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The Market Effect of Acute Biodiversity Risk: the Case of Corporate Bonds

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Abstract

In this paper, we investigate the relationship between biodiversity and companies, through the lens of corporate bonds. We focus on acute biodiversity events and address biodiversity as a risk, considering its looming losses. We illustrate the material and tangible operational risk that may arise from biodiversity losses and propose an event study to measure the market effect of acute biodiversity events on Australian and Brazilian corporate bonds' spreads. To our knowledge, this is one of the first papers to investigate the linkages between acute biodiversity events and micro-level security pricing. We show that most of the studied events appear to be priced into the corporate bond market segment linked to biodiversity impact. Our results indicate that on average, companies in the sectors that have the greatest impact on biodiversity have seen their corporate bond spreads widen in the wake of acute biodiversity events in the 2019-2022 period, providing empirical evidence of corporate financial effects triggered by biodiversity losses. We also illustrate the interlinkage between biodiversity, socio-economic and food systems. Our analyses indicate that the investor community's growing awareness of biodiversity issues is also justified given its integration in price discovery.

Keywords: biodiversity, ecosystems services, ESG, asset pricing, corporate bonds, corporate sustainability, natural language processing, event studies, food security.

JEL classification: G12, Q57, Q51.

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Key takeaways

- In this paper, we investigate the relationships between biodiversity and companies, through the lens of corporate bond spreads.
- Considering the alarming biodiversity losses, coined as a planetary crisis, we decided to address biodiversity as a risk, although opportunities from biodiversity also exist. Moreover, we focus on acute biodiversity events.
- To our knowledge this is one of the first studies that focuses on the linkages between acute biodiversity events and micro-level security prices.
- There is a dense corpus of studies on biodiversity, but the financial industry has not provided much empirical research related to security prices or spreads.
- We review numerous biodiversity initiatives that are already available. In particular, among the metrics that translate the state of biodiversity, Mean Species Abundance (MSA) is gaining acceptance among market practitioners. We also indicate that debate will continue, unlike with the Green House Gases (GHG) for climate issues.
- We illustrate how biodiversity loss is not confined to reputational risk and can trigger tangible operational and physical risks for companies, but may also turn systemic as illustrated by the food security case.
- We propose an event study, focusing on two "megadiverse" countries: Australia and Brazil.
  - Our analyses provide empirical support for the existence of financial impacts deriving from biodiversity on corporate bonds. Companies operating within the most harmful sectors face higher, statistically significant spreads following acute biodiversity events, which is evidence of a market effect.
  - Working on a subset of Australian companies from the sectors with the greatest impact on biodiversity, our results suggest the existence of a biodiversity risk premium.
  - This premium remains when periods following acute biodiversity events are dismissed, which brings up the question of market pricing of chronic biodiversity losses, as they have natural interlinkages with other environmental dimensions.

1 Introduction

Climate action is the thirteenth Sustainable Development Goal (SDG), however, we illustrated in our previous research (Le Guenedal *et al.*, 2022) that, at this time, companies had not silently engaged in the "race to Net Zero" on their own. Recent academic research has demonstrated that engagement initiatives by institutional ownership had a positive effect on corporates' climate disclosure and climate action (Bingler *et al.*, 2022). This positive involvement of institutional owners is required because for every public-policy sourced dollar committed to achieving the SDGs, there are about two dollars missing (UNCTAD, 2018). The thirteenth SDG refers to *urgent* action to combat climate change. Comparatively, *halting biodiversity loss* is stated within the fifteenth SDG without an explicit mention of urgency. However, this goal was already present in Agenda 21, the final text of the Earth Summit held in Rio de Janeiro, Brazil back in 1992[1]. In that same year, the EU adopted the Habitat Directive for the conservation of natural habitats and of wild fauna and flora[2]. More recently in 2018, the UN Biodiversity Conference (COP14) decided to formalize a post-2020 global biodiversity framework which would contribute to and benefit from the progress towards the SDGs (CBD, 2021). Similarly, the EU taxonomy regulation that came into force in 2020 encompasses the protection and restoration of biodiversity and ecosystems as one of its six environmental objectives. In its latest report, the World Economic Forum quoted biodiversity loss as the third biggest global risk that could arise over the next 10 years, ahead of debt crises for instance, which emphasizes the urge to take action (WEF, 2022).

Biodiversity is part of the Earth's natural capital and is at the cornerstone of a well-functioning planet, as highlighted in the seminal work of Costanza *et al.* (1997). Indeed, natural capital is both an input for biodiversity, but also an output. Ecosystem services such as pollination, soil fertility, and air and water purification can increase stocks of natural capital. They can therefore sustain economic and social value creation through tangible benefits such as supplying fuel, water, food and wood (Foll and Minton, 2022). Biodiversity encompasses complex mechanisms that arise from multiple and very diverse sources. This may explain why the topic as a whole has received comparatively little attention in the field of sustainability studies, compared

[1]https://sdgs.un.org/sites/default/files/publications/Agenda21.pdf.
[2]https://ec.europa.eu/environment/nature/legislation/habitatsdirective/.

to climate for instance. Interdependence between the fauna, flora and natural elements, humans and their activities and ecosystems needs to be modeled, but this is challenging. In addition, no single KPI can allow us to grasp how important biodiversity is, in the same way that GHG emissions help to measure climate change, although a market practice seems to be emerging.

Our study fits into the measurement of acute biodiversity risk (as opposed to chronic risk), a distinction that exists in the climate risk strand of research which is applied for instance in Bressan *et al.* (2022). The reason is threefold. First, by definition, analyzing chronic risks implies the assessment over long timeframes, due to the low speed at which state metrics change, which imposes a stringent constraint on data length. Second, we take the stance that, in the context of financial markets, acute risk benefits from greater visibility and hence is more likely to be impactful and measurable. Finally, as biodiversity loss and climate change accelerate, it will become increasingly likely that ecosystems will reach their tipping points and no longer provide their essential services. For instance, scientists have started to warn how the Amazon rainforest has been approaching its tipping point over the last couple of years. This reinforces the acute feature of biodiversity losses (Boulton *et al.*, 2022). In our analysis, we also address biodiversity as a risk, although of course there are opportunities as well, through natural capital creation and ecosystem services for instance. This choice is driven by the worrisome trends observed over previous decades. Biodiversity loss is positioned by UNEP (2022) as one of the three planetary crises, alongside climate change and pollution. Furthermore, considering the growing number of endangered species, the Amazon rainforest reaching a tipping point or the continuous increase in atmospheric concentration, we believe the picture is unbalanced and a long way from a biodiversity offset debate. These Biodiversity offset policies, based on a paying polluter structure, should indeed be implemented once "*appropriate efforts have been made first to avoid adverse impacts to biodiversity, then to minimize the unavoidable impacts, and finally to restore biodiversity on-site*" (OECD, 2016).

Despite modeling complexity, natural capital and biodiversity have entered economic models. Integrated Assessment Models (IAMs) were developed to model the links between multiple disciplines such as the economy, society and climate, through the lens of cost-benefit or techno economic analysis (Hourcade *et al.*, 2021). Dynamic Integrated Climate-Economy (DICE) models are an example of IAM cost-benefit models, generally employed to assess the social cost of carbon (Nordhaus, 1992). Specifications were subsequently developed, accounting for the stock of natural capital (see the DICE-NC model from Hackett and Moxnes (2015) or Bastien-Olvera (2021)'s Green-DICE model for instance). Integrated earth systems also exist, such as the Global Unified Metamodel of the Biosphere (GUMBO) from Boumans *et al.* (2002) that provides estimates of ecosystem services. On the economic front, Environment-Economy and Earth-Economy modeling tools emerged, such as those developed by the OECD. The ENV-linkage model is a Dynamic General Equilibrium model developed by the latter, relying on a global sectoral economic model (the Global Trade Analysis Project - GTAP) that allows interactions between sectors and regions to be measured. It is calibrated using GDP projections from the ENV-growth model, that depends in particular on natural resources (Château *et al.*, 2014). The GTAP general equilibrium model was enhanced over the years with the addition of components including nature related aspects. Indeed, the GTAP-InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) adds an ecosystem services model (Johnson *et al.*, 2021), while the GTAP-AEZ (Agro Ecological Zones) incorporates land use geospatial data (Lee, 2005). The World Bank also worked on a global Earth-Economy model in their seminal article by Johnson *et al.* (2021), producing forecasts of future biodiversity losses up to the 2030 horizon in order to assess how effective different policies are in mitigating such damages. Future biodiversity losses can also be assessed through the Shared Socioeconomic Pathway (SSP) framework, as demonstrated by Leclère *et al.* (2020). These analysis frameworks are very useful for policymaking and assessing economy-wide and macroeconomic dynamics at the aggregated level. Although techno economic IAM models provide a more granular view of sectors and regions, they often fail in the measurement of physical impacts from climate change (Hourcade *et al.*, 2021). More micro-oriented and sector-oriented models exist to evaluate the impact of ecosystems on the economy. However, there is a lack of comprehensive models to assess links between individual companies and biodiversity.

We intend to assess and quantify the impact of biodiversity losses on corporates. Although biodiversity losses have long been perceived as solely a reputational risk instead of a core responsibility from the viewpoint of corporates (Smith *et al.*, 2019), we aim to shed the light on their material and financial impact from the angle of companies. In fact, Dempsey (2013) identifies four different channels that can transform biodiversity losses into financial losses. Reputational risk can arise following a biodiversity scandal and damage a brand, but also operations. Operational (or physical) risk may also disrupt operations, increase costs or lead to shortages of materials. Regulatory risk may emerge following new government policies on taxes or natural resource extraction, but also from legal penalties. Market and product risk involves the possibility that customers turn to more virtuous suppliers or that governments impose new sustainable purchasing policies. Finally, financial risk can result in trickier access to market finance, if banks, stock markets or financial institutions are required to comply with potentially more stringent regulations.

In this paper, we aim to illustrate the potential impact on companies of acute biodiversity events, with a focus on operational costs and market pricing. Considering that the risks at stake for corporates can naturally permeate into their fundamentals and securities valuation, understanding the materiality of biodiversity losses is essential from an investor viewpoint. Business dependency and impact on biodiversity, also known as the double materiality principle, are often the prime prisms of analysis for assessing biodiversity-related risks at the portfolio level (Klug, 2021; Grigg *et al.*, 2021). Section 2 delves into the double materiality principle that is specific to the question of biodiversity while illustrating the financial materiality that companies may face on the operational front in light of recent biodiversity disruptions. In Section 3, we build Biodiversity risk indexes based on the GDELT (Global Data on Events, Location, and Tone) news dataset[3]. From these series, and focusing on biodiversity-impacting sectors we propose an event study estimating the impact of acute biodiversity events on corporate bond spreads in Australia and Brazil. We also test the existence of a biodiversity risk premium on a subset of Australian companies. We address biodiversity losses as a systemic risk through the food security question in Section 4. Section 5 offers some concluding remarks.

2 Double materiality

Investigating the relationship between corporate business and biodiversity losses implies addressing the double materiality principle of biodiversity, as highlighted by Schrapffer *et al.* (2022). Namely, we identify how human

[3]https://www.gdeltproject.org/.

activities can erode biodiversity, but also, in turn, how biodiversity losses can materialize on human activities. This comes down to quantifying businesses' impact and dependence on biodiversity.

2.1 How can human activities harm biodiversity?

Human activities can harm biodiversity in multiple ways. For instance, air pollution, notably from land use and combustion can have a tremendous impact on ecosystems. Indeed, sulfur and nitrogen emissions can turn into acid rains that are harmful to both fauna and flora (Greaver *et al.*, 2012). Similarly, nitrogen, as well as nutrient overloads, can lead to the eutrophication of aquatic ecosystems, raising carbon dioxide levels in coastal water, and acidifying ocean water (Sunda and Cai, 2012). Moreover, accelerating industrialization and urbanization around the globe for the past decades led to rising ground-level ozone and CO_2eq levels (Ainsworth *et al.*, 2020), causing respectively oxidative damage to fauna and flora and plants' lower photosynthesis capabilities entailing the provision of ecosystem services.

The fact that human activities can be held responsible for climate change also has implications on soil quality. Indeed, climate change degrades soil production and decomposition rate as well as carbon storage abilities through variation in precipitation, temperature, and CO_2eq concentration (Falloon *et al.*, 2007). Moreover, unsustainable agricultural practices (such as extensive tillage, or in-situ burning of crop residues) and poor crop management, can erode soil by altering its physical, chemical, and biological factors and curb crop production (Verhulst *et al.*, 2010). Agricultural intensification and extensification was found to threaten both the abundance and functional diversity of soil biota (Postma-Blaauw *et al.*, 2010). Haddad *et al.* (2015) showed that human activities destroyed and fragmented habitats, hence reducing biodiversity and impairing ecosystem functions. Land use conversion also contributes to soil degradation, so are unsustainable agronomic practices such as overgrazing or excessive wood harvesting. More generally, human over-exploitation of natural resources can strongly impair ecosystem services.

Human activities also play a key role in species extinction through hunting or habitat degradation (Mooney *et al.*, 2009). In fact, both the Living Planet Index (LPI) and the International Union for Conservation of Nature's (IUCN) Red List Index (RLI) of Threatened Species™ showed a strong degradation in wildlife and species diversity. According to the LPI (Almond *et al.*, 2022), species population size decreased by 69 % between 1970 and 2018 globally (a striking 94% decline was witnessed for Latin America), while the IUCN RLI demonstrated how the number of threatened species was multiplied by 4 between 2000 and 2022[4]. Almond *et al.* (2020) also cited changes in land and sea use (hence including habitat loss and degradation), and species over-exploitation (hunting, poaching or harvesting) as main threats to biodiversity. The authors also mentioned how invasive species can endanger native species or spread diseases. Invasive species are introduced by humans outside of their native environment. This is often unintentional and caused by human travel, which intensified over the past decades. In addition, pollution (by degrading species' environment and their access to food, but also potentially their reproductive performance) and climate change (impacting seasonal patterns in migration or reproduction) are also important threats to biodiversity.

2.2 What are the direct consequences of biodiversity loss?

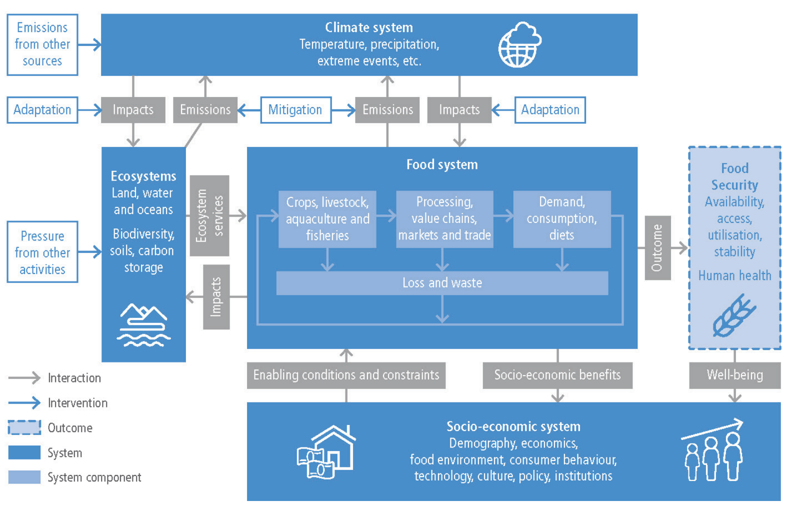
The double materiality principle of biodiversity implies that nature can stop providing vital ecosystem services to humans. This can have dramatic impacts, notably on health. To illustrate this point, Ellwanger *et al.* (2020) studied the channels between biodiversity degradation and infectious diseases. The authors showed how deforestation and urbanization deter wildlife habitat forcing species to migrate, which increases wildlife-human contact and facilitates the spread of zoonotic diseases. Extreme hydrological events (such as rainfall and flooding) caused by climate change are also a threat to human health when conducing to water contamination. Agricultural practices can also favor vectors of transmission, and even lead to the emergence of new influenza viruses (Yang *et al.*, 2013).

Human activities disrupt ecosystem processes and reduce the services they generate (Mooney *et al.*, 2009), which can also accelerate climate change. Indeed, terrestrial ecosystems constituting soil and vegetation can store substantial amounts of carbon. Marine ecosystems such as seagrass meadows are also known as a strong carbon sink (Duarte *et al.*, 2010).

[4] https://www.iucnredlist.org/resources/summary-statistics.

Food security also directly derives from biodiversity services. In fact, the food system is strongly intertwined not only with ecosystems but also with climate and socio-economic processes, as illustrated in Figure 1 by Mbow *et al.* (2019). The world population's increase raises the question of growing food demand management. It particularly pressures the agricultural sector, which often faces a trade-off between biodiversity preservation and efficient land use (Tscharntke *et al.*, 2012; Maurin *et al.*, 2022). Land sparing - segregating land devoted to intensive agriculture from preserved area - is often opposed to land sharing which implies a wildlife-friendly farming. However, the biodiversity-production mutualism needs to be accounted for, since wildlife-friendly areas ensure soil fertility, biocontrol, and pollination (Seppelt *et al.*, 2020), which are essential to ensure that crop yield can meet human population growth. In addition, Lal and Stewart (2010) argued that "*the significance of dependence of food security on soil quality is likely to increase with decrease in per capita land area, increase in extent and severity of soil degradation, and the projected global warming*".

Figure 1: Interlinkages between the Climate System, Food System, Ecosystems and Socio-economic systems



Source: Mbow *et al.* (2019)

We must also bear in mind second-order effects, as interdependencies are central to biodiversity. To illustrate, one specie's extinction can jeopardize an entire food web and become a food security issue. In a similar manner, accelerating climate change indirectly worsens all the previous effects cited previously. In fact, this mechanism of overlapping issues between these different dimensions of nature is known as the "climate biodiversity nexus" (Kan *et al.*, 2022) or more generally the "climate nature nexus" (Finance for Biodiversity Initiative, 2021). Climate change is responsible for biodiversity loss, while in turn damaged biodiversity ecosystems accelerate climate change. Such mechanism is notably accounted for in the Net Environmental Contribution (NEC) metric proposed by a collaborative initiative between different asset managers, presented in Peladan (2019) and sponsored by Institut Louis Bachelier. This metric represents the extent to which companies are aligned with the environmental transition, based on water, air quality, resources and waste, climate, and biodiversity issues (Guéant *et al.*, 2021). It actually shows how for most sectors, the climate and biodiversity issues are closely intertwined. For instance, the apparel textile sector, through fiber production, generates CO_2 emissions but also contributes to abiotic resource depletion and water eutrophication. The latter releases CO_2 which in turn acts on climate change. Worsening biodiversity can hence have snowballing effects.

Finally, as mentioned previously, biodiversity losses can engender business risk, that can materialize through different channels: reputational, operational, regulatory and financial risks (Dempsey, 2013). We are particularly interested in these dimensions, with a special focus given to operational (physical) and financial risks (such as market effect on securities).

2.3 Quantifying relationships between corporates and biodiversity

As Dempsey (2013) argued, it is often difficult to appraise individual risk from biodiversity losses from the viewpoint of corporates. This led to the development of numerous and various initiatives summarized in Table 1 and organized in multiple categories. First, the availability of data and visualization tools has rapidly grown recently. The IBAT alliance, for instance, maintains three global biodiversity datasets: the IUCN Red List of Threatened Species, the World Database on Protected Areas and Key Biodiversity areas. Going one step further, practical tools are now available, such as the ENCORE Exploring Natural Capital Opportunities, Risks and Exposure. Third, methodologies have been developed to help companies navigate the biodiversity issue. In fact, the initiatives proposed by various organizations to measure corporate biodiversity footprint are generally articulated around this double materiality principle: measuring companies' dependencies but also their impact on biodiversity. Such methodologies are generally composed of multiple modeling bricks (economic activities, environmental aspects, and impact measurements) and hence often make use of an input-output table to assess sector dynamics. GTAP and EXIOBASE which embeds an environmental extension are often employed (Finance for Biodiversity Initiative, 2022), although the frequency of updates is fairly low. Corporate Ecosystem Service Review (CESR) and Science Based Targets Network (SBTN) are methodologies that both propose to businesses to follow a 5 steps process to identify risks and opportunities from biodiversity. Corporate footprints are generally derived from their activity exposure to sectors that have been modeled, which tend to neglect company-specific dimensions. Some organizations target the finance industry (CERES Land Use and Climate Working Group, Biodiversity, Principles for Responsible Investment (PRI), Taskforce on Nature-related Financial Disclosures (TNFD), Partnership for Biodiversity Accounting, Finance @ Biodiversity). These initiatives aim at engaging asset owners and managers and helping them to measure biodiversity, setting targets and reporting standards. Fourth, advances are being made on the reporting front: for instance, the ALIGN initiative (Aligning Accounting Approaches for Nature) has the ambition to set standards in terms of biodiversity reporting, assisting the European Commission. On the accounting front, efforts have been undertaken for measuring nature's financial value. The French Chair of Comptabilité Ecologique[5] notably proposes the Comprehensive Accounting in Respect of Ecology (CARE) framework (Feger and Rambaud, 2020). Finally, countries are also accompanied on the topic of biodiversity by intergovernmental initiatives such as BIOFIN (the Biodiversity Finance Initiative).

In terms of metrics translating the state of biodiversity, different proposals exist. Leclère *et al.* (2020) notably quoted measures related to *species extinction* (Fraction of Regionally Remaining Species and Fraction of Globally Remaining Species), *extent of suitable habitat* (Extent of Suitable Habitat), *wildlife population density* (Living Planet Index) and *intactness of the local species composition* such as the Mean Species Abundance (MSA) and the Biodiversity Intactness Index (BII) which is also developed at the local level under the Local Biodiversity Intactness Index.

[5] https://www.chaire-comptabilite-ecologique.fr/.

Table 1: Examples of Initiatives on Biodiversity

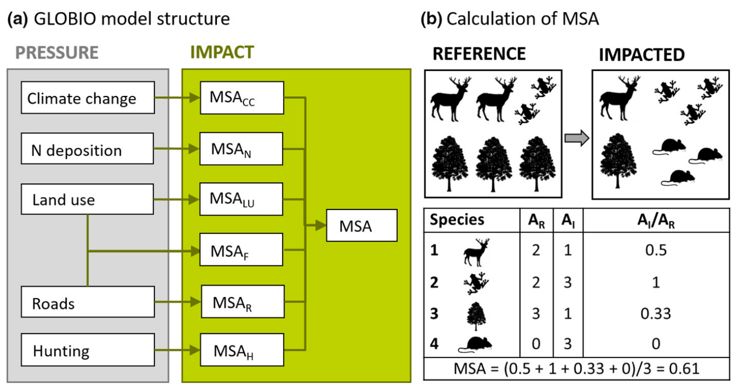
Datasets	Biodiversity indexes
UN World Conservation Monitoring Centre (WCMC)*	STAR (Risk of extinction)
World Database on Protected Areas (WDPA)*	Extent of Suitable Habitat (ESF)
Key Biodiversity Areas (KBAs)*	Living Planet Index (LPI)
Integrated Biodiversity Assessment Tool (IBAT)	Mean Species Abundance (MSA)
Global Distribution of Coral Reefs*	Biodiversity Intactness Index (BII)
Natural and Modified Habitat Screening Layer*	Local Biodiversity Intactness Index (LBBI)
Biodiversity Hotspots*	IUCN Red List of Threatened Species
Global Critical Habitat Screening Layer*	Biodiversity Habitat Index
Reefs at Risk*	Global Ecosystem Restoration Index
Global Distribution of Seagrasses*	Protected Area Representatives & Connectedness Indices
Global Relative Rate of Natural Capital Depletion*	Rate of Invasive Alien Species Spread Indicator
Human Pressures on Biodiversity, Water and Carbon*	Species Habitat Index (SIh)
CDP questionnaire for Forest-related risks	Species Protection Index
Hub Ocean	Species Status Information Index
Trade in Biodiversity-based products - UNCTAD*	Ecological Damage Potential (EDP)
Accounting	Potentially Disappeared Fraction (PDF)
Partnership for Biodiversity Accounting Financials (PBAF)	Life Cycle Impact Assessment Indicators (LCIA)
Comprehensive Accounting in Respect of Ecology (CARE)	Biodiversity Integrity Index
System of Environmental-Economic Accounting - Ecosystem Accounting	Ecological Footprint (WWF)
Methodologies for Financials	Methodologies for Corporates
LEAP - Taskforce on Nature-related Financial Disclosures (TNFD)	Corporate Ecosystem Service Review (CESR)
CERES Land Use and Climate Working Group	Science Based Targets Network (SBTN)
Finance for Biodiversity (F4B)	Product Biodiversity Footprint
Coalition for Private Investment in Conservation (CPIC)	Biodiv. Indicator for Extractive Companies (UNEP-WCMC)
Finance@Biodiversity Community	Biodiversity Impact Metric
Reporting	Tools
Global Reporting Initiative (GRI)	Exploring Natural Capital Opportunities, Risks & Exposure (ENCORE)
Align (Aligning accounting approaches for nature)	TRASE
Climate Disclosure Standards Boards (CDSB)	Iceberg Data Lab (Corporate Biodiversity Footprint)
Corporate Sustainability Reporting Directive (CSRD)	Biodiversity Metric 3.1
Intergovernmental methodologies	Carbon4Finance & CDC Biodiversité (Global Biodiversity Score)
Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)	Global Biodiversity Model for Policy Support (GLOBIO)
Biodiversity Finance Initiative (BIOFIN)	Portfolio Impact Analysis Tool for Banks (UNEP)
International Union for Conservation of Nature (IUCN)	Net Environmental Contribution Initiative (NEC)
Conf. of the Parties to the Convention on Biological Diversity (CBD)	
BioTrade Initiative - UNCTAD	

* refers to open-source datasets

Source: Amundi Institute.

Metrics translating the state of biodiversity generally articulate around the concepts of extent, condition, or significance (Lammerant *et al.*, 2021). Life Cycle Impact Assessment Indicators (LCIA) were also developed, such as ReCiPe, measuring the impact from a midpoint (global warming or terrestrial acidification for instance) to an endpoint (such as ecosystem damages) (Lammerant *et al.*, 2021). LCIA indicators generally report on Potentially Disappeared Fraction of species (PDF), representing the share of the species that have been lost in a given area, ranging from 0 to 100% (0 for the intact state of nature) or m^2eq / PDF. Such metrics do not account for species abundance.

Figure 2: Graphical Summary of the GLOBIO model, Showing (a) the Pressure-Impact Relationships and (b) the Calculation of the MSA Metric



Source: Schipper *et al.* (2020)

The MSA has often been retained by academics and practitioners (Alkemade *et al.*, 2009; CDC Biodiversité, 2022; Maurin *et al.*, 2022). This metric, illustrated in Figure 2, also translates ecosystem intactness, by comparing the species abundance between human-disturbed habitat (observed or projected) and natural habitats (from a reference point, 2010 for eg.). Compared to the Biodiversity Intactness Index (Scholes, 2005), it gives equal weight to different areas, while the former overweighs species-rich areas (Alkemade *et al.*, 2009). Intact ecosystems would imply a 100% ratio and would tend to 0% as species extinction worsens. It hence measures both abundance and richness. It is also declined under a surface-related metric, such as km^2 MSA. More focused on corporates' footprint, the NEC metric presented previously measures the impact of a company on various environmental dimensions (water use, GHG emissions, air quality, biodiversity, and resource waste), assigning a score that depends on the company's deviation from the average sector's impacts. This measure is also gaining momentum in the financial industry.

Similar to GHG in appraising climate change, practitioners would appreciate a consensus to be reached around an acceptable measure that could address reasonably all the biodiversity dimensions. However, in ecology, diversity is measured by the "*effective number of elements of a system*" which are designed with an order q. They are referred to as the Hill numbers ${}^{q}D$ (Jost, 2006, 2019) and they are realistic for biologists because they respect the so-called "*doubling property*", which states that doubling the equally common species will result in the doubling of the index.

When $q > 0$ and $q \neq 1$:

$$ {}^{q}D = \left(\sum_{i=1}^{S} p_i^q \right)^{1/(1-q)} \tag{1a} $$

When $q = 1$:

$$ {}^{1}D = exp \left(- \sum_{i=1}^{S} p_i \, ln \left(p_i \right) \right) \tag{1b} $$

where S is the number of species, p_i is the relative *abundance* of the i^{th} species (count of individuals in the i^{th} species relative to the total number of individuals in all S species).

These Hill numbers are themselves related to the generalized entropy proposed by Tsallis in the following relation (Tsallis, 1988; Marcon, 2018):

$$ {}^{q}H = ln_q \, {}^{q}D \tag{2} $$

The first Hill numbers are remarkable in the sense that ${}^{0}D$ is the species richness, ${}^{1}D$ is the exponential of the Shannon Index which relates to species evenness, and ${}^{2}D$ is the inverse of the Simpson Diversity index. As highlighted by Adajar *et al.* (2019), the Simpson Diversity index is known as the Hirschman-Herfindahl Index (HHI) when applied in economics. There are also similarities between biodiversity indexes and social inequality metrics. Recent literature which tries to unify biodiversity metrics proposed a combination of the Hill numbers of order 0, 1, and 2 (Gatti *et al.*, 2020). To illustrate the additional complexity of species analysis, Chao *et al.* (2010)

proposed a phylogenetic expansion to the Hill numbers which takes into account the species' relatedness. We expect to see the emergence of standards for biodiversity indexes for practitioners in finance because of the structure of the financial industry. Indeed, asset owners and investors need cross-sectional comparisons across their investment universes because they manage portfolios with securities. Species richness metrics are intuitive and could fit the purpose while debate, as highlighted by Rodwell *et al.* (2022), will certainly remain because of the real complexity of the ecological systems.

In addition, the scientific community is urging for an acceleration in the development of biodiversity scenarios. This would raise the attention to these issues in the public debate, as it was the case with climate change scenarios' emergence. Biodiversity has started to be accounted for in the impact measurement of SSP (Leclère *et al.*, 2020). According to the scenarios studied by Pereira *et al.* (2010), notably based on habitat loss, shift in the distribution of species, extinctions and species abundance variations, biodiversity should decline through the 21^{st} century. However, debates remain on the design of the scenarios, as illustrated by the Half-Earth proposal. Wilson (2016) proposes to maintain or restore at least 50% of land and sea surface in order to ensure sufficient habitat, and preserve species and our ecosystems, an idea that found some support in the scientific community. Still, opponents to the proposal claim that science lacks the knowledge to assess the Half-Earth ecological impacts. Wilhere (2021) states that the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) could provide IPCC-like[6] science but it would first need to deliver an influential assessment report for policymakers on global and ecoregional land-area targets for biodiversity conservation. He argues that developing robust scenarios will take time, considering the higher complexity of biodiversity compared to climate change modeling. Maurin *et al.* (2022) conducted a comprehensive review of biodiversity scenarios and concluded that although scenarios to assess the biodiversity-related financial risks (BRFRs) have limitations, practitioners and academics should not wait to apply scenarios with short-term pathways. Agarwala *et al.* (2022) employed a machine learning technique to incorporate biodiversity and nature loss on sovereign credit rating. They concluded that the scenarios from the seminal research from the World Bank (Johnson *et al.*, 2021) would impact the creditworthiness of lower-rated sovereigns. If lower-income economies are often more exposed to

[6] Intergovernmental Panel on Climate Change.

losses in ecosystem services in terms of GDP contribution and dependencies (Johnson *et al.*, 2021), biodiversity losses can also have a material impact on higher-income countries. Indeed, in prior research on ESG and sovereign risk (Semet *et al.*, 2021), we demonstrated how a species-threatening score had a material impact on sovereign bond spreads, yielding a supplementary 3.5% in explanatory power when compared to a pure macroeconomic model. In fact, when selecting the most meaningful extra financial metrics to explain high-income countries' creditworthiness, this biodiversity measure ranked 7^{th} among more than 70 indicators, highlighting that high income-countries are not immune to biodiversity losses.

2.4 Illustration of physical losses reported in the CDP Forest-related questionnaire

We saw how the impact of biodiversity losses on human activities can be multifaceted. Still, identifying and measuring spillovers from biodiversity damages can be challenging. In order to gain an understanding of such causal links, we decide to investigate the impact of direct biodiversity events on businesses' physical capabilities. With the purpose of doing so, we rely on the CDP Forest Response dataset published in October 2021. This questionnaire was filled out by nearly 450 companies for the year 2021 and allows us to gauge companies' ties with forest risk commodities through roughly 70 questions (140 for the Coal, Metals & Mining sector). We focus on the dataset's dimension that relates to the current state of companies' dependence on forest products. In Table 2, we summarize the different types of detrimental impacts suffered by companies according to their dependence on different commodities[7]. In total, CDP questionnaire reports 141 records for the 2021 dataset on this topic, and for a majority of them, the total financial impact associated.

We witness how reputational and market impacts dominate. Still, physical and regulatory risks represent a sizeable share of detrimental impacts from forests. According to respondents' answers, regulatory risk often encompasses the costs associated with new material certification or investments made to increase supply chain traceability. As far as reputational risk is

[7] We employ the question "F1.6a C2 Describe the forests-related detrimental impacts experienced by your organization, your response, and the total financial impact. - Impact driver type."

Table 2: Forests-related Detrimental Impacts Reported by Companies by Commodity for 2021

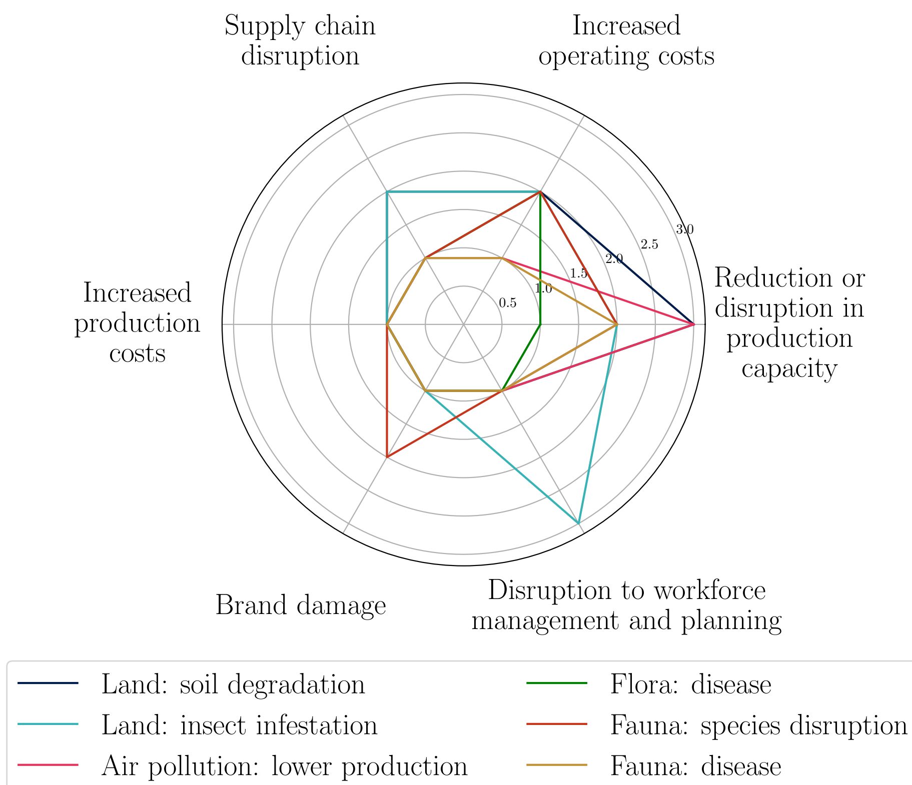
	#	Reputational and market	Physical	Regulatory	Technological
Timber	73	42%	42%	12%	3%
Soy	15	47%	33%	13%	7%
Cattle	19	68%	11%	21%	0%
Palm oil	26	73%	19%	4%	4%
Coffee	2	100%	0%	0%	0%
Cocoa	3	100%	0%	0%	0%
Rubber	2	0%	0%	50%	50%

Source: Authors' calculations, CDP, Amundi Institute.

concerned, companies generally quote financial costs associated with supplementary reporting to satisfy stakeholders with rising sustainability concerns, or reduced sales due to negative media coverage, although they often struggle to quantify such impact. We witness that many firms actually anticipate future brand image by ensuring that they can accurately identify their full supply chain spectrum, but also that they switch their operations towards more sustainable suppliers, which often comes at a premium cost. On the technological front, to illustrate, firms reported limited access to crop variety developed by other countries or poor innovative responses to changing raw materials.

Since we are particularly interested in tangible operational costs induced by biodiversity degradation, we focused on 17 cases where companies have reported physical impairment deriving directly, and in a straightforward manner, from biodiversity issues in the 2020 and 2021 datasets. As already mentioned, second-round indirect effects can be numerous following biodiversity losses, but also more difficult to evaluate because of these interlinkages. Our company sample spans a diverse geographical coverage (from Brazil, Finland, China, Japan and India among others). Considering that the CDP questionnaire relates to forest-related risk, companies' sectors are tilted toward Food & Beverage Processing, Wood & Paper Materials, Crop Farming, and Rubber Products. Direct physical losses were principally reported for companies concerned with timber products (9), palm oil (4), soy (2), rubber (1), and cattle products (1). In Figure 3, based on our sample of companies that recorded physical impairment deriving directly from biodiversity issues, we ranked the principal risks reported by the companies according to the type of biodiversity issues (air, land, fauna, and flora), from a range of 1 (low risk) to 3 (high risk) based on reported impairment frequency.

Figure 3: Financial Materiality from Biodiversity Losses



Source: Authors' calculations, CDP, Amundi Institute.

We witness how most of the biodiversity losses, independently of their origin, lead to a reduction or disruptions in production capacities. This is particularly severe for soil degradation and air pollution. For instance, prolonged drought periods or haze from forest fires can lessen crop yield or fruit production. Lack of pollination caused by extreme weather temperature was also mentioned by questionnaire respondents. Our analysis also shows that land deterioration, either caused by poorer soil quality or insect infestation, species disruption, and diseases infecting flora can trigger higher operating costs. Reported cases often highlight pest, spruce bark beetle infestation, or plant leaf disease. Damages caused by animals were also acknowledged by the questionnaire's respondents. Insect infestation may also disrupt workforce management and planning, but likewise the whole supply chain. Finally, brand damage can arise following species disruption issues, as illustrated a couple of years ago when NGO condemned companies engaged in deforestation for being responsible for the orangutan population decline.

These results concerning companies that rely on commodities subject to forest-related risk are insightful as they allow us to illustrate the tangible and material impact of biodiversity losses on business activities. Although resource scarcity due to natural capital depletion is an obvious threat to production processes, we witness how operations can be jeopardized by a worsening state of biodiversity. Similar questionnaires are provided by CDP for companies on the threats arising from climate change and water security, allowing to grasp other risks closely tied to biodiversity erosion and assess their financial and operational materiality for corporates. Such analyses are a first step toward the appraisal of corporate financial dependency on biodiversity, going beyond the resource dependency channel from the double materiality principle.

3 Event study: the impact of biodiversity stress on corporate spreads for Australia and Brazil

The objective of this event study is to shed the light on the market effect that may be at play for corporates' sub-industries and securities following acute biodiversity events, focusing on companies with the most impactful activities on biodiversity. The first step implies proposing a measure of biodiversity risk. Since we are keen to focus on acute biodiversity events, we choose to concentrate on days where biodiversity-related news volume compounded by the tonality of the news, peaks negatively for the studied country. We construct time-series measuring biodiversity risk for two megadiverse countries, and then investigate how the sector double materiality principle of biodiversity translates for corporates in these markets. Next, we evaluate corporate bond spreads movements following various acute biodiversity events, on water, land, air, fauna or more generic aspects.

3.1 GDELT news data for measuring biodiversity risk

In this subsection, we are keen to quantify the share of biodiversity risk in news coverage. In order to do so, we employ the GDELT dataset (Leetaru and Schrodt *et al.*, 2013), which records events from news (printed, online and broadcast) across the globe for more than 23 000 identifiers notably providing the location of events and sentiment associated with these pieces of news. In the spirit of Blanqué *et al.* (2022), we aggregate various identifiers under a set of qualitatively defined themes spanning the biggest biodiversity pressures identified by Dìaz *et al.* (2019): land-use and sea-use change, direct over-exploitation of natural resources and organisms, climate change, pollution, and the spread of invasive alien species.

Table 3: Themes Underlying Biodiversity risk index

Theme	Example Dimensions
Air	Air pollution, radioactive leaks, urban pollution
Water	Toxic spills, dam break, maritime disaster, floods, tsunamis, water management, freshwater ecosystems, ocean pollution
Fauna	Overfish, endangered species, insects, birds, fish, mammals, reptiles
Flora	Plant disease, natural habitats, plant variety protection
Land	Agriculture, forests, fires, earthquakes, wind, landslide, indigenous, soil management, storms
Climate change and generic	Climate change, biodiversity, natural disaster (heatwaves, severe weather...), ecosystems, natural resource management

Source: Amundi Institute.

Such an approach echoes the work of Engle *et al.* (2018) and Ardia *et al.* (2020), that respectively built time series related to climate news from textual analysis of news sources, and a Media Climate Change Concerns index on comparable sources. Similarly and more specifically, we construct distinct themes related to air, fauna, flora, land, and water. We also make use of a more generic category that comprises identifiers such as biodiversity and ecosystems and that can apply to different themes. Themes can encompass identifiers associated both with positive development (such as the UN initiative for Reduced Emissions from Deforestation and Forest Degradation) and risks (maritime disasters for instance). Table 3 sums up the principal dimensions associated with each theme, while detailed identifiers are available in Table 13 in Appendix A.1. GDELT allows to monitor the frequency at which the identifiers are mentioned in the news, with a 15 min interval, as well as the sentiment associated to these identifiers. We aggregate these metrics to obtain a daily volume and a daily tone metric for each identifier. To assess the overall strength of a theme, we aggregate the volume associated with its underlying identifiers compounded by the tonality of the news. Combining this volume weighted tone calculated on different themes in the specific location allows us to build a Biodiversity risk index for a given country.

Figure 4 presents the Biodiversity risk indexes as well as the share of biodiversity-related news associated to their location (Australia or Brazil)[8] According to Mittermeier *et al.* (1999), these countries are identified as "megadiverse" countries among the 17 listed. Territories of the megadiverse countries alone would account for between 60 and 80% of life on earth[9]. As a matter of fact, Brazil's membership is mainly explained by the Amazon rainforest, which is home to the most diverse flora and fauna on the planet. Moreover, Australia is one of the two developed countries included in the list of megadiverse countries and is pointed out as one of the world's leading countries for endemic species.

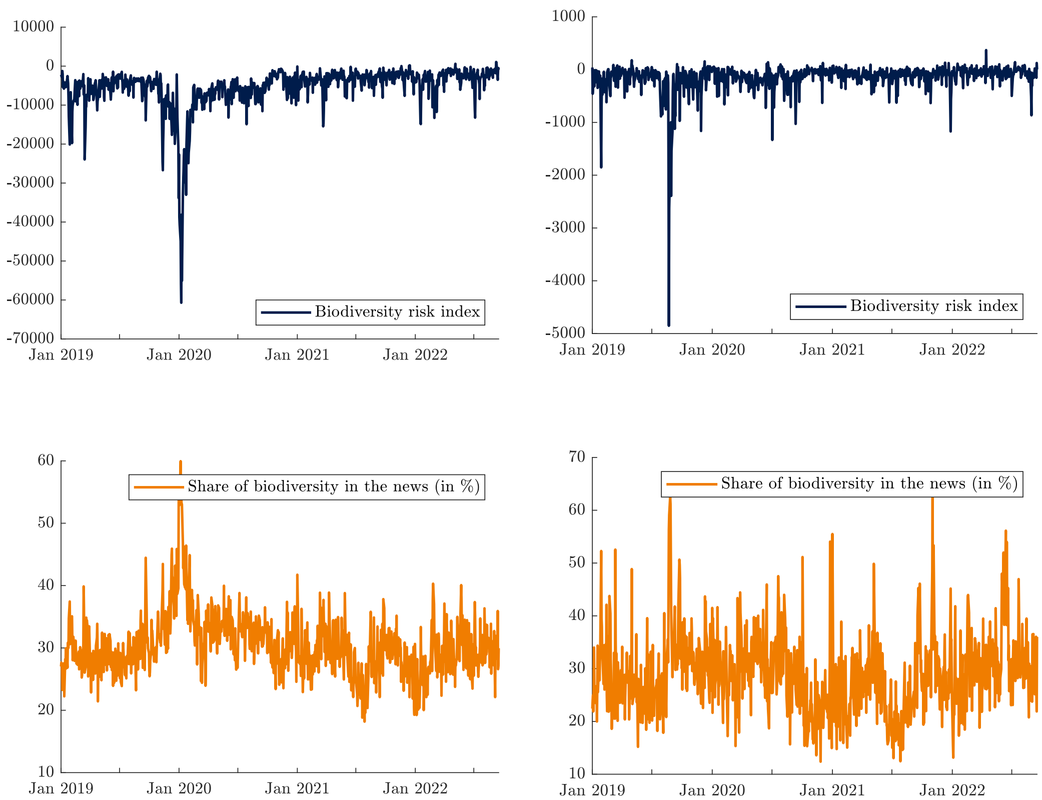
To show the central role that these countries play in global biodiversity loss, we report in Figure 5a and Figure 5b earth maps of the natural capital terrestrial hotspot layers reported by ENCORE[10]. Figure 5a displays terrestrial hotspots of biodiversity depletion measured with biodiversity intactness. It indicates the average richness of a large and diverse set of organisms associated with a given territory, relative to the population residing in this area.

[8] Each day we count the number of news from GDELT for which the *theme* metadata intersects with the selected identifiers underlying the Biodiversity risk index as defined in Appendix A.1. For robustness considerations, we introduce a threshold: we consider that an intersection is valid when it contains strictly more than two identifiers. We divide the corresponding number of news by the total number of news in the day according to GDELT.

[9] https://www.activesustainability.com/environment/megadiverse-countries.

[10] Natural Capital Finance Alliance (Global Canopy, UNEP FI, and UNEP-WCMC) (2022). ENCORE: Exploring Natural Capital Opportunities, Risks and Exposure. [Online], 09/2022, Cambridge, UK: the Natural Capital Finance Alliance. Available at: https://encore.naturalcapital.finance.

Figure 4: Biodiversity Risk Index and Visibility in the News

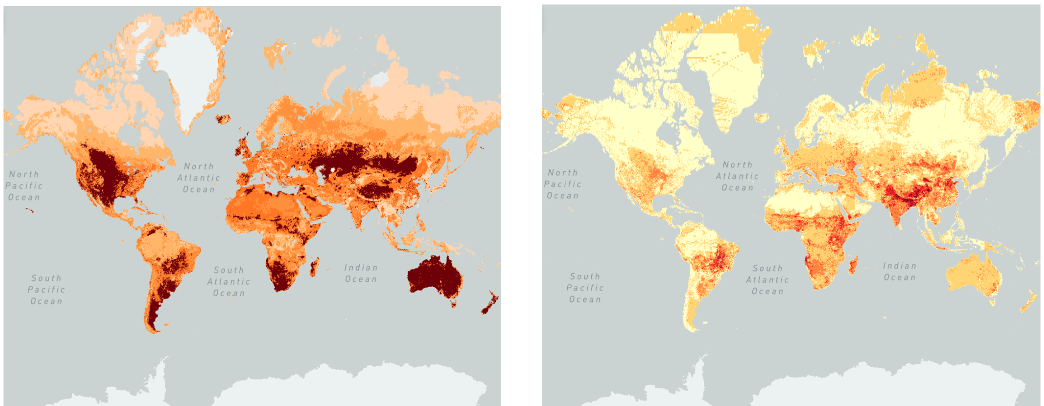


(a) Australia (b) Brazil

Source: Authors' calculations, Amundi Institute.

Accordingly, the darkest color on the map, covering the whole of Australia and part of Brazil, corresponds to the 20% highest relative depletion which coincides with the hotspots where the risks of loss or degradation of ecosystem services are the highest due to human activities. Furthermore, within the 20% highest relative depletion, Brazil has up to 4 natural capital stock depletion hotspots in several locations (on diverse aspects such as atmosphere, water, soil and sediments, biodiversity) for terrestrial habitat, as described in Figure 5b. These figures are all the more remarkable when compared to other areas around the world. Additionally, the risk of biodiversity loss does not stop at the borders of these two countries. In fact, they are suppliers of

Figure 5: Natural Capital Depletion Maps



(a) Terrestrial hotspots of biodiversity depletion

(b) Combined terrestrial hotspots of natural capital depletion

Source: ENCORE Hotspots maps.

biodiversity resources at a global scale, notably towards world powers such as China and the United States. The latter are among the top three importers of biodiversity trade flows[11]. The risk arising from biodiversity loss is thus multi-faceted as it can also impact global trade.

All things considered, it is therefore not a coincidence that biodiversity topics are often covered in the news of these countries. Going back to Figure 4, we observe that on days when the Biodiversity risk index is at its lowest, connoting a rising risk, the share of biodiversity-related news in the country peaks. For instance, in January 2020, the share of biodiversity-related news among all news of the day in Australia attained over 60%. For Brazil, the figures are even higher, reaching around 64% in August 2019. To compare, on the days following the murder of George Floyd, social news[12] accounted for about 17% of total news in the US, spiking from a low proportion of 2%. This illustrates the importance of the lexical field related to biodiversity in the news for these two countries and highlights how biodiversity-related news can be dominant in the public debate. For the different reasons aforementioned, we will focus on Brazil and Australia in the rest of our analysis.

[11] See https://unctadstat.unctad.org/EN/biotrade.html.

[12] We use the underlying GDELT identifiers of the social narrative (Blanqué *et al.*, 2022).

3.2 How does ecosystem degradation affect sub industries impacting biodiversity, from a financial viewpoint?

Leach *et al.* (2020) showed that Agricultural Products, Apparel, Accessories & Luxury Goods, Brewers, Electric Utilities, and Independent Power Producers & Energy Traders, Distillers & Vintners, Forest Products, and Water Utilities were the most dependent industries on biodiversity, through ecosystems services (soil quality, fibers...). If ecosystem degradation was to accelerate, the production from these sectors could drop significantly, with spillover effects across the whole economy. Interestingly enough, the companies that rely the most on biodiversity for their production, are not necessarily the ones that impact it the most. The Agricultural Products industry is both one of the most dependent industries but also one with the highest impact on biodiversity. Distribution, Mining, Oil & Gas (drilling, exploration, production, storage and transportation), Marine Ports and Airport Services are activities with sizeable repercussions on biodiversity. Damages can occur from different channels (air pollution, use of freshwater, spreading invasive species, or noise disturbances to species). Such sectoral analyses are very popular and insightful for a better understanding of the big picture, at the macro and sector level, but also for identifying which activities are the most harmful or dependent on biodiversity. Hence, the first objective of this subsection consists in exploring further the dual materiality at the business sub-industry level, focusing on Brazilian and Australian companies by constructing corporate bond indexes for these countries. The idea is then to measure the impact of acute biodiversity risk events on sub-industries corporate bonds spreads in the second round of analysis.

Corporate bond data derives from the selection of USD-denominated bonds for Brazilian or Australian risk countries from the Intercontinental Exchange Bank of America Merrill Lynch (ICE BofAML) Investment Grade Index on a daily basis from January 2019 to September 2022[13]. For the

[13]Source ICE Data Indices, LLC ("ICE DATA"), is used with permission. ICE DATA, its affiliates, and their respective third-party suppliers disclaim any and all warranties and representations, express and/or implied, including any warranties of merchantability or fitness for a particular purpose or use, including the indexes, index data and any data included in, related to, or derived therefrom. Neither ICE DATA, its affiliates nor their respective third-party suppliers shall be subject to any damages or liability with respect to the adequacy, accuracy, timeliness or completeness of the indices or the index data or

purposes of this study, we link credit bonds with their issuer business sub-industries[14] and remove from the composition the bonds having no equity companies affiliate. For the Brazilian index, we finally count an average of 24 bonds per day over our period of analysis. This index is led by highly cyclical sectors such as the Materials which dominate the composition for about 92% on average over the period. To illustrate, the Industrials sector represented around 14% of the index between January 2019 and June 2020. We believe that these sectors are more susceptible to negative events considering their correlation to economic cycles or their heightened sensitivity to trade wars, linked to geopolitical tensions. Moreover, the index is also driven by the defensive Consumer Staples sector from December 2021 to the end of the period, representing around 13% on average (see Figure 20 in Appendix A.2).

In the first round of analysis, we are keen to quantify the double materiality principle for our sample of corporates at the sub-industry level. Figure 6 and Figure 7 represent respectively, the ecosystem services dependency and impact drivers of sub-industries from the Brazilian index, employing the open-source ENCORE dataset. It illustrates the potential dependency of sub-industries on ecosystem services (such as fibers, and water quality...) and potential sub-industries impact on biodiversity loss through impact drivers (such as GHG emissions, and water pollutants...). ENCORE scores the activities of sub-industries up to the 4^{th} level of the GICS classification. We use the version of the database loaded at the end of September 2022. As ENCORE does not report time series, we undertake to use these scores for the study period observed from 2019 to 2022. Thereby, the ENCORE dataset relies on materiality scores ranked from "very high" to "very low", referring respectively to a rate of -5 to -1 in these heat maps. In this way, Figure 6 shows that the Paper Products sub-industry, for instance, has a very low potential dependency to climate regulation ecosystem service, a moderate potential dependency to fibers and other materials but also water flow maintenance. Finally, the sub-industry has a very high potential dependency to groundwater and surface water ecosystem services.

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[14] We use the GICS (Global Industry Classification Standard) classification and the equity ticker to map the businesses to the bonds.

Figure 6: Ecosystem Services Dependency Scores of Sub-Industries of Brazilian Index

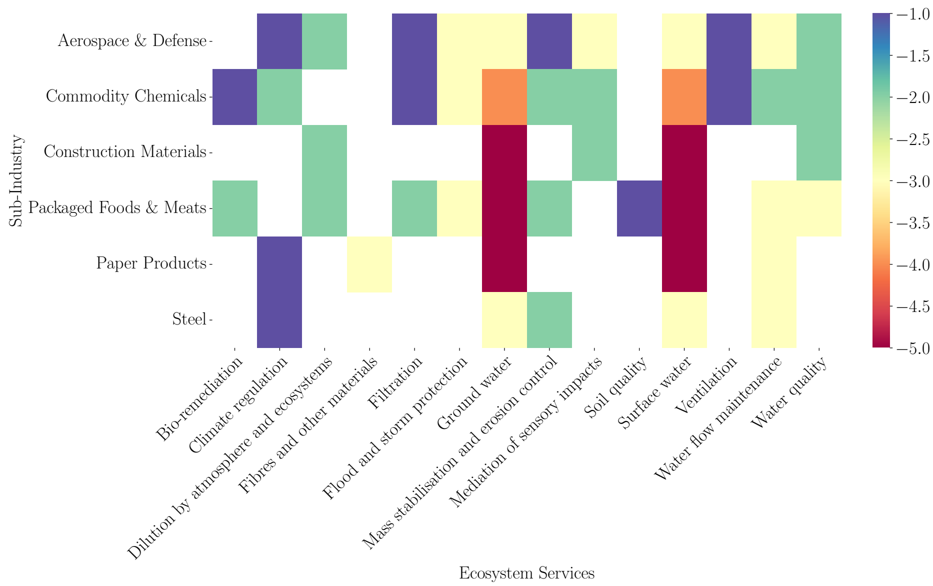
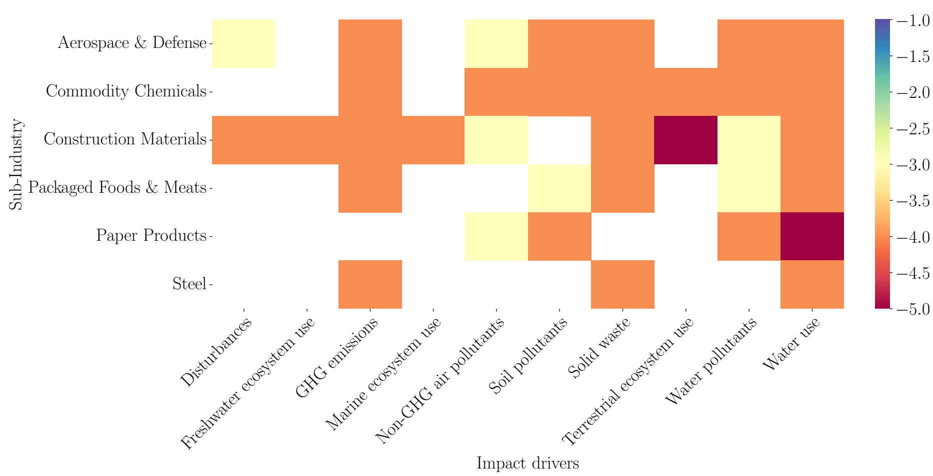


Figure 7: Impact Drivers Scores of Sub-Industries of Brazilian Index



Source: ENCORE dataset, Authors' calculations, Amundi Institute.

Figure 8: Ecosystem Services Dependency Scores of Sub-Industries of Australian Index

Figure 9: Impact Drivers Scores of Sub-Industries of Australian Index

Source: ENCORE dataset, Authors' calculations, Amundi Institute.

Concerning the impact drivers, Figure 7 reveals that the Commodity Chemicals sub-industry has a potentially high impact on biodiversity loss through the GHG or non-GHG emissions, soil pollutants, solid waste, terrestrial ecosystem use, water pollutants and water use impact drivers for example. We note that the sub-industries belonging to the index have a potential impact bias on biodiversity loss. Indeed, all of them have at least a potential moderate impact on biodiversity loss. In fact, 3/4 of the reported figures demonstrate a high potential impact of companies on biodiversity loss. On the contrary, Figure 6 exhibits that in over half of the cases, the selected sub-industries have a very low or low potential dependency on ecosystem services. Similarly, about 30% of the sub-industries have a potential medium dependency on ecosystem services and only 17% of these sub-industries have a high or very high potential dependency on ecosystem services.

For Australia, we observe that the sector allocation of the index is more diversified. We identify in Figure 8 and Figure 9 that 17 sub-industries incorporated in the index with a strong bias towards the Financials sector representing around 71% of the allocation on average over the period (see Figure 21 in Appendix A.2). The remainder of the allocation is distributed between the Real Estate sector (13% on average), the Material sector (around 11% on average), the Industrials and Utilities sectors (8% on average), the Energy sector (around 7% on average), the Heath Care sector (6% on average), the Communication Services sector (2.5% on average) and finally the Consumer Staples sector at around 1% of the index weight on average over the period. As illustrated earlier for the Brazilian index, we report in Figure 8 the ecosystem services dependency scores of sub-industries belonging to the Australian index. Similarly, Figure 9 displays the impact drivers scores of sub-industries of Australian bonds denominated in USD. Thus, on one hand, Figure 8 shows that Regional Banks or Property & Casualty Insurance companies, for instance, have a potential low dependency to the ecosystem service mass stabilization and erosion control. On the other hand, Figure 9 exhibits that these sub-industries have a potential medium impact on biodiversity loss through the solid waste impact driver for example. We note also for Australia that the sub-industries belonging to the index have high sensitivity to the impact drivers. Indeed, the colors of the heat map lean towards red which represents the highest materiality scores.

In addition, the Australian index is relatively diverse in terms of sub-industries, while being focused on a single sector, namely the financial sector. We, therefore, decide to filter out sub-industries that do not have an impact on biodiversity loss and exhibit low materiality scores in the ENCORE impact driver database. We also remove sub-industries with only one impact if the materiality score is not high or very high. We decide to focus our analysis on the impact drivers of biodiversity loss to be consistent with the study conducted in Brazil, where sub-industries are tilted toward impact. Hence we leave out from our analysis the Financials sector (Diversified Banks, Diversified Capital Markets, Property & Casuality Insurance and Regional Banks sub-industries) considering that they exhibit less direct links to biodiversity. We also drop the Integrated Telecommunications Services sub-industry that displays low potential materiality impact to soil and water pollutants. Finally, we remove from the composition assets related to Equity Real Estate Investment Trusts (REITs) industry because ENCORE does not display scores for this industry. Hence we keep 30 bonds on average per day in the Australian universe and the sub-industries reported in Figure 22 in Appendix A.2.

Table 4: Events in Brazil

Date	Tag	Theme	News (in %)	Comment
25-01-19	BR1	Water	33	Brumadinho dam disaster
22-08-19	BR2	Land	56	Amazon wildfires (highest since 2007)
28-11-19	BR3	Air	23	Amazon fires may cause Andes glacier to melt faster
22-09-20	BR4	Generic	28	Bolsonaro describes Amazon "disinformation"
14-07-21	BR5	Fauna	16	Species at risk of extinction in the Amazon
19-11-21	BR6	Land	32	Deforestation in Amazon accelerates at a 15-year high

Source: Authors' calculations, Amundi Institute.

Our selection process ensures that the selected sub-industries of the indexes have a negative impact on biodiversity factors through the ENCORE dataset. We now aim at demonstrating the financial impact that negative biodiversity events may have on sub-industries, based on news flows in Brazil and Australia. We witness that biodiversity is more frequently mentioned in the press when risks are high, which we quantify with a negative spike in our Biodiversity risk index for Brazil. In fact, the spikes we observe at the bottom of Figure 4 correspond to different substantial biodiversity events. Accordingly, we report in Table 4 the biodiversity-related news we have selected between 2019 and 2022 for Brazil, ensuring to cover the different themes. For instance, we examine natural disasters (such as forest fires) that may have a post-event direct impact on biodiversity through the destruction of flora and fauna. We also disclose accidents that result in, among others, water or soil pollution. Finally, news involving political discourses that may downgrade or could undermine efforts aimed at tackling biodiversity loss are also covered. Therefore, we cover a diversified spectrum of acute biodiversity-related events. It is worth noting that we try, as far as possible, to go back to the first date on which the event appeared in the news after selecting the event from the series on the different biodiversity risk themes. Indeed, we may capture days when the events simply deteriorated, so the event may, in our opinion, have already been priced in by the credit market.

Table 5: Ranking of Top Bonds Whose Spreads Have Increased Positively in Brazil After Acute Events on Biodiversity

Sector	Industry	Sub-Industry	Total (in %)
Materials	Paper & Forest Products	Paper Products	40.00
Materials	Metals & Mining	Steel	33.33
Materials	Chemicals	Commodity Chemicals	13.33
Industrials	Aerospace & Defense	Aerospace & Defense	6.66
Consumer Staples	Food Products Food	Packaged F & M	3.33
Materials	Construction Materials	Construction Materials	3.33

Source: Authors' calculations, Amundi Institute.

Following the previous study, we measure the potential biodiversity loss damages on business sub-industries by selecting top Brazilian and Australian bonds whose spreads have hiked after acute events, demonstrating how these biodiversity-impacting companies can in turn be financially impacted following an acute biodiversity event. Table 5 shows industries that have been most impacted at the bonds spread level by the news reported in Table 4 on the business day following an event. For Brazil, we observe in Table 5 a certain industry and sector concentration, as more than 40% of the Brazilian bonds concerned by the biodiversity events are from the Paper & Forest Products industry and 86.67% of these bonds come from the Materials GICS sector.

Moreover, we find a relationship between industries and the themes of biodiversity acute events. As a matter of fact, for water acute events, the bond sub-industries with the highest spreads the day after the event are all coming from the steel sub-industry. Figure 7 shows that the steel sub-industry has potential impact on water use driver. Moreover, for events affecting land, the most impacted sub-industries are the first three reported in Table 5 namely Paper Products, Steel and Commodity Chemicals. Figure 7 indicates that these sub-industries strongly impact the drivers referring to land. For instance, these three industries demonstrate high negative impact on the solid waste driver. Likewise, Paper Products and Commodity Chemicals sub-industries have a strong negative impact on soil pollutants and finally, the Commodity Chemicals sub-industry has a high materiality impact on terrestrial ecosystem use. Furthermore, evidence of the degradation of the ecosystem from these sub-industries is reinforced by the fact that when averaging the ENCORE scores for all the impact drivers, these aforementioned sub-industries have the worst scores and are actually the first three to be found in Table 5, i.e. those with the bonds spreads that increase the most after a negative event on biodiversity. It means that the sub-industries that have the greatest impact on biodiversity losses are also those that are the most affected on their spreads by acute biodiversity events in their securities pricing.

Table 6: Events in Australia

Date	Tag	Theme	News (in %)	Comment
30-12-2019	AU1	Land	40	Australia fires worsen following heat wave
23-01-2020	AU2	Water	46	Queensland Monsoonal flooding
23-01-2020	AU2	Water	46	Three firefighters killed in air tanker crash
28-10-2020	AU3	Fauna	27	Fires have broken out and destroyed between 23 and 34 million Ha
12-11-2021	AU4	Air	31	Australia pointed out as the “colossal fossil” of COP26
28-02-2022	AU5	Generic	37	IPCC report shows Australia is under real threat from climate change
27-06-2022	AU6	Water	23	Floods in New South Wales

Source: Authors’ calculations, Amundi Institute.

For Australia, we report in Table 6 dates corresponding to negative spikes in our Biodiversity risk index for Australia. As in the Brazilian exercise, we collect pieces of representative news for each theme. For example, we report on floods that repeatedly devastated the country, but also on fires that destroyed millions of hectares in 2019-2020. We also relate news blaming the

Table 7: Ranking of Top bonds Whose Spreads Have Increased Positively in Australia after Acute Events on Biodiversity

Sector	Industry	Sub-Industry	Total (in %)
Energy	Oil, Gas & Consumable Fuels	Oil & Gas Expl. & Prod.	36.67
Industrials	Transportation Infrastructure	Highways & Railtracks	16.67
Utilities	Gas Utilities	Gas Utilities	13.33
Materials	Metals & Mining	Gold	10.00
Materials	Metals & Mining	Diversified	6.67
Utilities	Electric Utilities	Electric Utilities	6.67
Materials	Containers & Packaging	Paper Packaging	3.33
Industrials	Transportation Infrastructure	Airport Services	3.33
Industrials	Commercial & Prof. Services	Commercial S & S	3.33

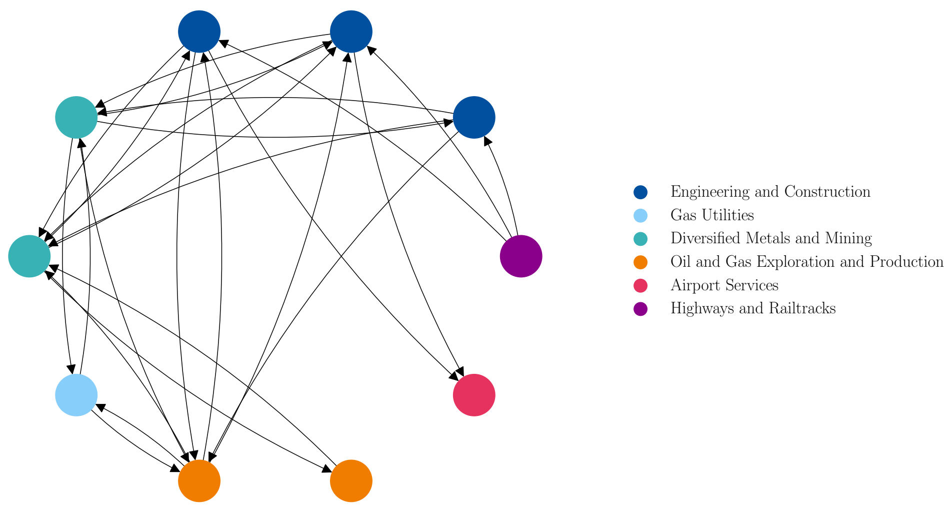
Source: Authors' calculations, Amundi Institute.

Australian government for its inaction on climate change or the IPCC reporting alarming climate change conditions in Australia. As with the Brazilian events, we try to return to the first day of the corresponding event after selecting the dates. The share of media coverage on these days ranges between 23 and 46% for these news items. Accordingly, we witness from Table 7 that the sub-industries reacting the most to an acute event on biodiversity are Oil & Gas Production & Exploration with 36.67%, then Gas Utilities for 16.67%, Highways and Railtracks sub-industry being part of the Transportation Infrastructure at 13.33% and finally Metals & Mining for 16.67%. We note that the two latter sub-industries seem to be actually related to the first one. Indeed, Oil & Gas Production & Exploration is the leading sub-industry affected by acute negative biodiversity events and might influence the functioning of the next two sub-industries through cascading effects. In this regard, gas utilities are companies working as producers or distributors of energy that is explored or produced within the first sub-industry. Moreover, the bitumen produced from crude oil is needed for the development, exploitation or maintenance of highways.

To demonstrate this argument, we present in Figure 10 the supplier and customer relationships existing between the companies of bonds reported in Table 7. The data derived from the FactSet Revere database[15]. We show that the Highways and Railtrack sub-industry firm is a customer to three Engineering and Construction sub-industry companies. Similarly, the latter

[15] https://open.factset.com/products/factset-supply-chain-relationships.

Figure 10: Supplier and Customer Relationship for companies in Australia



Source: FactSet Revere, Authors' calculations, Amundi Institute.

are suppliers of airport services, Oil & Gas Exploration & Production, and Diversified Metals & Mining businesses. Hence, the link between these companies exists through Engineering & Construction firms. Besides, we report a relationship between Gas Services, Diversified Metals & Mining and Oil & Gas Exploration & Production. As explained in our previous example, we show that Oil & Gas Exploration & Production companies are customers to the Gas Services sub-industry. We also find that there is a supplier connection between them. In addition, we confirm customer/supplier links between firms identified as Metals & Mining and companies of the Energy sector. Finally, this Figure illustrates how the Gas Utilities sector companies and one of the Diversified Metals & Mining companies are also linked across supplier/customer relationships. Thus, we provide substantial evidence that when a firm in one of these sub-sectors is affected by spread widening due to acute biodiversity-related events, the companies from other Australian sub-sectors from Figure 10 may experience an increase in spreads as well through a domino effect given the links between these firms.

To conclude, the sub-industries reacting the most to a negative biodiversity event are the sub-industries delivering the worst ENCORE impact scores. In average order, the latter are: Diversified Metals & Mining, Gold, Airport Services, Oil & Gas Exploration & Production, Paper Packaging, Electric Utilities, Construction Materials, Highways & Rail trails, Gas Utilities, Biotechnology and Diversified Support Services. In this list, only the Construction Materials sub-industry is not included in the ranking of top bonds sub-industries whose spreads have increased positively after extreme biodiversity events in Australia. This means that this sector materiality operates in one way only. In the following sub-section, for Australia, we will select only those sub-industries that impact biodiversity loss and that are affected, from a financial viewpoint, by ecosystem degradation similar to the Brazilian sub-industries. We, therefore, remove from the composition of the Australian index the following sub-industries: Biotechnology, Building Materials and Food Distribution, which do not seem to respond to negative biodiversity events according to their bond spread movements.

3.3 Impact of acute biodiversity events on corporate bond spreads

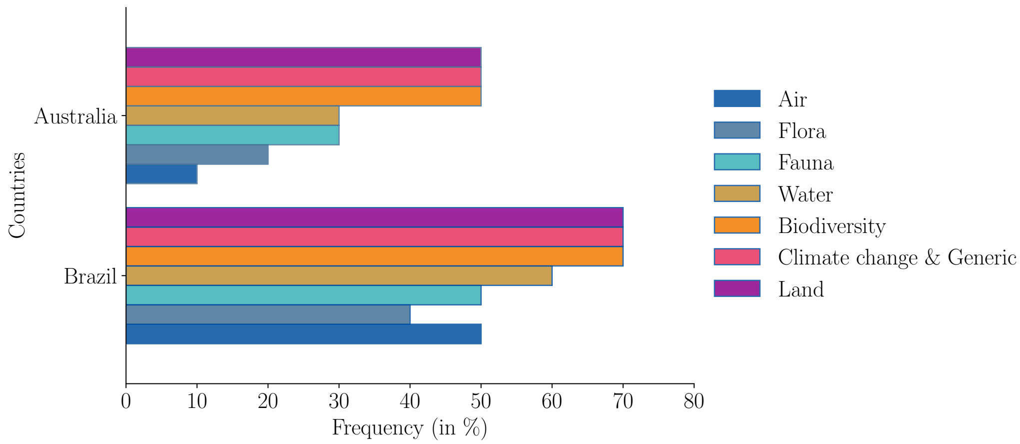
The objective is now to generalize our previous study to all periods of acute events identified in the series we built from GDELT. Still, we believe that appraising a company's financial dependence on biodiversity loss solely based on its sector activities might be a shortcut, concealing company-specific features. As a matter of fact, we conduct an event study to investigate the impact of acute events affecting biodiversity on corporate bonds given the negative spikes of the Biodiversity risk indexes listed in Table 3. As already mentioned, we focus our analysis on Australia and Brazil. We estimate the repercussions of bad news on biodiversity on bond spreads revealing widening of issuers spreads. Accordingly, we propose the following formula to measure the impact of acute biodiversity events on corporate bonds:

$$AD_t = \frac{1}{n}\sum_{i=t}^{t+n} \ln S_i - \frac{1}{n}\sum_{i=t-n-1}^{t-1} \ln S_i \qquad (3)$$

where t is the event date, n is the time window of the event study that we set at 3 and S is the equally weighted option adjusted spread vs. government of the selected bonds.

A positive AD_t indicates that average spreads after the perceived negative biodiversity events are higher than before, implying that events are priced

Figure 11: Frequency of Positive AD_t after Negative Events per Theme for Brazilian and Australian Issuers (in %)



Source: Authors' calculations, Amundi Institute.

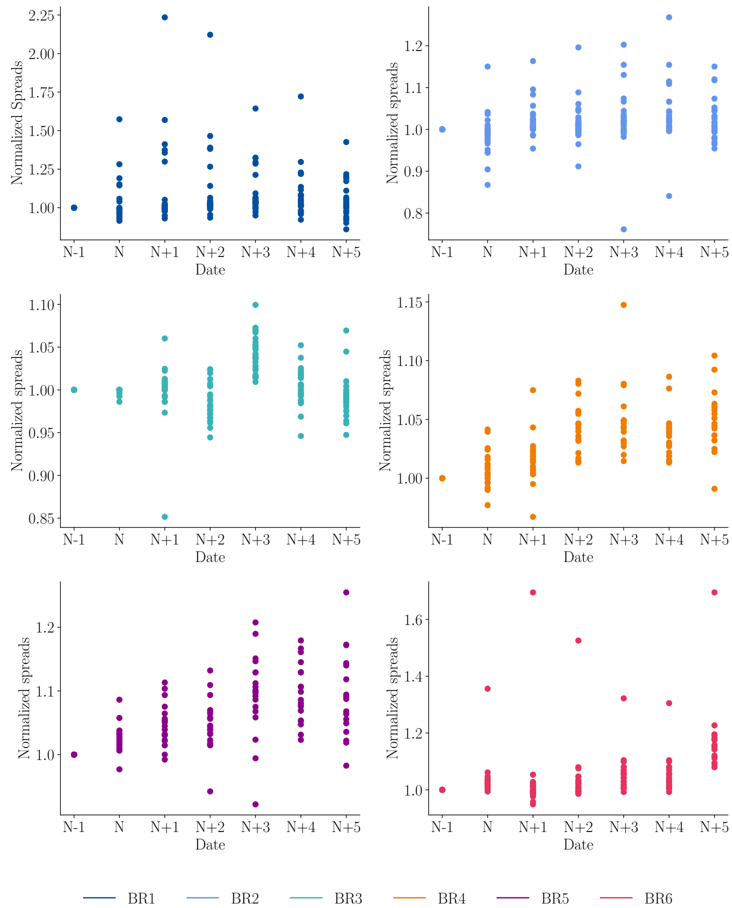
into the credit market. For the first study, we seek to demonstrate whether, as a whole, spreads respond to a large volume of news mixed with negative sentiment about biodiversity. For this purpose, using the Australian and Brazilian bonds indexes of Section 3.2, we show in Figure 11 the frequency of positive AD_t after acute biodiversity events and perceived as negative (according to sentiment data from GDELT) per Biodiversity risk index for Brazilian and Australian issuers. We determine that an event is recognized as negative when the volume weighted tone Biodiversity risk index for a given date is below its 1st percentile. Hence, among the Australian acute events on biodiversity that we observe, we show that 50% of AD_t are positive after acute biodiversity events (mixing all the themes) but also for climate change & generic and land themes. Then, 30% are positive after acute events on water and fauna. Finally, 20% of the AD_t stand in positive territory after events on flora. The air theme shows undoubtedly poor results since only 10% of AD_t are positive after an acute event on this theme. In fact, we raise an issue with Australian data related to acute biodiversity news. We sometimes experienced difficulties in finding a starting point for a news item. As a matter of fact, some events such as floods or fires may last for several months or even for a whole season. A jump in the news-derived Biodiversity risk index may mean that the situation has deteriorated, but the event may have started weeks before and already been priced into the corporate bonds market. In reality, the spikes on the news related to negative biodiversity events in Australia that we identified in our index are frequently related to physical climate change risks. We struggled to identify events other than physical risks. However, it is difficult to miss those events that are now common in Australia in such a way that 2/3 of the dates in the Table 6 relate to such events. Then, the results for Australia could be explained by the fact that the events from the themes the most prominent in the press (i.e having the highest negative sentiment and volume) are the ones conducting to an increase in average spread in the following 3 days. We can therefore hypothesize that if one of the themes related to biodiversity risk is in the spotlight, then spreads will react stronger to an event on that theme, compared to themes less often addressed in the press. For instance, the themes related to air and flora disasters show a fairly low volume of news between 2019 and 2022 in Australia, which could explain lower spreads reaction in case of events.

In contrast with results for Australia, it appears that in 70% of cases, Brazilian spreads' average increases in the 3 days following events on the generic Biodiversity risk index (integrating all biodiversity themes) but also for the climate change & generic and land series. Then, we note that in 60% of cases the average corporate bonds spreads rise after events related to water series. Finally, the average spreads of the corporate securities move upwards after an acute event on the air or the fauna theme in 50% of the cases, while this figure drops to 40% for the flora theme. These results are promising for a first study, which led us to investigate them further.

In the next analysis, we consider Brazilian news items related to acute biodiversity events, previously selected in Table 4. We then examine the spreads associated with these Brazilian issuers during the selected dates and present normalized bonds spread on the day before the event occurrence and all 5 days after the event's starting date (reported in Table 4) in Figure 12. Consequently, on the day prior to the event, spreads are normalized and all stand at 1. From that perspective, we observe that Brazilian bonds spreads denominated in USD generally increase following an acute event on biodiversity. In order to authenticate such result, we report in Table 8 the probability values from a statistic test that verifies whether figures are statistically different from another set of data.

The latter evaluates the null hypothesis that the average spreads value for each date following the event is equal to 1, hence not different from the

Figure 12: Normalized Spread for Brazilian Bonds Before and After the Negative Events on Biodiversity



Source: Authors' calculations, Amundi Institute.

Table 8: P-values Significance for Brazilian Spreads

Tag	N	N+1	N+2	N+3	N+4	N+5
BR1		**	**	* * *	* * *	*
BR2		* * *	*	*	* * *	**
BR3			* * *	* * *		
BR4	**	* * *	* * *	* * *	* * *	* * *
BR5	* * *	* * *	* * *	* * *	* * *	* * *
BR6	**		*	* * *	* * *	* * *

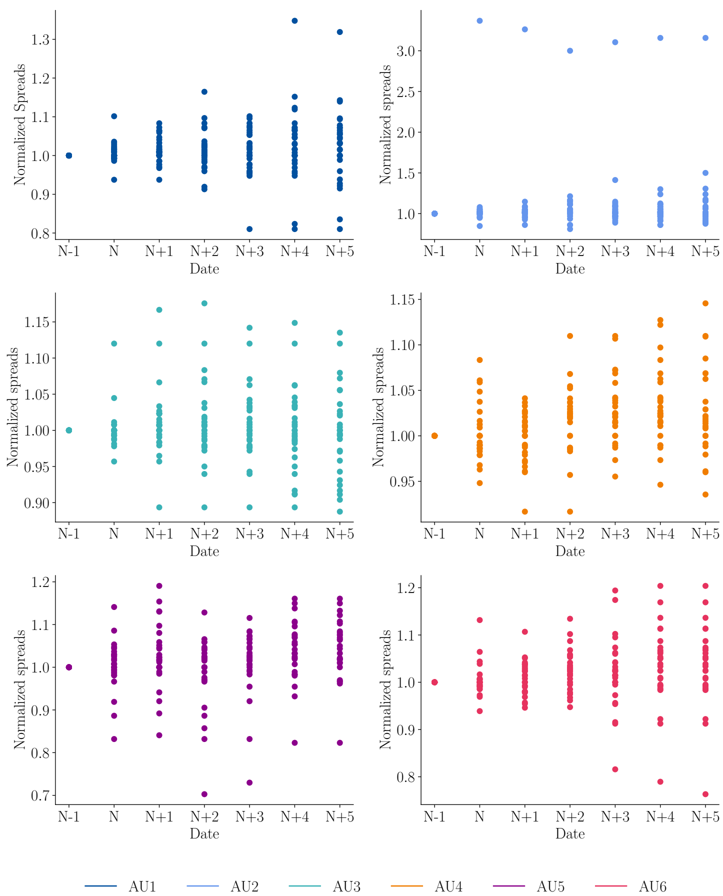
[1] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Authors' calculations, Amundi Institute.

day prior to the event. When we reject the null hypothesis, we check that the average spread is above 1, implying a spread widening. Consequently, 80.5% of the p-values reported in Table 8 indicate that we reject the null hypothesis with a significance level of 10%. Moreover, for 20 out of 30 dates, the significance (appraised through the p-values) of our tests is below 1%. These results confirm that for most of the event dates the average bond spreads are different from the day prior the event, or that the bond spreads are not flat during the occurrence of acute biodiversity events. Figure 24 in Appendix A.3, that exhibits the average spreads 5 days prior and after acute biodiversity events corroborates this idea. From Figure 12, we witness that some bonds are reacting more to negative events on biodiversity. We examined more closely these bonds and identified that their issuing companies where from the Steel sub-industry in particular, followed by the Paper Products and Commodity Chemicals sub-industries.

Afterwards, we conduct the same exercise on Australian bond spreads, based on the dates associated with local acute biodiversity events reported in Table 6. Hence we show in Figure 13 the normalized spread of Australian bonds 1 day before and 5 days after the event and report in Table 9 the p-values associated to the statistic test verifying whether the average spreads values in the following days were significantly different from spreads before the event (hence different from 1). The results are not as remarkable as in the case of Brazil as around 1/3 of the dates are significant at the 10% level (see Table 9). We notice in Figure 13 that for most of the dates the deviations are widely dispersed, both upwards and downwards, so that the average deviation is very close to 1 if we remove the outliers. The increase in spread observed in Figure 25 in Appendix A.3, showing the average credit bonds spreads 5 days before and after the events, seems to be driven by such outlying bonds that react strongly to acute biodiversity events. However, in contrast with Brazilian results, the reaction after the events is less persistent. We discussed previously in this Section reasons why biodiversity-related events in Australia might be harder to be priced into the credit market. We argued that the starting points of acute biodiversity risk events in Australia are difficult to capture in the news because such events may sometimes last for seasons, or the daily piece of news could actually relate to a worsening of the situation, not necessarily the start date of the event. For AU2 and AU3, for example, we have not identified starting points with high volume for these disasters.

Figure 13: Normalized Spread for Australian Bonds Before and After the Negative Events on Biodiversity



Source: Authors' calculations, Amundi Institute.

Table 9: P-values Significance for Australian Spreads

Tag	N	N+1	N+2	N+3	N+4	N+5
AU1		**				
AU2						
AU3						
AU4				**	***	***
AU5		*			***	***
AU6			***	*	**	**

[1] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Authors' calculations, Amundi Institute.

3.4 Biodiversity and corporate risk: what is priced into the credit bond market in Australia?

In the next study, we investigate whether a biodiversity risk-tilted portfolio integrating sub-industries impacting biodiversity loss can explain part of the excess returns of an equally-weighted credit bond benchmark index based on the Australian USD-denominated components of the ICE BofA Global Corporate Index. The study is in line with the work of Semet *et al.* (2021) where we indicated through a multi-factor analysis that biodiversity (captured by a biodiversity threatening score) was the 7^{th} feature retained among a wide list of ESG indicators explaining government bond spread movement in High-Income Countries (HIC). On an univariate analysis, the research specifies that adding the biodiversity indicator increases the explaining power of the model by 3.5% compared to the baseline model integrating macroeconomic factors only. We hence aim to verify whether we could observe similar materiality from biodiversity loss on corporate bond spreads.

Accordingly, we evaluate the credit excess return exposures of a biodiversity risk portfolio and of the credit risk premia that we identified in Ben Slimane *et al.* (2018) to the benchmark credit excess returns through a regression model. As specified by the authors, the corporate bond universe is composed of two categories of risk factors, the first being the traditional factors that explain a large part of the performance of a bond, and then factors that bring diversification, called alternative factors.

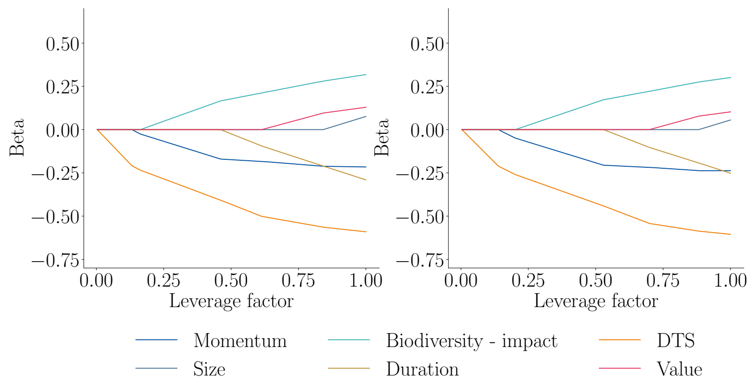
To start the analysis, on the one hand, we construct the associated corporate bond risk premia. They encompass three components that are often cited by academics as traditional bond risk factors, being the Duration, the Duration-Time-Spread (DTS) and the Liquidity risk premium, and can be enriched with alternative risk factors namely the Value, Size and Momentum. All the series are built by selecting the Australian bonds of the ICE BofA Global Corporate Index denominated in USD. On the other hand, we build a biodiversity risk portfolio using the methodology described by Klug (2021). The approach consists in building a portfolio by selecting, first, businesses having a high impact on biodiversity loss. Then, we rank bonds relative to the average of two Key issues scores of MSCI (MSCI, 2020): the Biodiversity & Land Use and Raw Material Sourcing scores. The first one attributes good scores to companies having programs and policies ensuring biodiversity protection and expressing collective concerns on land use. The second one scores well businesses that have implemented policies toward materials supply with lower environmental impact and took actions aimed at minimizing the environmental impact of raw materials production. Based on these metrics, the portfolio is built on the subset of bonds from companies having the 40% lowest/highest biodiversity scores. Finally, as for the selected risk premium, we choose from the ICE BofA Global Corporate Index, the Australian components denominated in USD, and conduct the study from January 2019 to January 2022. Thus, we estimate the excess return of a corporate bond with the following linear equation:

$$\begin{aligned} R_i(t) = \alpha(t) - MD_i(t) \times R^I(t) - DTS_i(t) \times R^S(t) + LTP_i(t) \times R^L(t) \\ +\beta_i^{SMB}(t) \times R^{SMB}(t) + \beta_i^{HML}(t) \times R^{HML}(t) + \beta_i^{WML}(t) \times R^{WML}(t) \\ +\beta_i^{BIO}(t) \times R^{BIO}(t) + \epsilon_i(t) \end{aligned} \tag{4}$$

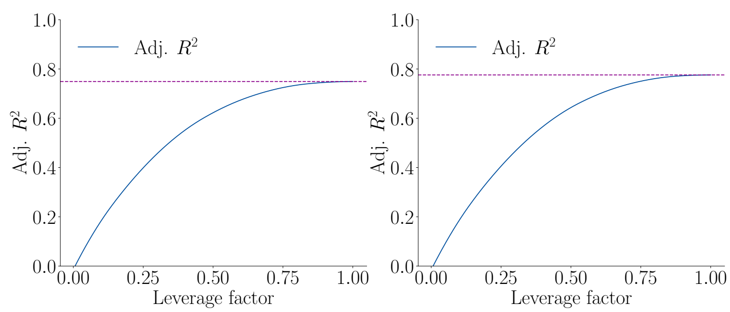
where $R_i(t)$ is defined as the credit excess return of a bond i at t and $\alpha(t)$ is a constant. $R^I(t), R^S(t)$ and $R^L(t)$ are the return components for respectively the interest rate movements, credit spread variation and change in liquidity. $MD_i(t)$, $DTS_i(t)$ and $LTP_i(t)$ are the sensitivities of bond i with respect to the three risk factors $R^I(t), R^S(t)$ and $R^L(t)$. $R^{SMB}(t)$, $R^{HML}(t)$, $R^{WML}(t)$ and $R^{BIO}(t)$ are the time-series of the factors returns for Size, Value, Momentum and Biodiversity factors. $\beta^{SMB}(t)$, $\beta^{HML}(t)$, $\beta^{WML}(t)$ and $\beta^{BIO}(t)$ represent the exposures to the factors returns for Size, Value, Momentum and Biodiversity factors.

The next step is to measure multicollinearity between the previous variables which, if it occurs in our model, would lead to unreliable statistical inferences and mislead our interpretation. Beforehand, looking at the correlations between the factors, we decide to remove the liquidity risk premium component from the regression considering its strong correlation (78.41%) with the DTS factor which would weaken the stability of the model. Then, we measure multicollinearity with the variance inflation factors (VIFs) and obtain figures between 1.2 and 1.7 suggesting a low probability of multicollinearity. In addition, the figures are relatively low compared to the figures we observed in Cherief *et al.* (2022). Indeed, we noticed higher VIFs factors in the EUR and USD-denominated corporate bond markets due to the link between the DTS and the Value factors. As a matter of fact, we do not observe such a strong correlation in the Australian corporate bond market.

Figure 14: Australian Risk Factors Exposures to the Credit Market Returns and Model Explanatory Power using LASSO Regression



(a) Risk factors exposures for the full sample vs. sample without acute events



(b) Adj R^2 of the model for the full sample vs. sample without acute events

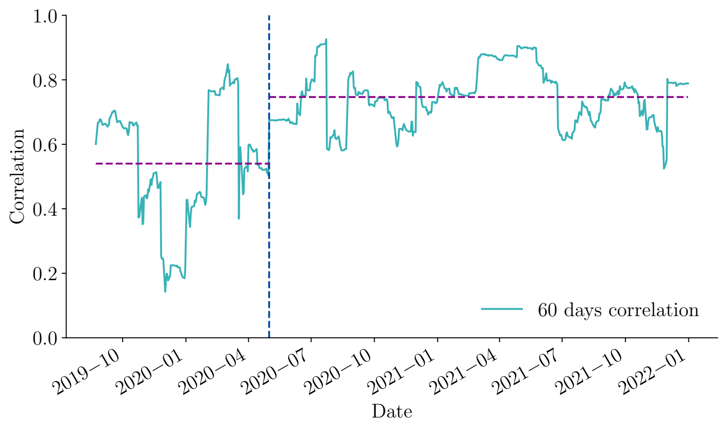
Source: Authors' calculations, Amundi Institute.

With the VIFs in an acceptable range, we decide to pursue our analysis. Figure 14a shows the risk factors exposures profile of the Australian corporate market returns using a LASSO (Least Absolute Shrinkage and Selection Operator) regression. This method allows regularization and variable selection for linear regression with the goal to enhance the accuracy of the model (Tibshirani, 1996). The objective is to minimize the residual sum of squares with a penalty on the sum of the absolute values of the coefficients. Accordingly, we present the betas of the risk factors as a function of values from 0 to 1 for the shrinkage parameter. However, based on the results of Subsection 3.2 and 3.3, we understand that Australian and Brazilian corporate bonds react to acute biodiversity events, which may imply a correlation between the credit market and a possible biodiversity risk premium during negative biodiversity events and bias our analysis. As a consequence, and to sweep off such potential effect we decide to refine our analysis into two sub-studies. The first one incorporates the full time-series from January 2019 to January 2022 while in the second analysis, we remove the periods around acute biodiversity events dates in Australia (from one day before until 10 days after the start date of the event). Results are presented respectively on the left-hand side and on the right-hand side of Figure 14a. We consider dates as acute events when the Biodiversity risk index stands below its 5% percentile. We take a larger threshold than in the previous studies to understand whether removing the acute negative news on Australia has an impact on the betas of the LASSO regression and hence potentially change the relationship between the returns of the biodiversity premium and the returns of the Australian benchmark.

We notice that in both Figures, as the leverage factor increases, three risk factors are retained by the model until the leverage factor reaches 0.5. The DTS is the first risk factor picked up in the model, the Momentum and the biodiversity factors follow, regardless of the time samples employed. These variables are hence identified as the most pertinent explanatory metrics in the models. The Duration, Value and Size factors are the last to appear in the models. We also report in Figure 14b the explanatory power of the model adjusted by the number of variables and by the number of observations. For the first model, we relay a maximum Adj. R^2 of 74.92% vs. 77.60% for the second model. This demonstrates that the behavior of the benchmark excess returns is highly explained by the behavior of the factors returns. We note that the marginal gain in term of explanatory power when moving from the 3-Factor model (integrating DTS, Momentum, Biodiversity risk) to the 6-Factor model is around 15% for both models. Thus, about 60% of the variance of the dependent variable can be explained by three factors, including Biodiversity risk.

Figure 14a demonstrates that the exposures to the excess returns of the Australian benchmark are positive for biodiversity, value and size factors. It implies that companies with a high impact on the Biodiversity & Land Use and Raw Material Sourcing aspects tend to post higher returns, which is consistent with the positive premium that should be theoretically observed on the so called “brown” assets (Roncalli and Laugel, 2022). These results show how the inclusion of periods around acute events on biodiversity only slightly modify the exposures to the benchmark returns and does not affect either the relationships' direction or the variables selection in the models. Hence, one may wonder whether the statistical link between the benchmark returns and the biodiversity performance might not be actually the result of chronic events.

Figure 15: 60 Days Correlation Between the Environment and Biodiversity Factors



Source: Authors' calculations, Amundi Institute.

When looking at the importance of the Biodiversity factor in explaining the returns of our subset of Australian bonds from biodiversity impacting sector, a question arises: could the biodiversity premium be actually a component of the environmental (E) indicator? Indeed, strong ties between these two dimensions could imply that the E factor[16] could be the main feature explaining the excess returns of the benchmark. In order to test this hypothesis we present in Figure 15 the 60 days correlation between the environment and biodiversity factors. The environment portfolio is built according to the methodology applied on the biodiversity portfolio where we replace the MSCI biodiversity scores of each company by Amundi's E indicators. In the Figure, we show that the variables can reach a maximum correlation of 92.58% over our period of analysis. Until May 2020, the average correlation is 54% and then it increases to 75% until the end of the period. Over the full period of analysis, the correlation between both variables is about 68%. This result might partly explain the striking importance of the chronic biodiversity indicator in our tests, which is in fact reflective of a broader environmental footprint.

[16]We use the Amundi E score which is described in Bennani *et al.* (2018).

4 Biodiversity: an incoming systemic risk? The case of food security

In this Section, we illustrate the risk transmissions which exist for biodiversity issues with a food security example. As mentioned in Section 2, access to food is strongly dependent on the biodiversity state. Soil quality and crop yield directly derive from ecosystem services, but the former is also home to micro-organisms and as highlighted by Mbow *et al.* (2019), strong interlinkages are at play between the climate system, ecosystems (including biodiversity), the food system, food security, and the socio-economic system. The authors also indicate that for the "middle of the road" Shared Socio-economic Pathway[17] global crop and economic models forecast a range of increases for cereal prices for the 2050 horizon, which puts further pressure on agricultural yield. Indeed, data from the FAO[18] shows how the wheat yield, for instance, has started to somehow stagnate since 2017, compared to its upward trend since the 1960s. Increase in land use intensity, biodiversity losses and climate change may all be held responsible for this phenomenon, notably because of their impact on soil quality. Combined with population growth, we believe that basic food supply, such as cereals, is likely to become a salient global issue reflective of broader biodiversity aspects.

Table 10: Themes underlying Food Security risk index

Theme	Example Dimensions
Aid group	World food programme
Cereals	Wheat, corn, grain
Fertilizer	Multi-nutrient fertilizers
Generic food security	Food price, agriculture & food security, poverty, nutrition & food security

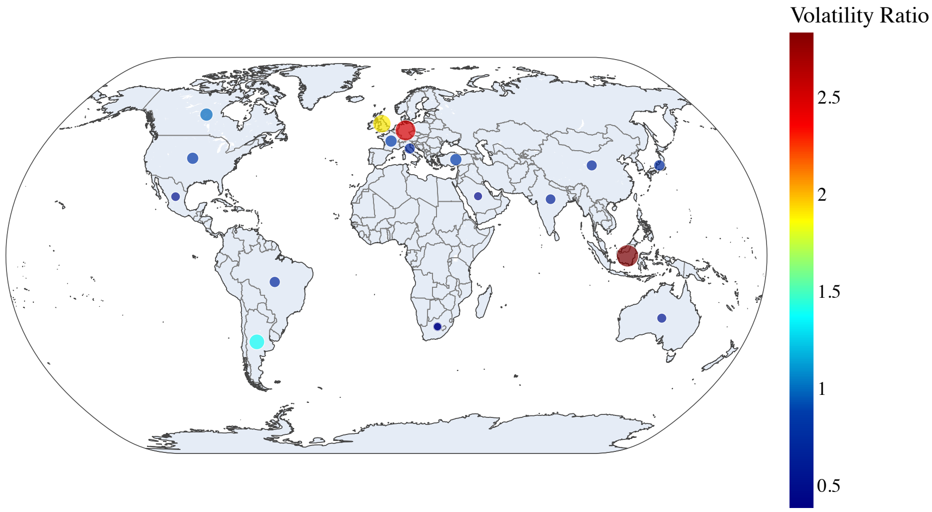
Source: Amundi Institute.

Hence, in order to be able to monitor such growing risk, we decide to build a Food Security risk index, in a similar manner to the Biodiversity risk index introduced in Section 3.1 on GDELT data. The associated themes are defined in Table 10, and cover different aspects of food security, from cereals to fertilizers, but also nutrition and aid groups, such as the World Food

[17] SSP1-sustainability SP2-middle of the road and SSP3-regional rivalry.

[18] https://ourworldindata.org/crop-yields.

Figure 16: Ratio of the Weekly Volatilities of the Food Security risk index After/ Before the Invasion of Ukraine in Feb. 2022

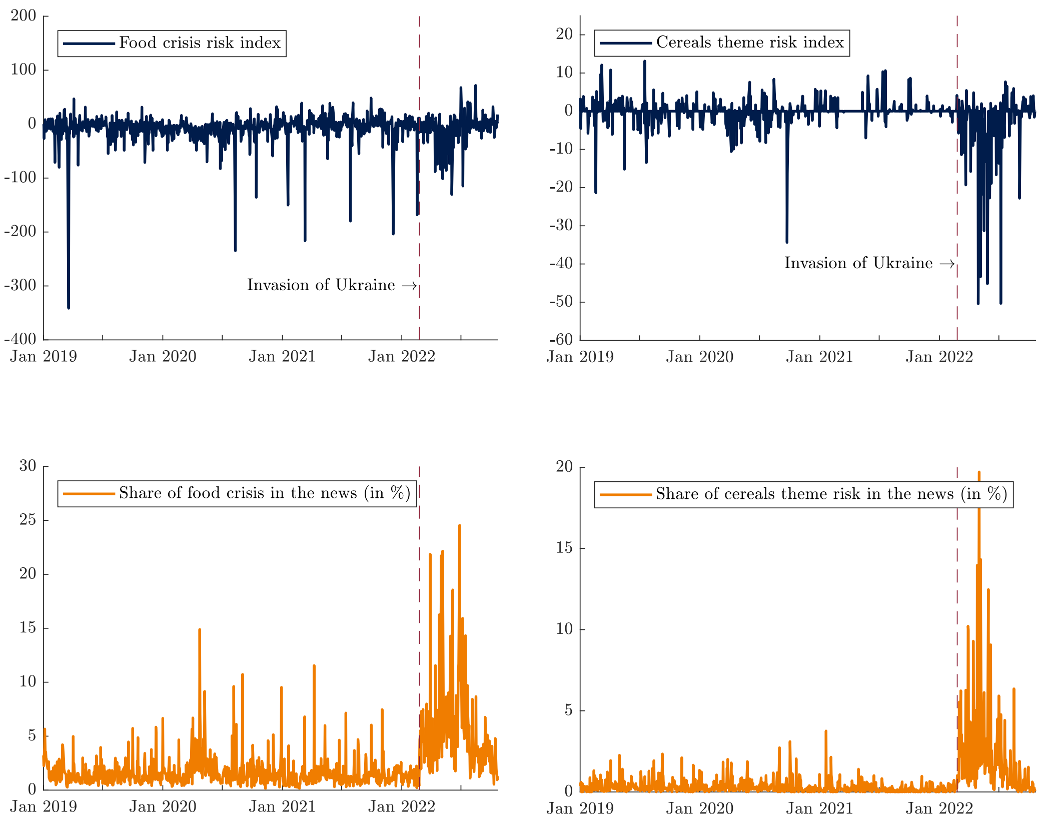


Source: GDELT, Authors' calculations, Amundi Institute.

Programme. We calculate the Food Security risk index for all countries of the G20-ex-Russia and we measure the ratio of its volatilities after/before the start of the Russian invasion of Ukraine in February 2022: $VR = \sigma_{post}/\sigma_{pre}$ where σ_{post} is the volatility of the Food Security risk index between February 25^{th}, 2022 and November 4^{th}, 2022 and σ_{pre} is the volatility of the same index between January 4^{th}, 2019 and February 18^{th}, 2022.

We identify in Figure 16 that Indonesia has had the highest spike in Food Security risk index volatility among the G20-ex-Russia countries since the end of February 2022. When we look at the underlying themes, Figure 17 indicates that the Cereals theme has been particularly volatile after the start of the invasion of Ukraine. Indeed, the share of the cereals risk theme in the news shows an impressive increase since the end of February to reach a level of 20% in early May 2022. Indonesia hence looks particularly vulnerable in terms of food security in the context of grain shortages and unstable trade flows of cereals. Although such pressures might be lifted once the Ukraine situation settles, Indonesia may still face fundamental difficulties. In fact, Bourgeois and Kusumaningrum (2008) projected correctly that in 2020, Indonesia's urbanization and income growth would bring an increase in wheat consumption and therefore of imports. Indeed, Indonesia does not produce wheat: the cost of importing cereals in total GDP that remains fairly low does not act as an incentive to pursue cereals self-sufficiency. The increase in wheat consumption in the country has been such that Indonesia, together with Egypt, are the top global importers in metric tons of wheat[19].

Figure 17: Food Security Risk index - Indonesia



(a) Food crisis risk

(b) Cereals risk theme

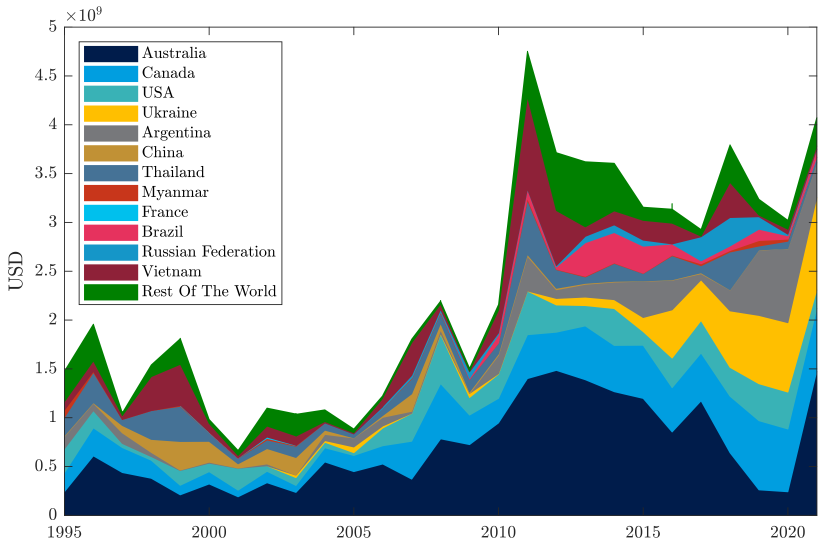
Source: Authors' calculations, Amundi Institute.

We break down the origins of cereal imports in Figure 18. The contribution of Ukraine to cereal imports moved up significantly from less than 1% in 2008 to 23% in 2021. The fairly recent Indonesia's dependency to Ukraine's cereals highlights how local changes, that could for instance result from socio

[19] https://apps.fas.usda.gov/psdonline/circulars/grain.pdf.

economic dynamic change or conflict, can accelerate biodiversity and agricultural issues and propagate in a systemic way to other regions of the world. Similar to the floods in 2011-2012 in Bangkok which disrupted the supply chains and the food stability in Thailand (Mbow *et al.*, 2019), the invasion of Ukraine is an extreme event that notably stressed the interlinkages between the ecosystems and food security.

Figure 18: Trade Value of Cereal Import to Indonesia (USD)



Source: UN Comtrade Database, Authors' calculations, Amundi Institute.

Table 11: Events in Indonesia

Date	Tag	Theme	News (in %)	Comment
29-04-22	ID1	Cereals	8	Food crisis warning by the World Bank
06-05-22	ID2	Cereals	22	Joint statement to WTO on food security
11-05-22	ID3	Cereals	6	Global food prices are reaching record levels
14-05-22	ID4	Cereals	8	India bans wheat exports following heat wave
29-06-22	ID5	Cereals	11	Indonesian President's visit to Russia and Ukraine
02-09-22	ID6	Cereals	4	Indonesia projected to be first global importer of wheat

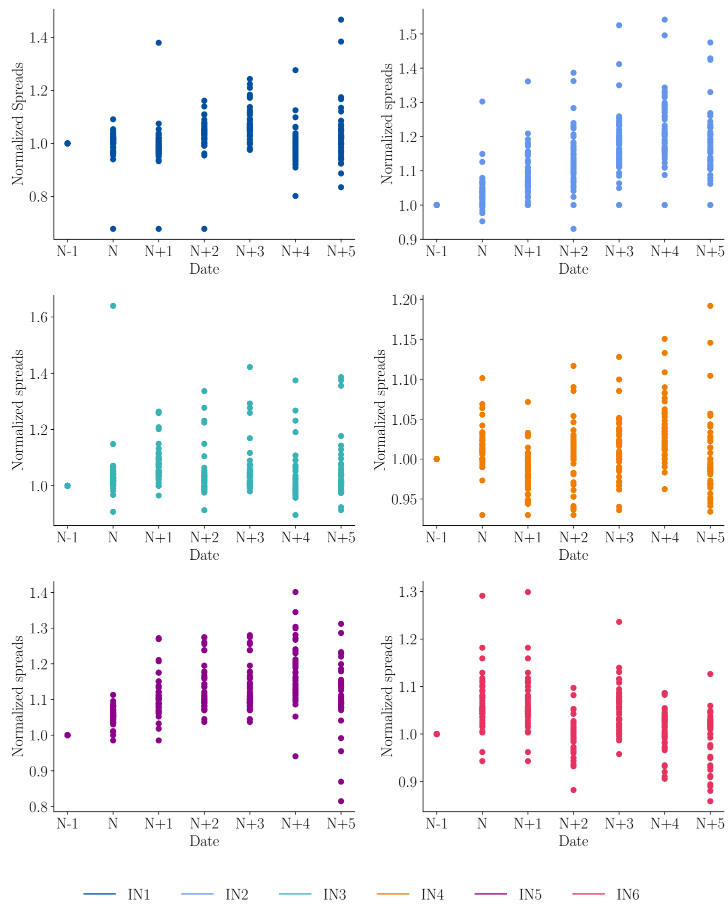
Source: Authors' calculations, Amundi Institute.

In the same spirit as Section 3.3, and considering the topical issue of cereals, we aim at quantifying the impact of food security risk through the prism of the cereals theme on corporate bond spreads in Indonesia. In order to do so, we isolate the lows from the cereal theme risk index. In fact, we are able to link such dates with prominent news on the topic, as illustrated in Table 11[20]. The events mentioned correspond to contemporary global tensions whose future effects are still uncertain, such as geopolitical tensions in the global food system, inflationary food trends, global food security and nutrition crisis, and uncertainty about climate change and/or population growth. We construct a database of USD-denominated corporate bond spreads for Indonesia, without filtering on the most impactful sectors. Indeed, we are keen to depict potential spillovers effects arising from stress on biodiversity sensitive commodities. Our dataset is composed of 41 bonds on average between January 2019 and September 2022. In terms of sub-industry representation, we witness how the corporate bond index is allocated in Figure 23 of Appendix A.2. This index is distributed over 6 industries which are in order of importance in the allocation: Utility, Energy, Basic Industry, Banking, Transportation and Consumer Goods. The latter industry is poorly represented compared to the others. Indeed, the Food Wholesale sub-industry represented 5.5% in average in the index from July 2021 and was not part of the index before that date. This sub-industry is the only one in the index that is related to food, we can then assess the systemic aspect of food security risk events.

We then evaluate security level spreads movement following negative events on the cereals theme, between the date prior to the event and up to 5 days after in Figure 19. We normalize spreads values so that they are equal to 1 on the day before the event. We notice already how these events seem to have put pressures on corporate bond spreads but also how some companies appear much more responsive to these pieces of news. To authenticate such moves, we test whether, in the days following an acute negative event on the cereals theme, the average spread of our subset of USD-denominated bonds from Indonesian companies is statistically different from 1, hence from the average spread level on the day prior to the event.

[20] Similar to our calculation in subsection 3.1, we maintain a robust calculation for the share of Food Security-related news associated to Indonesia. However, due to the relative sparseness of the GDELT identifiers that we associate with Food Security, we lower the threshold from 2 in subsection 3.1 to 1.

Figure 19: Normalized Spread for Indonesian Bonds Before and After the Negative Events on Biodiversity



Source: Authors' calculations, Amundi Institute.

Table 12: P-values Significance for Indonesian Spreads

Tag	N	N+1	N+2	N+3	N+4	N+5
IN1			* * *	* * *		**
IN2	* * *	* * *	* * *	* * *	* * *	* * *
IN3	* * *	* * *	* * *	* * *	*	* * *
IN4	* * *	* * *		* * *	* * *	
IN5	* * *	* * *	* * *	* * *	* * *	* * *
IN6	* * *	* * *		* * *	*	

[1] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Authors' calculations, Amundi Institute.

Results are presented in Table 12 and corroborate the idea that on average, bond spreads from our sample of Indonesian companies tend to widen following heightened risk on the cereals front.

Based on a corporate bond index covering a diversified range of sectors, we show how acute negative events on the theme of cereals can trigger material spread widening on the Indonesian corporate bond market. These results highlight how spillovers may occur from a risk, that may have appeared only connected to the food industry, impacting in-fine different sectors of the economy.

5 Conclusion

Our study aims to address the relationships between corporates and biodiversity losses. The double materiality principle is intrinsic to such linkages, in the sense that human activities can impact and alter the state of biodiversity but in turn, ecosystem services can curb human activities. While comprehensive literature exists on human activities' damages on biodiversity, companies' dependency on biodiversity has received less attention in the financial industry. In fact, corporate dependency is often assessed from a sector standpoint, and generally focuses on natural capital dependency. For instance, the Paper industry is often identified as being exposed to biodiversity losses because of its wood supply needs. From this viewpoint, biodiversity is an asset that can deliver services and therefore opportunities for companies and for human activities in general. In our paper, we depart from this dependency on natural capital and address biodiversity as a risk, from an operational/physical and financial viewpoint. Given that corporates often perceive biodiversity risk principally through the reputation channel (Dempsey, 2013), we were keen to firstly illustrate through actual company-reported cases how biodiversity losses can jeopardize companies' operational efficiencies. With a focus on food security, we also touched on spillovers that may arise, notably in light of biodiversity losses, and turn into systemic financial risk.

In the following part of the paper, we decided to address the financial market effect of biodiversity risk on corporates. A first step toward this goal was to qualify and quantify biodiversity risk. Based on the GDELT news database, we constructed Biodiversity risk indexes that allowed us to isolate acute biodiversity events. Such events are clearer to identify compared to chronic declines and more likely to have an unforeseen impact on financial markets. Analyses were run on two "megadiverse" countries, namely Australia and Brazil, although analyses could be expanded to other key biodiversity exporters such as China or the United-States (according to UNCTAD data)[21]. We built a corporate bonds dataset for these two universes, focusing on the sectors that have a material impact on biodiversity. We then assessed how corporate bond spread levels responded to national acute biodiversity events. To our knowledge, this is one of the first studies confronting biodiversity losses to security level prices or spreads. We demonstrate that the companies operating within the sectors that are the most harmful to biodiversity are particularly exposed to spread widening following acute biodiversity events. Continuing with companies from sectors with a significant impact on biodiversity, we showcased the possibility of a biodiversity risk premium in Australia between 2019 and 2022. This result also held when dismissing periods following acute biodiversity events. We acknowledge that the physical interlinkages between biodiversity and other environmental dimensions (the E pillar of ESG) materialize in periods of high correlation between biodiversity and the E pillar. We keep the question of chronic risk premium on biodiversity opened.

The fact that financial risk seems to materialize in corporate bond spreads raises the question of growing concern over potential future losses or defaults, which may accelerate once we pass biodiversity's tipping points. On a more positive note, the fact that spreads widen following acute biodiversity events demonstrates genuine investors awareness, acknowledging how biodiversity can be tied to credit risk.

[21] https://unctadstat.unctad.org/EN/Biotrade.html.

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A Appendix

A.1 Data for Biodiversity Risk Index

Table 13: GDELT Selected Identifiers Underlying Biodiversity

Theme	Identifiers
Air	Manmade disaster [radiation leak, toxic leak, nuclear accident, radioactive], WB 1717 urban pollution & environmental health, WB 1791 air pollution, WB 1795 ozone depleting substances, WB 1841 short lived climate pollutants, WB 1851 biocarbon, WB 1854 methane, WB 804 urban pollution
Land	Agriculture, ENV deforestation, ENV forestry, ETH indiginous, disaster fire, manmade disaster [infrastructure collaspe], manmade disaster mining disaster, manmade disaster housefire, natural disaster [earthquake, wind, fire, drought, landslide, eruption, storms], TAX ethnicity indigenous, TAX fncact farmers, TAX foodstaples TAX worldinsects soil insect, TAX worldinsects soil insects, WB 1001 soil salinity, WB 1057 sustainable forest management, WB 175 fertilizers, WB 1757 reduced emissions from deforestation & degradation, WB 1777 forests, WB 1913 soil management, WB 1980 agro forestry, WB 1981 pasture restoration, WB 1982 erosion control, WB 1986 mountains, WB 1987 salinity management, WB 2286 geological survey, WB 2287 land use laws, WB 2328 regional geological mapping, WB 2960 indigenous peoples, WB 435 agriculture & food security, WB 436 forestry, WB 621 health nutrition & population, WB 749 indigenous peoples, WB 896 geological mapping & databases
Fauna	ENV fishery, ENV overfish, ENV speciesendangered, ENV speciesextinct, TAX agriculharminsects [...], TAX political party party for the animals, TAX terror group animal defense league, TAX terror group stop huntingdon animal cruelty, TAX worldarachnids [...], TAX worldbirds [...], TAX worldcrustaceans[...], TAX worldfish[...], TAX worldinsects [...], TAX worldmammals [...], TAX worldmyriapoda [...], TAX worldreptiles [...], WB 177 animal production, WB 2194 animal welfare

[1] Prefixes followed by [...] implies that we selected all the identifiers starting with that prefix, while [x] means that we selected all the identifiers with such prefix, related to topic x.

Source: GDELT, Author's calculations, Amundi Institute.

Table 14: GDELT Selected Identifiers Underlying Biodiversity (continued)

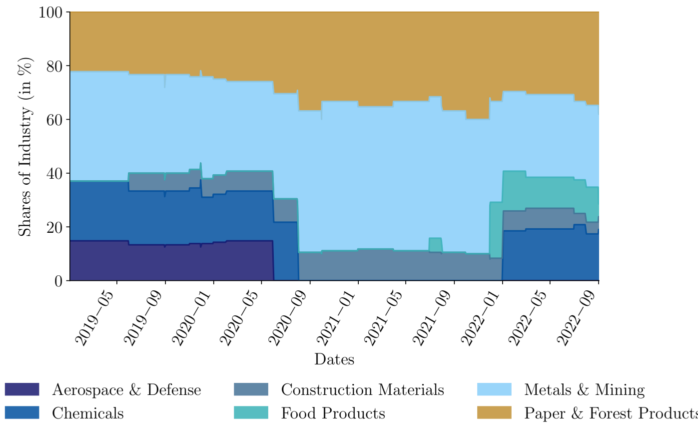
Theme	Identifiers
Flora	TAX plantdisease[...], WB 1787 natural habitats, WB 1864 plant variety protection
Climate Change and Generic	ENV carboncapture, ENV climatechange, ENV green, manmade disaster [...], Natural Disaster [...], UNGP climate change action, WB 163 low emissions transport, WB 1779 modified ecosystems, WB 1786 environmental sustainability, WB 1792 environmental health, WB 1979 natural resource management, WB 2084 biodiversity, WB 2965 toxic pollution, WB 566 environment & natural resources, WB climate change, WB 579 climate change mitigation, WB 580 low carbon development, WB 582 greenhouse gas accounting, WB 590 ecosystems, WB 601 pollution management
Water	Manmade disaster maritime disaster, manmade disaster [spill], manmade disaster abandon ship, natural disaster drowns, manmade disaster [sinking boat], natural disaster [dam, flood, drown, tidal wave, monsoon, rain, tsunami, overflowing], TAX disease algae bloom, UNGP forests rivers oceans, WB 1000 water management structures, WB 1048 marine protected areas, WB 1063 water allocation and water supply, WB 1064 water demand management, WB 1215 water quality standards, WB 1220 surface water management, WB 137 water, WB 140 agricultural water management, WB 150 wastewater reuse, WB 155 watershed management, WB 156 groundwater management, WB 1778 freshwater ecosystems, WB 1805 waterways, WB 1958 integrated coastal zone management, WB 1983 healthy oceans, WB 1984 ocean pollution, WB 2005 community water supply management, WB 2978 water pollution load, WB 2981 drinking water quality standards, WB 3014 wastewater disposal facilities, WB 423 integrated urban water management, WB 427 water allocation & water economics, WB 596 coastal & marine ecosystems

[1] Prefixes followed by [...] implies that we selected all the identifiers starting with that prefix, while [x] means that we selected all the identifiers with such prefix, related to topic x.

Source: GDELT, Author's calculations, Amundi Institute.

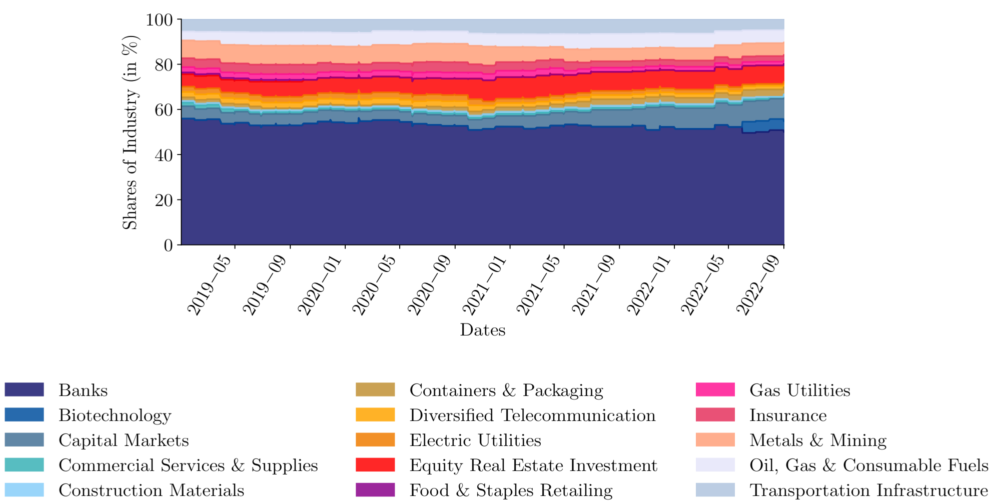
A.2 Sector distribution of the corporate bond indexes

Figure 20: Sector distribution for the Brazilian risk country index (in %)



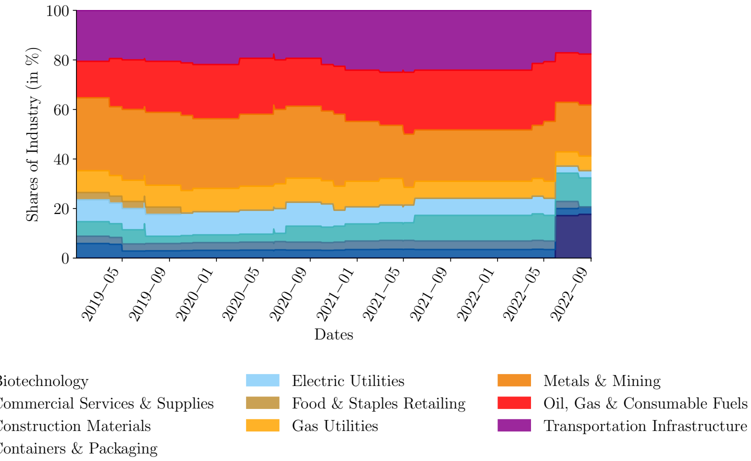
Source: Authors' calculations, Amundi Institute.

Figure 21: Sector distribution for the Australian risk country index (in %)



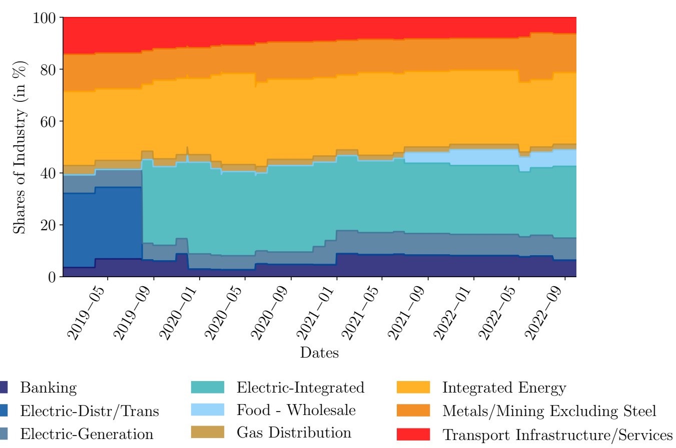
Source: Authors' calculations, Amundi Institute.

Figure 22: Sector distribution after filtering sub-industries for the Australian risk country index (in %)



Source: Authors' calculations, Amundi Institute.

Figure 23: Bond sector distribution for the Indonesian risk country index (in %)



Source: Authors' calculations, Amundi Institute.

A.3 Event study

Table 15: Events and Dates for Acute Biodiversity Events in Brazil

Code	Date	Event Source
BR1	25-01-2019	Brumadinho dam disaster https://www.sciencedirect.com/science/article/pii/S0303243420300192
BR2	22-08-2019	Amazon wildfires (highest since 2007) https://www.greenpeace.org/international/story/55533/amazon-rainforest-fires-2022-brazil-causes-climate/
BR3	28-11-2019	Amazon fires may cause Andes glacier to melt further https://www.bbc.com/news/science-environment-50573623
BR4	22-09-2020	Bolsonaro describes "disinformation" https://news.un.org/en/story/2020/09/1072982
BR5	14-07-2021	Species at risk of extinction in the Amazon https://www.reuters.com/business/environment/over-10000-species-risk-extinction-amazon-says-landmark-report-2021-07-14/
BR6	19-11-2021	Deforestation in Amazon accelerates at a 15-year high https://www.ecowatch.com/brazil-amazon-deforestation-2655765060.html

Source: Authors' calculations, Amundi Institute.

Table 16: Events and Dates for Acute Biodiversity Events in Australia

Code	Date	Event Source
AU1	30-12-2019	Australia fires worsen following heat wave https://gfmc.online/media/2019/12-2019/australia-fires-worsen-as-every-state-hits-40c.html
AU2	23-01-2020	Queensland Monsoonal flooding and three firefighters killed in air tanker crash https://www.theguardian.com/australia-news/2020/jan/23/all-three-crew-members-dead-in-crash-of-air-tanker-fighting-bushfires-in-snowy-monaro-region https://www.disasterassist.gov.au/Pages/disasters/current-disasters/Queensland/qld-monsoon-flood-20200124.aspx
AU3	28-10-2020	Fires break out and destroyed between 24 to 34 million Ha https://naturaldisaster.royalcommission.gov.au/publications/royal-commission-national-natural-disaster-arrangements-report
AU4	12-11-2021	Australia pointed out as the "colossal fossil"of COP26 https://www.theguardian.com/environment/2021/nov/12/australia-shown-to-have-highest-greenhouse-gas-emissions-from-coal-in-world-on-per-capita-basis
AU5	28-02-2022	IPCC reports Australia is at real risk from climate change https://theconversation.com/new-ipcc-report-shows-australia-is-at-real-risk-from-climate-change-with-impacts-worsening-future-risks-high-and-wide-ranging-adaptation-needed-176691
AU6	27-06-2022	Floods in New South Wales https://www.disasterassist.gov.au/Pages/disasters/current-disasters/New-South-Wales/nsw-severe-weather-and-flooding-27-june-2022-onwards.aspx

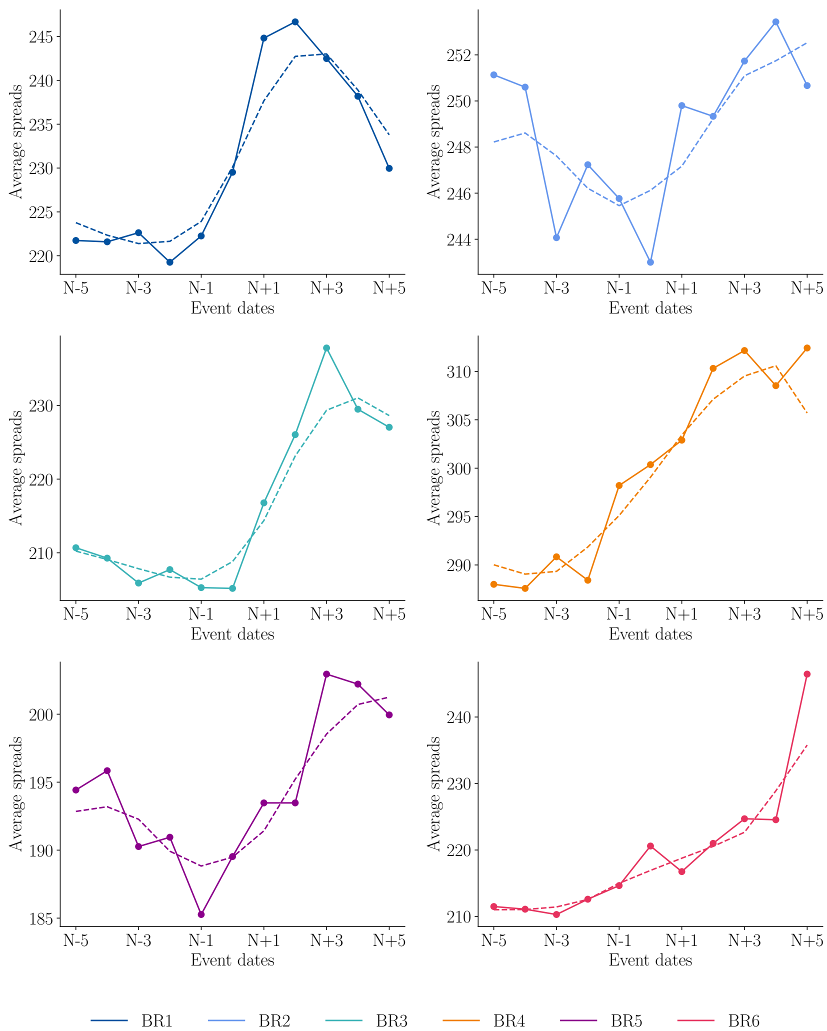
Source: Authors' calculations, Amundi Institute.

Table 17: Events and Dates for Acute Food Security (Cereal Theme Focus) Events in Indonesia

Code	Date	Event Source
ID1	29-04-2022	Food crisis warning by the World Bank https://www.middleeastmonitor.com/20220429-cost-of-the-ukraine-war-felt-in-africa-global-south/
ID2	06-05-2022	Joint statement to WTO on food security https://www.trtworld.com/europe/countries-vow-to-secure-food-security-as-ukraine-conflict-disrupts-supplies-56928
ID3	11-05-2022	Global food prices are reaching record levels https://www.weforum.org/agenda/2022/05/climate-change-conflict-global-food-prices-record-levels/
ID4	14-05-2022	India bans wheat exports following heat wave https://www.reuters.com/article/india-wheat-exports-idAFKCN2N001D Note: The ban started on Saturday the 14^{th} of May however in our analysis we selected the 16-05-2022 as the starting date for this event, hence considering the first trading day following the event
ID5	29-06-2022	Indonesian President's visit to Russia and Ukraine https://www.reuters.com/world/asia-pacific/indonesian-president-visits-ukraine-peace-mission-2022-06-29/
ID6	02-09-2022	Indonesia projected to be first global importer of wheat https://www.marketwatch.com/story/egypt-shifts-wheat-buying-strategy-to-cope-with-high-prices-271662122223

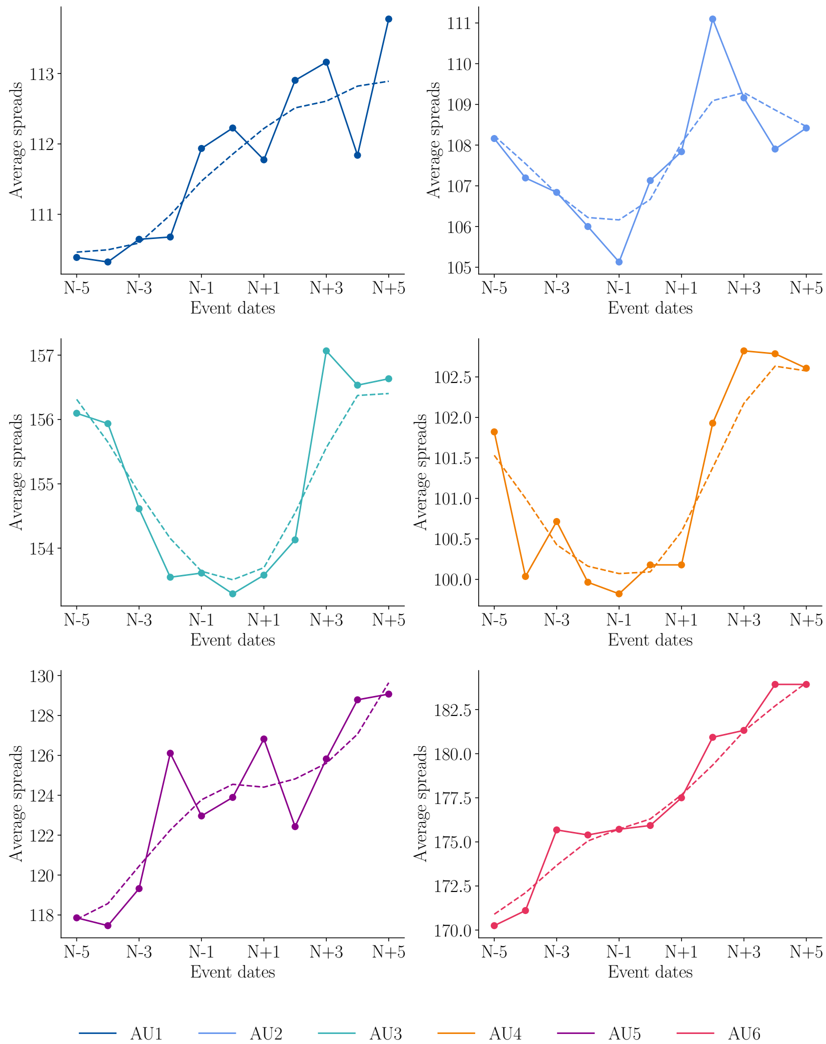
Source: Authors' calculations, Amundi Institute.

Figure 24: Average spread for Brazilian issuers before and after the negative events on biodiversity



Source: Authors' calculations, Amundi Institute.

Figure 25: Average spread for Australian issuers before and after the negative events on biodiversity



Source: Authors' calculations, Amundi Institute.

Important Information

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