# Natural Assets and Public Debt: Evidence from Sovereign Green Bonds*

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**Abstract**

Does risk to natural assets affect the cost of public debt? Analysis of sovereign green bonds between 2016 and 2024 reveals that deterioration in nature-related risk results into higher sovereign spreads. A 1% increase in risks to natural assets is associated with 21 to 40 basis-point higher yield. A novel dataset on green bond-funded projects, developed using an retrieval-augmented generative (RAG) based large language model (LLM), shows that "green intentions" alone do not influence asset prices without "green efforts." While carbon emissions per capita (carbon intensity) remain unchanged after issuance, 40% of bonds funding sustainable forestry projects result in a 0.2% increase in forest area (as a percentage of habitable land) compared to pre-issuance trends. These results are robust to endogenity tests and other battery of checks.

**KEYWORDS**: Biodiversity Loss; Natural Resources Depletion; Sovereign Green Bonds; Sustainable Forestry; Carbon Intensity.

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# 1. Introduction

Over half of the global economy is highly or moderately dependent on nature and the goods and services it generates (known as "ecosystem services").[1] According to one estimate, the recent losses of ecosystem services have been estimated to cause damages of USD 4 trillion to USD 20 trillion per year (Kapnick, 2022). Yet even this estimate does not cover all nature-related benefits. A significant responsibility for natural assets (or green public goods) such as biodiversity conservation and the preservation of natural resources rests with public institutions, such as governments and municipalities because private institutions like corporates invest mostly in those forms of natural capital that are direct inputs for provisioning services (such as farms, plantations, houses, and similar others) whose products are excludable (Flammer, Giroux, and Heal, 2022; Karolyi and Puente, 2023; Dasgupta 2021). Therefore, it is essential to understand the role of public organizations (such as sovereigns) and the potential risks to their external funding associated with natural assets such as biodiversity loss and the depletion of natural capital. This paper fills that gap. [2] We also evaluate whether sovereigns' intentions and efforts to mitigate these risks are priced in cost of debt.

Giglio, Kuchler, Stroebel, and Zeng (2026) conducted a comprehensive survey to gauge the perceptions of biodiversity risks among finance academics, professionals, public sector regulators, and policy economists globally. One of the key findings from this survey revealed that approximately half of the respondents believe these risks are not adequately reflected in the pricing of stock, commodity, sovereign debt, and real estate markets. Only 14% to

[1] *Source: World Economic Forum, Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy, 2020.*

[2] We focused on biodiversity loss and the natural capital depletion risks because recent evidence shows that environmental risks extend well beyond the climate change system to include these risks as well and the economic cost of these risks would exceed the GDP loss caused in 2020 by the Covid-19 pandemic in around half the countries (Pinzon et al. 2020; Dobson et al. 2020; Tollefson 2020). In addition, the global risks survey reports from 2021 to 2025 by World Economic Forum have ranked biodiversity loss and natural capital risk as 2nd and 4th among all 33 global risks.

19% of respondents feel that these risks are accurately priced. Recent cases of public finance investors engaging with Brazil and Bolivia on deforestation and biodiversity loss suggest that they are showing interest in mitigating these risks.[3] To understand whether investors price these risks to ecosystem services such as biodiversity loss and natural capital risk, we investigate the association of these risks with sovereign green bond pricing. Furthermore, we also analyze the environmental performance of the sovereigns who used green bond proceeds to invest in these services.

We focused on sovereign green bonds as these are financial instruments especially designed to address negative externalities, such as biodiversity loss and risks to natural capital. Since the proceeds from green bonds are intended for mitigating these negative externalities, we should not expect conventional bonds to incorporate these risks if investors are not pricing them into green bonds. Furthermore, we also investigate how "Green Intentions" and "Green Efforts" by sovereigns may influence this pricing dynamic. A sovereign's "Green Intentions" are reflected during the issuance of green bonds when the sovereign discloses the categories of green projects funded by the bond proceeds. On the contrary, "Green Efforts" are evident when the sovereign actually invests in those specified green categories.

To evaluate whether biodiversity and natural capital risks are incorporated into the pricing of sovereign green bonds, we analyze data from the Bloomberg Global Fixed Income Database. Our sample consists of 216 sovereign green bonds issued between 2016 and 2024. We exclude 65 zero-coupon bonds, as these are essentially stripped securities that do not directly finance green projects. Most of the bonds in our sample are senior unsecured and have been issued by countries from the Asia-Pacific region, Europe, and Latin America. Using Artificial Intelligence (AI) models such as RAG based large language models (LLMs), we have developed a novel database focused on green projects that are financed through the proceeds

[3] https://www.unpri.org/Uploads/h/w/p/investorstatementondeforestationandforestfiresintheamazon_1oct2019_825656.pdf

of the green bonds. This database provides details about the capital allocation on these projects and their impact. To create this database, we extract information from comprehensive reports related to each bond. These reports include ESG frameworks, impact reports, capital allocation reports, external review reports, term sheets, and prospectuses. Collecting these reports is essential because the ESG framework—which outlines the categories of green projects—is provided only once. In contrast, other reports, such as impact reports, capital allocation reports, and external review reports, may be issued multiple times throughout the life of the bond. Tracking these later reports alongside the issuance date is crucial for accurately monitoring the progress of the green projects. This detailed approach enables us to evaluate whether the sovereign's "Green Intentions", as outlined in the framework, and their "Green Efforts", as reflected in the outcomes from subsequent reports, correlate with bond pricing and to what extent these efforts help mitigate environmental externalities.

Our estimates of biodiversity loss and natural capital risk are derived from two primary sources. For the former, we use constructs on overfishing. We relied on overfishing measures due to two reasons. First, overfishing drives biodiversity loss by depleting species faster than they can reproduce, disrupting food webs through trophic cascades, and wiping out non-target species as bycatch. When key species collapse, others that depend on them follow, triggering cascading extinctions that destabilize entire marine ecosystems.[4] Second, in the direct measures on biodiversity loss such as biodiversity index or endangered species, there is less variation at the country-level and these measures mainly captures the historical concerns and not the future concerns of the risk which elevate the possibility of undervaluing the risk. We use three measures of overfishing from World Development Indicators (WDI) database-percentage of agriculture and fishing in gross domestic product (GDP) , logarithm of total fish production , and logarithm of wild catch fish production.

For natural capital risk, we rely on country-level ESG data from the World Bank, which

[4]https://www.worldwildlife.org/our-work/oceans/sustainable-seafood/wild-caught-seafood/overfishing/

includes estimates on forest cover loss, the depletion rate of forests (% of gross national income (GNI)), the depletion rate of natural resources (% of GNI), and the freshwater withdrawal rate (% of internal resources). In addition to our primary risk variables, we control for bond characteristics such as maturity, amount issued, option embeddedness, and coupon type (fixed or floating). Sovereign bond pricing could be influenced by macro variables such as the debt-to-GDP ratio, GDP growth, and terms of trade, as highlighted in previous research (Hilscher and Nosbusch, 2004; Duffie, Pedersen, and Singleton, 2003). We control for these variables as well. These macroeconomic variables are sourced from the World Bank database.

Our findings indicate that investors price risk to natural assets that is to the preservation of natural resources and to the biodiversity conservation. Specifically, an increase in overfishing ( risk to biodiversity conservation) and deforestation & depletion of natural resources (risk to preservation of natural resources) are associated with a rise in bond yields. In economic terms, we found that an increase in risk to natural assets by 1% increases the offer yield to maturity by 21-40 basis points. The positive association of bond yield with the overfishing and natural resource & forest depletion rates indicates that investors are concerned about the country's economic growth. as the depletion of these resources could lead to reduced economic growth in the future (Stiglitz, 1974; Dasgupta and Heal, 1974). These findings are robust even when compared with conventional bonds issued by the same issuer in the same year and possessing similar characteristics.

As biodiversity loss and risk to natural capital can be restrained by initiating and implementing the green projects using the bond proceeds, we examine whether the intention to initiate green projects and efforts to implement them change the relation between the risks and bond prices. We measure green intentions using the ESG framework reports, which the issuer provides to the investors at the bond issuance. The framework highlights the green project categories in which proceeds would be used, management of proceeds, and green re-

porting in the future. We found that mere intentions do not significantly influence investor behavior towards these risks. Using the impact and capital allocation reports, we measure "Green Efforts" as the actual number of green projects implemented per dollar amount of proceeds. We find that green efforts by the sovereigns are recognized by the investors if the efforts are aligned with the direction of risks.

We understand the concerns related to endogeneity issues especially the self-selection bias. To mitigate these concerns, we use two separate global supply chain shocks for biodiversity loss and natural capital risk. For the former, we use Peru Anchovian Crises 2023 and for the latter, we use European Union Deforestation Regulation (EUDR). We find the reduction in yield after these shocks. These results contrast with those of Garel et al. (2024), which showed that investors demand a 2.2% premium for corporate biodiversity risk after the convention. We hypothesized that bond yields would decline because these shocks highlighted the biodiversity loss and natural capital risk and investors knew that regulators would intervene after these shocks to mitigate these risks.

To ensure that the risk to natural assets and its impact on sovereign green bond yield is not capturing the effect of geopolitical risk or of transition risk, we show that our results are robust even controlling for these risks.

Lastly, we also assess the environmental performance of the issuers. Since biodiversity loss affects carbon emissions (Weiskopf et al., 2024), we analyze the country-level carbon emissions per capita (carbon intensity). We find that green bond-issuing sovereigns with interim and net-zero targets do not have lower carbon intensity compared to others, even after a three-year span. Since carbon intensity may not be a concern for all issuers and might not be a negative externality for every sovereign, we focus on their environmental performance based on the projects funded by their green bonds. As 40% of sovereign green bonds are used for sustainable forestry projects, we examine the percentage of forest area in habitable land and the loss of forest cover (in hectares) in these sovereigns and compare them

with other green bond issuers. We discovered a 0.2% increase in forest area as percentage of habitable land and a reduction of 68.4 million hectares in forest cover loss following the issuance of green bonds and investment in sustainable forestry.

Overall, our work shows that investors care about the risk to natural assets whether it is conservation of biodiversity or preservation of natural capital. This finding aligns with classic theoretical papers on exhaustible resources[5], which suggest that natural resources are crucial for a country's economic growth. We support this channel by providing a theoretical framework and empirical findings. Although green projects can be implemented to mitigate these risks, we discovered that merely expressing intentions to initiate such projects is insufficient to persuade investors. The efforts to implement these green projects must align with the perceived risks in order to influence investors' risk preferences effectively. Despite commitments to net-zero emissions, the improvement in environmental performance among these sovereigns issuing green bonds is not significant. As carbon intensity may not be a concern for all sovereigns, we focus on their environmental performance based on the sustainable forestry projects funded by their green bonds. We find the increase in forest area and reduction in loss of forest cover following these investments. These findings are robust across various tests.

The paper is structured as follows: Section 2 reviews the relevant literature and outlines our contributions. Section 3 covers data collection and the variables used for analysis. Section 4 presents our empirical specifications. Section 5 discusses the results, and Section 6 concludes the paper.

[5]Refer Stiglitz (1974), Dasgupta and Heal (1974), and similar others.

## 2. Related Literature and Contribution

Our research contributes to the rapidly expanding literature on the intersection of financial markets, asset prices, and environmental health. Recent studies have extensively explored the impact of risks related to climate change on financial assets (e.g., Giglio et al., 2023; Bolton and Kacperczyk, 2023; Aswani, Raghunandan, and Rajgopal, 2024a, 2024b; Aswani and Rajgopal, 2024). Comprehensive review of this body of work is provided by Giglio et al. (2021), Stroebel and Wurgler (2021), and Hong et al. (2020). Despite of these works, research into the impact of biodiversity risks on asset values and economic activity is nascent but rapidly expanding (Giglio, Kuchler, Stroebel, and Wang, 2025; Dimson, Kacperczyk, and Starks, 2026). Notable contributions in this area include Dasgupta (2021), who offers an overview of global biodiversity and the economic drivers behind its decline, and Flammer et al. (2025), who focus on financing for biodiversity conservation projects. Recent studies on impact of biodiversity loss mainly focuses on corporate outcomes. For instance, Giglio et al. (2026) provide quantitative measures of aggregate biodiversity risk and investigate its pricing within equity markets. Similarly, Garel, Romec, Sautner, and Wagner (2024) investigates whether corporate biodiversity footprint (CBF) (developed by Iceberg Data Lab) is associated with stock returns. Authors find no association between CBF and stock returns using the data from 2018-2021 overall but find premium of 2.2 % annual return following major biodiversity-related policy changes such as Kumming Declaration and the launch of Nature-related Financial Disclosure (TNFD) in 2021.

Differentiating from previous studies, our research examines how biodiversity loss and natural capital degradation affect sovereign credit risk. We focus on sovereigns for two key reasons. First, although sovereign risk is traditionally associated with emerging economies in Latin America and Asia, the U.S. credit rating downgrade in August 2011 and the subsequent Eurozone debt crisis shifted global attention toward sovereign risk in advanced economies

as well. Consequently, understanding the determinants of sovereign credit spreads and the cross-country differences in spread levels has become an important area of inquiry (Doshi et al., 2017). Second, the responsibility for providing public goods—such as biodiversity conservation and natural capital preservation - rests primarily with governments rather than corporations. Assessing how these environmental risks influence sovereign bond yields is therefore essential to determine whether international investors price such risks into sovereign debt. Moreover, because sovereign green bonds are specifically designed to finance projects that mitigate environmental externalities, analyzing their pricing dynamics and environmental implications can reveal whether investors genuinely account for these risk factors and whether countries effectively address them.

A vast body of research has examined the determinants of sovereign credit risk, identifying both country-specific and global factors. For example, Hilscher and Nosbusch (2004) find that debt-to-GDP ratios and terms of trade account for a significant share of the variation in sovereign yield spreads. Similarly, Cantor and Packer (1996) and Kamin and von Kleist (1999) highlight the role of sovereign credit ratings as key determinants of yield spreads. Pan and Singleton (2008) document a strong relationship between sovereign credit risk and global market volatility, as captured by the VIX index. Investigating the commonality in sovereign credit spreads, Longstaff et al. (2011) use the principal components of changes in CDS spreads across 26 developed and emerging economies and show that common global factors explain a substantial portion of sovereign credit risk—more so than they do stock returns. Building on this literature, our study introduces an environmental dimension by demonstrating that risks associated with biodiversity loss and natural capital degradation represent additional, country-specific determinants of sovereign credit risk, and that the pricing of these risks is modulated by sovereigns' green project intentions and implementation efforts.

We also contribute to the growing literature on the pricing and environmental impli-

cations of green securities. Green bonds are financial instruments specifically designed to mitigate environmental externalities by channelling proceeds exclusively toward environmentally beneficial projects. Flammer (2021) finds that corporate green bonds are issued at a premium relative to traditional corporate bonds and that issuers' environmental performance improves following issuance. Aswani and Rajgopal (2025) show that the observed "greenium" in the corporate green bonds market exists primarily for financial firms, whose environmental footprint is relatively small, and that this premium does not transmit to the green loan market. They also find that neither green bond issuers nor green loan borrowers exhibit significant improvements in environmental performance within a short horizon of three to five years. Extending this line of research, Aswani and Rigobon (2025) demonstrate that the adoption of sustainable governance mechanisms—such as appointing a Chief Sustainability Officer (CSO) or establishing an ESG committee—enhances issuers' ability to improve environmental performance following green bond issuance. In contrast, Larcker and Watts (2019), studying municipal green bonds, find no difference in the risk-adjusted pricing between green and conventional securities. Building on this literature, our study examines how risks associated with natural assets—specifically biodiversity loss and natural capital depletion—affect sovereign credit risk through the lens of green bond pricing. If investors recognize these environmental risks as material to sovereign creditworthiness, such concerns should be reflected in the pricing of sovereign green bonds earlier and more prominently than in traditional sovereign bonds.

We contribute towards the emerging literature on artificial intelligence applications in finance. Using retrieval-augmented generative (RAG) large language models (LLMs), we extracted and developed a structured dataset on project categories, capital allocation, and the impact outcomes of green projects initiated with proceeds from green bonds. We used this data to estimate intentions (Green Intentions) and efforts (Green Efforts) and to check whether these estimates influence sovereign green bond pricing. We show that "green inten-

tions" alone do not influence asset prices without "green efforts".

Lastly, we contribute to the growing literature on the impact of climate change, biodiversity loss, and natural capital risk on public debt. Painter (2020) provides evidence that counties affected by climate change pay higher underwriting fees and achieve higher yields when issuing municipal bonds than other counties. These results are significant only for long-term securities. In contrast, Larcker and Watts (2020) show that there is no green premium for municipal green bonds relative to conventional bonds. Using a case study of bat populations, Nakhmurina, Manning, and Fenichel (2026) show that changes in local biodiversity can affect the borrowing costs of the US rural county government. Compared to these papers, we focused on sovereign green bonds and examined how biodiversity loss and natural capital risk are priced in these bonds, and whether sovereigns' green intentions and efforts to mitigate these risks are factored into the debt valuation. Furthermore, we evaluate the changes in biodiversity and natural capital risks for which green projects (such as sustainable forestry) are initiated or implemented.

# 3. Natural Assets and Economic Growth - Theoretical Framework and the Channel

The economic theories on risk to natural assets can be traced back to Adam Smith but modern work begin from Hotelling (1931) and then progressed by Solow (1972), Stiglitz (1974), Dasgupta and Heal (1974) and others. This framework shows how marginal increase in risk to natural assets impact marginal economic growth. This model is motivated by Krautkraemer (1985).

$$\max \int U(C_t, N_t) e^{-\delta t} dt$$
$$\text{such that } \frac{dN}{dt} = -r_t$$

$$\text{and } C_t = \sigma^{\gamma t} r_t + f(N_t) e^{\omega t}$$

Here,

$r_t$ : Rate of depletion of natural assets. $\delta$ : $Discountrate$

F($P_t$): Production function for developed product using natural assets.

$\sigma$: It is a constant that converts the rate of depletion into a consumption rate.

$\gamma$ and $\omega$ : These are rates of technical progress in the natural assets sector and developed product sector. For simplicity, we are assuming them as zero i.e., $\gamma = \omega = 0$

$P_t$ : Developed product at time t.

Assuming quantity of resources is fixed,

$$P_t - P_0 = N_0 - N_t$$
$$f(N_t) = F(N_0 + P_0 - N_t) = F(P_t)$$

For simplicity, U(C, N) = U(C) + U(N) (Additive Preferences)

Setting the Hamiltonian equation,

$$H = U(C_t, N_t) - \lambda_t r_t$$

$\lambda_t$ : Shadow price of natural assets.

$$H = U(\sigma r_t + f(N_t), N_t) - \lambda_t r_t$$
$$H = U(\sigma r_t + f(N_t)) + U(N_t) - \lambda_t r_t$$

First order condition,

$$U_c(\sigma r_t + f(N_t)(\sigma - f_N(N_t)) - U_N N_t - \lambda_t = 0$$

$\lambda_t = \rho\lambda_t$

At steady state,

$$\frac{U_N(N)}{\rho} = U_c(f(N))\sigma - \frac{U_c(f(N)f_N(N))}{\rho}$$

$\frac{U_N(N)}{\rho}$ : Marginal benefit of natural assets.

$U_c(f(N)\sigma$: Marginal consumption from developed product.

$\frac{U_c(f(N)f_N(N))}{\rho}$: Marginal consumption from future value of natural assets (discounted to present).

This theoretical prediction shows how natural assets are associated with economic growth. The same we showed through empirics by running a regression of GDP growth on biodiversity loss and natural capital risk variables. We found the positive association between GDP growth and biodiversity loss & natural capital risk, and it is statistically significant. Refer Table B1 for details. As sovereign growth prospectus is counted in bond yield, the relationship between risk to natural assets and GDP growth shows why the former would also affect the bond yield.

# 4. Data

## 4.1. Sovereign Green Bonds

Our data on sovereign green bonds comes from the Bloomberg Global Fixed Income database. We keep only the sovereign bonds that Bloomberg classifies as green. This leads to the sample of 216 sovereign green bonds issued from 2016-2024.[6] We drop 65 zero-coupon

[6]There are no sovereign green bonds issued prior to 2016.

bonds from the sample, as these are strips from the existing bonds and have no association with the green projects. The majority of these bonds are senior unsecured and issued by countries from Asia-Pacific, Canada, Europe, and Latin America. Summary Statistics of these bonds are provided in Table 1 Panel D.

## 4.2. Biodiversity Loss

For the sovereign biodiversity loss, we use the measures on overfishing from World Development Indicators (WDI) database of World Bank.[7] We relied on overfishing measures because overfishing drives biodiversity loss by depleting species faster than they can reproduce, disrupting food webs through trophic cascades, and wiping out non-target species as bycatch. The bottom trawling destroys critical habitats like coral reefs and seagrass beds that serve as nurseries for countless species, while the selective removal of large, fit individuals erodes genetic diversity over time. When key species collapse, others that depend on them follow, triggering cascading extinctions that destabilize entire marine ecosystems.[8]

We use three measures of overfishing - percentage of agriculture and fishing in GDP (*Agriculture and Fishing Per GDP*), logarithm of total fish production (*Total Fish Production*), and logarithm of wild catch fish production (*Wild Catch Fish*). The summary statistics of these measures is provided in Table 1 Panel C and definition of these measures is reported in Appendix A.

## 4.3. Natural Capital Risk

The data on nature capital indicators comes from the World Bank Sovereign ESG database. The World Bank (Gratcheva, Emery, and Wang, 2021) has compiled data on the wealth of

[7]We use data on over-fishing for the biodiversity loss rather than direct measures such as biodiversity index or percentage of endangered species because there would be less variation in these variables at the country-level and also because, these measures mainly captures the historical concerns and not the future concerns of biodiversity loss. On using these variables, there is a possibility of undervaluing the risk.

[8]https://www.worldwildlife.org/our-work/oceans/sustainable-seafood/wild-caught-seafood/overfishing/

141 nations, divided into three major categories: human capital (discounted lifetime earnings), produced capital (e.g., machinery, buildings, urban land), and natural capital (e.g., forests, cropland, protected areas, subsoil assets). Natural capital, or natural wealth, is further divided into renewable and non-renewable resources. The term "renewables" refers to natural capital that can produce benefits in perpetuity under sustainable management. The ESG database provides time-series data on 71 environmental and social indicators across 17 groups; however, we focus only on indicators related to natural capital endowment and management. The database provides five indicators for natural capital risk: natural forest depletion rate (% of GNI), natural resources depletion rate (% of GNI), freshwater withdrawal (in %), Forest cover loss, Forest area (% of total land), and Terrestrial and marine protected area. We didn't include forest cover loss and forest area (% of total land) in the bond pricing analysis, as these variables are similar proxies to the natural forest depletion rate (% of GNI).

## 4.4. Control Variables

For regression analysis, we control for the bond characteristics such as maturity, coupon, option embeddedness, and whether the bond is fixed income or floating. Maturity is the number of years between the issue year and the year of maturity. Options is an indicator variable that takes the value 1 if the bond has options embedded, otherwise 0. Fixed is an indicator variable that takes the value 1 if the bond is straight (fixed-income), otherwise 0. Amount Issued is a logarithm of the amount issued by the sovereign issuing the green bond. In addition to controlling for bond characteristics, we also control for other determinants of sovereign credit risk, such as the Debt to GDP ratio, the natural logarithm of GDP, and terms of trade.

## 4.5. Green Intentions and Green Efforts of Sovereigns

Before issuing a green bond, the issuer establishes a general framework to identify which areas are eligible for sustainable finance and which projects qualify for funding. For instance, in 2020, Chile published a framework that included support for victims of human rights violations, as well as access to education and healthcare. In the same year, Mexico issued a bond to finance projects aligned with the UN Sustainable Development Goals (SDGs), covering areas such as education, agricultural development, healthcare, and sustainable infrastructure. Once a project receives approval from an external evaluator, funds are disbursed, and the project is monitored with periodic reporting.

We manually collected 118 impact reports, 115 capital allocation reports, 103 external review reports by auditors, 85 ESG framework reports, 39 prospectuses, and 19 term sheets for these bonds and linked them to each bond level. As there can be multiple impact reports, allocation reports, and external review reports, it is crucial to link these reports at the bond level to understand the time series of development of green projects. For instance, Belgium issued a green bond in 2019, which has one framework report, one capital allocation report, three impact reports, and one external review report. Here we have briefly discussed the types of reports and their contents.

**ESG Framework Report:** A green bond framework is a document created by the issuer that clearly articulates the company's proposed use of proceeds for the bond. The framework should include information on the eligible categories (as per the Green Bond Principles) under which the projects being financed or refinanced fit. This disclosure enables investors to better assess the green eligibility of the projects and make more informed investment decisions.[9] For instance, Belgium's framework report of 2019 green bond suggests that the sovereign has decided to invest in five green project categories - *Energy Efficiency, Clean Transportation,*

[9]https://www.sustainalytics.com/esg-research/resource/corporate-esg-blog/about-green-bond-principles

*Renewable Energy, Circular Economy,* and *Living Resources and Land Use.* These projects would be managed by the Belgian Debt Agency, ensuring that the allocation of proceeds will not allow for the listing of the same budget allocation twice. The report also mentions that the sovereign would provide allocation and impact reports for this bond, and the green project categories would be verified by a third party.

**Second Opinion Report (SPO):** Issuers obtain a SPO on their green bond framework from an external reviewer, such as Climate Bond Initiative (CBI) or its approved agencies, to confirm its alignment with the components of the Green Bond Principles. This step adds credibility to the issuer's proposal to issue a green bond. For instance, Belgium uses the services of Sustainalytics for the green bond issued in 2019 for the second opinion on green project categories.

**Capital Allocation Report:** This report provides information on the allocation of bond proceeds, in dollar terms, on green projects and their distribution across the countries. For instance, Belgium allocates the green bond proceeds on tax exemption green investment, tax deduction and exemption on clean transportation, and reduced package charge for individual reusable drink packages.

**Impact Report:** This report provides information on impact parameters and their values for green projects. Belgium measured the impact of the green projects using parameters such as avoided carbon emissions and reduced use of materials – soda, lime, and sand for drink packages.

We utilized the methodology for large language models (LLMs) as outlined by Aswani (2025) to extract information from various reports. This allowed us to gather data on green project categories, the number of green projects, capital allocation to these projects, and the overall impact of the reports. We measure "*Green Intentions*" as the green projects' categories within the ESG framework report. These categories reflect the government's intentions regarding green initiatives in specific areas. Additionally, we quantify "*Green*

*Efforts*" as the number of green projects initiated per dollar amount of proceeds, as detailed in the impact and capital allocation reports.

# 5. Empirical Specification

To investigate whether sovereign green credit risk (proxied as green bond yield) is associated with biodiversity loss and natural capital depletion, we begin by using a simple specification,

$$Yield_i = \alpha + \beta\, BiodiversityLoss_i\,(or\, NaturalCapitalDepletion_i) + \gamma\, X_i + \delta\, Z_i + \epsilon_i \quad (1)$$

*Yield* is the sovereign green bond's offer yield to maturity. *Biodiversity Loss* is a vector of agriculture and fishery as % of GDP, logarithm of total fish production, and logarithm of wild catch fish production. *Natural Capital Depletion* is a vector of natural resources depletion (in %), natural forests depletion (in %), and freshwater withdrawal (in %). X is a vector of bond characteristics such as maturity, option embeddedness, fixed/floating coupon, and amount issued. Z is a vector of macroeconomic variables, including the debt-to-GDP ratio, terms of trade, and the natural logarithm of GDP. We test this specification using primary-market yield and monthly secondary-market yield. $\epsilon$ is the error term with a normal distribution.

The green bond disclosures, such as impact reports, capital allocation reports, and second-opinion reports, are provided after the bond issuance and continue till maturity. There is a possibility that the availability of the new information from these reports can influence the relation between yield and biodiversity loss & natural capital risk. Therefore, we investigate Eq. (1) for the secondary market as well, controlling for the illiquidity measure.

$$Yield_{i,t} = \alpha + \beta\, BiodiversityLoss_{i,t}\,(or\, NaturalCapitalDepletion_{i,t}) + \lambda\, Illiquidity_{i,t} + \gamma\, X_i + \delta\, Z_{i,t} + \epsilon_{i,t} \tag{2}$$

Here, illiquidity risk is measured as,

$$Illiquidity = |BidYield - AskYield| \tag{3}$$

We further examine whether the sovereign's green intentions to mitigate these risks affect bond pricing. To test that, we use the following specification,

$$Yield_i = \omega_1 + \omega_2\, GreenIntentions_i(or\, Green_Efforts_i) + \omega_3\, X_i + \omega_4\, Z_i + \nu_i \tag{4}$$

*Green Intentions* is a vector of two indicator variables – Biodiversity and Natural Resources. Biodiversity indicator variable takes the value 1 if the bond's ESG framework report mentions starting a green project to conserve biodiversity; otherwise, 0. Similarly, the Natural Resources indicator variable takes the value 1 if the ESG framework report mentions starting a green project to preserve natural resources; otherwise, it takes the value 0. $\nu$ is the error term with a normal distribution. "*Green Efforts*" is the number of green projects initiated per dollar amount of proceeds as detailed in the impact and capital allocation reports.

We also test whether a sovereign's green intentions impact the yield, especially when the sovereign has these risks.

$$Yield_i = \phi_1 + \phi_2\, GreenIntentions_i(or\, Green_Efforts_i) * BiodiversityLoss_i\,(or\, NaturalCapitalDepletion_i) + \phi_3\, X_i + \phi_4\, Z_i + \lambda_i \tag{5}$$

The coefficient of interest in all the regressions is $\phi_2$. The interaction term assesses whether green intentions (green efforts) improve external financing for sovereigns, particu-

larly those facing these risks.

Finally, we assess the environmental performance of sovereign green bond issuers by examining whether their interim targets or net-zero commitments contribute to a reduction in carbon intensity (carbon emissions per capita) over a three-year period compared to other issuers. We use the following specification to conduct this analysis,

$$\Delta CarbonIntensity_i = \eta_1 + \eta_2 Net - Zero_Commitment_i + \eta_3 X_i + \eta_4 Z_i + \mu_i \quad (6)$$

Here, carbon intensity is carbon emissions per capita.[10] $\Delta$ is difference between third year from issuance and the year of issuance. Commitment is a vector of indicator variables – Interim Target and Net Zero Target. Interim Target takes value 1 if the sovereign has the interim target (year) of reducing the emissions; otherwise, 0. Net Zero Target takes value 1 if the sovereign has the net-zero target (year); otherwise, 0.

## 5. Natural Assets and Sovereign Green Bonds : Resolving the endogeneity Issues using Global Supply Chain Shocks

As relation between sovereign bond yield and biodiversity & natural capital risks are endogenous due to self-selection bias, we mitigate these concerns using two separate shocks - one for biodiversity loss and one for natural capital risk. For the former, we use Peru Anchovian Crises 2023, and for the latter, we use the European Union Deforestation Regulation (EUDR).

***Peru Anchovian Crises 2023 :*** Peru is not just a regional fishing power - it is the backbone of the global fishmeal and fish oil supply chain. In June 2023, Peru's Ministry of

[10]We use carbon intensity and not level emissions because Aswani, Raghunandan, and Rajgopal (2024a, 2024b) justified that scaled carbon emissions are preferred by the investors over the level of emissions. Although choosing the carbon intensity three years from issuance is random, our results are robust to this choice.

Production (PRODUCE) canceled the country's first anchovy fishing season in the north-central zone — the world's largest anchovy fishery by volume. A second season was eventually authorized in late October with a total allowable catch (TAC) of 1.68 million metric tons, well below the 2.28 million MT set for the same season in 2022. The cancellation of the first fishing season resulted in an estimated USD 1.4 billion in lost revenue from fishmeal and fish oil exports. Peru's national GDP was expected to fall between 0.3 and 0.4 percent as a direct result.

The crisis led to thousands of layoffs and affected more than 250,000 families and 3,500 small- and medium-sized enterprises that depend on industrial fishing. This crises highlighted the global food chain fragility as the heavy reliance on a single species from a single country for fisheries exposed it to systemic risk. We use this crises as a shock to our biodiversity risk constructs and conduct a difference-in-difference regressions using the indicator variable (*Anchoveta*) which takes value 1 for year 2023 and after, otherwise 0.

***European Union Deforestation Regulation (EUDR) :*** As the exogenous shock to natural capital risk, we use EUDR. The EU Deforestation Regulation (EUDR) is a landmark piece of EU legislation aimed at ensuring that certain commodities and products sold in or exported from the EU have not contributed to deforestation or forest degradation worldwide. The regulation covers 7 key commodities- cattle, coffee, cocoa, palm oil, soy, wood, rubber, and their derived products. The companies placing these products on the EU market must ensure that products must not have been produced on land deforested after 31 December 2020, products are in compliance with the laws of the country of origin, and the companies must submit a due diligence statement with geo-referencing data, risk assessments, and mitigation measures. There are also penalties for non-compliance such as fines of at least 4% of annual EU turnover, confiscation of products and revenues, temporary exclusion from public procurement, prohibition from placing products on the market.

The EUDR has significant implications beyond Europe — it affects producer countries in

Latin America, Southeast Asia, and Africa, pushing them to adopt stronger forest governance and traceability systems to maintain access to the EU market. In essence, the EUDR is a major step toward making EU supply chains deforestation-free, shifting the burden of proof onto companies to demonstrate their products don't contribute to forest loss.

The timeline of EUDR is as follows:

• 2021 — The European Commission published a proposal for the regulation in November 2021, which kicked off the legislative process.

• 2023 — The regulation was formally adopted and entered into force on 29 June 2023, after being published in the Official Journal of the EU.

• 2020 — This year is significant within the regulation itself, as the cut-off date: products must not come from land deforested after 31 December 2020.

We use the EUDR as an exogenous shock to the natural capital risk constructs and conduct a difference-in-difference regressions using the indicator variable ($EUDR$) which takes value 1 for year 2021 and after, otherwise 0. We empirically test our hypothesis using the following specification.

$$Yield_i = \alpha + \beta_1 BiodiversityLoss_i + \beta_2 Anchoveta(EUDR) + \beta_3 Anchoveta(EUDR)X \\ BiodiversityLoss_i (or\, NaturalCapitalDepletion_i) + \gamma X_i + \delta Z_i + \epsilon_i \tag{7}$$

Furthermore, we also explore the possibility of Achovian crises (EUDR) impact on the association between bond pricing and green intentions. We test it by interacting the green intention variables in eq(3) by *Anchoveta (EUDR)* indicator variable.

$$Yield_i = \phi_1 + \phi_2 GreenIntentions_i + \phi_3 Anchoveta(EUDR) + \phi_4 Anchoveta(EUDR)X \\ GreenIntentions_i + \phi_5 X_i + \phi_6 Z_i + \lambda_i \tag{8}$$

The results for these tests are in Table 8.

## 6. Sustainable Forestry Projects and Deforestation

The deforestration is the result of market failure as the prices of forest-related products are undervalued ignoring its economic cost. Addressing the deforestation is equally crucial as the climate change considering the fact that world has lost 30 % of forest area on habitable land in last 10,000 years and 50% of it in last 100 years. According to UN Food and Agriculture Organization's (FAO) assessment, the 10 million hectares of land is cut down every year. [11] The deforestration directly impacts the timber, paper, construction, furniture, tourism, and related industries but its indirect consequences impacts every business as it releases carbon emissions in the atmosphere contributing towards climate change, increase extreme weather events, sea-level rise, and reduced agricultural productivity. The sustainable forestry is a solution to the loss in forest coverage and can provide economic benefits while protecting forests. The Sustainable forestry practices include selective logging, reforestation, and forest conservation. These practices help to maintain forest health, protect biodiversity, and provide a sustainable supply of forest products. [12]

From the 151 sovereign green bonds issued, excluding zero coupon bonds, 59 (40 %) green bonds proceeds are used for sustainable forestry projects. These projects are initiated by Canada, Brazil, China, Hungary, India, Indonesia, Nigeria, and Chile (see, Figure 4 for details). It is not surprising that the sustainable forestry projects are initiated at Europe, South America, Asia, Africa, and in Canada as these continents (or countries) have the greatest share of forest area, and therefore, the forest depletion or deforestation affects these areas more than others. To examine whether initiating the sustainable forestry projects help these sovereigns, we investigate the changes in forest area percentage of habitable land and the loss of forest cover (in hectares) in the sovereigns which used green bond proceeds for

[11] https://ourworldindata.org/deforestation

[12] https://climate.sustainability-directory.com/question/what-are-the-economic-impacts-of-deforestation/

these projects compare to sovereigns which used the bond proceeds for other projects.

$$ForestArea\,(ForestCoverLoss)_{i,t} = \alpha_i + \beta_{i,t}\, SustainableForestryCountry_i \\ (Post - GreenBondIssunace_{i,t}) + \gamma_c + \gamma_y + \epsilon_{i,t} \tag{9}$$

Here, *Sustainable Forestry Country* is an indicator variable which takes value 1 if the country has issued at least one green bond to support the projects related to sustainable forestry and 0 for countries which issued green bonds for other projects. *Post-Green Bond Issuance* is the indicator variable which takes the value 1 for years post green bond issuance supporting sustainable forestry projects; otherwise 0. Results for these tests are in Table 10.

# 6. Results and Discussion

Figure 1 illustrates the yearly and country-level distribution of sovereign green bond issuances. There is a sharp increase in issuances starting in 2018, especially of fixed and floating types. Reaching a peak in 2022-2023, with over 50 sovereign green bonds issued. Most of these bonds have been issued by countries in Europe, the Asia-Pacific, Canada, and Central America. Notably, Hong Kong (China), Canada, India, Chile, Hungary, and Indonesia have issued a considerable number of these bonds.

Figure 2 shows the credit rating of these bonds. In the sample, 63 % are rated; among these, 40 are rated AA, 12 are rated BBB, 8 are rated BBB-, and 3 are rated differently. Figure 3 shows the variation in biodiversity loss and natural capital risk with economic growth (proxied as the logarithm of gross domestic product (GDP)). Two hypotheses exist on the relationship between GDP and biodiversity/natural capital risk. The first hypothesis suggests that GDP is high for high biodiversity /natural capital risk, because countries grow using these resources. This leads to an increase in biodiversity / natural capital risk with GDP. The second hypothesis proposes that GDP is high in countries with low biodiversity

loss and natural capital risk because they have access to capital to conserve (or preserve) biodiversity (natural resources). Graphs in Figure 3 support the first hypothesis, as the logarithm of wild catch fish production (Figure 3(a)) and forest cover (Figure 3(b)) have increased linearly with the logarithm of GDP.

Table 1 reports the characteristics and summary statistics of these bonds. Table 1 Panel A reports the distribution based on coupon type. Of the 216 sovereign green bonds, 151 are fixed (or floating) bonds, and 65 are stripped (or zero-coupon bonds). Panel B reports the distribution of green certifications for these bonds. Roughly 98% are green-certified by the Climate Bond Initiative (CBI) or its approved agencies. Panel C provides the distribution on maturity of these bonds. About 96% of these bonds expire on maturity, and only 3-4% are option embedded and can be called before maturity. The maturity of these bonds ranges from 1 to 50 years, but most mature in 2, 3, 5, 7, 10, and 30 years. Panel D reports the summary statistics of the bond characteristics. The average yield and amount issued of these bonds are 4.3% and 3.1 billion USD. The average coupon for these bonds is 3.4%. Other bond characteristics include indicator variables for option embeddedness, green certification, and for a straight (or fixed income) bond.

Table 2 presents the summary statistics for biodiversity loss and natural capital risk measures. The average percentage of agriculture, forestry, and fisheries in GDP among these sovereign nations is 6.713%, with a maximum of 28.345%. The average values for the logarithm of total fish production and wild catch fish production are 14.676 and 13.576, respectively. On average, the depletion rate of natural resources in these countries is 1.2%, with some countries experiencing a maximum depletion rate of 14% due to extensive resource extraction. For the countries issuing green bonds, the average forest area represents 31% of total land area, while the maximum recorded is 68%. The average depletion of natural forests accounts for 4.2% of Gross National Income (GNI). Another key measure of natural capital risk is total annual water withdrawal as a percentage of internal resources. The average water

withdrawal is 1.77%, with some countries reaching a maximum of 77.5%. These variables provide diverse estimates of biodiversity and natural capital risk.

Table 3 presents information about green reporting and disclosures by the sovereign green bond issuers. During the bond issuance process, the issuer provides a framework outlining the green project categories, which are based on the Green Bond Principles developed by the International Capital Market Association (ICMA). While we have access to information on green project categories for all the bonds from database, we managed to collect framework reports for 85 of these bonds. The allocation of proceeds to green projects is detailed in capital allocation reports. In some cases, the capital allocation report and the impact report are issued together. We have obtained 113 capital allocation reports related to these bonds. Some sovereign issuers have released multiple capital allocation reports from the date of issuance to maturity to update stakeholders on the management of proceeds. To share the progress of the green projects with the investors, the sovereign provides impact outcomes in impact reports. These outcomes include metrics such as carbon emissions avoided, kilowatt-hours (KWH) of energy generated using renewable resources, green infrastructure developments, and the number of buses or trains operating on renewables as part of smart transportation projects. We have collected 118 impact reports for these 85 bonds. Additionally, we gathered 39 prospectuses and 19 term sheets, which, while not directly useful for our analysis, assist in verifying information such as bond characteristics from term sheets against Bloomberg data or matching mentions of green projects in the framework with those in the prospectuses.

Panel B shows the green project categories in the ESG framework reports. It also reflects the sovereign's intentions to begin green projects in these categories to mitigate risks in these areas. Although renewable energy, energy efficiency, and smart transportation projects are common among the green bond issuers, the ESG frameworks of sovereign issuers suggest that 77% and 54% of these projects would be related to biodiversity conservation and preservation

of natural resources. The investment in green projects in these categories is much higher for sovereigns than for corporates, which supports the notion that public goods such as biodiversity conservation and natural resources preservation rely on the support from public organizations such as sovereigns and municipalities (local government).

Table 4 Panel A presents the regression results of offer yield to maturity on the biodiversity risk measures for the primary bond market. Columns (1) to (3) show results without any controls, while Columns (4) to (6) show results incorporating bond-level controls. Columns (7) to (9) results include bond-level controls along with error clustering at the country and year level. Our findings indicate that the yield increased by 40 - 50 basis points due to the biodiversity risk (proxies by measures of over-fishing) and these results are statistically significant. We confirm these results across all three specifications.

Panel B of the table reports the results of the primary market yield concerning natural capital measures. For this analysis, we focused on three specific measures of natural capital risk: natural forest depletion (as a percentage of total area), natural resources depletion (as a percentage of GNI), and freshwater withdrawal (as a percentage of internal resources). We found that the yield is positively associated with all three natural capital risk measures, and these results are consistent across all three specifications. Economically, our findings suggest that a 1% increase in natural resource depletion results in an increase of 98 basis points in the offer yield to maturity, while a 1% increase in the natural forest depletion rate raises the offer yield by 32 basis points. Similar results we found for fresh water withdrawl (in %). The negative response from debt holders to both biodiversity loss and natural capital risk measures indicates that investors are concerned about the risks to natural assets which is closely tied to country's economic growth.

Table 5 Panel A reports the regression results of secondary market yield on biodiversity loss and natural capital risk measures. We have 3,681 monthly yield values for 127 bonds from 2016-2024. Like regression for primary market yield, our specification for this test

includes the bond level controls and error clustering at the country level and year level. We found that biodiversity loss and natural capital risk are positively associated with yield. For instance, the 1 % increase in logarithm of wild catch fish production increases the yield by 21.9 basis points and 1 % increase in natural forest depletion increases the yield by 40 basis points. We found the similar results for other variables. These results are in line with primary market results and support the theoretical predictions of Stiglitz (1974), Dasgupta and Heal (1974), Dasgupta and Heal (1974) and others on exhaustible natural assets. Stiglitz (1974) concluded that stocks of natural assets are complementary to capital markets and instability in the natural assets market would impact capital markets.

In Panel A, the bond yield is unadjusted to the liquidity risk. However, as past literature has showed that illiquidity explains 30-40% of bond yield, it is crucial to adjust yield to liquidity risk. We adjust the yield to illiquidity risk controlling for other bond characteristics and country and year level error clustering. To better understand the impact of biodiversity loss and natural capital risk on sovereign green bond yield , we rerun the eq (1) controlling for illiquidity (*Illiquidity*) measure. The results are in Table 5 Panel B and Panel C. Similar to Panel A results, we find that the biodiversity loss and natural capital risk factors increase the liquidity-adjusted yield. We find that biodiversity risk factors affects the liquidity-adjusted yield by 15-17 basis point. The natural resources depletion and natural forest depletion affect the liquidity-adjusted yield by 43 basis point and 78 basis point. These results are statistically significant. Table 5 Panel B shows the results of biodiversity loss and Panel C shows the results of natural capital risk. Overall, the Table 4 and Table 5 results suggest that risk to natural assets has an impact on the sovereign green bond yield in the primary as well as in the secondary market.

Table 6 reports the regression results of yield on the sovereign's green intentions to initiate a biodiversity or natural resources management projects. Sovereigns share this information with investors at the issuance of green bonds, using the ESG framework. As discussed in

Section 3, the ESG framework includes details on green project categories in which sovereigns have decided to use the proceeds. We use this information from the framework report to generate two indicator variables. Biodiversity is an indicator variable that takes value 1 if the framework reports the biodiversity as a green project category; otherwise, it takes the value 0. Similarly, Natural Resources is the indicator variable, which takes the value 1 if the framework report has natural resources management as the green project category; otherwise, it takes the value 0. Table 6 indicates that sovereign intentions to initiate green projects, including those focused on biodiversity, have no significant impact on bond yields. Testing for the effect of intentions to address natural capital risks also shows no impact on green bond yields, even in countries with these risks. This suggests that investors care less about the intentions of green bond issuers reported in framework reports. Consequently, it is essential to assess whether the impact outcomes of these projects are reflected in bond pricing in the secondary market, as information about capital allocation, project development, and impact achievements becomes available post-issuance.

Table 7 presents the results concerning the impact of bond issuers' green initiatives on secondary market yields. The green initiatives (green efforts) are quantified by the number of green projects funded for each dollar raised. This approach benefits investors, as diversifying green projects reduces risk compared to investing all proceeds into a single project. The regression analysis indicates that green efforts are negatively correlated with bond yields. The increase in green efforts lowers bond yields. Nevertheless, the results are prominent when these efforts align with efforts to mitigate risks to natural assets.

To address endogeneity, we use Peru Achovian Crises 2023 as a shock to biodiversity loss, and EUDR as a shock to natural capital risk. We examine whether these shocks altered the relationship between sovereign green bonds yield and biodiversity & natural capital risks. Results are reported in Table 8 Panel A and Table 8 Panel B. We find a reduction in yield after these shocks, compared to before, for biodiversity loss and natural capital risks. These

results contrast with those of Garel et al. (2024), which showed that investors demand a 2.2% premium for corporate biodiversity risk after the convention. We hypothesized that bond yields would decline because these shocks highlighted the biodiversity loss and natural capital risk and investors knew that regulators would intervene after these shocks to mitigate these risks. We also investigate whether green intentions matter for the bond yield after these shocks, we don't find any robust results for that. These results are in Table 8 Panel C.

So far, we have investigated the impact of biodiversity & natural capital risks on sovereign green bond pricing and compared it with conventional bonds. Nevertheless, it is also essential to check whether the issuance of green debt improves the environmental performance of these sovereigns. Table 9 illustrates the impact of green bond issuances on carbon intensity, measured as carbon emissions per capita, for issuers with net zero commitments versus those without. Table 9 Panel A outlines the types of commitments made by green bond issuers regarding carbon emission reduction. Notably, 44% of these bonds are issued by entities with net-zero targets, primarily aimed at 2050, although some have targeted 2040 or 2070. These issuers also establish interim targets for emission reductions, focusing on years such as 2025 or 2030. Panel B presents the regression results concerning the relationship between carbon intensity and the commitments made by green bond issuers. Our findings suggest that setting both interim and net-zero targets does not significantly reduce the carbon intensity of these issuers compared to their counterparts.

Since carbon intensity may not be a concern for all sovereigns, we focus on their environmental performance based on the projects funded by their green bonds. Approximately 40% of 151 green bonds, or 59 bonds, are used for sustainable forestry projects. Therefore, we examine the percentage of forest area in habitable land and the loss of forest cover (in hectares) in these sovereigns and compare them with other green bond issuers. Table 10 shows the results for these measures. We find that green bond issuers who invested in sustainable forestry projects have 2.5% more forest area and a high forest cover loss of 159

million hectares compared to those who invested in other projects. To gain deeper insights, we analyze these parameters both before and after green bond issuances for the sovereigns that invested in sustainable forestry. After issuing green bonds and investing in sustainable forestry, these sovereigns experienced a 0.2% increase in forest area and a reduction of 68.4 million hectares in forest cover loss.

Lastly, we conducted an external validity test of sovereigns' green intentions using the Sustainable Development Goals (SDGs) they have adopted. Since green bond issuers have also adopted SDGs, and two of these are related to biodiversity and natural capital risks, this provides a setting to verify the results in Table 6. SDG 14, "Life below Water," supports biodiversity by promoting the conservation and sustainable use of oceans, seas, and marine resources for sustainable development, protecting and restoring marine ecosystems, ending harmful fisheries subsidies, reducing marine pollution, and conserving coastal areas, among other goals. Similarly, SDG 15, "Life on Land," promotes natural capital by advocating for the end of desertification, the conservation and restoration of forests, wetlands, mountains, and drylands, reducing habitat loss, and restoring degraded land, among other objectives. There are 67 green bonds related to SDG 14 and 119 related to SDG 15. We examine whether adopting these SDGs influences bond pricing in the primary and secondary markets. The results are presented in Table 11. We find no effect of these SDGs on sovereign green bond yields, neither in the primary nor in the secondary market. These findings also confirm our results in Table 6, which suggest that green intentions are insufficient to influence the pricing of sovereign green bonds.

# 7. Additional Tests

## 7.1. Geopolitical Risk

There is a possibility that positive association between green bond yield and risk to natural assets exists because of missing variable, such as geopolitical risk, in our empirical specification. Thus, this positive association reflects geopolitical risk and not the biodiversity & natural capital. To mitigate such concerns, we include geopolitical risk index as a control variable in our main specification and reconduct the analysis. Geopolitical risk index is based on Caldara and Iacoviello (2022). Even controlling for this measure of geopolitical risk, we found the same results that yield is positively associated with biodiversity loss and natural capital risk.

## 7.2. Transition Risk due to Climate Change

Similar to geopolitical risk, another possibility is that positive relation between yield and biodiversity loss & natural capital risk is due to missing transition risk measure in the regression specification. To alleviate such issues, we rerun the main regression controlling for transition risk measure. The transition risk measure is adaptive capacity of sovereigns' to tackle climate change. It is one of the components of Notre Dame Global Adaptation Initiative's (ND-GAIN) Country Index. We found the same results even controlling for this measure which confirms our main results are not influenced by the exclusion of transition risk in the regression specification.

## 7.3. Green Bonds vs. Conventional Bonds

As the risk to natural assets can affect conventional bond yields differently from green bond yields, we examine the effect of these risks on the yield differential. Results are in Table

12. We use the nearest-neighbour algorithm to match green bond data with conventional bonds issued by the same issuer and with the same issuance year, coupon type, maturity years, amount issued, and coupon rate. We matched 150 green bonds with 184 conventional bonds based on these criteria. Our findings indicate that green bonds more explicitly account for the risks associated with natural assets compared to conventional bonds. This may be because green securities are specifically designed to mitigate such risks, unlike their conventional counterparts.

# 8. Conclusion

Our paper explores whether public debt pricing is influenced by risk to natural assets such as biodiversity and natural capital, a crucial issue highlighted by Giglio et al. (2026) and Flammer et al. (2025). We specifically focus on sovereign green bonds because the responsibility for providing public goods, such as biodiversity conservation and natural capital preservation, rests primarily with governments rather than corporations. Assessing how these environmental risks influence sovereign bond yields is therefore essential to determine whether international investors price such risks into sovereign debt. Moreover, because the sovereign green bonds are specifically designed to finance projects that mitigate environmental externalities, analyzing their pricing dynamics and environmental implications can reveal whether investors genuinely account for these risk factors and whether countries effectively address them. Analysis of sovereign green bonds issued between 2016 and 2024 reveals that bond yields are affected by both biodiversity loss proxied as overfishing measures and natural capital risk proxied as natural resource depletion, forest depletion, and freshwater withdrawal. A 1% increase in risk to natural assets is associated with a 21 to 40 basis-point rise in bond yield. These findings are robust even when compared with conventional bonds issued by the same issuer in the same year and possessing similar characteristics.

Compared to corporate green bonds, 70% of these bonds are associated with projects

related to biodiversity conservation and natural resource management. Our investigation assesses whether biodiversity loss and natural capital risk affect bond pricing and whether sovereign's green intentions' and 'green efforts' impact this relationship. Using the large language models (LLMs), the 'Green Intentions' are estimated from ESG framework reports, which detail the types of green projects the sovereign intends to develop. 'Green Efforts' are measured through capital allocation and impact reports and proxied as number of green projects implemented per dollar amount of the bond proceeds. By manually linking each report to the bond level, we track the timing of capital allocation and impact reports from issuance to maturity. Using this novel data, we found that mere intentions do not significantly influence investor behavior towards these risks and that the green efforts by the sovereigns are recognized by the investors if the efforts are aligned with mitigating biodiversity loss and natural capital risk.

Regarding the environmental performance of issuers, we find that green bond-issuing sovereigns with interim and net-zero targets do not have lower carbon emissions per capita compared to others, even after a three-year span. Since carbon intensity may not be a concern for all issuers, we focus on their environmental performance based on the projects funded by their green bonds. As 40% of sovereign green bonds are used for sustainable forestry projects, we examine the percentage of forest area in habitable land and the loss of forest cover (in hectares) in these sovereigns and compare them with other green bond issuers. We discovered a 0.2% increase in forest area and a reduction of 68.4 million hectares in forest cover loss following the issuance of green bonds and investment in sustainable forestry.

Overall, our work shows that investors price the risk to natural assets—both biodiversity loss and natural capital depletion into sovereign green bond yields. This finding aligns with classic theoretical papers on exhaustible resources, which suggest that natural resources are crucial for a country's economic growth. Although green projects can be implemented to mitigate these risks, we discovered that merely expressing intentions to initiate such projects

is insufficient to persuade investors. The efforts to implement these green projects must align with the perceived risks in order to influence investors' risk preferences effectively. Despite commitments to net-zero emissions, the improvement in environmental performance among these sovereigns issuing green bonds is not significant. As carbon intensity may not be a concern for all sovereigns, we focus on their environmental performance based on the sustainable forestry projects funded by their green bonds. We find the increase in forest area and reduction in loss of forest cover following these investments. These findings are robust to battery of checks.

# References


Aswani, Jitendra. "Debt Markets Retort to Mandatory Corporate Social Responsibility." Working Paper (2024).

Aswani, Jitendra, Aneesh Raghunandan, and Shiva Rajgopal. "Are Carbon Emissions Associated with Stock Returns?." Review of Finance 28, no. 1 (2024): 75-106.

Aswani, Jitendra, Aneesh Raghunandan, and Shiva Rajgopal. "Are Carbon Emissions Associated with Stock Returns?—Reply." Review of Finance 28, no. 1 (2024): 111-115.

Aswani, Jitendra, and Shivaram Rajgopal. "Rethinking the value and emission implications of green bonds." Management Science (2025).

Aswani, Jitendra, and Roberto Rigobon. "Investment and Governance: Through the Lens of Sustainability." Working Paper (2025).

Bolton, Patrick, and Marcin Kacperczyk. "Do investors care about carbon risk?." Journal of financial economics 142, no. 2 (2021): 517-549.

Caldara, Dario, and Matteo Iacoviello. "Measuring geopolitical risk." American economic review 112, no. 4 (2022): 1194-1225. Cantor, Richard, and Frank Packer. "Determinants and impact of sovereign credit ratings." Economic Policy Review 2, no. 2 (1996).

Dasgupta, Partha. The Economics of Biodiversity: The Dasgupta Review. Hm Treasury, 2021.

Dasgupta, Partha S., and Geoffrey M. Heal. Economic theory and exhaustible resources. Cambridge University Press, 1979.

Dimson, Elroy, Marcin Kacperczyk, and Laura Starks. "Biodiversity and Natural Resource Finance." Review of Finance 30, no. 1 (2026): 1-9.

Dobson, Andrew P., Stuart L. Pimm, Lee Hannah, Les Kaufman, Jorge A. Ahumada, Amy W. Ando, Aaron Bernstein et al. "Ecology and economics for pandemic prevention." Science 369, no. 6502 (2020): 379-381.

Doshi, Hitesh, Kris Jacobs, and Virgilio Zurita. "Economic and financial determinants of credit risk premiums in the sovereign CDS market." The Review of Asset Pricing Studies 7, no. 1 (2017): 43-80.

Duffie, Darrell, Lasse Heje Pedersen, and Kenneth J. Singleton. "Modeling Sovereign Yield Spreads: A Case Study of Russian Debt." The Journal of Finance 58, no. 1 (2003): 119-159.

Flammer, Caroline. "Corporate Green Bonds." Journal of Financial Economics 142, no. 2 (2021): 499-516.

Flammer, Caroline, Thomas Giroux, and Geoffrey M. Heal. "Biodiversity finance." Journal of Financial Economics 164 (2025): 103987.

Garel, Alexandre, Arthur Romec, Zacharias Sautner, and Alexander F. Wagner. "Do investors care about biodiversity?." Review of Finance 28, no. 4 (2024): 1151-1186.

Giglio, Stefano, Theresa Kuchler, Johannes Stroebel, and Xuran Zeng. "Biodiversity Risk." *Review of Finance* 30, no. 1 (2026): 131–161.
Giglio, Stefano, Theresa Kuchler, Johannes Stroebel, and Olivier Wang. "Nature and Biodiversity Loss: A Research Agenda for Financial Economics." NBER Working Paper No. 34286 (2025).

Hilscher, Jens, and Yves Nosbusch. "Determinants of Sovereign Risk." Department of Economics, Harvard University, mimeo (2004).

Hong, Harrison, G. Andrew Karolyi, and José A. Scheinkman. "Climate Finance." The Review of Financial Studies 33, no. 3 (2020): 1011-1023.

Hotelling, Harold. "The Economics of Exhaustible Resources." Journal of Political Economy 39, no. 2 (1931): 137-175.

Kamin, Steven B., and Karsten Von Kleist. "The Evolution and Determinants of Emerging Market Credit Spreads in the 1990s." Working Paper (1999).

Kapnick, Sarah, "The Economic Importance of Biodiversity: Threats and Opportunities," Working Paper (2022).

Karolyi, G. Andrew, and John Tobin-de la Puente. "Biodiversity Finance: A Call for Research into Financing Nature." Financial Management 52, no. 2 (2023): 231-251.

Krautkraemer, Jeffrey A. "Optimal growth, resource amenities and the preservation of natural environments." The Review of Economic Studies 52, no. 1 (1985): 153-169.

Larcker, David F., and Edward M. Watts. "Where's the Greenium?." Journal of Accounting and Economics 69, no. 2-3 (2020): 101312.

Longstaff, Francis A., Jun Pan, Lasse H. Pedersen, and Kenneth J. Singleton. "How sovereign is sovereign credit risk?." American Economic Journal: Macroeconomics 3, no. 2 (2011): 75-103.

Nakhmurina, Anya, Dale T. Manning, and Eli P. Fenichel. "The Fiscal Impact of Biodiversity Loss and a Pathway for Conservation Finance", Science 391, no 6790 (2026): 1110-1113

Painter, Marcus. "An inconvenient cost: The effects of climate change on municipal bonds." Journal of Financial Economics 135, no. 2 (2020): 468-482.

Pan, Jun, and Kenneth J. Singleton. "Default and Recovery Implicit in the Term Structure of Sovereign CDS Spreads." The Journal of Finance 63, no. 5 (2008): 2345-2384.

Pinzon, Alexandra, Nick Robins, M. McLuckie, and G. Thoumi. "The sovereign transition

to sustainability: Understanding the dependence of sovereign debt on nature." London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, and Planet Tracker (2020). Solow, R. M. "Intergenerational

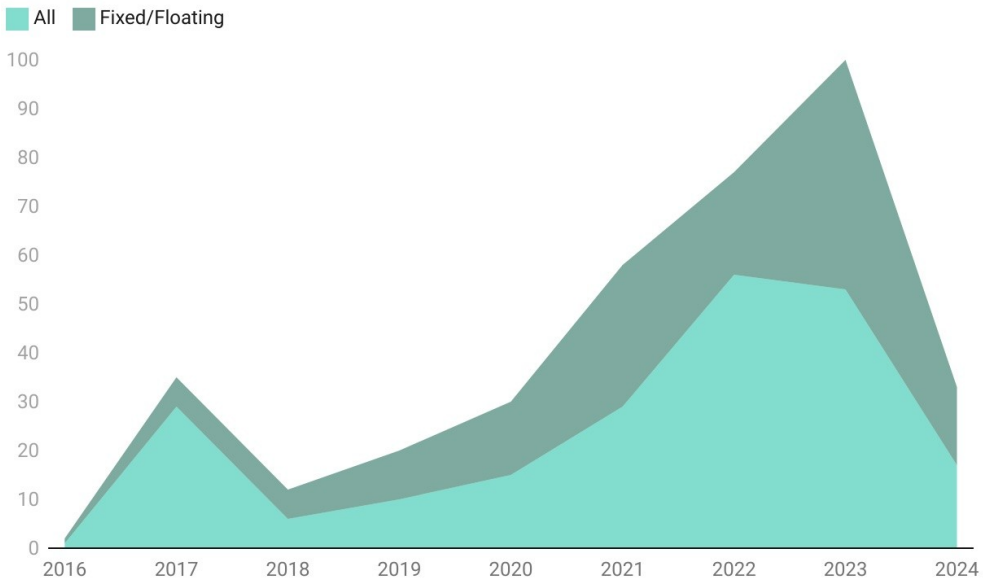
Equity and Exhaustible Resources." The Review of Economic Studies 41, no. 5 (1974): 29-45.

Stiglitz, Joseph E. "Growth with Exhaustible Natural Resources: the Competitive Economy." The Review of Economic Studies 41, no. 5 (1974): 139-152.

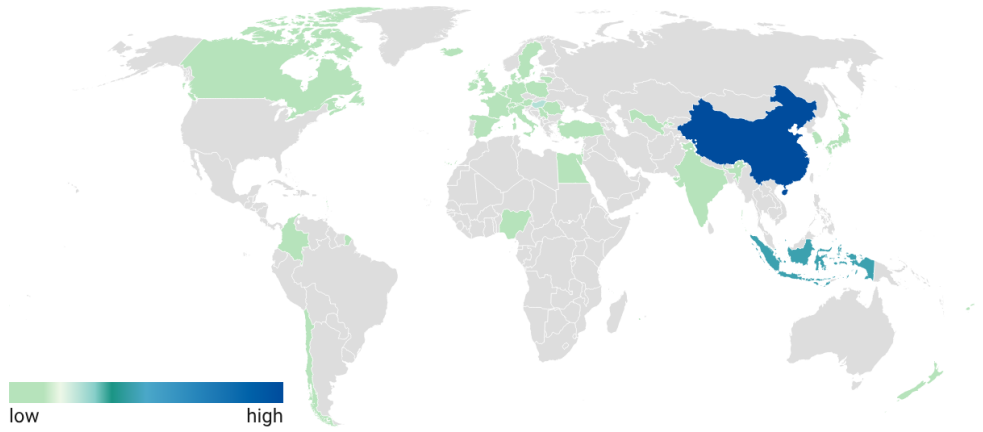
Stroebel, Johannes, and Jeffrey Wurgler. "What do you think about Climate Finance?." Journal of Financial Economics 142, no. 2 (2021): 487-498. Tollefson, Jeff. "Why De-

forestation and Extinctions make Pandemics more likely." Nature 584, no. 7820 (2020): 175-177.

Weiskopf, Sarah R., Forest Isbell, Maria Isabel Arce-Plata, Moreno Di Marco, Mike Harfoot, Justin Johnson, Susannah B. Lerman et al. "Biodiversity loss reduces global terrestrial carbon storage." Nature Communications 15, no. 1 (2024): 4354.




a) Yearly Distribution of Sovereign Green Bonds




b) Country-level Distribution of Sovereign Green Bonds

**Figure 1**: **Yearly and Country Level Distribution**. Figure 1 a shows the yearly distribution of all sovereign green bonds as well as for fixed (of floating) coupon type. Figure 1 b shows the country level distribution of sovereign green bonds.

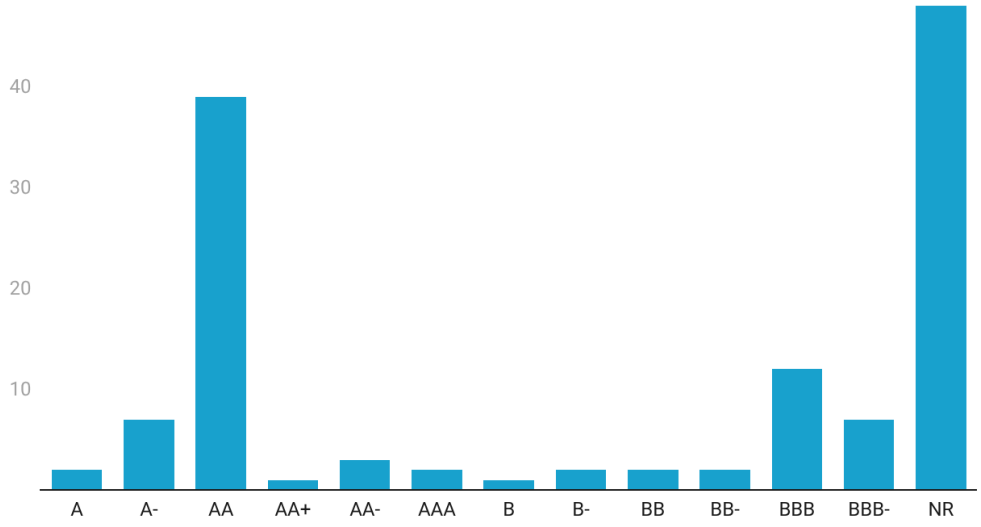
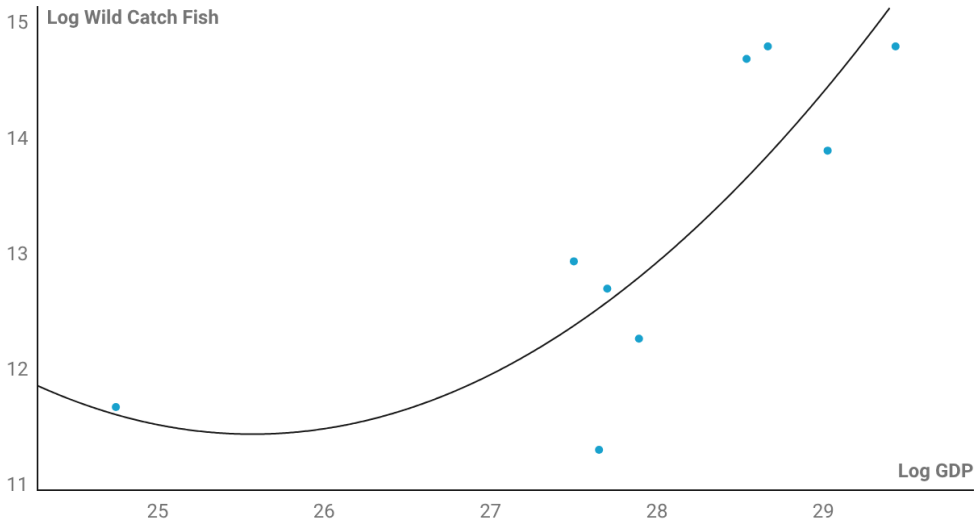
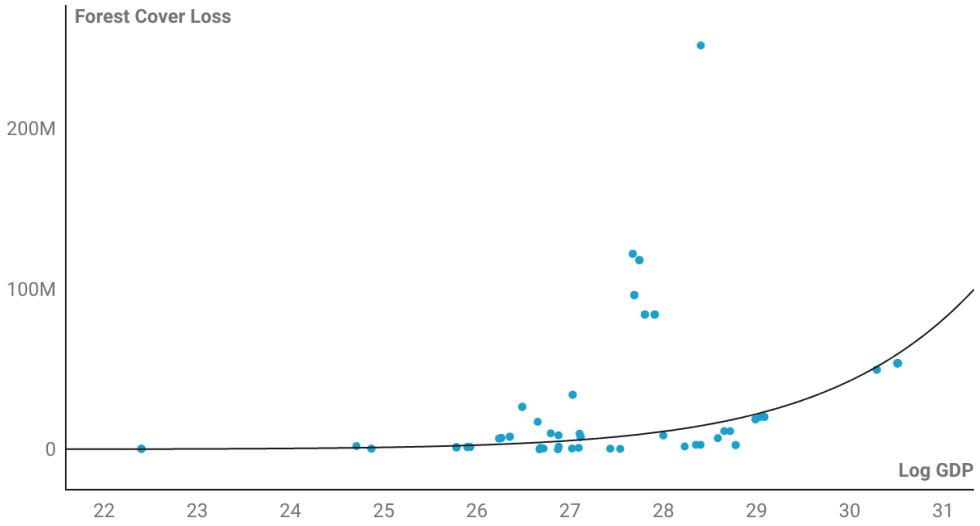



**Figure 2: Credit Ratings of Sovereign Green Bonds.** This figure shows the distribution of credit ratings of sovereign green bonds. 37 % green bonds are not rated, and among the rated bonds, 30% are rated AA.




a) Log GDP vs Biodiversity Risk




b) Log GDP vs Natural Capital Risk

**Figure 3: Biodiversity and Natural Capital Risk versus Gross Domestic Product (GDP)**. This figure compares the biodiversity risk and natural capital risk with the natural logarithm of GDP. Biodiversity Risk is measured as natural logarithm of wild catch fish production. Natural Capital Risk is measured as forest cover loss (as % of territorial area).

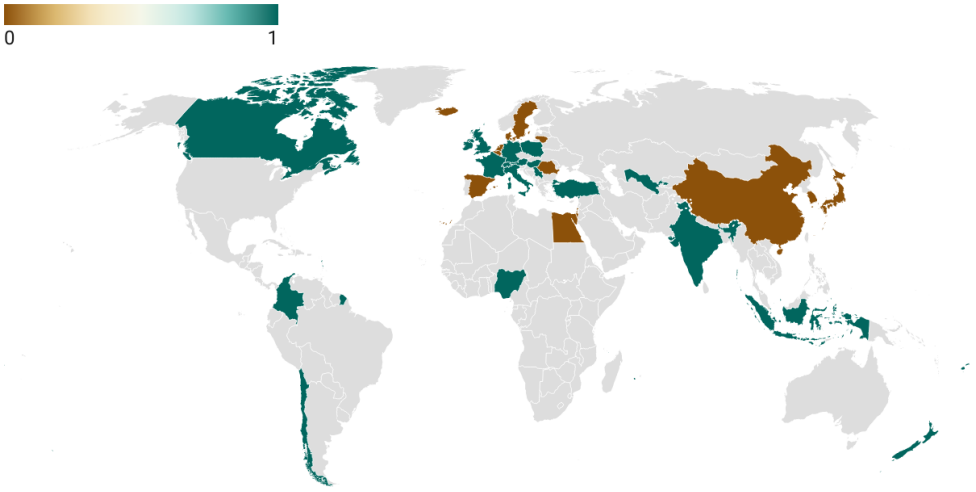



**Figure 4**: **Sustainable Forestry using Sovereign Green Bonds**. This figure shows the countries which use the green bond proceeds for sustainable forestry projects compare to countries which use the green bond proceeds for other projects.

**Table 1**
**Sovereign Green Bond Characteristics**

**Panel A**: Coupon-Type

| Coupon Type | Frequency | Percentage |
|---|---|---|
| Fixed/Floating | 151 | 69.91 |
| Zero Coupon | 65 | 30.09 |
| Total | 216 | 100 |

**Panel B:** Green Certification

| Certified | Freq. | Percent | Cum. |
|---|---|---|---|
| N | 2 | 1.32 | 1.32 |
| Y | 149 | 98.68 | 100 |
| Total | 151 | 100 | |

**Panel C:** Bond Maturity

| Maturity Type | Frequency | Percent |
|---|---|---|
| Maturity | 146 | 96.69 |
| Callable | 5 | 3.31 |
| Total | 151 | 100 |

**Panel D:** Summary Statistics

| Variable | Mean | Std. Dev. | Max |
|---|---|---|---|
| Yield | 4.373 | 2.645 | 18.138 |
| Amount Issued (million USD) | 3,151 | 6,125 | 37,861 |
| Coupon | 3.437 | 2.817 | 16.25 |
| Fixed | 0.947 | 0.225 | 1 |
| Certified | 0.987 | 0.115 | 1 |
| Option | 0.033 | 0.180 | 1 |

***Notes.*** **Sovereign Green Bond Characteristics.** This table provides the bond characteristics of sovereign green bonds. Panel A shows the distribution of coupon types. As green reports are available only for fixed/floating coupon type bonds and not for zero coupon (or strip) bonds, the paper focuses on the former. Panel B provides the distribution of green certification. Panel C provides distribution based on maturity type. Panel D provides summary statistics. Yield is offering yield to maturity (%). Amount Issued is in million USD. Coupon is in percentage. Fixed equals 1 if fixed income, 0 for floating. Certified equals 1 if certified by CBI or affiliated agencies. Option equals 1 if option embedded. Details in Appendix A.

**Table 2**
**Biodiversity and Natural Capital Risk Indicators**

| **Biodiversity Risk** | | | |
|---|---|---|---|
| Indicator | Mean | Standard Deviation | Maximum |
| Agriculture and Fisheries Per GDP | 6.713 | 5.118 | 28.345 |
| Total Fish Production | 14.676 | 3.226 | 18.334 |
| Wild Catch Fish Production | 13.576 | 2.940 | 16.467 |

| **Natural Capital Risk** | | | |
|---|---|---|---|
| Indicator | Mean | Standard Deviation | Maximum |
| Natural resources depletion (% of GNI) | 1.216 | 1.83 | 14 |
| Net forest depletion (% of GNI) | 4.2 | 19.7 | 1 |
| Annual freshwater withdrawals, total (% of internal resources) | 1.33 | 8.957 | 77.5 |

***Notes.*** **Biodiversity and Natural Capital Risk Indicators**. This table provides the summary statistics of biodiversity and natural capital risk measures. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, annual fresh water withdrawals as percentage of internal resources. Further details on variable definition are provided in Appendix A.

**Table 3**
**Sovereign Green Projects: Disclosure and Category**

Panel A: Distribution of Disclosures on Sovereign Green Bonds

| Index | Type of Report | # Numbers |
|---|---|---|
| 1 | Impact Reports | 118 |
| 2 | Allocation reports | 115 |
| 3 | External Review | 103 |
| 4 | ESG Framework | 85 |
| 5 | Prospectus | 39 |
| 6 | Term Sheet | 19 |

Panel B: Sovereign Green Project Category

| Green Project Category | # Numbers | Percentage |
|---|---|---|
| Biodiversity | 116 | 77 |
| Natural Resources and Management | 82 | 54 |
| Energy Efficiency | 136 | 90 |
| Pollution Prevention and Control | 92 | 61 |
| Climate Change Adaptation | 109 | 72 |
| Circular Economy | 89 | 59 |
| Renewable Energy | 144 | 95 |
| Green Buildings | 95 | 63 |
| Clean Transportation | 146 | 97 |
| Sustainable Water Management | 113 | 75 |

***Notes.*** **Sovereign Green Projects: Disclosure and Category**. Panel A shows the distribution of reports provided by the sovereigns' issuing green bonds. In the green reports, sovereign issues ESG framework, allocation reports, impact reports, prospectuses, external review, and term sheets. The ESG framework provides a description of the green categories and the project's intended purpose. Second Opinion Report (SPO) provided by the auditor to verify whether those projects are aligned with green bond principles (developed by ICMA). Impact report provides details on the impact of these projects measured as carbon emissions avoided, electricity generation using renewable sources, and similar measures. Allocation reports provide the details on capital allocation for the green projects using the bond proceeds. The Term Sheet provides the final contractual terms related to the bond. These reports are hand-collected and used to develop a structured database on green projects using Artifical Intelligence (AI) model as suggested in Aswani (2024). This database is matched at the bond level. Panel B shows the distribution of green project categories provided in the ESG Framework as per green bond guidelines suggested by ICMA.

## Table 4
## Is Sovereign Sustainable Bond Pricing Associated with Biodiversity and Nature Capital Loss?

**Panel A**: *Primary Market Bond Yield and Biodiversity Loss*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield | (7) Yield | (8) Yield | (9) Yield |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture and Fisheries Per GDP | 0.435*** | | | 0.435*** | | | 0.509*** | | |
| | (0.035) | | | (0.092) | | | (0.118) | | |
| Total Fish Production | | 0.596*** | | | 0.596*** | | | 0.501** | |
| | | (0.152) | | | (0.131) | | | (0.204) | |
| Wild Catch Fish Production | | | 0.459*** | | | 0.459** | | | 0.400* |
| | | | (0.144) | | | (0.148) | | | (0.185) |
| Observations | 126 | 116 | 116 | 126 | 116 | 116 | 126 | 116 | 116 |
| R-squared | 0.562 | 0.128 | 0.091 | 0.562 | 0.128 | 0.091 | 0.601 | 0.144 | 0.134 |
| Bond Level Controls | No | No | No | No | No | No | Yes | Yes | Yes |
| Error Clustering | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |

**Panel B**: *Primary Market Bond Yield and Natural Capital Depletion*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield | (7) Yield | (8) Yield | (9) Yield |
|---|---|---|---|---|---|---|---|---|---|
| Natural Resources Depletion (in %) | 1.001*** | | | 1.001*** | | | 0.987*** | | |
| | (0.085) | | | (0.096) | | | (0.095) | | |
| Natural Forests Depletion (in %) | | 0.320** | | | 0.320*** | | | 0.321*** | |
| | | (0.140) | | | (0.036) | | | (0.037) | |
| Fresh Water Withdrawal (in %) | | | 0.064*** | | | 0.064*** | | | 0.061*** |
| | | | (0.024) | | | (0.008) | | | (0.008) |
| Observations | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 |
| R-squared | 0.523 | 0.04 | 0.054 | 0.523 | 0.04 | 0.054 | 0.53 | 0.102 | 0.111 |
| Bond Level Controls | No | No | No | No | No | No | Yes | Yes | Yes |
| Error Clustering | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Sovereign Bond Pricing and Biodiversity/Natural Capital Risk**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk in the primary market. Panel A shows the regression of bond yield on biodiversity risk measures. Panel B shows the regression of bond yield on natural capital risk measures. In Panel A, Columns (1) – (3) show the regression results without controlling for bond level controls and without error clustering at the country level. Columns (4) – (6) show the results with country-level error clustering but without controlling for bond-level controls. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. In Panel B, Columns (1) – (3) show the regression results without controlling for bond level controls and without error clustering at the country level. Columns (4) – (6) show the results with country-level error clustering but without controlling for bond-level controls. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

**Table 5**
**Secondary Market of Sovereign Sustainable Bond and Biodiversity & Natural Capital Risk**

**Panel A**: *Liquidity Un-adjusted Bond Yield and Biodiversity & Natural Capital Risk*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Agriculture and Fisheries Per GDP | 0.417** | | | | | |
| | (0.135) | | | | | |
| Total Fish Production | | 0.326* | | | | |
| | | (0.145) | | | | |
| Wild Catch Fish Production | | | 0.219* | | | |
| | | | (0.110) | | | |
| Natural Resources Depletion (in %) | | | | 1.303** | | |
| | | | | (0.500) | | |
| Natural Forests Depletion (in %) | | | | | 0.404*** | |
| | | | | | (0.088) | |
| Fresh Water Withdrawal (in %) | | | | | | 0.070*** |
| | | | | | | (0.020) |
| Observations | 3,655 | 3,648 | 3,648 | 3,681 | 3,681 | 3,681 |
| R-squared | 0.347 | 0.088 | 0.075 | 0.087 | 0.066 | 0.065 |
| Bond Level Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes |

**Panel B:** *Liquidity Adjusted Bond Yield (LAY) and Biodiversity Risk*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Illiquidity | 12.344 | 17.240* | 17.433** | 17.885** | 18.470** | 17.511* |
| | (7.878) | (7.267) | (7.017) | (6.053) | (7.097) | (7.657) |
| Agriculture and Fisheries Per GDP | 0.185** | | | 0.170* | | |
| | (0.072) | | | (0.079) | | |
| Total Fish Production | | 0.179* | | | 0.197** | |
| | | (0.079) | | | (0.078) | |
| Wild Catch Fish Production | | | 0.140 | | | 0.150* |
| | | | (0.083) | | | (0.074) |
| Observations | 1,874 | 1,863 | 1,863 | 1,874 | 1,863 | 1,863 |
| R-squared | 0.239 | 0.183 | 0.145 | 0.287 | 0.204 | 0.163 |
| Bond Level Controls | No | No | No | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes |

**Panel C:** *Liquidity Adjusted Bond Yield (LAY) and Natural Capital Risk*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Illiquidty | 14.268* | 16.092* | 15.550** | 19.643** | 14.708 | 14.594 |
| | (7.390) | (6.890) | (5.944) | (6.060) | (8.849) | (8.146) |
| Natural Resources Depletion (%) | 0.575** | | | 0.432** | | |
| | (0.231) | | | (0.173) | | |
| Natural Forest Depletion (%) | | 0.668 | | | 0.787* | |
| | | (0.461) | | | (0.413) | |
| Fresh Water Withdrawl (%) | | | 0.012 | | | 0.011 |
| | | | (0.007) | | | (0.007) |
| Observations | 1,890 | 1,890 | 1,890 | 1,890 | 1,890 | 1,890 |
| R-squared | 0.178 | 0.107 | 0.131 | 0.258 | 0.124 | 0.143 |
| Bond Level Controls | No | No | No | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Secondary Market of Sovereign Sustainable Bond and Biodiversity & Natural Capital Risk** This table shows the regression results of the association between secondary market bond yield and biodiversity & natural capital risks. Panel A reports the results of illiquidity un-adjusted yield on biodiversity & natural capital risks. Panel B reports the results of illiquidity adjusted yield on biodiversity risk factors. Panel C reports the results of illiquidity adjusted yield on natural capital risk factors. Illiquidity adjusted yield ($LAY$) is residual from panel regression of bond yield on illiquidity risk. The illiquidity risk is measured as the absolute value of bid yield minus ask yield ($|BidYield - AskYield|$). Yield is the monthly offer yield to maturity, measured in percentage. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, annual freshwater withdrawals as percentage of internal resources. All regressions have bond-level controls and country-level error clustering. Bond level controls comprise - logarithm of amount issued, indicator variable for whether the bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** shows the statistical significance at 10 %, 5 %, and 1% level.

**Table 6**
**Sovereign's Green Intentions and Bond Pricing**

**Panel A:** *Bond Pricing and Sovereign Green Intention to Mitigate Biodiversity and Natural Capital Risk*

| | Primary Market | | | | Secondary Market | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) |
| VARIABLES | Yield | Yield | Yield | Yield | Yield | Yield | Yield | Yield |
| Biodiversity | -0.399 | | -0.720 | | -1.802 | | -2.929 | |
| | (0.875) | | (0.902) | | (2.659) | | (3.371) | |
| Natural Resources | | 0.813 | | 1.032 | | 0.485 | | 0.994 |
| | | (0.689) | | (0.788) | | (1.304) | | (1.706) |
| Observations | 130 | 130 | 130 | 130 | 3,690 | 3,690 | 3,690 | 3,690 |
| R-squared | 0.0036 | 0.0238 | 0.0705 | 0.0971 | 0.009 | 0.001 | 0.079 | 0.06 |
| Bond Level Controls | No | No | Yes | Yes | No | No | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

**Panel B:** *Biodiversity Risk, Green Intentions, and Primary Market Bond Pricing*

| | (1) | (2) | (3) |
|---|---|---|---|
| VARIABLES | Yield | Yield | Yield |
| Biodiversity | 0.517 | 1.181 | -1.136 |
| | (0.522) | (3.275) | (3.776) |
| Agriculture and Fisheries Per GDP | 0.540*** | | |
| | (0.119) | | |
| Biodiversity x Fisheries Per GDP | -0.043 | | |
| | (0.121) | | |
| Total Fish Production | | 0.571 | |
| | | (0.300) | |
| Biodiversity x Total Fish | | -0.087 | |
| | | (0.202) | |
| Wild Catch Fish Production | | | 0.324 |
| | | | (0.250) |
| Biodiversity x Wild Catch Fish | | | 0.080 |
| | | | (0.251) |
| Observations | 126 | 116 | 116 |
| R-squared | 0.604 | 0.145 | 0.134 |
| Bond Level Controls | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes |

**Panel C:** *Natural Capital Risk, Green Intentions, and Secondary Market Bond Pricing*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield |
|---|---|---|---|
| Natural Resources | 0.448 | 1.386 | 2.258 |
| | (1.555) | (1.602) | (2.685) |
| Natural Resources Depletion (in %) | 1.05 | | |
| | (1.575) | | |
| Resources Depletion x Natural Resources | 0.248 | | |
| | (1.412) | | |
| Natural Forest Depletion (in %) | | 0.469*** | |
| | | (0.044) | |
| Forest Depletion x Natural Resources | | 0.103 | |
| | | (1.153) | |
| Fresh Water Withdrawal (in %) | | | 0.078*** |
| | | | (0.009) |
| Water Withdrawal x Natural Resources | | | -0.033 |
| | | | (0.054) |
| Observations | 3,681 | 3,681 | 3,681 |
| R-squared | 0.089 | 0.072 | 0.079 |
| Bond Level Controls | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes |

***Notes.*** **Green Intentions and Sovereign Bond Pricing.** This table provides the regression results of bond yield on sovereign's green intentions related to biodiversity and natural capital risk. Panel A shows the regression results of sovereign yield on green intentions measured as a vector of indicator variables- *Biodiversity* and *Natural Resources*. *Biodiversity* is an indicator variable which takes value 1 if the sovereign's green project is related to biodiversity; otherwise, 0. *Natural Resources* is an indicator variable which takes value 1 if the sovereign's green project is related to risk to natural resources management; otherwise, 0. ESG framework report by green bond issuing sovereign provides the intentions to allocate the capital in the green projects aligned with green bond principles. Yield is monthly offer yield to maturity, measured in percentage. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual freshwater withdrawals as percentage of internal resources. All regressions have bond level controls and country-level error clustering. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** shows the statistical significance at 10 %, 5 %, and 1% level.

**Table 7**
**Green Efforts, Green Intentions, and Sovereign Bond Yield**

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield |
|---|---|---|---|---|---|
| Number of Green Projects (per USD) | -0.004* | -0.012*** | -0.015*** | 0.087 | -0.023*** |
| | (0.002) | (0.003) | (0.004) | (0.068) | (0.006) |
| Biodiversity | | | | 0.711 | |
| | | | | (0.700) | |
| Biodiversity X Number of Green Projects | | | | -0.100 | |
| | | | | (0.066) | |
| Natural Resources | | | | | -0.214 |
| | | | | | (0.549) |
| Natural Resources X Number of Green Projects | | | | | 0.010* |
| | | | | | (0.006) |
| Observations | 63 | 63 | 63 | 63 | 63 |
| R-squared | 0.040 | 0.200 | 0.373 | 0.400 | 0.404 |
| Bond Controls | No | Yes | Yes | Yes | Yes |
| Country-level Controls | No | No | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Green Efforts, Green Intentions, and Sovereign Bond Pricing.** This table provides the regression results of bond yield on sovereign's green efforts related to biodiversity and natural capital risk. Columns (1) - (3) reports the regression results of yield on green efforts (*Green Efforts*) with and without bond-level and country-level controls. Columns (4) - (5) report the results of yield on the interaction of green intentions and green efforts. *Green Efforts* is measured as number of green projects developed by the sovereign using the sustainable debt proceeds i.e., number of green projects per USD of proceeds amount. The green intentions is measured as a vector indicator variables - *Biodiversity* and *Natural Resources*. Biodiversity is an indicator variable which takes value 1 if the sovereign's green project is related to biodiversity; otherwise, 0. Natural resources is an indicator variable which takes value 1 if the sovereign's green project is related to risk to natural resources management; otherwise, 0. All regressions have bond level controls and country-level error clustering. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** shows the statistical significance at 10 %, 5 %, and 1% level.

## Table 8
## Natural Assets and Sovereign Green Bonds: Resolving the endogeneity Issues

**Panel A:** *Anchovian Crises, Sovereign Green Bond Yield, and Biodiversity Risk*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield |
|---|---|---|---|
| Anchoveta | 0.287 | 7.700** | 8.900*** |
| | (0.372) | (2.248) | (2.239) |
| Agriculture and Fisheries Per GDP | 0.511*** | | |
| | (0.118) | | |
| Anchoveta x Fisheries Per GDP | -0.004 | | |
| | (0.012) | | |
| Total Fish Production | | 0.564** | |
| | | (0.169) | |
| Anchoveta x Total Fish | | -0.477** | |
| | | (0.155) | |
| Wild Catch Fish Production | | | 0.510*** |
| | | | (0.124) |
| Anchoveta x Wild Catch Fish | | | -0.603** |
| | | | (0.167) |
| Observations | 126 | 116 | 116 |
| R-squared | 0.603 | 0.202 | 0.212 |
| Bond Controls | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes |

**Panel B:** *European Deforestration Regulation (EUDR), Sovereign Green Bond Yield, and Natural Capital Risk*

| VARIABLES | Yield | Yield | Yield |
|---|---|---|---|
| EUDR | 0.087 | 0.066 | -1.208 |
| | (0.269) | (0.578) | (0.675) |
| Natural Resources Depletion (in %) | 1.863*** | | |
| | (0.209) | | |
| EUDR x Natural Resources Depletion (in %) | -0.913*** | | |
| | (0.199) | | |
| Natural Forest Depletion(in %) | | 0.311*** | |
| | | (0.038) | |
| EUDR x Natural Forest Depletion (in %) | | -0.037 | |
| | | (0.409) | |
| Fresh Water Withdrawl | | | 0.001*** |
| | | | (0.000) |
| EUDR x Fresh Water Withdrawl | | | 0.028** |
| | | | (0.009) |
| Observations | 127 | 127 | 127 |
| R-squared | 0.563 | 0.111 | 0.328 |
| Bond Controls | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes |

**Panel B:** *Anchovian Crises, EUDR, Green Intentions, and Sovereign Green Bond Yield*

| VARIABLES | (1) Yield | (2) Yield |
|---|---|---|
| Anchoveta | -1.644 | |
| | (1.395) | |
| Biodiversity | -1.118 | |
| | (1.505) | |
| Anchoveta x Biodiversity | 2.035 | |
| | (1.418) | |
| EUDR | | -2.278 |
| | | (1.331) |
| Natural Resources | | -1.352 |
| | | (1.013) |
| EUDR x Natural Resources | | 3.020* |
| | | (1.308) |
| Observations | 130 | 130 |
| R-squared | 0.100 | 0.132 |
| Bond Controls | Yes | Yes |
| Error Clustering | Yes | Yes |

***Notes.*** **Natural Assets and Sovereign Green Bonds: Resolving the endogeneity Issues**. This table reports the regression results of sovereign bond yield on biodiversity & natural capital risks resolving the endogeneity issues using the Peruvian Achovian Crises 2023 and European Deforestration Regulation (EUDR). Panel A compares the regression results of bond yield on biodiversity risks post Peruvian Achovian Crises 2023. The coefficient of interaction term of each biodiversity risk dimension with Peruvian Achovian Crises 2023 (*Anchoveta*) is of interest. *Anchoveta* is indicator variable which takes value 1 if the bond is issued post 2022; otherwise 0. *Biodiversity Risk* is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Panel B compares the regression results of bond yield on natural capital risks post EUDR. The *EUDR* is indicator variable which takes value 1 if the bond is issued in year 2021 or after; otherwise 0. *Natural Capital Risk* is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual freshwater withdrawals as percentage of internal resources. Panel C compares the regression results of yield on green intentions post Peruvian Achovian Crises 2023 and European Deforestration Regulation (EUDR). The green intentions is measured as a vector indicator variables - *Biodiversity* and *Natural Resources*. Biodiversity is an indicator variable which takes value 1 if the sovereign's green project is related to biodiversity; otherwise, 0. Natural resources is an indicator variable which takes value 1 if the sovereign's green project is related to risk to natural resources management; otherwise, 0. Bond controls comprise bond maturity, amount issued, indicator variable for fixed coupon, and indicator variable for option embeddedness. Country controls comprise natural logarithm of GDP and Debt to GDP ratio. The specification also includes clustering the error at country level. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

**Table 9**
**Environmental Performance of Sovereign Green Bond Issuers**

**Panel A:** *Distribution of Carbon Commitments*

| Carbon Commitments of Green Bond Issuers | | | |
|---|---|---|---|
| Commitments | Number of Bonds | Percent | Cumulative |
| Carbon neutral(ity) | 59 | 39.07 | 39.07 |
| Climate neutral | 13 | 8.61 | 47.68 |
| Emissions intensity target | 2 | 1.32 | 49.01 |
| Emissions reduction target | 8 | 5.3 | 54.3 |
| Net zero | 67 | 44.37 | 98.68 |
| Other | 2 | 1.32 | 100 |
| Total | 151 | 100 | |

**Panel B:** *Carbon Intensity of Green Bond Issuers: Are Net-Zero Committers Doing Better?*

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | ΔCarbon Intensity | ΔCarbon Intensity | ΔCarbon Intensity | ΔCarbon Intensity |
| Interim Target | -0.092 | -0.07 | | |
| | (0.207) | (0.152) | | |
| Net Zero Target | | | -0.174 | -0.104 |
| | | | (0.223) | (0.166) |
| Constant | 0.278 | -1.939** | 0.509 | -1.841** |
| | (0.264) | (0.848) | (0.389) | (0.863) |
| Observations | 23 | 23 | 23 | 23 |
| R-squared | 0.284 | 0.658 | 0.3 | 0.662 |
| Bond Controls | Yes | Yes | Yes | Yes |
| Country Controls | No | Yes | No | Yes |

***Notes.*** **Environmental Performance of Sovereign Green Bond Issuers**. This table shows the regression results of environment performance of green bond issuing sovereigns. Panel A reports the distribution of carbon emissions related commitments of green bond issuers. Panel B reports the regression results of change in carbon emissions intensity on interim target and net zero target indicator variables. Δ is difference between third year from issuance and the year of issuance. Interim Target is an indicator variable which takes value 1 if the sovereign has the interim target year for reducing emissions; otherwise, 0. Net Zero Target is an indicator variable which takes value 1 if the sovereign has the net zero target year for reducing emissions; otherwise, 0. Bond controls comprise bond maturity, amount issued, indicator variable for fixed coupon, and indicator variable for option embeddedness. Country controls comprise natural logarithm of GDP and Debt to GDP ratio. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

## Table 10
## Sustainable Forestry and Sovereign Green Bond Issuance

**Panel A:** *Sustainable Forestry Projects by Sovereign Green Bond Issuers*

| Sustainable Forestry | Freq. | Percent | Cum. |
|---|---|---|---|
| 0 | 92 | 60.93 | 60.93 |
| 1 | 59 | 39.07 | 100 |
| Total | 151 | 100 | |

**Panel B:** *Need of Sustainable Forestry for Sovereign Green Bond Issuers*

| | Country Comparison | | Pre and Post Green Bond Issuance | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| VARIABLES | Forest Area (%) | Forest Cover Loss | Forest Area (%) | Forest Cover Loss | Forest Area (%) | Forest Cover Loss |
| Sustainable Forestry Country | 2.551** | 159,156.029** | | | | |
| | (0.047) | (7,173.653) | | | | |
| Post-Green Bond Issuance | | | 6.920*** | -17,261.821 | 0.209* | -68,358.027*** |
| | | | (2.145) | (46,255.929) | (0.114) | (20,550.373) |
| Observations | 544 | 544 | 320 | 320 | 320 | 320 |
| R-squared | 0.005 | 0.031 | 0.020 | 0.000 | 0.997 | 0.944 |
| Country | No | No | No | No | Yes | Yes |
| Year | Yes | Yes | No | No | No | No |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Sustainable Forestry and Sovereign Green Bond Issuance**. Panel A shows the distribution of bonds targetting sustainable forestry projects using the proceeds amount. Panel B Columns (1) - (2) report the regression results of forest area percentage of land (Forest Area (%)) and forest cover loss in hectares (Forest Cover Loss) on countries which target sustainable forestry projects using the green bonds proceeds versus the countries which issued green bonds but did not target sustainable forestry projects. Panel B Columns (3) - (6) report the regression results of forest area percentage of land (Forest Area (%)) and forest cover loss in hectares (Forest Cover Loss) on post green bond issuances in countries which target sustainable forestry projects using the green bond proceeds. Columns (3) -(4) show results without country fixed effects and columns (5) -(6) show results with country fixed effects. *Sustainable Forestry Country* is an indicator variable which takes value 1 if the country has issued atleast one green bond to support the projects related to sustainable forestry and 0 for countries which issued green bonds for other projects. *Post-Green Bond Issuance* is the indicator variable which takes the value 1 for years post green bond issuance supporting sustainable forestry projects; otherwise 0. Empirical specification also includes error clustering at country level and year level. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

**Table 11**
**Sustainable Development Goals (SDGs) and Sovereign Green Bond Pricing: External Validity of Green Intentions**

**Panel A:** *Distribution of SDG 14 ("Life Below Water") and SDG 15 ("Life over Land")*

| SDG 14 | Freq. | Percent |
|---|---|---|
| 0 | 84 | 55.63 |
| 1 | 67 | 44.37 |
| Total | 151 | 100 |

| SDG 15 | Freq. | Percent |
|---|---|---|
| 0 | 32 | 21.19 |
| 1 | 119 | 78.81 |
| Total | 151 | 100 |

**Panel B:** *Impact of SDGs on Sovereign Green Bond Pricing*

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield |
|---|---|---|---|---|
| SDG_14 | 0.525 | | -0.227 | |
| | (0.662) | | (0.536) | |
| SDG_15 | | -0.911 | | -0.976 |
| | | (1.162) | | (1.257) |
| Observations | 3,690 | 3,690 | 130 | 130 |
| R-squared | 0.066 | 0.076 | 0.061 | 0.078 |
| Bond Controls | Yes | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes |

***Notes.*** **Sustainable Development Goals (SDGs) and Sovereign Green Bond Pricing**. Panel A shows the distribution of bonds based on "Life on Land" (sustainable development goal (SDG) 15) and "Life below Water" (sustainable development goal (SDG) 14). SDG 14 covers biodiversity issues and SDG 15 covers natural resources management issues. Adoption of these SDGs helps to test the impact of green intentions on bond pricing. Panel B reports the regression results of these SDGs on sovereign green bond pricing. Panel B Columns (1) - (2) reports the impact of these SDGs on secondary market yield and Columns (3) - (4) reports the impact of these SDGs on primary market yield. Bond controls comprise bond maturity, amount issued, indicator variable for fixed coupon, and indicator variable for option embeddedness. Empirical specification also includes error clustering at country level and year level. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

**Table 12**
**Green Bond vs. Conventional Bonds: Risk to Natural Assets and Public Debt**

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Green Bond | -1.049 | -4.745** | -4.611** | -1.072 | 0.016 | 0.088 |
| | (0.907) | (1.757) | (1.783) | (1.203) | (0.869) | (1.073) |
| Agriculture and Fishing Per GDP | -0.119 | | | | | |
| | (0.083) | | | | | |
| Green Bond x Fishing Per GDP | 0.155** | | | | | |
| | (0.051) | | | | | |
| Total Fish Production | | -0.386 | | | | |
| | | (0.269) | | | | |
| Green Bond x Total Fish Production | | 0.307*** | | | | |
| | | (0.080) | | | | |
| Wild Catch Fish | | | -0.299 | | | |
| | | | (0.206) | | | |
| Green Bond x Wild Catch Fish | | | 0.322** | | | |
| | | | (0.104) | | | |
| Natural Resources Depletion | | | | -0.989* | | |
| | | | | (0.503) | | |
| Green Bond x Natural Resources Depletion | | | | 0.977** | | |
| | | | | (0.332) | | |
| Natural Forest Depletion | | | | | 1.215*** | |
| | | | | | (0.239) | |
| Green Bond x Natural Forest Depletion | | | | | -1.004*** | |
| | | | | | (0.233) | |
| Fresh Water Withdrawl | | | | | | 0.436 |
| | | | | | | (1.081) |
| Green Bond x Fresh Water Withdrawl | | | | | | -0.402 |
| | | | | | | (1.083) |
| Observations | 204 | 178 | 178 | 221 | 221 | 221 |
| R-squared | 0.660 | 0.670 | 0.666 | 0.702 | 0.682 | 0.680 |
| Country Level Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Bond Level Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*****Natural Assets and Sovereign Green Bond Yield**. This table shows the regression results of the comparing the yield of green bond with conventional bond and natural capital risk. Green Bond is an indicator variable which takes value 1 if the bond is green bond; otherwise 0 for conventional bond.Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. All specification include bond level and country level controls. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

# Appendix A

| Index | Variable Name | Definition | Source |
|---|---|---|---|
| 1 | Annual freshwater withdrawals, total (% of internal resources) | Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100 percent of total renewable resources where extraction from nonrenewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals for agriculture and industry are total withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes. | World Bank |
| 2 | Adjusted savings: natural resources depletion (% of GNI) | Natural resource depletion is the sum of net forest depletion, energy depletion, and mineral depletion. Net forest depletion is unit resource rents times the excess of roundwood harvest over natural growth. Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas. Mineral depletion is the ratio of the value of the stock of mineral resources to the remaining reserve lifetime (capped at 25 years). It covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate. This indicator is expressed as a percentage of Gross National Income (GNI) which is the total income earned by all residents within an economic territory during an accounting period. | World Bank |
| 3 | Adjusted savings: net forest depletion (% of GNI) | Net forest depletion is calculated as the product of unit resource rents and the excess of roundwood harvest over natural growth. This indicator is expressed as a percentage of Gross National Income (GNI) which is the total income earned by all residents within an economic territory during an accounting period. | World Bank |
| 4 | Terrestrial and marine protected areas (% of total territorial area) | Terrestrial protected areas are totally or partially protected areas of at least 1,000 hectares that are designated by national authorities as scientific reserves with limited public access, national parks, natural monuments, nature reserves or wildlife sanctuaries, protected landscapes, and areas managed mainly for sustainable use. Marine protected areas are areas of intertidal or subtidal terrain–and overlying water and associated flora and fauna and historical and cultural features–that have been reserved by law or other effective means to protect part or all of the enclosed environment. Sites protected under local or provincial law are excluded. | World Bank |
| 5 | Agriculture and Fisheries per GDP | This indicator measures the contribution of agriculture, forestry, and fishing sectors to the economy as a percentage of GDP. | World Development Indicators |
| 6 | Total Fish Production | A natural logarithm of total fish production in metric tonnes (MT). | World Development Indicators |
| 7 | Wild Catch Fish Production | A natural logarithm of total wild catch fish production in metric tonnes (MT). | World Development Indicators |
| 8 | Yield | Bond yield, measured in %. | Bloomberg and LSEG |
| 9 | Coupon | Coupon of the issued bond. Measured in Percentage. | Bloomberg and LSEG |
| 10 | Amount Issued | Amount issued using the sovereign green bond. | Bloomberg and LSEG |
| 11 | Maturity | Difference of years between maturity date and issue date. | Bloomberg and LSEG |
| 12 | Biodiversity | Indicator variable which takes value 1 if the green-bond issuing sovereign intend to begin a biodiversity project using the bond proceeds; otherwise 0. | Green Bond Disclosures |
| 13 | Natural Resources | Indicator variable which takes value 1 if the green-bond issuing sovereign intend to begin a natural resources management project using the bond proceeds; otherwise 0. | Green Bond Disclosures |
| 14 | Illiquidity | Absolute value of bid yield minus ask yield. The yield is measured in percentage. | Bloomberg |
| 15 | Green Efforts | Number of green projects implemented per dollar value of proceeds. | Green Bond Disclosures and Bloomberg |
| 16 | Forest Area | Forest area as percentage of habitable land. | World Bank |
| 17 | Forest Cover Loss | The loss of forest cover in hectares. | World Bank |
| 18 | Gross Domestic Product (GDP) | The gross domestic product (GDP) of a country, measured in USD. | World Bank |
| 19 | Terms of Trade | The terms of trade of a country, measured in percentage. | World Bank |
| 20 | Debt to GDP Ratio | The ratio of debt to GDP of a country. | World Bank |
| 21 | Kunming | An indicator variable that takes the value 1 if a bond is issued after 19th December 2022; otherwise 0. | Bloomberg and LSEG |
| 22 | Interim Target | An indicator variable that takes the value 1 if a sovereign has an interim target (year) for carbon neutrality; otherwise, 0. | |
| 23 | Net Zero Target | An indicator variable that takes the value 1 if a sovereign has an net-zero target (year) for carbon neutrality; otherwise, 0. | |
| 24 | Sustainable Forestry Country | An indicator variable that takes the value 1 if a sovereign used green bond proceeds for a sustainable forestry project; otherwise, 0. | Green Bond Disclosures and Bloomberg |
| 25 | Post-Green Bond Issuance | An indicator variable that takes the value 1 if the year is the same or post-green bond issue year for the green bond issuing sovereigns who invested on sustainable forestry projects; otherwise, 0. | Green Bond Disclosures and Bloomberg |
| 26 | SDG_14 | An indicator variable that takes the value 1 if the green-bond issuing sovereign has adopted sustainable development goal (SDG) 14 i.e., "Life below Water" ; otherwise, 0. | Green Bond Disclosures |
| 27 | SDG_15 | An indicator variable that takes the value 1 if the green-bond issuing sovereign has adopted sustainable development goal (SDG) 15 i.e., "Life on Land" ; otherwise, 0. | Green Bond Disclosures |
| 28 | Green Bond | An indicator variable that takes the value 1 if the bond is green bond; otherwise 0 for conventional bond. | |

# Appendix B

## Table B1 - Natural Assets and Economic Growth

*Panel A: Biodiversity Loss and Economic Growth*

| VARIABLES | (1) GDP Growth | (2) GDP Growth | (3) GDP Growth | (4) GDP Growth | (5) GDP Growth | (6) GDP Growth |
|---|---|---|---|---|---|---|
| Agriculture and Fishery Per GDP | 0.046*** | 0.033* | | | | |
| | (0.011) | (0.017) | | | | |
| Total Fish Production | | | 0.083** | 0.102*** | | |
| | | | (0.034) | (0.034) | | |
| Wild Catch Fish | | | | | 0.060** | 0.063** |
| | | | | | (0.029) | (0.029) |
| Transition Risk | | 1.138 | | 2.822*** | | 2.735*** |
| | | (0.887) | | (0.538) | | (0.539) |
| Observations | 2,074 | 2,074 | 2,070 | 2,070 | 2,061 | 2,061 |
| R-squared | 0.198 | 0.199 | 0.192 | 0.200 | 0.192 | 0.199 |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| Hubber-White SE | Yes | Yes | Yes | Yes | Yes | Yes |

*Panel B: Natural Capital Risk and Economic Growth*

| VARIABLES | (1) GDP Growth | (2) GDP Growth | (3) GDP Growth | (4) GDP Growth | (5) GDP Growth | (6) GDP Growth |
|---|---|---|---|---|---|---|
| Natural Resources Depletion (in %) | 0.100*** | 0.079** | | | | |
| | (0.035) | (0.039) | | | | |
| Natural Forest Depletion (in %) | | | 0.161*** | 0.112*** | | |
| | | | (0.029) | (0.035) | | |
| Fresh Water Withdrawl (in %) | | | | | 0.000 | 0.000 |
| | | | | | (0.000) | (0.000) |
| Transition Risk | | 1.969*** | | 1.967*** | | 2.753*** |
| | | (0.673) | | (0.656) | | (0.551) |
| Observations | 2,039 | 2,039 | 2,039 | 2,039 | 1,980 | 1,980 |
| R-squared | 0.195 | 0.198 | 0.193 | 0.196 | 0.189 | 0.197 |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| Hubber-White SE | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Natural Assets and Economic Growth**. This table shows the regression results of the GDP growth on biodiversity and natural capital risks. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Panel A reports the results for biodiversity loss and Panel B reports the results for natural capital risk. In Panel A, column (1) and column (2) show the regression results for biodiversity risk using *Agriculture and Fisheries per GDP*. Column (3) and column (4) show the regression results for biodiversity risk using *Total Fish Production*. Column (5) and column (6) show the regression results for biodiversity risk using *Wild Catch Fish Production*. In Panel B, column (1) and column (2) show the regression results for natural capital risk using *Natural Resources Depletion (in %)*. Column (3) and column (4) show the regression results for natural capital risk using *Natural Forest Depletion (in %)*. Column (5) and column (6) show the regression results for natural capital risk using *Fresh Water Withdrawl (in %)*. Transition risk is adaptive capacity measure from ND-GAIN Country Index. All specifications include year fixed effect and Hubber-White standard error correction. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table B2: **Natural Assets and Sovereign Green Bond Yield**

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Agriculture and Fishery Per GDP | 0.229* | | | | | |
| | (0.099) | | | | | |
| Total Fish Production | | 0.248** | | | | |
| | | (0.094) | | | | |
| Wild Catch Fish | | | 0.219** | | | |
| | | | (0.074) | | | |
| Natural Resources Depletion (in %) | | | | 0.296 | | |
| | | | | (0.217) | | |
| Natural Forest Depletion (in %) | | | | | 0.236*** | |
| | | | | | (0.036) | |
| Fresh Water Withdrawl (in %) | | | | | | 0.039*** |
| | | | | | | (0.006) |
| Maturity | 0.016 | 0.013 | 0.012 | 0.018 | 0.019 | 0.020 |
| | (0.010) | (0.018) | (0.017) | (0.015) | (0.015) | (0.015) |
| Amount Issued (Log) | 0.293*** | 0.120 | 0.058 | 0.070 | 0.075 | 0.083 |
| | (0.082) | (0.100) | (0.073) | (0.079) | (0.093) | (0.096) |
| Fixed | 0.599 | 0.630 | 0.520 | 0.452 | 0.543 | 0.551 |
| | (0.481) | (0.553) | (0.531) | (0.487) | (0.557) | (0.557) |
| Coupon | 0.619*** | 0.827*** | 0.832*** | 0.707*** | 0.843*** | 0.840*** |
| | (0.100) | (0.090) | (0.086) | (0.197) | (0.075) | (0.076) |
| Option | 0.631 | -0.171 | -0.095 | 0.363 | 0.690 | 0.693 |
| | (0.515) | (0.976) | (0.883) | (0.739) | (0.640) | (0.641) |
| GDP (Log) | -0.237** | -0.533*** | -0.438*** | -0.124*** | -0.146** | -0.141** |
| | (0.070) | (0.101) | (0.042) | (0.029) | (0.047) | (0.047) |
| Debt to GDP | -0.003 | -0.001 | -0.001 | -0.005 | -0.008** | -0.008** |
| | (0.003) | (0.005) | (0.005) | (0.003) | (0.003) | (0.003) |
| Observations | 126 | 116 | 116 | 127 | 127 | 127 |
| R-squared | 0.798 | 0.760 | 0.762 | 0.769 | 0.768 | 0.766 |
| Error Clustering (Country & Year) | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*Natural Assets and Sovereign Green Bond Yield**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Transition risk is adaptive capacity measure from ND-GAIN Country Index. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table B3: **Natural Assets, Geopolitical Risk, and Sovereign Green Bond Yield**

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Geopolitical Risk Index | -0.442 | -0.888 | -0.953 | -0.308 | -1.349* | -1.371* |
| | (0.897) | (0.750) | (0.832) | (0.531) | (0.634) | (0.626) |
| Agriculture and Fishery Per GDP | 0.146* | | | | | |
| | (0.076) | | | | | |
| Total Fish Production | | 0.272** | | | | |
| | | (0.085) | | | | |
| Wild Catch Fish | | | 0.193 | | | |
| | | | (0.119) | | | |
| Natural Resources Depletion (in %) | | | | 0.607* | | |
| | | | | (0.317) | | |
| Natural Forest Depletion (in %) | | | | | 0.263*** | |
| | | | | | (0.036) | |
| Fresh Water Withdrawl (in %) | | | | | | 0.045*** |
| | | | | | | (0.006) |
| Observations | 110 | 104 | 104 | 114 | 114 | 114 |
| R-squared | 0.591 | 0.589 | 0.581 | 0.636 | 0.637 | 0.636 |
| Country Level Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Bond Level Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Error Clustering (Country & Year) | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Natural Assets, Geopolitical Risk, and Sovereign Green Bond Yield**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk adjusting for geopolitical risk. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Geopolitical risk is geopolitical risk index from Caldara and Iacaviello (2022). Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table B4: **Natural Assets, Transition Risk, and Sovereign Green Bond Yield**

| VARIABLES | (1) Yield | (2) Yield | (3) Yield | (4) Yield | (5) Yield | (6) Yield |
|---|---|---|---|---|---|---|
| Transition Risk | 1.924 | 6.762* | 6.566* | 7.479* | 7.634* | 7.802* |
| | (3.797) | (2.976) | (3.047) | (3.429) | (3.422) | (3.400) |
| Agriculture and Fishery Per GDP | 0.201* | | | | | |
| | (0.096) | | | | | |
| Total Fish Production | | 0.075 | | | | |
| | | (0.104) | | | | |
| Wild Catch Fish | | | 0.091 | | | |
| | | | (0.078) | | | |
| Natural Resources Depletion (in %) | | | | 0.278 | | |
| | | | | (0.181) | | |
| Natural Forest Depletion (in %) | | | | | 0.230*** | |
| | | | | | (0.031) | |
| Fresh Water Withdrawl (in %) | | | | | | 0.040*** |
| | | | | | | (0.006) |
| Observations | 126 | 116 | 116 | 127 | 127 | 127 |
| R-squared | 0.800 | 0.783 | 0.784 | 0.804 | 0.805 | 0.805 |
| Bond Level Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Error Clustering | Yes | Yes | Yes | Yes | Yes | Yes |

***Notes.*** **Natural Assets, Transition Risk, and Sovereign Green Bond Yield**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk adjusting for transition risk. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Transition risk is adaptive capacity measure from ND-GAIN Country Index. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.