costs of capital, a proxy for expected returns, after the Kunming Declaration.

By contrast, unexpectedly higher earnings or cash flows cannot explain our result patterns. First, we document that large-CBF firms do not experience greater earnings surprises in the post-Kunming years (and neither before Kunming). Second, unexpectedly high earnings or cash flows should be more likely in the months before Kunming; however, for this period we found non-significant return effects of the CBF. Our evidence is also hard to explain as being due to unexpected shifts in investor preferences, as this channel predicts large-CBF stocks would earn lower returns in the months after Kunming.

A potential concern is that our results are driven by the firms' carbon emissions, rather than by their broader impacts on biodiversity. Carbon emissions do negatively affect biodiversity, and do enter into the CBF computation. However, our results hold when controlling for carbon emissions and the proxy for regulatory climate change exposure from Sautner et al. (2023). They are also unchanged if we use an "emissions-free" CBF metric.

We contribute to a new literature on biodiversity finance. Closely related to our work is that of Giglio et al. (2023), who construct measures of U.S. firms' biodiversity risks from a

[5] The central declaration was made on October 13, 2021. Because the outcomes of the declaration were not determined beforehand, the event qualifies as a plausible shock to investors' expectations regarding the transition risks faced by firms with large biodiversity footprints. COP15 was marked by tense talks and a deep divide between wealthy and developing countries, which made the final agreements uncertain until the day of the announcement (Eihorn 2022; Mychasuk 2022).

[6] Given that the TNFD launch was only 4 months before the Kunming Declaration, we do not claim that October 2021, the month we used to split our sample for the cross-sectional returns tests, was a unique point defining a regime shift. We find similar results if we relate returns to the CBF for the period after June 2021 (instead of October 2021). We do not detect any differential return dynamics between large- and small-CBF firms around the Montreal Agreement, which constitutes the second part of COP15. This result indicates that this summit did not provide additional information regarding firms' exposures to transition risks (possibly as the outcomes were more widely anticipated, compared to the Kunming Agreement).

binary firm-level indicator for disclosures in 10-Ks. They then show that returns of portfolios sorted on the industry-average of those measures covary positively with biodiversity news. This approach complements ours in terms of methodology, focus, and sample. We study the relation of firm-specific monthly returns with the biodiversity footprint, and we also document how investors revised their valuation of large- versus small-CBF firms following two global biodiversity-related events. The key feature of the CBF is that it quantifies the impact of a firm on biodiversity, and it does so for an international sample. As we show, the vast majority of our sample firms, including those with large CBF values, do not disclose biodiversity information in their 10-Ks, and so would not appear in Giglio et al.'s (2023) sample of biodiversity risk-exposed US firms.

Both approaches are valuable. As explained by Cenedese, Han, and Kacperczyk (2023) for the case of climate risks, there are two principal ways of measuring biodiversity risks, one based on the actual footprint and another based on textual analysis. The first provides a quantitative link to a specific objective function, in this case, a firm's current impact on biodiversity; the benefit of the second approach is its forward-looking nature. The CBF quantifies exposure to biodiversity transition risk, but it is not forward-looking, that is, it does not take into account future efforts that may affect investor perceptions of a firm's biodiversity performance, such as whether the firm has set targets or taken strategic actions to reduce its footprint. Textual analysis of 10-Ks (or earnings calls), however, can often be used to identify a firm's willingness to take such actions. Further, while the CBF quantifies the impacts of a firm's activities on biodiversity, it does not provide information regarding physical risks from biodiversity loss; these, too, can potentially be captured from corporate text. A limitation of text-based approaches is that they rely on firms communicating or disclosing biodiversity information; currently only a minority of firms are found to do so, though this situation will likely change in the future.[7]

Several other studies on the pricing of biodiversity have been conducted recently. Hoepner et al. (2023) study 68 infrastructure firms to show that firms with better biodiversity risk management have more favorable financing conditions (lower credit default swap slopes). Xin et al. (2023) relate MSCI's biodiversity exposure and management scores to returns and operating performance, but find no relationships in their sample between 2013 and 2020. Coqueret, Giroux, and Zerbib (2024) find that US firms in sectors heavily depending on or impacting biodiversity display higher expected returns, with the effect emerging since 2021, consistent with our findings. Finally, there is also an emerging literature on the use of private capital to finance biodiversity conservation and restoration (see, e.g., Flammer, Giroux, and Heal 2023).

2. Biodiversity footprint: quantifying biodiversity loss

2.1 Biodiversity loss and MSA

The CBF was developed by IDL to provide investors with a science-based indicator to help them measure and manage their investments' impact on biodiversity. The CBF reflects the extent to which ecosystems affected by a firm's activities have been degraded from their pristine natural state. It aggregates the effects of multiple environmental pressures, such as land use, nitrogen deposition, emissions, or the release of toxic compounds, to quantify the biodiversity loss resulting from a firm's annual activities.

The CBF is based on the concept of MSA, which was proposed during the development of the GLOBIO3 model. The CBF methodology uses MSA because: (1) it offers the largest and most robust toolbox (in terms of damage functions) in the scientific literature; (2) it is a holistic approach that adapts well to appraising portfolios, unlike more microscopic indicators, which are better-fitted to project analysis; and (3) it is endorsed by the scientific

[7] Recent advances in textual analysis, relying on machine-learning approaches, hold some promise in terms of identifying how firms communicate biodiversity-relevant information (Schimanski et al. 2023).

community and multilateral organizations (e.g., CBD, IPBES, and IPCC) and recommended by the UN (Iceberg Data Lab 2023).

MSA measures the relative abundance of native species. An area with an MSA of 0 percent has completely lost its native biodiversity (or is exclusively colonized by invasive species), whereas one with an MSA of 100 percent is considered equal in biodiversity to an ecosystem undisturbed by human activities and pressures. Supplementary Appendix figure A1 provides an illustration of MSA variation for forests and grasslands, and Supplementary Appendix Section B provides a numerical example.

The CBF expresses a firm's negative impacts on biodiversity in terms of square kilometers of "artificialized" or "denatured" land (i.e., km^2.MSA). For example, a CBF of –100 km^2 means that 10 percent of the original biodiversity has been lost in an area of 1,000km^2 or that a proportionally smaller amount of biodiversity, 5 percent, has been lost in an area of 2,000km^2. In this article, we multiply the CBF scores by –1 so that higher values indicate a more negative impact on biodiversity.

2.2 From MSA to CBF

The CBF is calculated in three steps, which we summarize in this section. Supplementary Appendix Section C explains each step in more detail, drawing on an example from Danone. First, IDL assesses, by sector, the products and services bought and sold by a firm throughout its value chain.[8] This step is based on IDL's internal physical input/output model ("Wunderpus"), which is an enhanced proprietary version of EXIOBASE, a detailed multi-regional environmentally extended supply-use and input–output database. Second, IDL calculates the firm's environmental pressure, based on the flow of goods and services its business depends on. Using a life-cycle analysis, four forms of environmental pressure (land use, GHG emissions, air pollution, and water pollution) are individually calculated along the firm's entire value chain, including its processes, products, and supply chains. Third, IDL translates each of these estimated pressures, using pressure-impact functions, into a biodiversity impact unit expressed in km^2. MSA. Finally, IDL aggregates the four impacts into a single overall impact. Supplementary Appendix figure A2 illustrates the steps involved in the calculation of the CBF.[9]

2.3 CBF applications in practice

Major institutional investors, including BNP Paribas Asset Management, AXA Investment Managers, Robeco, and Mirova, use the CBF to measure the biodiversity impact of their investments. The data are also used by three biodiversity-related funds to screen and manage stocks (HSBC World Biodiversity Screened Equity ETF, Ossiam Food for Biodiversity ETF, and AXA IM ACT Biodiversity Equity ETF); Giglio et al. (2023) used these funds to build one of their biodiversity risk measures. In addition, IDL's biodiversity measurement approach is based on impact metrics recommended in the TNFD disclosure guidelines (Milleret 2023) and is listed in the Tools Catalogue of the TNFD (2023b).

2.4 Limitations of MSA and the CBF

The CBF comes with limitations, some of which stem from how MSA measures biodiversity loss. Finance for Biodiversity (2022), NGFS and INSPIRE (2022), and OECD (2023) discuss these limitations, and also mention other approaches used to measure a loss of biodiversity. In short, MSA does not allow the loss of an individual species, or class of species, to be tracked, and it treats all species as equally valuable, independent of whether they are

[8] IDL collects these activities on the "NACE4" level (which refers to a four-digit level of specificity within the European Union's statistical classification of economic activities), providing a relatively detailed view of the firm. NACE is similar to the North American Industry Classification System (NAICS).

[9] As shown in the figure, IDL also computes scaled versions of the CBF. For example, CBF Capital Employed is the CBF relative to the capital used by the firm. We compute such standardizations ourselves, using accounting data from Capital IQ/Compustat.

abundant or threatened. It does not account for an increase in a species, which is problematic, as an increase in abundance can have a stabilizing effect on an ecosystem, an idea often referred to as the insurance hypothesis (see, e.g., Yachi and Loreau 1999; Xu et al. 2021). MSA also does not allow for a comparison with the absolute number of species prevalent in an area. In addition, the ultimate quantity of interest, for both economic valuation and regulatory efforts, often is not a fall in MSA per se, but a reduction in ecosystem services. The CBF does not quantify or value the damage to these services. Furthermore, the reference points in the GLOBIO model, which constitutes a key element in the MSA calculation, are dated (going back to the 1990s), and limited information is available about the assumptions used to create the model. Some critics also argue that the GLOBIO model is biased toward the most studied species and ecosystems (Finance for Biodiversity 2022). Despite all these shortcomings, MSA provides a harmonized measure. Aggregating other, perhaps superior, specialized local indicators has proved to be too challenging so far.

Alternatives to MSA exist, with two that can be constructed for a large set of firms having received attention by investors and regulators. The first, the Potentially Disappeared Fraction of Species (PDF), is similar in spirit to MSA; it measures the fraction of species that are lost due to environmental pressures, such as land use or climate change, over a specified time frame on $1\,m^2$ land or $1\,m^3$ water. In value, PDF ranges between 0 percent (no species disappeared) and 100 percent (all species disappeared), but it does not reflect a decline in the population of a given species.[10] The second metric, Species Threat Abatement and Restoration (STAR), contains two components. The threat abatement component measures the risk of extinction in a specific area, calculated as the sum of the risks weighted by the species' threat status. The calculation excludes species for which extinction is not a concern. The second component indicates the potential for restoration.[11]

The CBF has an additional shortcoming when MSA is applied in a corporate context. Notably, because of limited data availability, a large part of the CBF calculation is based on sector averages and estimates, rather than on granular, firm-specific information. Finally, the CBF does not yet capture soil degradation or invasive species, and only partially captures the impact on freshwater and marine biodiversity. Despite these limitations, according to Finance for Biodiversity (2022), the CBF is the only currently available impact measure on a firm level that seeks to cover scope 3 downstream impacts.

2.5 Climate transition risks and the CBF

Biodiversity loss and climate change are interrelated (CBD Secretariat 2016), making it important to address the potentially confounding effects of carbon emissions on the CBF both conceptually and empirically. Climate change, which is generated by GHG emissions (primarily carbon), negatively affects biodiversity. There is also a reverse effect, as the loss of the biodiversity needed for natural carbon sinks in oceans, vegetation, and soils to function, for example, accentuates climate change.

While a firm's carbon footprint and its biodiversity footprint are positively correlated, there are also fundamental differences, and even conflicts, between the two environmental concepts. Efforts by firms to lower their carbon emissions (e.g., to achieve net-zero targets) may lead to more loss of biodiversity (e.g., Paulson 2023). For example, many solar farms are being built on forested land, negatively impacting natural ecosystems and habitats. Likewise, expanding renewable energy and the use of electric cars requires an increased

[10] Data providers have started to offer PDF-based metrics, usually in combination with MSA. ISS ESG launched one in 2022Q3, and MSCI is planning to introduce one in 2024. To our knowledge, these databases do not (yet) contain historical data, but primarily include data for the most recent year.

[11] In 2023, S&P started offering a Nature and Biodiversity Risk Profile utilizing the STAR method. Other metrics with more limited scope also exist (for an overview table, see Finance for Biodiversity 2022). The Biodiversity Intactness Index (BII) reflects changes due to land use (relative to a reference state). The Biodiversity Impact Metric (BIM) builds on MSA, but focuses only on a firm's supply chain. The use of geospatial, satellite, or acoustic data to measure biodiversity loss, combined with data on a firm's locations, may lead to alternative firm-level metrics.

supply of metals, such as lithium and cobalt; the mining and extraction of these metals have severe impacts on biodiversity.[12]

As we show below, empirically, the principal component of the CBF is land use, which indicates that a firm's biodiversity footprint is not identical to its carbon footprint. However, in light of the conceptual links between biodiversity loss and carbon emissions, we document that our results are robust when we account for a firm's carbon footprint.

3. Data, summary statistics, and sample selection

3.1 Data sources and sample construction

Our sample construction starts with all 2,724 publicly listed firms for which CBF data are available from IDL between 2018 and 2021, and for which a match in Compustat/CRSP exists. We drop 480 firms with missing monthly returns or control variables, or with negative total assets or book equity values; 60 firms from sixteen countries with fewer than ten firms (the minimum number required for our cross-country analysis); and 78 firms from two countries with missing data on biodiversity protection (Bermuda and the Cayman Islands). These data filters provide us with a final sample of 2,106 firms across 34 countries. The returns analysis relates annual CBF data for these firms to monthly returns from 2019 through 2022, resulting in a panel of 89,132 firm–month observations.[13] As the CBF is highly skewed, we use Ln(CBF) in most tests. The majority of sample firms are members of the MSCI All Country World Index (MSCI ACWI), the universe that IDL seeks to cover.

Data on firm-level carbon emissions (CO_2 Emissions) are from Trucost; we use the sum of scope 1, 2, and 3 emissions, as the CBF includes corresponding scope 1, 2, and 3 components. Data on regulatory climate change exposure ($CCExposure^{Reg}$) are from Sautner et al. (2023).[14] The correlation between Ln(CO_2 Emissions) and Ln(CBF) is 0.60, and that between $CCExposure^{Reg}$ and Ln(CBF) is 0.20. Accounting and stock price data are from Compustat, data on E scores are from Refinitiv, and country-level data on biodiversity protection are from Yale University. Appendix A defines all variables.

3.2 Descriptive statistics of the CBF

Table 1 reports summary statistics of the CBF. The mean (median) value of Ln(CBF) is 4.79 (5.28), indicating that the average (median) firm has a biodiversity impact corresponding to the complete loss of biodiversity over an area of 120.3 km^2 (196.4 km^2).

In figure 1, Panel A, we decompose the CBF into its four sources: (1) land use, (2) GHG emissions, (3) water pollution, and (4) air pollution. The greatest impact on biodiversity originates from land use (49 percent of the CBF), followed by GHG emissions (22.5 percent), water pollution (20 percent), and air pollution (8.5 percent). In figure 1, Panel B, we decompose the CBF into its scope 1 to 3 dimensions. Scope 3 contributes about 79 percent to the CBF value, while scope 1 and scope 2 account for, on average, 15 percent and 6 percent, respectively. Scope 3 dominates, because most large firms either assemble and distribute products or provide services, and so do not directly impact the environment; for such firms (retailers, banks, or tech firms), the majority of the scope 3 footprint originates from activities upstream (e.g., provision of farmland or extraction of raw materials) or downstream (usage of products by clients, or financing activities by banks).[15]

12 Beyond these specific examples, Giglio et al. (2023) show that an aggregate biodiversity index behaves differently from an aggregate climate news index (Engle et al. 2020), suggesting that periods of high media coverage of biodiversity issues differ from periods of high media coverage of climate change issues.

13 For some firms in our sample, CBF data are missing in some years (especially 2021). We fill forward these missing CBF values, increasing our firm–month observations by 20 percent, from 66,890 to 89,132; our results do not depend on this choice.

14 Data on CO_2 Emissions (on $CCExposure^{Reg}$) are available for 99 percent (59 percent) of the observations entering our returns analysis.

15 Supplementary Appendix Table A1 reports additional summary statistics on the CBF decomposition.

Table 1. Summary statistics.

Note: This table presents summary statistics at the firm–month level of the variables used in the returns analysis. The sample period uses returns from 2019 to 2022. The CBF, accounting, ESG, and CO_2 Emission variables are measured at an annual frequency and lagged by 1 year. Market capitalization, volatility, and momentum are measured at a monthly frequency and lagged by 1 month. Appendix A provides variable definitions.

Variables	#Obs.	Mean	S.D.	Min	25%	50%	75%	Max
Ln(CBF)	89,132	4.79	3.11	−9.25	3.17	5.28	7.01	13.78
Ln(CBF GHG)	89,132	2.27	2.97	−12.33	0.24	2.51	4.42	10.08
Ln(CBF land use)	88,820	3.60	3.56	−15.88	1.75	4.10	6.06	13.77
Ln(CBF water pollution)	89,132	1.37	4.27	−15.53	−1.15	2.21	4.40	11.34
Ln(CBF air pollution)	89,132	1.47	3.29	−13.47	−0.39	1.96	3.71	9.12
Ln(CBF scope 1)	89,012	0.88	3.82	−12.69	−2.03	0.98	3.81	13.77
Ln(CBF scope 2)	88,856	−4.54	5.51	−30.77	−8.70	−3.18	−0.15	6.57
Ln(CBF scope 3)	89,120	4.36	3.45	−11.26	2.78	5.01	6.78	12.11
Ln(CBF/Total assets)	89,132	−4.34	2.73	−11.28	−5.50	−3.86	−2.45	0.10
Ln(CBF/Sales)	89,108	−3.75	2.61	−10.21	−4.88	−3.17	−1.90	0.30
Monthly return (%)	89,132	1.18	10.53	−25.63	−5.28	0.81	7.02	34.40
Monthly ICC (%)	52,315	0.93	0.63	0.00	0.50	0.79	1.21	3.86
Volatility (%)	89,132	0.10	0.04	0.04	0.07	0.09	0.12	0.24
Momentum (%)	89,132	0.01	0.04	−0.05	−0.01	0.01	0.03	0.19
Ln(Total assets)	89,132	9.15	1.47	5.83	8.13	9.10	10.09	12.93
Ln(Market cap)	89,132	23.46	1.40	20.19	22.51	23.33	24.33	27.25
Book-to-market	89,132	0.42	0.57	0.01	0.12	0.24	0.49	3.87
Leverage	89,132	0.26	0.17	0.00	0.13	0.26	0.38	0.69
Capex/Total assets	89,132	0.04	0.03	0.00	0.01	0.03	0.05	0.18
ROA	89,132	0.06	0.06	−0.14	0.02	0.05	0.09	0.27
PPE/Total assets	89,132	0.28	0.22	0.00	0.10	0.23	0.43	0.86
Asset growth	89,132	0.13	0.25	−0.19	0.00	0.07	0.16	1.56
Sales growth	89,132	0.10	0.23	−0.45	−0.02	0.06	0.17	1.14
E score	84,074	53.09	26.98	0.00	33.48	57.45	75.32	99.09
Ln(CO_2 Emissions)	88,113	14.08	1.93	9.48	12.75	14.04	15.44	18.48
$CCExposure^{Reg}$	45,266	0.16	0.39	0.00	0.00	0.00	0.13	5.93

In Table 2, Panel A, we present a ranking of industries, using the overall CBF, as well as source- and scope-based measures. The industries with the highest average CBF values are Retail and Wholesale, Paper and Forest, and Food, consistent either with their intensive land use (mostly indirectly through their supply chains in the case of, for example, food or fashion retailers) or their toxic emissions into air and water. These industries are followed by Asset Management, with scope 3 biodiversity harm (indirectly through financing) being the major component of the sector's overall footprint. Firms with large scope 1 footprints, that is, with business models that have a large direct effect on local biodiversity, tend to operate in the Paper and Forest or Metals and Mining sectors.[16]

In Table 2, Panel B, we present a ranking of countries, again using the overall CBF, as well as source- and scope-based measures. The top five countries with the highest average CBF values are Brazil, Finland, Saudi Arabia, Germany, and Canada.[17]

[16] In Supplementary Appendix Table A2, we replace the industry ranking with industry-average proportions of each CBF source or scope. For instance, for the Waste industry, scope 1 accounts for 78.3 percent of the total CBF, whereas in Asset Management, scope 3 accounts for 99.9 percent. Chemicals and Metal & Mining impact biodiversity mainly via the release of toxic compounds and through land use. The impact of air pollution is strongest for Transportation. In the Food, Beverages, Paper and Forest, and Tobacco sectors, land use contributes about 90 percent to the CBF.

[17] In Supplementary Appendix Table A3, we do not observe a large variation across countries, in terms of the CBF decompositions.

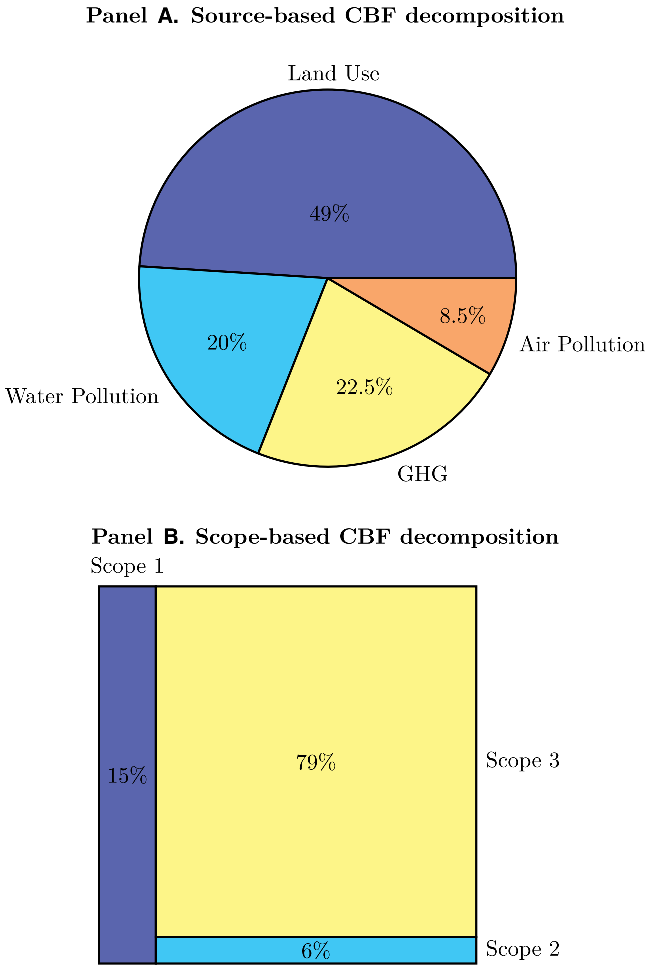

Figure 1. Decomposition of the CBF.

Note: The CBF reflects the biodiversity loss caused by a firm's annual activities. Panel A decomposes the CBF into its constituent topical sources. Panel B decomposes the CBF into its scope 1, scope 2, and scope 3 dimensions. Scope 1 measures the environmental pressure of the firm's direct activities; scope 2 measures the pressures induced by the firm's purchase of electricity, heat, and cooling; and scope 3 measures all indirect pressures.

3.3 Sample selection concerns

Our sample departs from the MSCI ACWI for two reasons. First, IDL expanded its coverage to some U.S., European, and Chinese firms outside of the index. As mentioned, the initial IDL data include 2,724 firms with a Compustat match. While 72 percent or 1,954 of these firms belong to the MSCI ACWI, 28 percent or 770 firms are from outside of the index (conversely, about 72 percent of all MSCI ACWI firms are covered by IDL). Second, the data requirements described in Section 3.1 lead to further deviations from the MSCI ACWI. As a result, our final sample of 2,106 firms includes 70 percent or 1,477 firms from the MSCI ACWI and 30 percent or 629 firms from outside of the index. For comparison, the ACWI universe from 2017 to 2022 contains 2,642 firms. Supplementary Appendix Section D analyzes the determinants of IDL's data coverage. As we detect some observable differences between covered and non-covered MSCI firms, we verify below that our results hold if we restrict the sample to firms in the MSCI ACWI.

Table 2. The CBF: rankings by industry and country.

Note: This table reports rankings of the CBF across industries (Panel A) and countries (Panel B) (reported vertically). The different CBF measures are reported horizontally. Lower rank values indicate larger biodiversity footprints. The rankings are based on mean values across all firms in an industry or country, whereby the most recent value per firm is considered. IDL's industry classification is similar to the Revere Business Industry Classification System (RBICS). Appendix A provides variable definitions.

Panel A. Rankings by industry

	Ln(CBF)	Ln(CBF/TA)	Ln(CBF/Sales)	Ln(CBF air poll.)	Ln(CBF GHG)	Ln(CBF land use)	Ln(CBF water poll.)	Ln(CBF scope 1)	Ln(CBF scope 2)	Ln(CBF scope 3)
Asset Management	4	30	35	11	7	5	6	33	34	4
Automotive and Logistics	18	21	18	6	4	16	21	19	14	17
Beverages	15	27	29	25	27	10	25	24	22	15
Building Products	26	18	17	23	22	26	20	17	17	26
Chemicals	9	29	27	16	18	13	3	14	7	9
Construction and Real Estate	20	13	15	4	17	17	17	6	21	22
Defense	13	14	12	9	6	27	4	30	29	13
Education	35	8	7	35	35	35	35	34	35	35
Electrical Equipment	8	31	32	2	2	20	5	18	23	7
Electronics	24	12	10	20	15	23	19	23	18	24
Financial Services	7	6	9	14	11	6	7	35	24	6
Food	3	35	33	13	16	4	10	10	15	3
Healthcare	25	16	16	26	29	21	14	26	26	25
Hotel and Accommodation	21	22	28	19	20	15	18	20	6	19
Household Goods	17	19	14	10	14	1	16	4	16	18
Industrial Equipment	22	20	19	15	9	28	9	22	32	20
Insurance	14	7	6	17	13	11	8	8	27	14
Internet and Data	31	4	5	28	21	29	28	27	13	29
Leisure	27	10	11	30	31	24	29	21	31	28
Materials	16	26	26	12	8	12	30	7	4	16
Media	33	5	4	32	32	34	26	32	20	31
Metals and Mining	6	32	30	3	3	14	1	3	3	8
Oil and Gas	5	24	24	1	1	9	11	2	5	5
Paper and Forest	2	34	34	22	24	3	23	1	11	2
Pharmaceutical	10	23	22	21	23	18	2	16	33	10
Power	19	15	21	8	5	19	12	5	2	23

(continued)

Table 2. (continued)

Panel A. Rankings by industry

	Ln(CBF)	Ln(CBF/TA)	Ln(CBF/Sales)	Ln(CBF air poll.)	Ln(CBF GHG)	Ln(CBF land use)	Ln(CBF water poll.)	Ln(CBF scope 1)	Ln(CBF scope 2)	Ln(CBF scope 3)
Retail and Wholesale	1	33	31	5	10	2	22	11	1	1
Services	34	3	3	34	33	33	32	28	25	32
Software	28	2	1	27	34	32	13	31	30	27
Telecommunications	32	1	2	33	30	31	31	29	9	30
Textiles	12	28	23	18	25	8	27	9	28	12
Tobacco	11	25	25	31	26	7	24	25	19	11
Transportation	23	17	20	7	12	22	15	15	8	21
Waste	30	9	8	29	19	30	33	13	10	34
Water	29	11	13	24	28	25	34	12	12	33

Panel B. Rankings by country/region

	Ln(CBF)	Ln(CBF/TA)	Ln(CBF/Sales)	Ln(CBF air poll.)	Ln(CBF GHG)	Ln(CBF land use)	Ln(CBF water poll.)	Ln(CBF scope 1)	Ln(CBF scope 2)	Ln(CBF scope 3)
Australia	26	15	18	21	20	25	19	18	11	27
Belgium	15	16	17	33	32	11	15	26	23	15
Brazil	1	32	31	12	19	2	30	1	18	3
Canada	5	14	21	6	8	7	4	8	21	5
China	12	23	24	4	6	13	11	14	6	11
Denmark	31	28	27	14	33	1	24	32	8	30
Finland	2	29	26	22	3	3	27	3	27	1
France	13	8	7	3	9	15	14	11	3	14
Germany	4	12	11	17	4	14	1	20	7	4
Hong Kong	29	7	10	16	10	30	25	22	1	29
India	24	26	23	5	12	27	9	13	26	25
Indonesia	19	30	29	13	15	17	21	21	24	19
Ireland	28	10	5	27	18	24	26	29	31	26
Israel	34	2	2	34	34	33	34	34	34	34
Italy	27	4	6	15	5	28	29	16	30	28
Japan	20	18	13	19	14	23	6	23	9	18

(continued)

Table 2. (continued)

Panel B. Rankings by country/region	Ln(CBF)	Ln(CBF/TA)	Ln(CBF/Sales)	Ln(CBF air poll.)	Ln(CBF GHG)	Ln(CBF land use)	Ln(CBF water poll.)	Ln(CBF scope 1)	Ln(CBF scope 2)	Ln(CBF scope 3)
Korea	22	21	19	7	11	22	16	12	13	21
Malaysia	30	25	28	10	28	26	33	15	12	31
Mexico	18	22	22	26	24	20	8	5	5	23
The Netherlands	17	3	1	9	23	16	17	30	29	17
Norway	33	6	8	23	22	32	22	24	28	33
Philippines	9	31	34	24	25	5	31	27	20	7
Poland	7	24	20	2	2	12	18	4	25	10
Saudi Arabia	3	19	25	1	1	4	13	2	2	2
Singapore	14	1	4	28	30	10	32	33	17	12
South Africa	21	34	33	8	21	21	12	6	4	24
Spain	11	11	15	18	13	29	2	10	19	13
Sweden	25	20	16	31	31	18	20	19	32	22
Switzerland	16	13	12	30	27	19	5	28	16	16
Taiwan	23	5	3	32	26	34	3	31	22	20
Thailand	10	27	32	11	7	9	28	9	15	9
Turkey	32	33	30	29	29	31	23	25	33	32
UK	8	17	14	25	17	8	10	7	14	8
USA	6	9	9	20	16	6	7	17	10	6

4. Biodiversity footprint: validation and determinants

4.1 Nature Action 100 (NA100) targets and the CBF

Reliability and transparency are critical whenever a new measure is introduced to the literature. To this end, we conduct several validations of the CBF. As an outside validation, we test whether a firm's CBF relates to it being targeted by Nature Action 100 (NA100). Similar to Climate Action 100+, NA100 is an institutional investor initiative that has identified 100 firms, across eight sectors, to engage with in order to tackle biodiversity and nature loss.[18] To identify its targets, NA100 used four principles: (1) the firm operates in a sector deemed to be systemically important to reversing nature loss; (2) an analysis conducted by the Finance for Biodiversity Foundation indicates the firm has a high potential impact on nature; (3) the firm has a large market capitalization (within its sector); and (4) the firm is from a developed or emerging market. NA100 was launched at COP15 and is supported by 200 institutions, representing $27 trillion in assets under management or advice as of 2023.

We calculate that the mean value of Ln(CBF) is twice as large for NA100 targets, compared to non-targeted firms (8.76 versus 4.63, significantly different at the 1 percent level). If we use CBF/Total assets, then the difference is even greater, with NA100 targets having CBF intensities that are more than four times larger. Further, the majority of NA100 targets are in the top percentiles of the CBF distribution: In figure 2, more than 50 percent of the NA100 targets are located in the top 10 percent of the CBF distribution (Panel A), and 69 percent in the top 20 percent (Panel B).[19] We conclude that there is a correspondence between the CBF and the set of priority targets with which institutional investors are engaging to address biodiversity loss.

4.2 Textual analysis of corporate disclosures and the CBF

4.2.1 Corporate annual reports and the CBF

While acknowledging that the CBF and the textual analysis of corporate annual reports have different objectives, we borrow the method of Giglio et al. (2023) to further validate the CBF. Giglio et al. (2023) develop a biodiversity dictionary and use it to create an indicator that equals one if a 10-K contains at least two sentences related to terms that reflect biodiversity issues (e.g., biodiversity, ecosystem(s), habitat(s), species, (rain)forest(s), deforestation, aquatic, desertification, or carbon). Their data indicate that only 3.8 percent of 10-K reports from 2015 through 2020 mention biodiversity issues. That number is 3.3 percent for our US-listed sample firms, from 2018 through 2020. Using these data, we calculate that our CBF metric exhibits a modest positive correlation of 9.7 percent with their 10-K measure.[20] More importantly, figure 3 shows the CBF distribution for firms which do and do not mention biodiversity terms in their 10-K filings. While, on average, firms that do mention biodiversity have higher CBF values, there is a significant overlap of the two distributions. This result means that many firms without 10-K biodiversity disclosures have higher CBFs than firms with such disclosures.

In Supplementary Appendix Section E, we provide case study excerpts to show how biodiversity issues are discussed in corporate annual reports. We focus on Danone, which ranks among the sample firms with the largest CBF, is a target of NA100, and is used in Supplementary Appendix Section C to illustrate the CBF calculation. Danone is an exception in how extensively it discusses biodiversity issues. Its annual reports explain how food

[18] The eight sectors are biotechnology and pharmaceuticals; chemicals; household and personal goods; consumer goods retail, including e-commerce and specialty retailers and distributors; food; food and beverage retail; forestry and packaging; and metals and mining. The target list, released on June 26, 2023, is provided here. It includes such firms as Bayer, Danone, Glencore, Home Depot, Nestlé, Procter & Gamble, and Rio Tinto.

[19] The fact that NA100 focuses on only eight sectors explains why some large-CBF firms in our sample are not on their target list. The two firms in the third CBF decile, in Panel A, are Charoen Pokphand Indonesia, a poultry processer, and the US veterinary drug producer Zoetis.

[20] Consistent with 10-Ks emphasizing direct biodiversity impacts, the 10-K-based measures exhibit stronger correlations with the scope 1 component of the CBF than with the scope 2 and 3 ones (Supplementary Appendix Table A17).

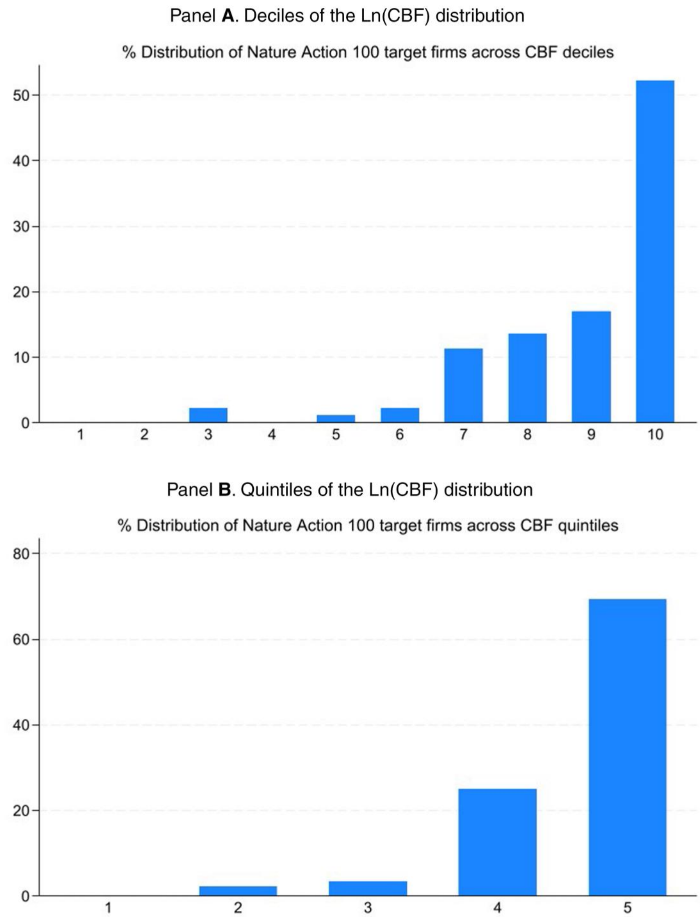

Figure 2. The CBF and Nature Action 100 targets.

Note: This figure reports the presence of Nature Action 100 target firms across deciles (Panel A) and quintiles (Panel B) of the Ln(CBF) distribution. The CBF reflects the biodiversity loss caused by the firm's annual activities. For each firm, we consider the latest observation in our sample to construct the distribution. We restrict our sample in the figures to industries covered by Nature Action 100.

production and farming depend on biodiversity and that the firm strives to protect and restore it.

4.2.2 Earnings conference calls and the CBF

Similarly, we perform a textual analysis of earnings calls to explore whether firms disclose more on biodiversity when interacting with analysts. Earnings calls are key corporate events, in which financial analysts listen to management and ask questions about a firm's current and future developments. One benefit of earnings calls is that they are available for firms outside of the USA. We collect earnings call transcripts from Refinitiv Street Events from 2019 through 2022, and identify the relevant text using the biodiversity dictionary of Giglio et al. (2023).

We again find that biodiversity is mentioned only rarely, making a text-based validation exercise challenging: just 5.0 percent of the quarterly calls in our sample contain at least one biodiversity term. For 2021, in almost 94 percent of the earnings calls of NA100 targets, there is

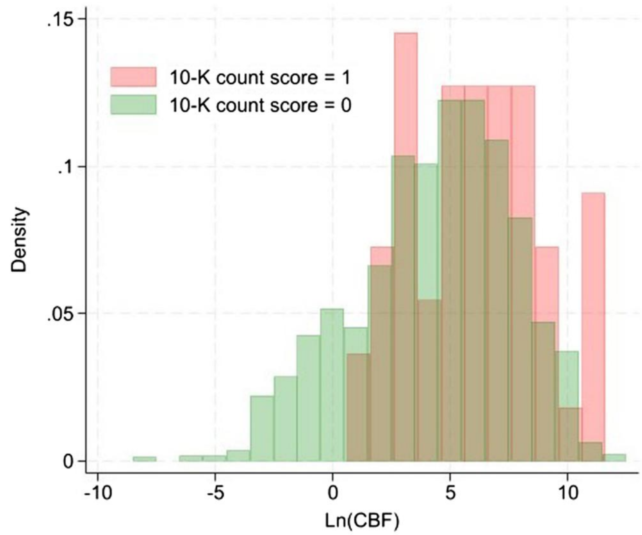

Figure 3. The CBF and biodiversity terms in 10-Ks.

Note: This figure displays the CBF distribution for firms with and without disclosure of biodiversity terms in their 10-K reports. The measure of biodiversity disclosure is based on Giglio et al.'s (2023) variable "10-K Biodiversity Count Score."

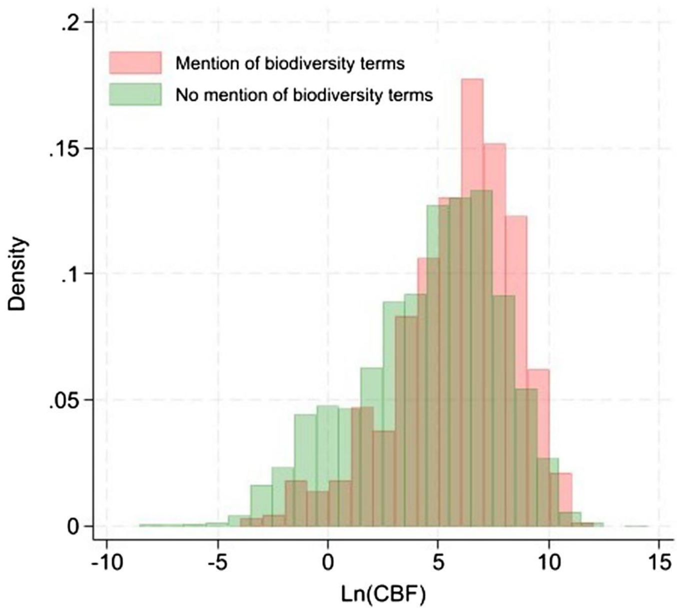

Figure 4. The CBF and biodiversity terms in earnings calls.

Note: This figure displays the CBF distribution for firms with and without mentions of biodiversity terms in their earnings calls.

no mention of biodiversity. Unsurprisingly, the correlation between the CBF and the (yearly average) number of biodiversity terms in earnings calls is also just 8.8 percent. This low correlation provides some insights into the challenges of using textual analysis to identify biodiversity transition risks. Figure 4 shows the CBF distribution for firms with and without mentions of biodiversity terms in their earnings calls. Notably, the low correlation is the result of many large-CBF firms not discussing any biodiversity-related issues in their earnings calls. The significant overlap between the distributions in the figure further indicates that many firms that do not mention biodiversity have *higher* CBF values than those that do.

With these limitations in mind, Supplementary Appendix Section E provides—as case studies—excerpts from earnings calls that discuss biodiversity issues. The examples come from Archer-Daniels-Midland (AMD), a food processing and commodities trading firm, and Sysco, a firm active in the marketing and distribution of food products (among others). Both firms score high in the CBF metric (top 1 percent of the sample) and are on the NA100 list. AMD explains how it has accelerated the deadline for a deforestation-free supply chain from 2030 to 2025, and Sysco emphasizes how it has improved sustainable grazing across 1 million acres of grassland.

4.2.3 Interpretation of text-based evidence

That simple text-based biodiversity measures overlap poorly with the biodiversity footprint is remarkable from an investor or regulatory perspective. Many firms with a large negative impact on biodiversity appear to not address the associated transition risks in their corporate reports and earnings calls, and analysts do not probe them on these risks. More advanced natural language processing techniques may be able to pick up more variation in biodiversity-related discussions among firms (Schimanski et al. 2023). Moreover, in the near future, investor demand for biodiversity disclosure will likely grow; biodiversity topics, even when measured simply, should in turn become more prominent in earnings calls and 10-Ks.[21]

4.3 Firm-level determinants

We examine firm-level drivers of the CBF by estimating the following regression for firm i in year t:

$$\text{Ln(CBF)}_{i,t} = \beta_0 + \beta_1 \mathbf{X}_{i,t} + \gamma_t + \delta_c + \mu_j + \varepsilon_{i,t}, \tag{1}$$

where $\text{Ln(CBF)}_{i,t}$ is the natural logarithm of the CBF (in km^2.MSA). The vector $\mathbf{X}_{i,t}$ contains various firm characteristics. We include different sets of fixed effects, capturing year (γ_t), country (δ_c), and industry (μ_j) dimensions, and fixed effects at the country-by-year ($\delta_c \times \gamma_t$) or industry-by-year ($\mu_j \times \gamma_t$) level. Standard errors are clustered at the firm level.

Table 3 presents the estimations of Equation (1). Firm size positively relates to the biodiversity footprint, which is plausible, as the CBF metric reflects the loss of biodiversity caused by a firm's activities in km^2.MSA; larger firms typically have a larger spatial impact. Firms with greater asset tangibility (PPE over assets) also have a larger footprint, which is again intuitive, given that the main CBF source is land use (firms with more tangible assets likely contribute more to the degradation of biodiversity). Consistent with Bolton and Kacperczyk (2021) for carbon emissions, the biodiversity impact is smaller for firms with higher capex. Firms with higher carbon emissions also have larger biodiversity footprints, in part because emissions are one of the pressures considered in the CBF computation. Finally, firms with better Refinitiv E scores have worse biodiversity footprints.[22] An unreported variance decomposition, assessing the relative contributions of the fixed effects in

[21] According to the head of Schroders, reporting on biodiversity is where reporting on climate change was 5–10 years ago (Agnew 2022). Ilhan et al. (2023) show that institutional investors currently value and demand climate risk disclosures.

[22] This result indicates that it may be misleading to rely on aggregate E scores, when seeking to incorporate biodiversity into investment decisions, as a negative biodiversity impact does not necessarily translate into a lower E score. One reason is that most ESG raters, including Refinitiv, focus on aspects that are financially material to shareholder value, rather than impact materiality.

Table 3. Determinants of the CBF.

Note: This table reports regressions relating annual values of Ln(CBF) to firm characteristics. The data frequency is yearly, and the sample period is from 2018 to 2021. Ln(CBF) is measured in year *t*, and firm characteristics in year *t*. The CBF reflects the biodiversity loss caused by the firm's annual activities. Standard errors are clustered at the firm level. Intercepts are not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01, respectively. Appendix A provides variable definitions.

	Ln(CBF)					
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Total assets)	0.851***	0.629***	−0.033	0.663***	0.661***	0.662***
	(0.045)	(0.052)	(0.066)	(0.063)	(0.063)	(0.063)
Book-to-market	−0.106	−0.046	−0.164*	−0.058	−0.064	−0.063
	(0.099)	(0.095)	(0.089)	(0.073)	(0.074)	(0.074)
Leverage	−1.045***	−1.425***	−1.652***	−1.245***	−1.264***	−1.262***
	(0.402)	(0.389)	(0.364)	(0.299)	(0.302)	(0.302)
Capex/Total assets	−9.027***	−9.692***	−10.274***	−4.162***	−4.196***	−4.077***
	(2.059)	(2.064)	(1.795)	(1.331)	(1.353)	(1.342)
PPE/Total assets	3.983***	3.807***	1.256***	−0.025	−0.023	−0.041
	(0.317)	(0.312)	(0.313)	(0.270)	(0.274)	(0.273)
ROA	1.835*	0.901	−1.335	−0.527	−0.522	−0.587
	(0.938)	(0.949)	(0.861)	(0.671)	(0.687)	(0.682)
Asset growth	−0.784***	−0.589***	−0.069	−0.324***	−0.319***	−0.326***
	(0.168)	(0.165)	(0.148)	(0.107)	(0.109)	(0.108)
Sales growth	−0.011	0.133	0.001	−0.086	−0.089	−0.077
	(0.186)	(0.172)	(0.157)	(0.116)	(0.129)	(0.122)
E score		0.027***	0.011***	0.004*	0.004*	0.004**
		(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Ln(CO_2 Emissions)			0.933***	0.352***	0.354***	0.354***
			(0.048)	(0.048)	(0.048)	(0.048)
Year fixed effects	Yes	Yes	Yes	Yes	No	No
Country fixed effects	Yes	Yes	Yes	Yes	Yes	No
Industry fixed effects	No	No	No	Yes	No	Yes
Country×year fixed effects	No	No	No	No	No	Yes
Industry×year fixed effects	No	No	No	No	Yes	No
#Obs.	7,489	7,059	6,996	6,996	6,996	6,996
R^2	0.243	0.278	0.403	0.630	0.633	0.632

the table, shows that more than half of the CBF variation plays out at the firm level (though there is a sizeable industry component).

5. Cross-section of returns

5.1 Estimation design: cross-sectional regressions

In this section, we rely on cross-sectional regressions relating individual firms' returns to their CBF values. As in Bolton and Kacperczyk (2023), we employ a characteristic-based approach, rather than a factor-based model, which is well suited, given the rich cross-sectional variation in firm characteristics in our sample. With a characteristics-based approach, there is no need to make assumptions about the underlying asset pricing model.[23]

[23] As explained by Bolton and Kacperczyk (2023), a conceptual difficulty with the choice of asset pricing model, in the context of a complex pricing problem such as climate risks, is that no such model has yet been formulated. The same argument applies in our setting, especially since biodiversity risks have received less attention than climate risks.

We link the return of firm i in month m of year t to its corresponding biodiversity footprint in year $t-1$:

$$\text{Monthly return}_{i,m,t} = \beta_0 + \beta_1 \text{Ln(CBF)}_{i,t-1} + \beta_2 \mathbf{X}_{i,t-1} + \gamma_t + \delta_c + \mu_j + \varepsilon_{i,m,t}, \quad (2)$$

where Monthly $\text{return}_{i,m,t}$ is the return of firm i in month m of year t, and $\text{Ln(CBF)}_{i,t-1}$ is the natural logarithm of the biodiversity footprint of firm i in year t–1. We control for various firm characteristics, following prior studies on the asset pricing implications of environmental externalities (e.g., Bolton and Kacperczyk 2023; Hsu, Li, and Tsou 2023). Specifically, $\mathbf{X}_{i,t-1}$ includes Ln(Total assets) (annual), Ln(Market cap) (monthly), Book-to-market (monthly), Leverage, Capex/Total assets, PPE/Total assets, ROA, Asset growth, Sales growth (all annual), as well as Volatility and Momentum (both monthly). Annual (monthly) variables are lagged by one year (month). We control for year–month, industry, and country fixed effects, and double cluster standard errors at the year–month and firm level.

5.2 The CBF and the cross-section of returns: baseline results

Table 4, Column 1, reports the results of estimating Equation (2) with time, country, and industry fixed effects across the full sample period, using monthly returns between January 2019 and December 2022. While the coefficient on Ln(CBF) is positive, it is not statistically significant. Hence, on average, a larger biodiversity footprint is *not* associated with higher (or lower) returns. In Column 2, this average non-result holds when we account for time-varying unobserved heterogeneity at the industry level (with industry-by-time fixed effects).

Investors may start considering the risks associated with a firm's biodiversity footprint in response to important policy-related news that increased regulatory or legal uncertainty. Particularly relevant is the Kunming Declaration, which—together with the subsequent Montreal Agreement—has been hailed as the biodiversity equivalent of the climate-focused Paris Agreement. The Kunming Declaration was adopted at the 15th Conference of the Parties of the CBD (COP15) in October 2021.[24] More than 100 countries committed to developing, adopting, and implementing an effective global framework to put biodiversity on a path to recovery by 2030. Analogous to the Paris Agreement, the Declaration stresses the need to align financial flows in support of the conservation and sustainable use of biodiversity. COP15 is seen as the most important UN event of the decade related to biodiversity (CBD Secretariat 2021).

The commitments into which countries entered at COP15 have far-reaching consequences for firms, by triggering (or accelerating) biodiversity-related regulation and litigation.[25] For example, the EU Deforestation Regulation (EUDR), which came into effect in 2023, puts pressure on food companies by banning food products (cattle, cocoa, coffee, oil palm, soy, wood, and rubber) linked to deforestation and forest degradation. This regulation comes with substantial compliance costs (tracing the origin of products), and potentially high fines and reputational costs in case of violation; importantly, the extent of these costs is highly uncertain. Further, the proposed EU Nature Restoration Law aims to restore nature on 20 percent of the EU territory (among other goals), which can only be achieved if biodiversity-negative corporate activities are restricted or taxed.

Motivated by the significance of the Kunming Declaration, in Table 4, Columns 3–6, we split stock returns into two periods: from January 2019 to September 2021 (pre-Kunming period) and from October 2021 to December 2022 (post-Kunming period). In Columns

[24] Supplementary Appendix Section F provides a historical overview of global and regional policy developments and initiatives.

[25] While the COP15 agreements are not legally binding, the signatory countries committed to demonstrating progress toward meeting the agreed-upon targets. Similar to the Nationally Determined Contributions (NDCs) under the Paris Agreement, COP15 led to National Biodiversity Strategy and Action Plans (NBSAPs) on which countries need to provide updates.

Table 4. The CBF and stock returns.

Note: This table reports regressions relating monthly stock returns to Ln(CBF). The CBF reflects the biodiversity loss caused by the firm's annual activities. The sample period in Columns 1–2 includes monthly returns over the full sample period, from January 2019 to December 2022; that in Columns 3–4 includes monthly returns from January 2019 to September 2021 (COP15 in Kunming started in October 2021); and that in Columns 5–6 includes monthly returns from October 2021 to December 2022. Ln(CBF) is measured as of the end of the previous year. The accounting-based right-hand variables are measured as of the last fiscal year. Market capitalization, volatility, and momentum are measured as of the end of the previous month. Standard errors are clustered at the year–month and firm level. Intercepts are not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01, respectively. Appendix A provides variable definitions.

	Monthly return (%)					
	Whole period		Pre-Kunming period		Post-Kunming period	
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(CBF)	0.003	–0.000	–0.036	–0.036	0.061**	0.057**
	(0.019)	(0.018)	(0.022)	(0.022)	(0.026)	(0.026)
Ln(Total assets)	0.211	0.158	0.143	0.112	0.336	0.290
	(0.171)	(0.164)	(0.192)	(0.187)	(0.329)	(0.313)
Ln(Market cap)	–0.468***	–0.393***	–0.426**	–0.382**	–0.372	–0.305
	(0.153)	(0.143)	(0.187)	(0.178)	(0.252)	(0.238)
Book-to-market	–0.086	–0.043	–0.072	–0.047	–0.057	–0.043
	(0.159)	(0.158)	(0.196)	(0.189)	(0.285)	(0.289)
Leverage	0.353	0.372	0.630	0.701	–0.524	–0.496
	(0.351)	(0.347)	(0.438)	(0.435)	(0.562)	(0.576)
Capex/Total assets	1.933	2.265	6.695***	6.459***	–6.763*	–5.955
	(2.200)	(2.089)	(2.100)	(2.070)	(3.518)	(3.411)
PPE/Total assets	0.327	0.353	–0.319	–0.270	1.624*	1.569*
	(0.401)	(0.414)	(0.425)	(0.427)	(0.760)	(0.747)
ROA	2.216	2.014	0.979	0.969	5.534	5.109
	(1.864)	(1.724)	(1.712)	(1.584)	(3.493)	(3.457)
Asset growth	–0.408	–0.300	0.221	0.167	–1.491**	–1.343**
	(0.336)	(0.316)	(0.334)	(0.320)	(0.566)	(0.552)
Sales growth	–0.038	–0.218	0.047	0.398	0.101	–0.403
	(0.480)	(0.374)	(0.676)	(0.509)	(0.476)	(0.340)
Volatility	5.433	5.012	14.644**	13.513*	–2.692	–2.214
	(5.096)	(5.077)	(7.126)	(7.115)	(6.226)	(6.473)
Momentum	4.407	3.134	–1.459	–0.438	–3.682	–1.515
	(5.382)	(4.770)	(6.418)	(5.913)	(8.548)	(7.804)
Wald test (p-value): Column 3 vs. 5			0.019			
Wald test (p-value): Column 4 vs. 6					0.036	
Year–month fixed effects	Yes	No	Yes	No	Yes	No
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	No	Yes	No	Yes	No
Industry×year–month fixed effects	No	Yes	No	Yes	No	Yes
#Obs.	89,132	89,132	58,218	58,218	30,914	30,914
R^2	0.251	0.320	0.245	0.309	0.255	0.324

3–4, we continue to find no significant effects of the CBF in the pre-Kunming period. By contrast, in Columns 5–6, larger CBF values are associated with significantly greater returns in the post-Kunming period. In Column 5, a one-standard-deviation increase in Ln(CBF) is associated with an additional monthly return of 18.5 basis points, or a 2.2 percent annualized increase. In Wald tests of coefficient equality, the coefficients on Ln(CBF) are different across the pre- and post-Kunming periods (p-values of 0.019 and 0.036, respectively).

5.3 The CBF and the cross-section of returns: country heterogeneity

To shed light on the mechanism behind these results, we examine whether the cross-sectional return effects differ across countries, depending on two measures of biodiversity protection: (1) the Biodiversity habitat index, which assesses countries' actions toward retaining natural ecosystems and protecting biodiversity within their borders; and (2) the Ecosystem vitality index, which captures how well countries are preserving, protecting, and enhancing ecosystems and the services they provide. We create two dummy variables that each equal one if biodiversity protection in a country falls below the median ("Low protection"), and zero otherwise ("High protection"); both variables are measured as of before the Kunming Declaration (end of 2020). Values of the indexes by country are reported in Supplementary Appendix Table A4. We then estimate an augmented version of Equation (2) for the post-Kunming period:

$$\text{Monthly return}_{i,m,t} = \beta_0 + \beta_1 \text{Ln(CBF)}_{i,t-1} \times \text{Low protection}_c + \beta_2 \text{Ln(CBF)}_{i,t-1} + \beta_3 \mathbf{X}_{i,t-1} + \gamma_t + \delta_c + \mu_j + \varepsilon_{i,m,t}, \quad (3)$$

where Monthly $\text{return}_{i,m,t}$ and $\text{Ln(CBF)}_{i,t-1}$ are defined as above, and Low protection_c in country c is constructed as just explained. We include the same control variables and fixed effects as in Equation (2). Low protection_c is absorbed by the country fixed effects.

Table 5 reports the estimations of Equation (3). In Columns 1 and 4, the effects of large-CBF stocks on returns are amplified in low-protection countries: the coefficients on $\text{Ln(CBF)}_{i,t-1} \times \text{Low protection}_c$ are positive and significant in both columns. The stand-alone effects for Ln(CBF) are not significantly different from zero, implying that the returns for large-CBF stocks accrue in low-protection countries. We find similar results if we use sample splits into low- and high-protection countries instead of interaction terms (Columns 2–3, 5–6).

5.4 The CBF and the cross-section of returns: further results

Given the conceptual links and overlaps between biodiversity and climate change, as discussed in Section 2.5, one concern is that our results may reflect a carbon risk premium, rather than the broader biodiversity impacts of firms. To address this concern, we test whether our results hold when directly controlling for two measures of climate transition risk: carbon emissions and regulatory climate change exposure.[26]

Supplementary Appendix Table A5 reports the results of our robustness tests of Table 4. In Columns 1–4, we add Ln(CO_2 Emissions) and CCExposure^{Reg} as control variables. While the CBF continues to be unrelated to returns over the full sample period, Ln(CBF) remains related to returns in the post-Kunming period. Though significant only at the 10 percent level, the magnitudes of the post-Kunming estimates are similar, compared to the baseline (0.060 and 0.063 in Columns 2 and 4, which compares to 0.061 in Table 4, Column 5). As a complementary robustness check, reported in Columns 5–6, we compute the CBF considering only land use, air pollution, and water pollution (that is, we exclude the GHG component). We find that this "emissions-free" CBF is positively associated with returns in the post-Kunming period. Results are even stronger in Supplementary Appendix Table A6, which documents the robustness of Table 5 after we have added the two measures of climate transition risks.

[26] We verify that our sample firms earn a carbon premium using the method in Bolton and Kacperczyk (2023) (and using the same 2005–2018 sample period). For the 2019–2022 sample period in our article, emissions remain positively associated with returns, but the estimate is more noisy (t-statistic of 1.24). This result is possibly due to two factors: (1) the trend toward ESG investing during the past few years may have led to unexpected shifts in climate concerns and investors' preferences, pushing up realized returns for low-emission stocks, as noted by Pástor, Stambaugh, and Taylor (2022); and (2) according to Bolton and Kacperczyk (2023), the rise in the carbon premium since the Paris Agreement originates mostly from Asian firms, which constitute a comparatively smaller fraction in our sample.

Table 5. Heterogeneity in country biodiversity protection and stock returns.

Note: This table reports regressions of monthly stock returns on Ln(CBF) after the Kunming Declaration for firms in countries with high or low biodiversity protection. The sample period includes monthly returns from October 2021 to December 2022. Ln(CBF) is measured as of the end of the previous year. The CBF reflects the biodiversity loss caused by the firm's annual activities. Low protection is a dummy variable that equals one if a country is below the median value of the Biodiversity habitat index (or below the median value of the Ecosystem vitality index) as of the end of 2020, and zero otherwise. We also report regressions using interaction terms of Ln(CBF) × Low protection. The regressions use the same control variables as Table 4 (not reported). Standard errors are clustered at the year–month and firm level. Intercepts are not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01, respectively. Appendix A provides variable definitions.

	Monthly return (%)					
	Biodiversity habitat index			**Ecosystem viability index**		
	(1)	Low (2)	High (3)	(4)	Low (5)	High (6)
Ln(CBF)	−0.021	0.091***	−0.046	−0.002	0.086***	−0.018
	(0.030)	(0.027)	(0.048)	(0.027)	(0.028)	(0.048)
Ln(CBF) × Low protection	0.111**			0.085**		
	(0.040)			(0.038)		
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year–month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
#Obs.	30,899	20,714	10,185	30,899	20,691	10,208
R^2	0.255	0.225	0.346	0.255	0.220	0.363

A further concern is that realized returns are noisy and can lead to effects due to luck, especially in short samples (e.g., Elton 1999; Lundblad 2007). Pástor, Sinha, and Swaminathan (2008) show that the trade-off between risk and expected returns can sometimes be more easily detected using the implied cost of capital (ICC), instead of realized returns. The ICC is the discount rate (or internal rate of return) that equates a firm's market value to the present value of its expected future cash flows. Similarly, Cenedese, Han, and Kacperczyk (2023) argue, in a climate finance context, that estimates for expected returns derived from valuation models can corroborate that effects observed in realized returns indeed reflect required, expected returns, rather than luck. We therefore construct an ICC measure and relate it to the CBF. Following Lee, So, and Wang (2021), the ICC measure is computed as an average across four valuation models.[27] In Supplementary Appendix Table A7, we re-estimate Equation (2) after replacing Monthly return$_{i,m,t}$ with Monthly ICC$_{i,m,t}$.[28] We find that, after Kunming, the CBF has a positive and significant

[27] Our ICC measure is the mean value of those derived from the GLS (Gebhardt, Lee, and Swaminathan 2001), CAT (Claus and Thomas 2001), MPEG (Easton 2004), and AGR (Ohlson and Juettner-Nauroth 2005) models. The GLS and CAT models are based on variants of the residual-income model; they differ in terms of their forecasting horizon and terminal value estimation. The MPEG and AGR models are based on the abnormal-growth-in-earnings model; they differ in their formulation of the long-term growth in abnormal earnings. For details on the computations, see Lee, So, and Wang's (2021) Appendix B.2. All four ICC measures are based on earnings forecasts derived from the cross-sectional mechanical forecast model of Hou, Van Dijk, and Zhang (2012), and do not rely on analyst forecasts, which facilitates the ICC computation for a large cross-section of international firms.

[28] We match the ICC measure, computed at the end of month m, so that it corresponds to the realized return over the following month.

association with ICC, though a Wald test indicates that the coefficient is not statistically different from the (imprecisely estimated, but much smaller) coefficient in the pre-Kunming period. After Kunming, a one-standard-deviation increase in Ln(CBF Value) is associated with a monthly ICC increase of 0.041 percent (0.50 percent annualized).

Finally, the relation between realized returns and the CBF may originate, in part, from unexpected changes in corporate earnings. To address this concern, we follow Atilgan et al. (2023) and calculate two measures of earnings surprises. SUE1 is the 1-year earnings surprise, calculated as the actual earnings per share (EPS) for the fiscal year ending in year t minus the consensus (median) analyst forecast, scaled by the end-of-year stock price. The consensus forecast is taken as of 8 months prior to the end of the forecast period, i.e., 4 months after the prior fiscal year-end. Similarly, SUE2 is the 2-year earnings surprise, calculated in an analogous manner, with the consensus forecast taken 20 months prior to the end of the forecast period.[29] We then regress in Supplementary Appendix Table A8 each of these two measures on 1-year-lagged values of the CBF. In these firm–year regressions, we observe no statistically significant relationship between the CBF and earnings surprises, independent of whether we consider the whole sample period or the pre- and post-Kunming years.

5.5 The CBF and the cross-section of returns: robustness

We have conducted a wide range of robustness tests. First, we investigated whether our results might be confounded by non-linear size effects. However, in Supplementary Appendix Table A9, we obtain positive and significant return effects also for intensity measures (the CBF scaled by total assets or sales; this evidence is useful, as the TNFD focuses on scaled measures). Second, as shown in Supplementary Appendix Table A10, our baseline results hold when we implement alternative standard error clusterings. In Columns 1 and 2, we cluster standard errors at the firm–year level, in Columns 3 and 4 at the firm level, and in Columns 5 and 6 at the firm and year levels (as in Bolton and Kacperczyk 2021, 2023). Our choice of clustering in the baseline estimation by year–month (48 groups), instead of year (four groups), is motivated by the small number of clusters generated otherwise. Third, we verify in Supplementary Appendix Table A11 that our results hold if we restrict the estimation to firms inside the MSCI ACWI universe; these results are reassuring, as they suggest that IDL's coverage decision within the MSCI ACWI does not unduly bias our estimates.

6. Event study evidence

6.1 Estimation design: event study

We conduct an event study in which we examine daily returns of firms with large versus small biodiversity footprints around the date of the Kunming Declaration. This allows us to dissect how investors revised their valuations of large-CBF stocks around the declaration, and it helps address the concern that the returns after Kunming are due to confounding factors correlated with a firm's CBF. We estimate the following regression at the firm–day level, over a window of 3 days before to 3 days after the event:

$$\text{Daily return}_{i,t} = \beta_0 + \beta_1 \text{Large CBF}_i \times \text{Post}_t + \delta_i + \gamma_t + \varepsilon_{i,t}, \quad (4)$$

where $\text{Daily return}_{i,t}$ is the return of firm i in day t, Large CBF_i equals one if the firm has a large biodiversity footprint (i.e., the firm's CBF is above the median), and Post_t equals one after the event. The event date is October 13, 2021 (the day of the adoption of the Kunming Declaration), which is also the first day of the post-event window (denoted as

29 We remove observations where the forecast error is larger than 10 percent of the stock price. The median 1-year (2-year) earnings surprise is about 0.00 percent (−0.00 percent) with a standard deviation of 1.64 percent (1.99 percent).

$t = 0$). We label the event window as [–3,+2] days, reflecting the 3 days before the event date and the event date plus the 2 following days. We control for firm (δ_i) and day (γ_t) fixed effects. The firm fixed effects control for firm characteristics or potential determinants of stock returns that are fixed around the days of the event. The standalone variables Large CBF$_i$ and Post$_t$ are absorbed by, respectively, the firm and time fixed effects. Standard errors are clustered at the country level. The coefficient of interest, β_1, captures the differential in daily returns for large-CBF stocks, relative to small-CBF stocks, following the Kunming Declaration.

6.2 Event study of the Kunming Declaration

Table 6 reports the results of estimating Equation (4). In Columns 1–4, we report results for raw returns, and in Columns 5–8, for abnormal returns (in excess of the domestic market index). In Column 1, the coefficient on Large CBF × Post is negative and statistically significant at the 1 percent level, indicating that large-CBF firms experienced statistically lower returns than small-CBF firms. On average, following the October 13 announcement, the daily returns of large-CBF firms were 0.38 percent below those of small-CBF firms. These effects reach a cumulative valuation decline of –1.14 percent over the 3-day period. The results are similar if we control for country- or industry-wide reactions, as shown in Columns 2–3, and if we use abnormal returns, as shown in Columns 5–7. In Columns 4 and 8, we replace the Post variable with dummies capturing the individual days surrounding the Kunming Declaration. In this dynamic specification, we estimate effects relative to day $t = -3$. The negative price reaction for large-CBF firms mostly spans the day of the declaration and the following day ($t = 0$ and $t = +1$), both in Columns 4 and 8. Before the declaration, we observe no significant differences in the returns of large- versus small-CBF firms. An exception is $t = -1$ in Column 4, for raw returns, where we find a weakly significant effect; this effect disappears in Column 8, with abnormal returns.

To capture possible pre-trends and reversals, we expand the time window to [–5;+5] days. Figure 5 reports the average difference in returns between large- and small-CBF stocks for a given day. While there are no significant differences before the Kunming Declaration, there is a significant relative price drop for large-CBF firms on the day of the declaration ($t = 0$). There is no significant valuation reversal following the declaration.

In Supplementary Appendix Table A12, we show that the event study results hold when we control for carbon emissions and regulatory climate change exposure. In Supplementary Appendix Table A13, we re-estimate variants of Table 6, Column 1, documenting negative and significant return reactions for three of the four sources of pressure. We also observe a negative reaction when we categorize stocks into large- versus small-CBF groups based on intensity measures. Our results are also unchanged if we define as large-CBF firms those with a CBF value in the top quartile or top tercile, or use the continuous CBF measure instead of the Large CBF dummy. Supplementary Appendix Table A14 shows the event study results hold if we restrict the sample to MSCI ACWI stocks. Our results are also robust to clustering standard errors at the industry or firm levels (unreported).

6.3 Event study of the TNFD launch

The Kunming Declaration emerges as a key event, due to which the prices of large-CBF stocks were bid down. The bid-down prices, in turn, imply higher (expected) returns for large-CBF stocks, as we document by splitting the sample into a pre- and post-Kunming period in our cross-sectional tests. While these results closely align, we do not posit that the Kunming Declaration was the only relevant biodiversity-policy event or that it uniquely triggered valuation declines. Other recent events, such as the launch of the TNFD, may have contributed to changes in investors' perceptions of biodiversity transition risks. The

Table 6. Stock price reactions to the Kunming Declaration.

Note: This table reports regressions documenting the stock price reactions to the Kunming Declaration, with the focal date of the event being October 13, 2021. We report results for firms with large versus small CBF values. The event window consists of the [–3,+2]-day window around the focal date. The market reaction is computed as the within-firm difference in daily returns between the 3 trading days before versus after the event. Large CBF equals one for firms with a CBF value above the median (as of the beginning of the year), and zero otherwise. The CBF reflects the biodiversity loss caused by the firm's annual activities. Post equals one in the 3 days after the event (days *t*=0 to *t*=+2), with day *t*=0 being the event date. Abnormal returns are returns in excess of their domestic stock market index returns (using MSCI domestic indices). Standard errors are clustered at the country level. Intercepts are not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01, respectively. Appendix A provides variable definitions.

	Daily return (%)				**Abnormal daily return** (%)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Large CBF × Post	–0.381***	–0.372***	–0.189**		–0.295***	–0.380***	–0.209**	
	(0.064)	(0.057)	(0.084)		(0.073)	(0.055)	(0.078)	
Large CBF × t = –2				0.040				–0.043
				(0.213)				(0.204)
Large CBF × t = –1				–0.504*				–0.361
				(0.278)				(0.277)
Large CBF × t = 0				–0.671***				–0.590**
				(0.218)				(0.226)
Large CBF × t = +1				–0.642***				–0.461**
				(0.193)				(0.196)
Large CBF × t = +2				–0.301*				–0.241
				(0.164)				(0.166)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Day fixed effects	Yes	No	No	Yes	Yes	No	No	Yes
Country×day fixed effects	No	Yes	No	No	No	Yes	No	No
Industry×day fixed effects	No	No	Yes	No	No	No	Yes	No
#Obs.	12,301	12,301	12,301	12,301	12,301	12,301	12,301	12,301
R^2	0.240	0.332	0.298	0.243	0.192	0.256	0.245	0.194

TNFD developed a risk management and disclosure framework for organizations to report and act on evolving nature-related risks, releasing a first draft in early 2022 and its final recommendations in September 2023 (TNFD 2023a). While initially voluntary, the TNFD recommendations are widely expected to become mandatory. Because four versions of the framework had been released previously, the final version contained little surprising information. Therefore, we focus on the formal launch of the TNFD initiative, with endorsement by the G7 countries, on June 4, 2021 (just 4 months before the Kunming Declaration).[30]

In Table 7, we examine how investors reacted to the TNFD launch by re-estimating Equation (4) around June 4, 2021. In Column 1, we show that in the 3 days following the TNFD launch, relative to the 3 days before it, large-CBF stocks experienced a significant decline of −0.5 percent per day. This estimate is robust to alternative fixed effects, as shown in Columns 2–3, and we find no pre-trends, as shown in Column 4. Columns 5–8 show our conclusions are also unaffected when we use abnormal returns. Motivated

[30] A potentially confounding event was the announcement, on the same day, of a proposed regulatory revision to the Endangered Species Act (ESA) by the U.S. Fish and Wildlife Service, rescinding changes made during the Trump Administration.

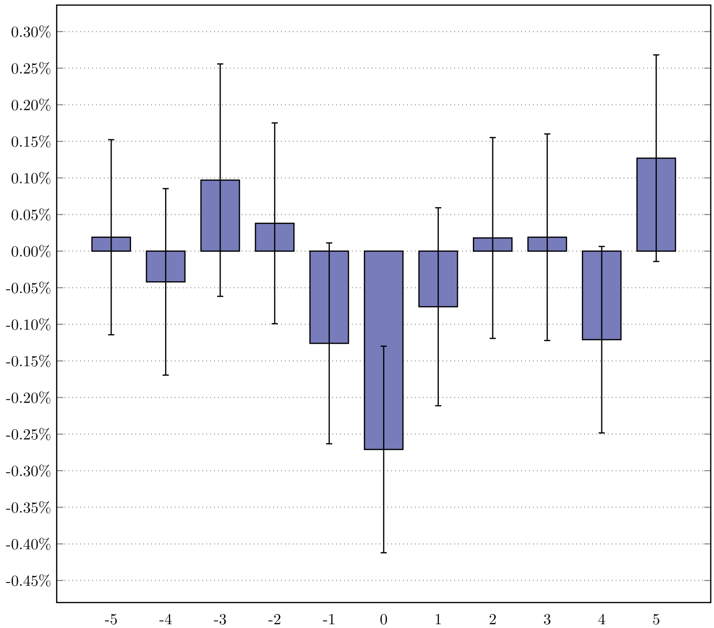

Figure 5. The Kunming Declaration: Return differences between large- and small-CBF firms.

Note: This figure reports daily mean stock abnormal return differences around the Kunming Declaration between large- and small-CBF firms. It covers the event window [–5,+5]. The day of the Kunming Declaration (event date) is $t = 0$. Raw returns are winsorized at 1 percent and 99 percent by country. Abnormal returns are computed in excess of the mean daily return of the country and the mean daily return of the industry. Large-CBF (small-CBF) firms have a CBF value that is above (below) the median, as of the end of 2020. We also report 95 percent confidence intervals based on standard errors from t-tests on the equality of means for abnormal returns in both groups (small-CBF and high-CBF firms) on each day. The CBF reflects the biodiversity loss caused by the firm's annual activities.

by this finding, we re-estimate the cross-sectional regression from Equation (2) for the post-TNFD period, instead of the post-Kunming period. Unsurprisingly, given the close proximity of the two events, Ln(CBF) positively and significantly relates to returns in the post-TNFD period. Overall, the two events appear to have shifted return dynamics.[31]

7. Interpreting the overall evidence

While we have established links between the CBF and returns, the question that emerges is what economic channel explains these patterns consistently. We evaluate three possible channels: (1) shifts in investor preferences; (2) unexpected cash flow shocks; or (3) a biodiversity transition risk premium.

According to the first channel, investor preferences change over time due to a heightening of concern for biodiversity. These changes imply gradual shifts in fund flows and equity

[31] In Supplementary Appendix Table A15, we re-estimate Equation (4) as a placebo test around the launch of the climate disclosure initiative, TCFD. Since the CBF captures a firm's impact on biodiversity, we do not expect a stock market reaction for large-CBF firms when an initiative is launched that is not specifically related to biodiversity. If, however, our results reflect a reaction to (environmental) disclosure generally, then we should also find an effect for the TCFD launch. We consider two dates: November 9, 2015, when the Financial Stability Board published its proposal to create a disclosure task force on climate risks, and December 4, 2015, when the TCFD was formally established. We do not find evidence that investors revised their valuations of large-CBF firms around either of these two dates.

Table 7. Stock price reactions to the TNFD launch.

Note: This table reports regressions documenting the stock price reactions to the launch of the Taskforce on Nature-related Financial Disclosure (TNFD), with the focal date of the event being June 4, 2021. We report results for firms with large versus small CBF values. The event window consists of the [–3,+2]-day window around the focal date. The market reaction is computed as the within-firm difference in daily returns between the 3 trading days before versus after the event. Large CBF equals one for firms with a CBF value above the median (as of the beginning of the year), and zero otherwise. The CBF reflects the biodiversity loss caused by the firm's annual activities. Post equals one in the 3 days after the event (days *t*=0 to *t*=+2), with day *t*=0 being the event date. Abnormal returns are returns in excess of their domestic stock market index returns (using MSCI domestic indices). Standard errors are clustered at the country level. Intercepts are not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01, respectively. Appendix A provides variable definitions.

	Daily return (%)				Abnormal daily return (%)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Large CBF × Post	–0.502***	–0.479***	–0.212**		–0.423***	–0.479***	–0.195**	
	(0.108)	(0.108)	(0.098)		(0.103)	(0.107)	(0.093)	
Large CBF × t=–2				0.133				0.220
				(0.172)				(0.143)
Large CBF × t=–1				–0.143				–0.038
				(0.122)				(0.113)
Large CBF × t = 0				–0.516**				–0.336*
				(0.227)				(0.172)
Large CBF × t=+1				–0.431**				–0.317**
				(0.162)				(0.130)
Large CBF × t=+2				–0.569***				–0.435***
				(0.155)				(0.144)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Day fixed effects	Yes	No	No	Yes	Yes	No	No	Yes
Country×day fixed effects	No	Yes	No	No	No	Yes	No	No
Industry×day fixed effects	No	No	Yes	No	No	No	Yes	No
#Obs.	12,392	12,392	12,392	12,392	12,392	12,392	12,392	12,392
R^2	0.208	0.279	0.255	0.208	0.164	0.229	0.210	0.165

investments toward small-CBF firms and away from large-CBF firms. Though this channel may be plausible in other ESG contexts (Pástor, Stambaugh, and Taylor 2021, 2022), our overall evidence does not support it. In contrast to our results, this channel would predict that large-CBF firms have *lower* (not higher, as we found) returns in the months after the Kunming Declaration.[32] Our results are also hard to reconcile with the second channel, which predicts unexpectedly high earnings or cash flows in large-CBF firms. First, we document that the CBF does not correlate with earnings surprises in the post-Kunming years (and before too). Second, unexpectedly high earnings or cash flows should be much more likely before Kunming; however, for this period, we found non-significant return effects of the CBF. It is in turn conceptually unclear why unexpectedly higher cash flows of large-CBF stocks would materialize only in the months after Kunming.

Instead, the positive cross-sectional link between the CBF and returns is consistent with a biodiversity transition risk premium. This channel aligns with the pricing of carbon

32 Pástor, Stambaugh, and Taylor (2022) document that the strengthening of climate concerns is responsible for the outperformance of "green" stocks relative to "brown" stocks from 2012 to 2020.

transition risks, proxied using the corporate carbon footprint (Bolton and Kacperczyk 2021, 2023). Accordingly, the CBF provides a proxy for a firm's exposure to biodiversity transition risks, and our results reflect the pricing of such risks. Our cross-country results support this interpretation: in countries with low biodiversity protection, the uncertainty about, and expected stringency of, future regulations is highest; the risk premium, thus, is larger. By the same token, firms located in countries that have already taken ambitious actions to protect biodiversity have lower exposure to transition risks, as there is much less uncertainty about future regulations. The results of our event studies also line up with the risk premium channel: they indicate that the Kunming Declaration was a key event around which the prices of large-CBF stocks were bid down, arguably in response to changes in investors' beliefs about biodiversity transition risks. The bid-down stock prices, in turn, implied higher expected returns for these large-CBF stocks. Our TNFD results can be interpreted within the risk premium channel as well. While primarily about disclosure, the TNFD launch plausibly also raised biodiversity transition risks, as more disclosure can increase the odds of a firm being targeted by litigation. Hence, like Kunming, the TNFD launch may have contributed to changing investors' awareness of biodiversity transition risks.

The risk premium that we document may arise in response to cash flow uncertainty. Specifically, investors may worry that future biodiversity-related regulations or litigation will affect corporate investments, create stranded assets, or impair the operating performance of a firms, all of which comes with heightened cash flows uncertainty. Another possible source of the risk premium relates to changes in a firm's discount rates, that is, in how investors perceive biodiversity transition risks; for example, there may be changes in the economic model investors use to price these risks. Both factors likely contribute to our findings.

A transition risk premium compensates investors for future losses related to the realization of biodiversity risks. BloombergNEF (2023) provides evidence, in a series of case studies, that such risks have indeed started to materialize. One case, for example, is that of chemicals producer 3M, who, in June 2023, entered into a $10.5 billion settlement with U. S. water authorities for having introduced substances known as PFAS into water; PFAS have been shown to be harmful to hundreds of species. The case was associated with a large share price decline in 3M's stock.

8. Comparison with MSCI and Refinitiv's measures

We compare the CBF to two biodiversity measures provided by commercial data vendors: 1) MSCI's biodiversity & land use exposure score and 2) Refinitiv's biodiversity impact reduction indicator. These measures are also available for a longer time-series, but are not based on the biodiversity impact metrics discussed in Section 2. Hence, they differ conceptually from the CBF, which uses MSA to quantify a firm's biodiversity impact.[33] Supplementary Appendix Table A16 contrasts our CBF metric with MSCI's and Refinitiv's measures, and we explain in detail how both vendors construct their scores in Supplementary Appendix Section G.[34]

In brief, MSCI scores a firm's biodiversity and land use exposure on a 0–10 scale (10 corresponds to the highest risk). The score aims to capture three risks for a firm: loss of license to operate; litigation by landowners and other affected parties; and increased costs of land protection and reclamation. In comparison, the CBF provides a more complete measure of

[33] As explained above, MSCI and other data providers plan on introducing impact-based measures in 2024, initially without a time-series. Hoepner et al. (2023) employ another measure of a firm's biodiversity impact, which was constructed by Eiris (now majority-owned by Moody's); however, Eiris stopped providing the measure in January 2018.

[34] MSCI also provides a biodiversity & land use *management* score, which evaluates a firm's ability to manage its exposure. This score, utilized by Xin et al. (2023), is available for a small sample.

the firm's biodiversity impact. Specifically, the MSCI score is not a quantitative measure of the firm's impact on biodiversity, and it is in turn not considered in the review of biodiversity metrics by Finance for Biodiversity (2022). Further, MSCI focuses on the direct operations of a firm, especially land use, rather than on the overall life cycle of its products.[35] By contrast, the life cycle assessment in the CBF calculation captures the total potential environmental impacts associated with the production of a good or service. It takes into account all or part of each production stage, from the supply of raw materials to the end of the product's life.

Refinitiv's measure is a dummy variable indicating whether or not a firm reports its impact on biodiversity, or its activities to reduce this impact. The indicator positively correlates with Ln(CBF) (correlation of 0.31), suggesting that firms with larger biodiversity footprints disclose more on the topic (Supplementary Appendix Table A17). Supplementary Appendix figure A3 reports the distributions of CBF values for disclosing and non-disclosing firms, according to the Refinitiv's measure. While firms disclosing more on biodiversity tend to have larger CBFs, many non-disclosing firms also have much larger CBFs than disclosing firms.

Beyond this simple comparison, we replicate our main results after replacing the CBF metric with MSCI's score. Supplementary Appendix Table A18, Panel A, reports a positive impact of the MSCI score on returns in the post-Kunming period, whereas there is no effect before.[36] When using MSCI's measure, our post-Kunming results are so strong that, even in the overall sample, the MSCI score is positive and statistically significant. In Panel B, for the event study, we find a negative and significant reaction for firms with above-median MSCI scores around the Kunming Declaration.

9. Conclusion

Biodiversity loss and climate change are two of the major crises of our era. Research on climate finance has grown rapidly over the past years, thereby improving our understanding of the potential consequences of climate change for financial markets. By stark contrast, there has been very little research on biodiversity finance. Although the two crises are related, biodiversity preservation can clash with actions taken to address climate change. For example, renewable energy and electric cars require lithium, cobalt, magnesium, and nickel, the mining of which comes with severe impacts on biodiversity (and on the human communities that rely on biodiversity). Therefore, it is important to separately analyze finance's role in the loss of biodiversity. Our article offers a first step toward understanding the interplay between finance and biodiversity by introducing a measure of the CBF and exploring whether it is priced by investors.

Examining a large sample of international stocks, we find that, over our sample period, investors did not price the impact of firms on biodiversity, on average. However, the situation appears to be changing, as we document the emergence of a biodiversity footprint premium in the months following the Kunming Declaration (the first part of COP15) and the launch of the TNFD. Consistent with this effect, we document negative stock price reactions for firms with large biodiversity footprints in the days following the Kunming Declaration and the TNFD launch. Our results indicate that investors have started to ask for a risk premium in light of the uncertainty associated with future biodiversity regulation.

[35] Consistent with this observation, the MSCI score has a correlation of 0.56 with the Scope 1 component of the CBF, but only a –0.01 (0.33) correlation with the scope 2 (scope 3) components (Supplementary Appendix Table A17).

[36] The MSCI score is also available for years before 2019. We do not find a significant relation with returns even when we include additional years in the pre-Kunming period.

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Supplementary material

Supplementary data are available at *Review of Finance* online.

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Data availability

All of the data underlying the article's empirical analyses are publicly available from the sources listed in the article. Most of these sources require a paid subscription, but our understanding is that any researcher who wishes to purchase any of the data may freely do so.

References

Agnew, H. 2022. "Biodiversity Quickly Rises up the ESG Investing Agenda." *Financial Times*, September 20, 2022. https://www.ft.com/content/abbcec95-0154-40cd-83b9-d988bd3271b9

Ardia, D., K. Bluteau, K. Boudt, and K. Inghelbrecht. 2023. "Climate Change Concerns and the Performance of Green vs. Brown Stocks." *Management Science* 69: 7607–7632.

Atilgan, Y., K. O. Demirtas, A. Edmans., and A. D. Gunaydin. 2023. "Does the Carbon Premium Reflect Risk or Mispricing?" Available at *SSRN 4573622*. https://dx.doi.org/10.2139/ssrn.4573622.

BloombergNEF. 2023. When the Bee Stings: Counting the Cost of Nature-Related Risks, December 9, 2023. https://tnfd.global/wp-content/uploads/2023/12/BNEF_Case-Studies_-Nature_Risk_When-bees-sting.pdf

Bolton, P., and M. T. Kacperczyk. 2021. "Do Investors Care about Carbon Risk?" *Journal of Financial Economics* 142: 517–549.

Bolton, P., and M. T. Kacperczyk. 2023. "Global Pricing of Carbon-Transition Risk." *Journal of Finance* 78: 3677–3754.

CBD Secretariat. 2016. Biodiversity and Climate Change. Convention on Biological Diversity. https://www.cbd.int/climate/doc/biodiversity-ar5-brochure-en.pdf

CBD Secretariat. 2020. Global Biodiversity Outlook Report 5. Convention on Biological Diversity. https://www.cbd.int/gbo5

CBD Secretariat. 2021. Financial Sector Guide for the Convention on Biological Diversity. https://www.cbd.int/doc/c/8e24/f151/326b69024f014a8fb9684a8d/cbd-financial-sector-guide-f-en.pdf

Cenedese, G., S. Han., and M. T. Kacperczyk. 2023. "Carbon-Transition Risk and Net-Zero Portfolios." Available at *SSRN 4565220*. https://dx.doi.org/10.2139/ssrn.4565220.

Choi, D., Z. Gao, and W. Jiang. 2020. "Attention to Global Warming." *Review of Financial Studies* 33: 1112–1145.

Claus, J., and J. Thomas. 2001. "Equity Premia as Low as Three Percent? Evidence from Analysts' Earnings Forecasts for Domestic and International Stock Markets." *Journal of Finance* 56: 1629–1666.

Coqueret, G., T. Giroux, and O. D., Zerbib. 2024. "The Biodiversity Premium." *Available at SSRN 4489550*, https://dx.doi.org/10.2139/ssrn.4489550.

Dasgupta, P. 2021. The Economics of Biodiversity: The Dasgupta Review. UK: Her Majesty's Treasury.

Di Giuli, A., A. Garel, R. Michaely, and A. Petit-Romec. 2022. "Climate Change and Mutual Fund Voting on Environmental Proposals." *Available at SSRN 3997730*. https://dx.doi.org/10.2139/ssrn.3997730.

Easton, P. D. 2004. "PE Ratios, PEG Ratios, and Estimating the Implied Expected Rate of Return on Equity Capital." *The Accounting Review* 79: 73–95.

Eihorn, C. 2022. "Nearly Every Country Signs on a Sweeping Deal to Protect Nature." *New York Times*, Deceber 19, 2022. https://www.nytimes.com/2022/12/19/climate/biodiversity-cop15-montreal-30x30.html

Elton, E. J. 1999. "Presidential Address: expected Return, Realized Return, and Asset Pricing Tests." *Journal of Finance* 54: 1199–1220.

Engle, R. F., S. Giglio, B. Kelly, H. Lee, and J. Stroebel. 2020. "Hedging Climate Change News." *Review of Financial Studies* 33: 1184–1216.

Finance for Biodiversity. 2022. Guide on Biodiversity Measurement Approaches. https://www.financeforbiodiversity.org/wp-content/uploads/Finance-for-Biodiversity_Guide-on-biodiversity-measurement-approaches_3rd-edition-1.pdf

Flammer, C., T. Giroux, and G. M. Heal. 2023. "Biodiversity Finance." *Available at SSRN 4379451*, https://dx.doi.org/10.2139/ssrn.4379451.

Gebhardt, W. R., C. M. C. Lee, and B., Swaminathan 2001. "Toward an Implied Cost of Capital." *Journal of Accounting Research* 39: 135–176.

Giglio, S., T. Kuchler, J. Stroebel, and X. Zeng. 2023. "Biodiversity Risk." *Available at SSRN 4410107*, https://dx.doi.org/10.2139/ssrn.4410107.

Heal, G. M. 2003. "Bundling Biodiversity." *Journal of the European Economic Association* 1: 553–560.

Heal, G. M. 2004. "Economics of Biodiversity: an Introduction." *Resource and Energy Economics* 26: 105–114.

Hoepner, A. G. F., J. Klausmann, M. Leippold, and J., Rillaerts. 2023. "Beyond Climate: 'EU Taxonomy' Criteria, Materiality, and CDS Term Structure." *Available at SSRN 4351633*, https://dx.doi.org/10.2139/ssrn.4351633.

Hou, K., M. A. Van Dijk, and Y. Zhang. 2012. "The Implied Cost of Capital: a New Approach." *Journal of Accounting and Economics* 53: 504–526.

Hsu, P.-H., K. Li, and C.-Y. Tsou. 2023. "The Pollution Premium." *Journal of Finance* 78: 1343–1392.

Iceberg Data Lab. 2023. Corporate Biodiversity Footprint—Methodological Guide. https://www.iceberg datalab.com/wp-content/uploads/2023/04/CBF_client_methodological_guide_March_23.pdf

Ilhan, E., P. Krueger, Z. Sautner, and L. Starks. 2023. "Climate Risk Disclosure and Institutional Investors." *Review of Financial Studies* 36: 2617–2650.

IPBES. 2020. Workshop on Biodiversity and Pandemics: Workshop Report. Intergovernmental Science-Policy Platform on Biodiversity / Ecosystem Services.

Karolyi, G. A., and J. Tobin-de la Puente. 2023. "Biodiversity Finance a Call for Research into Financing Nature." *Financial Management* 52: 231–251.

Kunming Declaration. 2021. Declaration from the High-Level Segment of the UN Biodiversity Conference 2020 (Part 1) under the Theme: Ecological Civilization: Building a Shared Future for All Life on Earth.

La Banque Postale Asset Management. 2022. *Biodiversity Policy*.

Lee, C. M. C., E. C. So, and C. C. Y. Wang. 2021. "Evaluating Firm-Level Expected-Return Proxies: implications for Estimating Treatment Effects." *Review of Financial Studies* 34: 1907–1951.

Lundblad, C. 2007. "The Risk Return Tradeoff in the Long-Run: 1836-2003." *Journal of Financial Economics* 85: 123–150.

Metrick, A., and M. L. Weitzman. 1998. "Conflicts and Choices in Biodiversity Preservation." *Journal of Economic Perspectives* 12: 21–34.

Milleret, E. 2023. "Measuring the Biodiversity Footprint of a Portfolio." *Environmental Finance*, January 18, 2023. https://www.environmental-finance.com/content/market-insight/measuring-the-biodiversity-footprint-of-a-portfolio.html

Montreal Agreement. 2022. COP 15: Nations Adopt Four Goals, 23 Targets for 2030 In Landmark UN Biodiversity Agreement.

Mychasuk, E. 2022. "UN Summit Reaches Landmark Biodiversity Agreement." *Financial Times*, December 19, 2022. https://www.ft.com/content/9bb13b79-c2d8-41e7-965f-467929109558
NGFS. 2023. Nature-Related Financial Risks: A Conceptual Framework to Guide Action by Central Banks and Supervisors. Network for Greening the Financial System (NGFS). https://www.ngfs.net/sites/default/files/medias/documents/ngfs_conceptual-framework-on-nature-related-risks.pdf
NGFS and INSPIRE. 2022. Central Banking and Supervision in the Biosphere. Network for Greening the Financial System (NGFS) - International Network for Sustainable Financial Policy Insights, Research & Exchange (INSPIRE), Study Group on Biodiversity / Financial Stability. https://www.ngfs.net/sites/default/files/medias/documents/central_banking_and_supervision_in_the_biosphere.pdf
OECD. 2023. Assessing Biodiversity-related Financial Risks: Navigating the Landscape of Existing Approaches. https://www.oecd.org/environment/assessing-biodiversity-related-financial-risks-d52137a5-en.htm
Ohlson, J. A., and B. E. Juettner-Nauroth. 2005. "Expected EPS and EPS Growth as Determinants of Value." *Review of Accounting Studies* 10: 349–365.
Pástor, L., M. Sinha, and B. Swaminathan. 2008. "Estimating the Intertemporal Risk–Return Tradeoff using the Implied Cost of Capital." *Journal of Finance* 63: 2859–2897.
Pástor, L., R. F. Stambaugh, and L. A. Taylor. 2021. "Sustainable Iinvesting in Equilibrium." *Journal of Financial Economics* 142: 550–571.
Pástor, L., R. F. Stambaugh and L. A. Taylor. 2022. "Dissecting Green Returns." *Journal of Financial Economics* 146: 403–424.
Pástor, L., and P. Veronesi. 2012. "Uncertainty about Government Policy and Stock Prices." *Journal of Finance* 67: 1219–1264.
Paulson, H. 2023. "We Must Stop Climate Solutions from Killing Biodiversity." *Financial Times*, July 16, 2023. https://www.ft.com/content/755d794a-7052-4512-86eb-6971cbeda003
Rockström, J., W. Steffen, K. Noone, A. Persson, F. S. Chapin, E. F. Lambin, T. M. Lenton et al. 2009. "A Safe Operating Space for Humanity." *Nature* 461: 472–475.
Sautner, Z., L. van Lent, G. Vilkov, and R. Zhang 2023. "Firm-Level Climate Change Exposure." *Journal of Finance* 78: 1449–1498.
Schimanski, T., C. Colesanti Senni, G. Gostlow, J. Ni, T. Yu, and M. Leippold. 2023. "Exploring Nature: Datasets and Models for Analyzing Nature-related Disclosures." *Available at SSRN* 4665715, https://dx.doi.org/10.2139/ssrn.4665715.
Steffen, W., K. Richardson, J. Rockström, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs et al. 2015. "Planetary Boundaries: guiding Human Development on a Changing Planet." *Science* 347: 1259855.
TNFD. 2023a. Recommendations of the Taskforce on Nature-Related Financial Disclosures. Taskforce on Nature-related Financial Disclosures (TNFD). https://tnfd.global/wp-content/uploads/2023/08/Recommendations_of_the_Taskforce_on_Nature-related_Financial_Disclosures_September_2023.pdf
TNFD. 2023b. Tools Catalogue. Taskforce on Nature-related Financial Disclosures (TNFD). https://tnfd.global/guidance/tools-catalogue/
Weitzman, M. L. 1992. "On Diversity." *Quarterly Journal of Economics* 107: 363–405.
Weitzman, M. L. 1993. "What to Preserve? An Application of Diversity Theory to Crane Conservation." *Quarterly Journal of Economics* 108: 157–183.
World Bank. 2020. Mobilizing Private Finance for Nature. https://thedocs.worldbank.org/en/doc/916781601304630850-0120022020/original/FinanceforNature28Sepwebversion.pdf
World Economic Forum. 2020. Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy. https://www.weforum.org/publications/nature-risk-rising-why-the-crisis-engulfing-nature-matters-for-business-and-the-economy/
WWF. 2022. World Wide Fund for Nature: Living Planet Report. https://wwf.ca/wp-content/uploads/2022/10/lpr_2022_full_report_en.pdf
Xin, W., L. Grant, B. Groom, and C. Zhang. 2023. "Biodiversity Confusion: The Impact of ESG Biodiversity Ratings on Asset Prices." Available at *SSRN 4540722*. https://dx.doi.org/10.2139/ssrn.4540722.
Xu, Q., X. Yang, Y. Yan, S. Wang, M. Loreau, and L. Jiang. 2021. "Consistently Positive Effect of Species Diversity on Ecosystem, but Not Population, Temporal Stability." *Ecology Letters* 24: 2256–2266.
Yachi, S., and M. Loreau.1999. "Biodiversity and Ecosystem Productivity in a Fluctuating Environment: the Insurance Hypothesis." *Proceedings of the National Academy of Sciences* 96: 1463–1468.

Appendix A: Variable definitions

Variables	Definitions	Sources
CBF-related variables		
CBF	Biodiversity loss caused by the firm's annual activities. It results from four environmental pressures: land use transformation, emission of GHGs, emission of nitrogen oxides, and release of toxic compounds into the environment. It is expressed in km^2. MSA, which is equivalent to the pristine natural area destroyed by the firm's annual activities. MSA is a metric characterizing the level of biodiversity in an ecosystem. The original CBF metric is a negative number, corresponding to the degradation of biodiversity caused by the firm. We multiply this variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
Large CBF	Dummy variable that equals one if the firm has a large biodiversity footprint (CBF is above the median) as of the beginning of the year, and zero otherwise. Annual data.	Iceberg Data Lab
CBF GHG	Biodiversity loss due to the firm's GHG emissions. In addition to direct GHG emissions due to the firm's energy consumption, GHG emissions resulting from the electricity consumption and emissions of products purchased in the firm's upstream supply chain are taken into account. We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
CBF land use	Biodiversity loss due to the firm's transformation of pristine land into agricultural land or artificialized areas. The firm's direct pressures on land use, such as its physical assets, buildings, or plantations, are factored in. The land use impact of the firm's upstream supply chain (i.e., purchased products) is also taken into account. We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
CBF water pollution	Biodiversity loss due to the firm's release of toxic compounds into the water. Release of substances due to the firm's direct activity (e.g., processing food or fertilizing crops) are taken into account, as well as those of the firm's upstream supply chain. We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
CBF air pollution	Biodiversity loss due to the firm's release of nitrogen oxides (NOx) into the air. Direct pressures coming from the firm, such as NOx emissions arising from its fuel consumption, are taken into account, as are NOx emissions arising from the electricity consumption and emissions of products purchased in the firm's upstream supply chain. We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
CBF scope 1	Biodiversity loss due to the firm's direct activities (i.e., surface artificialized or occupied). We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab

(continued)

(continued)

Variables	Definitions	Sources
CBF scope 2	Biodiversity loss due to the firm's purchase of electricity, heat, and cooling. We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
CBF scope 3	Biodiversity loss due to the firm's indirect activities (such as its products sold or investments made, or products purchased by the firm). We multiply the original variable by –1 so that higher values indicate a more negative impact on biodiversity. Annual data.	Iceberg Data Lab
CBF/Total assets	CBF value scaled by total assets in $. Winsorized at the 2.5 percent and 97.5 percent levels. Annual data.	Iceberg Data Lab
CBF/Sales	CBF value scaled by revenue in $. Winsorized at the 2.5 percent and 97.5 percent levels. Annual data.	Iceberg Data Lab
Stock return variables		
Monthly return (%)	Monthly stock return. We build total return using stock prices expressed in $ (prccd), adjustment factors (ajexdi), exchange rates (exratd), and total return factors (trfd). Winsorized at the 1 percent and 99 percent levels. Monthly data.	Compustat
Volatility (%)	Standard deviation of the monthly returns over the 36 preceding months. Winsorized at the 1 percent and 99 percent levels. Monthly data.	Compustat
Momentum (%)	Average monthly return over the twelve preceding months. Winsorized at the 1 percent and 99 percent levels. Monthly data.	Compustat
Monthly ICC (%)	Monthly implied cost of capital (ICC). Following Lee, So, and Wang (2021), we construct the variable as the mean value across four ICC values of the following valuation models: GLS (Gebhardt, Lee, and Swaminathan 2001), CAT (Claus and Thomas 2001), MPEG (Easton 2004), and AGR (Ohlson and Juettner-Nauroth 2005). The GLS and CAT models are based on variants of the residual-income model; they differ in terms of their forecasting horizon and terminal value estimation. The MPEG and AGR models are based on the abnormal-growth-in-earnings model; they differ in their formulation of the long-term growth in abnormal earnings. We compute the mean across the four ICC measures, requiring ICC values to be non-missing for at least three measures. We winsorize the individual ICC measures at the 1 percent and 99 percent levels and trim the mean ICC values below 0.	Compustat
Daily return (%)	Daily stock return. We build total return using stock prices (prccd) expressed in $, adjustment factors (ajexdi), exchange rates (exratd), and total return factors (trfd). Winsorized at the 1 percent and 99 percent levels. Monthly data.	Compustat
Firm characteristics		
Total assets	Total assets. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat
Book-to-market	Ratio of book equity to market capitalization. Winsorized at the 1 percent and 99 percent levels. Monthly data.	Compustat
Leverage	Total debt, divided by total assets. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat

(continued)

(continued)

Variables	Definitions	Sources
Capex/Total assets	Capital expenditures, divided by total assets. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat
PPE/Total assets	Net property, plant, and equipment, divided by total assets. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat
ROA	Income before extraordinary items, divided by total assets. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat
Asset growth	Percentage change in total assets. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat
Sales growth	Percentage change in sales. Winsorized at the 1 percent and 99 percent levels. Annual data.	Compustat
E score	Score that reflects how a firm uses best management practices to avoid environmental risks and to capitalize on environmental opportunities to generate long-term shareholder value. Higher numbers indicate better environmental performance. Winsorized at the 1 percent and 99 percent levels. Annual data.	Refinitiv
Market cap	Market Capitalization. Winsorized at the 1 percent and 99 percent levels. Monthly data.	Compustat
SUE1	1 year earnings surprise. Calculated as the actual earnings per share (EPS) for the fiscal year ending in year *t* minus the consensus (median) analyst forecast, scaled by end-of-the-year stock price. The analyst consensus forecast is taken 8 months prior to the end of the forecast period, i.e. 4 months after the prior fiscal year-end. We remove observations where the forecast error is larger than 10 percent of the stock price.	IBES
SUE2	2 year earnings surprise. Calculated as the actual earnings per share (EPS) for the fiscal year ending in year *t* minus the consensus (median) analyst forecast, scaled by end-of-the-year stock price. The analyst consensus forecast is taken 20 months prior to the end of the forecast period. We remove observations where the forecast error is larger than 10 percent of the stock price.	IBES
Climate transition risk variables		
CO_2 Emissions	Total CO_2 and CO_2 equivalent emissions, in tonnes. It encompasses the sum of scope 1, scope 2, and scope 3 emissions. Winsorized at the 1 percent and 99 percent levels. Annual data.	Trucost
High emissions	Dummy variable that is equal to one if CO_2 Emissions is above the median value, and zero otherwise. Calculated as of the end of 2020. Annual data.	Trucost
$CCExposure^{Reg}$	Regulatory climate change exposure measure from Sautner et al. (2023). Reflects the relative frequency with which bigrams that capture regulatory shocks related to climate change occur in the transcripts of earnings conference calls. The measure uses the average over the last four quarters. Annual data.	Sautner et al. (2023)
High $CCExposure^{Reg}$	Dummy variable that is equal to one if $CCExposure^{Reg}$ is above the median value, and zero otherwise. Calculated as of the end 2020. Annual data.	Sautner et al. (2023)
Trucost estimated emissions	Dummy variable that is equal to one if data on a firm's carbon emissions is estimated, and zero if data on a firm's carbon emissions is disclosed.	Trucost

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Variables	Definitions	Sources
Other biodiversity-related variables		
10-K Biodiversity count score	Dummy variable that is equal to one if a firm's 10-K statement contains at least two sentences related to biodiversity, and zero otherwise. Annual data.	Giglio et al. (2023)
Biodiversity habitat index	This measure assesses countries' actions toward retaining natural ecosystems and protecting the full range of biodiversity within their borders. It consists of seven indicators, some of which are based on separate indexes: Terrestrial biome protection, Marine protected areas, Protected Areas Representativeness Index, Species Habitat Index, Species Protection Index, and Biodiversity Habitat Index. Measured as of 2020.	Yale Center for Environmental Law and Policy
Ecosystem vitality index	This measure captures how well countries are preserving, protecting, and enhancing ecosystems and the services they provide. It comprises 42 percent of the total EPI score and is made up of six issue categories: Biodiversity and Habitat, Ecosystem Services, Fisheries, Acid Rain, Agriculture, and Water Resources. Measured as of 2020.	Yale Center for Environmental Law and Policy
Low protection	Dummy variable that is equal to one if a country is below the median value of the Biodiversity habitat index (Ecosystem vitality index) as of the end 2020, and zero otherwise.	Self-constructed
Biodiversity & land use exposure score	Score from 0 to 10 indicating the extent to which a firm's business is exposed to the issue of biodiversity and land use based on its unique mix of business and geographic segments. Examples of criteria assessed include the products and services a firm provides, location of firm operations, and the nature of those operations. Higher scores indicate greater risk. Annual data.	MSCI
Biodiversity impact reduction	Dummy variable that is equal to one if a firm reports on its impact on biodiversity or on activities to reduce its impact, and zero otherwise. Annual data.	Refinitiv

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