Do Green Financial Policies Offset the Climate Transition Risk Penalty Imposed on Long-Term Sovereign Bond Yields?

Abstract

Asset valuations in high-carbon sectors face significant corrections due to climate risks. This paper specifically analyses whether markets impose a penalty on long-term sovereign bonds issued by countries facing higher climate-related transition risk while rewarding those that have implemented green financial policies to mitigate these risks. We find that higher carbon dioxide emissions and a less sustainable development score (both proxies for transition risks) lead to an increase in long-term sovereign bond yields. However, the presence of green financial policies appears to offset this climate transition risk premium.

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Colour should be used for any figures in print.

1. Introduction

The financial risks posed to firms and the financial sector due to climate change are taking on increasing significance globally. Several economies are forging ahead with the implementation of green financial policies to mitigate these risks as well as to mobilize funds from the private sector for green financing (Gruenewald, 2020, D'Orazio and Popoyan, 2019). The momentum will only gather pace, given the international consensus reached in recent COP-26 meetings on limiting the global temperature rise and reducing greenhouse gas emissions. A recently published mixed-method systematic review of green finance research highlights six major emerging hotspots in this field[1], of which the green bond market and "greenium" is one, to which our current study aims to contribute (Debrah et al., 2022).

Much of the discussion on climate-related financial risks has highlighted how capital markets are gradually pricing in these risks in asset valuations (Stroebel and Wurgler, 2021, Furukawa et al., 2020). In a global perception-based survey of 439 institutional investors, Krueger et al. (2020) find that most survey respondents ascribe climate risks as being consequential to their asset holdings and firm returns, even though they agree that climate risks are not currently fully reflected in asset valuations. Using voluntary disclosures by S&P500 firms to the Carbon Disclosure Project from 2006-2008, Matsumura et al. (2014) find a systematic negative correlation between the value of a firm and its carbon emissions, apart from the finding that firms which disclose carbon emissions have generally higher median values of firm value vis-à-vis those that do not.

A growing body of academic literature has examined whether equity markets adequately price in climate-related costs, finding evidence of higher returns associated with high-carbon firms, yet with some asset mispricing. For instance, Bolton and Kacperczyk (2021)

[1] The other five research hotspots include: green loans (credit); carbon investment and market; green banking; market stress and green finance; and domestic and international climate finance policies (Debrah et al., 2022).

find that investors command a 'carbon risk premium' on US equities, after controlling for other economic determinants of stock returns in a cross-sectional setting. Similarly, Marshall et al. (2021) find that climate disasters (representing the physical risks posed by climate change) have an effect on the carbon exposure of investors' portfolios and prompts them to focus on investing in more ESG-focused mutual funds. Zhang (2022) finds that perceptions of changes in climate risks adversely impact stock prices in general, with low-carbon (green) firms being rewarded whereas carbon-intensive firms being penalized in response to an increase in climate risks. However, they report a lower climate-risk sensitivity in emerging market equity prices vis-à-vis those in advanced economies.

Investors' informational biases and salience effects also play a key role in demonstrating the impact of newly documented transition risks, such as new research on the magnitude of "unburn-able carbon" (translating into stranded assets*)* to keep global temperature increase below 2 degrees, on firm valuations. Transition risks broadly refer to the risks encountered in the transition from a high-carbon to a low-carbon economy and could arise either due to shifts in climate regulatory policies, or technological advancements in green sectors, or a change in consumers' tastes and preferences towards green goods and services.

For instance, Griffin et al. (2015) conduct an event study analysis to show that the publication of two academic articles in *Nature* in 2009 predicting more than half of the world's fossil fuel reserves will have to remain unburned to meet the Paris Agreement pledges (Meinshausen et al., 2009, Frame et al., 2009), led to stock prices of the 63 largest oil and gas firms in the US dropping by 1.5-2% within 1-3 days of the publication. Their analysis demonstrates that investors respond rationally to new information pertaining to the economic impact of carbon risks, which is reflected in negative stock price corrections, yet they do not exhibit economically significant responses to re-publishing of the same information in media outlets, which may be more biased and/or politically loaded vis-à-vis journal articles.

A few studies have also examined the impact of physical risks from climate changes (referring to risks associated with extreme weather events and gradual sea level rise) on real estate prices. For instance, Bernstein et al. (2019) find that properties at risk of being inundated by the global sea level rise sell at a discount vis-à-vis identical properties located at unexposed locations. Baldauf et al. (2020) report that climate risk perceptions also play a major role in determining property prices. House prices in neighbourhoods where residents believe in climate change sell at a discount compared to houses in US counties inhabited by climate change deniers.

The literature examining climate risks in the bond markets is still in its infancy. In the case of municipal bonds, Goldsmith-Pinkham et al. (2022) demonstrate the pricing in of sea level rise projections in both short- and long-term US municipal bond markets from around 2011, with some statistical differences along the eastern and western coast suggesting a greater recognition of near-term risks from storm surges rather than the longer-term risks of gradual sea level rise which should affect all coastal areas equally. The effect of sea level rise exposure on corporate bond issuance is investigated by Allman (2022). Corporate bonds could exhibit different behaviour vis-à-vis municipal bonds since private firms have the choice to avoid physical risks from climate change by locating themselves and operating in areas which are relatively unaffected by climate disasters and insulated from the gradual effects of global warming.

However, using a sample of over 6000 bonds issued by 871 US public firms between 2010 and 2018, Allman (2022) argues that empirical evidence points to the contrary. Here, a one standard deviation increase in firms' exposure to sea level rise is associated with a 3% increase in spread of average bond yields and there is no significant adverse effect of a firm's sea level rise exposure on its credit ratings at issuance. Boitan and Marchewka-Bartkowiak (2022) examine the impact of several climate risk metrics on sovereign bond yields and risk premia for EU countries from 2000-2020. They demonstrate that countries with higher exposures to physical climate risks and with lower mitigation capability are associated with a greater risk premium on their sovereign debt, with bond yields of Euro-Area countries being relatively lower than non-members.

Emerging literature examining the yields of green bonds vis-à-vis conventional bonds shows the existence of a "greenium", viz. a negative premium on green bonds suggesting that investors are willing to accept a lower yield on green bonds. For instance, Duan et al. (2023) investigate the existence of a carbon risk premium in a cross-section of US corporate bond returns. Contrary to expectations of a carbon risk premium, they find that bonds issued by carbon-intensive firms command significantly low returns vis-à-vis those with low carbon emissions intensity (CEI), and this is likely because investors 'under-react' to climate risk. In a meta-analysis of approximately 25 academic papers on green bond yields in the primary and secondary markets, MacAskill et al. (2021) find an average "greenium" of -1 to -9 basis points on the secondary markets for both corporate and municipal bonds, whereas the evidence is less clear-cut in the case of green bonds issued in primary markets. Zerbib (2019) reports a negative green bond premium of -2 basis points in a sample of 110 corporate, municipal, and financial bonds from July 2013 to December 2017.

However, not all empirical evidence points towards a clear-cut negative "greenium". Karpf and Mandel (2018), in a comparative analysis of green and conventional bonds in the US municipal bond market, report a positive premium on the latter. In contrast to this, Baker et al. (2018) report a greenium of -6 basis points on average using a pooled regression model for yields at issue. They attribute the contradictory findings to the fact that Karpf and Mandel (2018) conflate taxable and non-taxable securities, not taking into account the sensitivity of the US municipal bond market to tax status. Larcker and Watts (2020) also find no existence of a greenium in a sample of 640 pairs of green securities matched with nearly identical conventional securities in the municipal bond market. Similarly, Tang and Zhang (2020) do not find any evidence of a consistently significant greenium when examining green bonds issued by firms in 28 countries from 2007-2017.

A related strand of literature also examines the impact of climate risks on sovereign credit ratings. Boehm (2022) examines the impact of long-term temperature deviations of countries from their historical averages on sovereign creditworthiness. He finds that greater temperature deviations increase sovereign risk, and this effect is more pronounced for countries that are warmer on average. Simultaneously, he also reports the counteracting effect of strong institutions in mitigating/reducing the adverse impact of physical climate risks on sovereign risk levels. Klusak et al. (2021) claim to develop the world's first climate-adjusted sovereign ratings for 108 countries by simulating the effect of various global warming scenarios on credit ratings. They find that although a low-warming scenario consistent with the Paris Agreement pledges would almost negate any adverse impact of climate risks on credit ratings, higher emissions scenarios risk imposing severe credit downgrades of 2.5 notches on 80 countries by 2100.

Alongside the private sector, governments are also important participants in the capital markets via their sovereign borrowings to raise funds for capital expenditure. Sovereign bonds are an important asset class held by investors across the world and constitute a major portion of the global bond market. This paper focuses on the impact of climate transition risk on the cost of long-term sovereign financing.

Aside from physical risks from climate change, transition risks have become equally (if not more) pertinent now given the emphasis on facilitating a smooth (and imminent) decarbonization process as governments become more aggressive in dealing with climate change. The risks encountered in that change are likely to manifest themselves as abrupt and volatile changes in economic parameters, including the magnitudes of assets left stranded, and the reduction in share of brown industries to GDP. What has been missing are studies examining this nexus between transition risks and bond yields. We focus specifically on long-term sovereign bond yields since transition risks are slow moving and are only expected to materialize/become salient in the medium-to-long term, such as when the net-zero by 2050 target (agreed to by countries at the UNFCCC COP-21 Paris meetings in 2015) becomes imminent.

Transition risks could operationally comprise two dimensions[2]. First, it encapsulates the intrinsic commitment of a country towards sustainable development, evidenced by lower carbon emissions and/or a higher consumption of renewable energy. This ensures that a country can transition smoothly from a high-carbon to low-carbon economy without substantial economic and financial instability/restructuring, and therefore lower transition risks. This is supported by the FSB (2021), which alludes to economic shocks hitting those countries that are excessively reliant on high carbon energy, given the adverse impact on their fiscal revenues. However, even for countries that are highly committed to a green growth strategy, transition risks could still arise from sudden regulatory shocks or unexpected global developments in the climate sphere, which comprises the second dimension of transition risks. This paper focuses on the impact of the first aspect of transition risk, viz. the inherent commitment of a country towards a sustainable development strategy, on the cost of sovereign financing[3].

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[2] Since the literature in this field is still nascent with limited empirical studies (albeit growing), there is yet no broad consensus about the most appropriate proxies for measuring transition risks at the country level (FSB, 2021). This is augmented by a lack of standardized metrics to ensure the comparability of self-reported transition risks across firms and/or countries.

[3] There are other useful alternative emerging approaches to measuring transition risks. For instance, Donadelli et al. (2019) develop a macro asset pricing model for the climate transition based on increasing levels of carbon tax imposed to match the socially optimal cost of carbon. They then calculate – what they refer to as -- the climate policy risk premia imposed on the clean and dirty sectors as a result of climate regulatory shocks and find this premium to be negative for fossil fuel firms. However, since our paper aims to analyze the impact of climate transition risks on sovereign bond yields at a macro level and not their disaggregated impact on green vs brown bonds, we contend that it is difficult to extrapolate/extend the concept of the climate policy risk premium in this context. We thank an anonymous reviewer for referring us to this paper.

Specifically, we are interested in exploring two related research questions. First, do markets impose a penalty on long-term sovereign bond yields of countries confronted with higher transition risks? Second, can 'green' financial and regulatory policies offset the transition risk penalty imposed on these bond prices? For this, we use a self-constructed index measuring the intensity of these policies for 29 countries from 1995 till 2021 using data from the E-axes Green Financial and Monetary Policies (GFMP) Tracker (E-axes, 2021). To preview our main conclusions, we find that markets do incorporate climate-related transition risks into asset prices, charging a premium on long-term sovereign bonds issued by countries facing higher transition risks. However, the imposition of green financial policies appears to offset this transition risk premium.

The rest of paper is structured as follows. Section 2 lays out our empirical model. Section 3 outlines data, sources, and definitions and discusses the results. Section 4 concludes the paper.

2. Empirical Model

We empirically examine the impact of climate transition risks on the long-term (10-year) government bond yields in a panel setting using a two-way fixed effects model. There exists a well-developed strand of literature examining the macroeconomic and financial determinants of bond yields which we use as our reference point. We then extend the conventional model of government bond yields determinants with variables proxying the transition risks from climate change, viz. higher carbon dioxide emissions and a lower sustainable development score. Specifically, we hypothesize that transition risks raise long-term bond yields. Countries that have higher carbon emissions and a less sustainable growth trajectory will find it more difficult to transition smoothly to a decarbonized economy, thereby raising transition risks. This will further impact medium-term macroeconomic forecasts and projections for economic growth, fiscal health, and external sector vulnerability which in turn will feed into markets' perceptions of their risk profile and raise yields on sovereign bonds.

Based on this hypothesis, we estimate a two-way fixed effects model using the following benchmark estimating equation:

$$yield_{i,t} = \alpha_i + \theta_t + \beta_1 TransitionRisks_{i,t} + \gamma \boldsymbol{X_{i,t}} + \varepsilon_{i,t} \quad (1)$$

where $yield_{i,t}$ is the government bond yield in country i and time t; α_i denotes time-invariant country fixed effects; θ_t denotes country-invariant time fixed effects; $\boldsymbol{X_{i,t}}$ is the vector of economic determinants of government bond yields in country i at time t that is commonly used in the literature. These include the real GDP growth, inflation, central government debt as a share of GDP, fiscal deficit as share of GDP, current account balance as a percentage of GDP, terms of trade, financial development indicator, VIX and institutional quality indicators; β_1 and γ denote parameters to be estimated; and $\varepsilon_{i,t}$ is the idiosyncratic error term.

Generally speaking, the main macroeconomic factors influencing bond yields on the domestic side include economic growth, price dynamics and variability, fiscal health and debt sustainability indicators (Afonso and Nunes, 2015, Beck, 2001, Poghosyan, 2014). On the external side, favourable and less volatile terms of trade may indicate better export earnings and a greater ability to repay debt, thereby pushing bond yields down (Aizenman et al., 2016, Nosbusch and Hilscher, 2010). Some studies find that financial development and openness to capital flows could have partially counteracting effects. This arises as the former indicates a higher capacity of the financial sector to hedge against risks thus mitigating their effects on bond yields, while the latter could increase the transmissibility of external shocks to sovereign yields and increase risk premia during episodes of global uncertainty (Csonto and Ivaschenko, 2013). Studies also incorporate political risks in determining sovereign bond yield spreads (Eichler, 2014).

In the first stage we estimate the impact of transition risks on long-term sovereign bond yields to set the baseline determinants of bond yields. In the second stage we split the data into green financial policy implementers and non-implementers and examine the impact of transition risks on bond yields in the two sub-samples.

3. Data and Results

3.1 Data

We use annual data over 1995-2018 for 25 countries for our empirical analysis[4]. The dependent variable is the 10-year government bond yields, data for which are collected from the Global Financial Data (GFD)[5]. The main independent variables comprise two proxies for transition risk, viz. (reversed) Sustainable Development Index (SDI) scores and CO2 emissions of a country proportional to GDP.

The Sustainable Development Index (SDI) is developed by Hickel (2020) for 163 countries from 1990 till 2019. This index supplants the Human Development Index by incorporating ecological sustainability growth criteria into calculations. It is comprised of five sub-indictors, the first three of which (education, life expectancy, and income) constitute a development index, and the last two -- CO2 emissions and material footprint per capita -- capture the ecological index[6]. The SDI is computed as the development index divided by the

[4] The sample size varies in different specifications as it is constrained by available data for each variable series.

[5] https://globalfinancialdata.com/

[6] More accurately, the ecological index measures the overshoot of a country's per capita CO2 emissions and material footprint vis-à-vis planetary boundaries (Hickel, 2020).

ecological index, and final index values range from 0-1. Since the SDI captures the extent of sustainable development with a higher index value indicating a more sustainable growth strategy, we reverse the scores by subtracting from 1 for purposes of interpretation and to represent our theoretical construct of transition risks more accurately. The resulting SDI scores range from 0.184 to 0.915 in our sample.

Our second measure aims to capture the CO2 emissions of a country as a proportion of its GDP over time, using a dataset constructed by Ritchie and Roser (2020). As higher carbon emissions through human activities have been demonstrated as a key contributor to climate change and reducing carbon emissions is included as one of the main international pledges to stem the rise in global temperatures at the UNFCCC COP meetings, a higher stock of CO2 emissions is likely to pose system-wide risks to economies in the transition to a green economy[7]. The dataset measures the CO2 emissions as a proportion of GDP of over 200 countries from 1950 till 2020. CO2 emissions in our sample range from 0.07 to 1.4 percent of GDP.

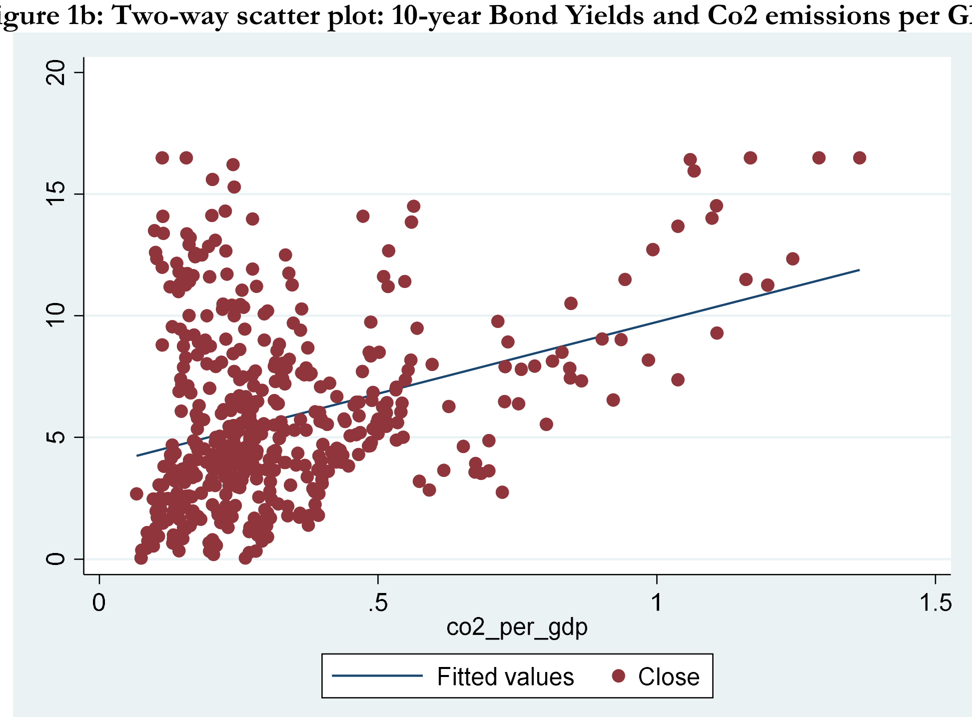
In Figure 1a below, we present a simple scatter plot of 10-year government bond yields and reversed SDI scores. At first glance the figure seems to indicate a negative relationship between the two variables, suggesting that greater transition risks conveyed by a high reversed SDI score correspond to a lower bond yield. However, Figure 1b, which uses CO2 emissions normalised by GDP instead of SDI, shows an upward sloping (positive) relationship. To rule out the effect of other financial and economic variables driving sovereign bond yields, it is important to include them in our statistical model.

[7] The agreement arrived upon by countries at the UNFCCC COP-21 meetings in Paris in 2015 to keep the global temperature rise within 2 degrees Celsius is underpinned by the need to achieve net-zero carbon emissions by 2050. Reducing carbon emissions up to a level where no new carbon is being added to the environment is vital to contain global warming.

Figure 1a: Two-way scatter plot: 10-year Bond Yields and (Reversed) SDI Scores

NOTE: We use winsorized data at 1 per cent at each tail of the distribution for 10-year bond yields

Figure 1b: Two-way scatter plot: 10-year Bond Yields and Co2 emissions per GDP



NOTE: We use winsorized data at 1 per cent at each tail of the distribution for 10-year bond yields

To assess the impact of climate-related policies on long-term bond yields we use a new self-constructed index measuring the green financial policy intensity of 29 countries from 1995-2021. Data for this index are taken from the E-axes Green Monetary and Financial Policies (GMFP) Tracker which contains information on financial, monetary and additional policies implemented by selected countries from 1995 till present (E-axes, 2021).

Among these, we focus only on financial policies since they are targeted specifically at the financial sector to mitigate the firm-level and systemic risks to financial stability arising from climate-related physical and transition risks. Broadly speaking, they entail the alignment of a climate objective to conventional supervisory, credit guidance, and (micro- and macro) prudential policies. A list of all financial policies included in the database are outlined in Table 1 below. Of all financial policies, supervisory guidelines emerge as the most popularly implemented green policy tool by almost all countries (implemented over time in 28 instances across countries). This is followed closely by disclosure requirements (issued by countries in 24 instances over the considered time period).

Table 1: Financial policies in E-axes Green Monetary and Financial Policies (GMFP) tracker

FINANCIAL POLICY	Credit Guidance Policy	Priority Sector Lending Policy (3)
	Prudential Policy	Preferential green capital requirements (Micro-prudential policy) (2)
	Supervisory Policy	Climate stress test (12)
		Disclosure requirements (24)
		Supervisory expectations and guidelines (28)
		Survey of practices (10)

Note: Figures in parenthesis indicate the frequency of implementation of a particular policy across countries.

To construct the index, we create a binary coding, assigning 1 to those countries that have implemented a green financial policy in a particular year, and 0 otherwise. Thereafter, we incrementally adjust upwards by 1 whenever a country rolls out a subsequent green policy in future years. This gives us an index ranging from 0-12 in a panel setting, documenting both the number of policies implemented and the year of implementation for all countries in the dataset.

Data for other control variables are compiled from IMF World Economic Outlook, the World Bank World Development Indicators databases, and the Federal Reserve Economic Data (FRED). A list of all 25 countries included in our analysis, along with data sources used for all control variables/covariates, and summary statistics of all variables can be found in Appendix A Tables A1, A2, and A3.

3.2 Baseline Results: Impact of Transition Risk

Before assessing the impact of climate risks on bond yields we first establish the reference model by regressing long-term bond yields on their usual macroeconomic and financial determinants noted previously. We estimate the two-way fixed effects model for 10-year sovereign bond yields. Results are presented in column 1 of Table 2. Then we incorporate transition risk proxies to our reference model to estimate their additional impact on bond yields in columns 2 and 3 of Table 2.

Table 2: Climate transition risks as a determinant of bond yields

VARIABLES	(1) Bond Yield	(2) Bond Yield	(3) Bond Yield
SDI_rev		3.954**	
		(1.600)	
CO2_per_gdp			5.682***
			(1.796)
GDP Growth	-0.318***	-0.305***	-0.308***
	(0.0519)	(0.0518)	(0.0529)
Inflation	0.136***	0.131***	0.0954***
	(0.0228)	(0.0227)	(0.0258)
Debt to GDP ratio	0.0219***	0.0233***	0.0169**
	(0.00660)	(0.00658)	(0.00717)
Fiscal deficit	0.0383	0.0498	0.0756*
	(0.0403)	(0.0403)	(0.0443)
Current a/c balance	-0.0656*	-0.0685*	-0.0589

	(0.0360)	(0.0357)	(0.0370)
Terms of trade	-0.0114	-0.0107	-0.00316
	(0.00774)	(0.00770)	(0.00829)
VIX	3.129***	3.723***	-0.964***
	(0.562)	(0.608)	(0.228)
Financial Development	-7.352***	-6.460***	-6.215***
	(2.223)	(2.238)	(2.338)
Govt Stability	-0.163*	-0.183**	-0.164*
	(0.0900)	(0.0898)	(0.0917)
Constant	-24.73***	-34.12***	22.42***
	(7.503)	(8.367)	(3.416)
Observations	439	439	416
R-squared	0.612	0.618	0.616
Number of countries	25	25	24

Note: All time fixed effects omitted from reporting. Standard errors in parentheses.

From column 1 we see that, among domestic macro determinants of bond yields, higher GDP growth is correlated with lower bond yields, whereas higher inflation causes bond yields to inch upwards. Both coefficients are statistically significant, and the results are in line with existing studies. Higher economic growth is an indicator of bullish prospects for investors in the future. This increases investor confidence in the economy and causes interest rates on sovereign borrowings to move downwards. On the other hand, higher inflation tends to steepen the yield curve by triggering an upward movement in bond yields.

On the fiscal side, a higher debt-to-GDP ratio increases bond yields. There are two channels through which a higher stock of fiscal debt could cause bond yields to increase. First, higher fiscal debt indicates dis-saving by the government (excess of government expenditure over revenue), which lowers the overall national saving of the country. Absent capital inflows, this causes an excess demand of loanable funds causing interest rates to rise, which further feed into increases in the interest rates on sovereign debt. Second, higher debt-to-GDP ratios are a signal to the markets about credit risk and the probability of sovereign default, and investors price in these sovereign risks into bond prices, thereby pushing bond yields upwards. However, fiscal deficits do not have any statistically significant effect on bond yields. This could be due to the high correlation of fiscal deficit with debt-to-GDP[8].

On the external side, a higher current account balance and more favourable terms of trade are negatively correlated with bond yields, though the former is weakly statistically significant whereas the latter is not[9]. Higher current account balances, or a current account surplus, indicates an excess of foreign currency inflows and suggests a greater repayment capacity of foreign-currency debt, thereby pushing bond yields downwards. In a similar vein, more favourable terms of trade are an indicator of high export earnings which also signal higher debt repayment ability and therefore lower bond yields.

Among the financial indicators, a higher level of financial development is inversely correlated with bond yields and is highly statistically significant. Greater financial development means that financial markets are deep and possess a greater ability to hedge risks arising from different sources, thus resulting in lower sovereign yields. On the other hand, the volatility index (VIX) is positively correlated with bond yields. This is intuitive insofar as higher global uncertainty increases the risk premium for investors, thereby pushing bond yields up.

The effect of government stability as a proxy for overall institutional quality is also consistent with our priors. Government stability -- a proxy for political risks -- is negatively correlated with bond yields and the effect is statistically significant as expected a priori (i.e., lower levels of political risks push bond yields downwards).

Having established the reference model for economic and financial determinants of sovereign yields, in column 2 we add reversed SDI scores to the previous model. From the table we see that more unsustainable growth has an economically and statistically significant

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[8] Dropping debt-to-GDP ratio does not affect the results.

[9] Current account balance is weakly significant in our reference model and in the regression incorporating reversed SDI scores, but not in the case of CO_2 emissions as a proportion of GDP.

positive impact on bond yields. A 0.1-unit increase in the unsustainable development score increases bond yields by 0.39 percentage points. All other controls remain virtually unchanged from column 1, both in terms of their statistical significance and the coefficient size.

In column 3, we assess the impact of CO_2 emissions (as a proportion of GDP) on bond yields, controlling for all other economic and financial determinants of bond yields in column 1. We again find that higher CO_2 emissions tend to raise sovereign yields, with a 0.1 percentage point increase in CO_2 emissions as a proportion of GDP causing bond yields to rise by 0.57 percentage points. Most of the controls remain unchanged from our reference model in column 1, except for fiscal deficit which turns weakly significant in this case and the sign is positive and in line with priors. From columns 2 and 3 of Table 2 we see that more unsustainable growth and higher CO_2 emissions push up sovereign bond yields, and the effect is economically and statistically significant in both cases[10]. This suggests that markets do price in climate transition risks into long-term (10-year) sovereign bond yields and penalize countries which are not prepared for/committed to a smooth transition[11].

3.3 Impact of Green Financial Policies on Transition Risks and Bond Yields

Our baseline results suggest that transition risks encountered by economies have an economically and statistically significant positive impact on the price of long-term sovereign debt. Next, we examine whether the implementation of green financial policies by countries can mediate or offset the correlation between transition risks and long-term bond yields.

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[10] Given the varying development status of countries in our sample, we also conduct heterogeneity analysis by splitting our sample of countries into developed and EMDEs (emerging market and developing economies). However, when we run the baseline regression of 10-year government bond yields on transition risk proxies, our resulting sub-samples are rather small, which reduces the statistical power of our analysis. Moreover, the coefficients on transition risk proxies turn insignificant for both developed economies and EMDEs.

[11] While the VIX coefficient turns negative and is statistically significant, it remains positive if we use its lead (one period forward) value.

For this analysis we use the self-constructed index of green financial policy intensity and split countries into two: those which have implemented zero green financial policies in a particular year on one hand (green policy = 0), and those with some positive number of green financial policies implemented in a year (green policy > 0) on the other. Columns 1 and 3 in Table 3 present results for the sub-sample of countries which have implemented no green policy, while columns 2 and 4 depict results for the sub-sample of countries with some positive intensity of green policy implementation.

Table 3: Green policies, transition risks, and sovereign bond yields

VARIABLES	(1) Bond Yield (No green policy)	(2) Bond Yield (Green Policy>0)	(3) Bond Yield (No green policy)	(4) Bond Yield (Green Policy>0)
SDI_rev	2.795***	6.703		
	(1.055)	(6.604)		
CO2_per_gdp			9.457***	-3.745
			(2.510)	(3.511)
GDP Growth	-0.0113	-0.107	-0.0100	-0.0665
	(0.0418)	(0.101)	(0.0411)	(0.110)
Inflation	0.348***	0.0555	0.322***	0.0493
	(0.0457)	(0.0385)	(0.0451)	(0.0421)
Debt to GDP ratio	0.0177***	0.0339	0.0104**	0.0347
	(0.00424)	(0.0214)	(0.00454)	(0.0245)
Fiscal deficit	-0.00278	0.211***	-0.0188	0.253***
	(0.0328)	(0.0791)	(0.0319)	(0.0882)
Current a/c balance	-0.0301	-0.144**	-0.0221	-0.172**
	(0.0268)	(0.0706)	(0.0268)	(0.0751)
Terms of trade	0.00823	-0.000149	0.0105**	-0.00826
	(0.00503)	(0.0169)	(0.00499)	(0.0199)
VIX	3.620***	2.911	-0.660***	-1.081
	(0.409)	(1.985)	(0.190)	(0.788)
Financial Development	-2.185	-14.16**	-2.776**	-20.13***
	(1.344)	(7.111)	(1.323)	(7.213)
Govt Stability	-0.0143	-0.552**	-0.0155	-0.614**
	(0.0546)	(0.222)	(0.0534)	(0.248)
Constant	-39.77***	-20.16	11.45***	37.93***
	(5.598)	(26.30)	(3.080)	(11.77)
Observations	256	183	251	165
R-squared	0.803	0.711	0.809	0.718
Number of ifs	16	19	16	18

Note: All year effects omitted from reporting.
Standard errors in parentheses

From columns 1 and 2 of Table 3 we see that green financial policies indeed make a difference for countries with higher unsustainable development scores. While countries with no green financial policies experience an increase in bond yields of 0.28 percentage points for every 0.1-point rise in the (reversed) SDI index and the effect is highly statistically significant, the imposition of green financial policies renders the effect of unsustainability on bond yields insignificant. Similarly, from column 3 of Table 3 we see that in the absence of green financial policies, higher CO2 emissions are associated with higher interest rates on sovereign-issued debt, with a 0.1 percentage point rise in CO2 emissions as a share of GDP raising bond yields by 0.95 percentage points. However, this correlation breaks down in the presence of green policies (column 4), and the coefficient on CO2 emissions turns negative[12].

Thus, our results suggest that green financial policies could counteract the adverse impact of climate transition risks by raising sovereign bond yields. While we acknowledge that these policies could themselves be a source of transition regulatory risk, as more stringent green financial policies could amplify transition risks and thus contribute to raising bond yields, we contend that this is unlikely to be the case for two reasons. First, the scope of these policies, as it currently stands, is currently restricted largely to some entities in the financial sector. Thus, they are not very representative of economy-wide transition risks posed by climate change and may instead be regarded as signaling the commitment by the country's central bank or financial regulator to initiate the incorporation of climate risks into financial institutions' risk management and balance sheets. Second, we view these policies as a tool for mitigating transition risks by facilitating a more transparent and accurate discovery of climate risks in asset prices, thereby enabling a smooth decarbonization process. To that extent, we hypothesize

[12] We also note that a number of controls lose their significance in this step of our analysis, particularly in the subset of countries with a positive green policy intensity. This suggests that there may be some interaction effects between green financial policies and these macro determinants, and the former might absorb the impact of these other variables.

that a greater uptake of these policies should lower the climate (transition) risk penalty on sovereign bond yields insofar as these policies increase a country's commitment (and that of its financial sector, more narrowly) to tackling climate-related financial risks early on.

This prior is confirmed empirically when we run an extended two-way fixed effects model with the full set of controls, estimating the impact of green financial and regulatory policy intensity directly on 10-year government bond yields. Results presented in Table 4 below indicate that the imposition of green financial policies is negatively correlated with sovereign bond yields, with a 1-unit increase in green financial policy intensity leading to a decline in 10-year sovereign bond yields by 0.2 percentage points. This suggests that the introduction of green financial policies is not a source of transition risk to the economy, rather it facilitates a smoother decarbonization process, which is consistent with our narrative in the paper.

Table 4: Green financial policy intensity as a determinant of government bond yields

VARIABLES	(1) GB10yrYield
Green Policy	-0.235***
	(0.0893)
GDP Growth	-0.0841**
	(0.0390)
Inflation	0.308***
	(0.0426)
Debt to GDP ratio	0.0127***
	(0.00394)
Fiscal deficit	-0.0214
	(0.0286)
Current a/c balance	-0.0318
	(0.0246)
Terms of trade	-0.000285
	(0.00512)
VIX	3.811***
	(0.350)
Financial Development	-0.636
	(1.377)
Govt Stability	-0.0105
	(0.0534)
Constant	-40.03***
	(4.693)
Observations	333
Number of countries	17
R-squared	0.796

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To check the robustness of our findings, we also replicated the sub-sample splitting model with medium-term (2-year maturity) sovereign bond yields. Results, presented in Table 5 below, are broadly consistent with those obtained for long-term (10-year) sovereign bond yields, though slightly statistically weaker in this case. This could be partly attributable to the fact that there are fewer observations for medium-term sovereign bond yields as not all countries issue 2-year government bonds. Moreover, yields on bonds with short- and medium-term maturities are likely to be affected by other (more short-term factors) beyond long-term macroeconomic and external sector fundamentals, such as liquidity conditions and monetary policy[13].

Table 5: Green Policies, Transition Risks, and 2-year Sovereign Bond Yields

	GB2YrYield			
VARIABLES	(1) No green policy	(2) Green policy > 0	(1) No green policy	(2) Green policy > 0
SDI_rev	3.123*	-1.557		
	(1.717)	(5.962)		
CO2_per_GDP			6.241*	-4.855
			(3.274)	(5.746)
GDP Growth	0.157***	-0.0682	0.135**	-0.0587
	(0.0540)	(0.0808)	(0.0525)	(0.0859)
Inflation	0.254***	0.220*	0.162**	0.256
	(0.0782)	(0.129)	(0.0781)	(0.153)
Debt to GDP ratio	0.0207***	-0.0552***	0.0156***	-0.0531***
	(0.00496)	(0.0177)	(0.00474)	(0.0176)
Fiscal deficit	-0.000145	-0.0850	-0.0347	-0.0518
	(0.0366)	(0.0690)	(0.0340)	(0.0787)
Current a/c balance	-0.0256	-0.00411	-0.0304	-0.00963
	(0.0286)	(0.0629)	(0.0285)	(0.0713)
Terms of trade	0.00442	0.000544	0.00451	0.00781
	(0.00599)	(0.0304)	(0.00565)	(0.0340)
VIX	3.018***	-0.0190	-0.791***	0.164
	(0.518)	(0.119)	(0.212)	(0.256)
Financial Development	-0.0476	-4.882	-0.855	-6.613
	(1.460)	(6.835)	(1.410)	(7.656)
Govt Stability	0.00831	-0.0615	0.00468	-0.115
	(0.0590)	(0.180)	(0.0568)	(0.229)
Constant	-35.93***	10.58	11.48***	8.618
	(7.495)	(7.994)	(3.661)	(7.551)
Observations	226	99	222	87
R-squared	0.795	0.662	0.802	0.676
Number of countries	14	13	14	13

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[13] This point is further reiterated when we conduct the sub-sample splitting regressions using 5-year sovereign bond yields and very short-term T-bill yields which mature within a year. The findings indicate that while results hold for 5-year sovereign bond yields, they do not hold for T-bill yields. This is consistent with the argument that short-term bond yields are affected by a host of other factors especially monetary shocks. We thank an anonymous referee for their suggestion to look at the impact of transition risks across the term structure of various bonds.

4. Conclusion

This paper specifically examines the pricing of climate transition risks in the context of sovereign bonds, and whether green financial policies can help mitigate these impacts. Our baseline results indicate that countries confronted with greater transition risks due to climate change tend to be faced with higher bond yields. This suggests that financial markets and investors do price in transition risks while making investment decisions. Our results are robust after controlling for standard domestic and external economic, financial, and institutional indicators such as GDP, inflation, fiscal balance, terms-of-trade, financial development, capital account openness, and government stability. We further find that markets recognize policy efforts taken by countries to mitigate climate risks. Taken together, these results suggest that green policies can offset an increase in sovereign bond yields for countries facing high transition risks from climate change.

Overall, the findings provide evidence in favour of a more widespread uptake of green financial policies. Although these policies are conventionally undertaken to mitigate climate-related financial risks at the firm-level and macro-level along with facilitating the flow of green finance, this paper also sheds light on another effect of these policies. Specifically, these green financial policies appear to indirectly affect bond prices by offsetting the impact of climate risks on bond yields, thereby helping keep the cost of capital low in the countries that face climate risks.

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Appendix A

Table A1: List of Countries Included in Analysis (25)

Argentina	Kenya
Australia	Mexico
Bangladesh	Morocco
Brazil	Norway
Canada	Russia
Colombia	Singapore
Denmark	South Africa
France	Sweden
Germany	Switzerland
India	Turkey
Indonesia	United Kingdom
Italy	United States
Japan	

Table A2: Details of Control Variables/Covariates

Indicator	Proxy for	Source
GB 10-yr Yield	Sovereign bond yields	Global Financial Database
Green financial policy intensity index	Green financial and regulatory policies implemented by central banks and financial supervisors	Self-constructed index based on data from the E-axes Green Monetary and Financial Policies (GMFP) tracker
Real GDP growth		World Economic Outlook
Consumer price Index (CPI)	Inflation	World Economic Outlook
Central govt debt (% of GDP)	Debt-to-GDP ratio	World Development Indicators (World Bank)
Fiscal deficit (% of GDP)	Fiscal health	World Development Indicators (World Bank)
Current a/c balance (% of GDP)	External sector indicator	World Economic Outlook
Terms of trade	External sector indicator	World Economic Outlook
Average VIX (year average from daily data)	Volatility Index	FRED (Federal Reserve Bank of St Louis)
Financial Development Index	Depth, access, and efficiency of financial institutions and financial markets	Financial Development Index Database (IMF)

Table A3: Descriptive Statistics

	Unit	N	Mean	min	max	St.Dev	p25	Median	p75
Green Policy	Index (0-12)	396	.5	0	8	1.097	0	0	1
SDI (reversed)	Index (0-1)	565	.495	.184	.915	.193	.335	.448	.653
CO2 per GDP	%	507	.322	.067	1.364	.215	.177	.264	.386
GDP growth	%	536	3.106	-7.821	15.24	2.836	1.592	2.818	4.618
Inflation	%	533	3.884	-1.35	85.742	5.51	1.326	2.356	5.068
Debt-to-GDP ratio	%	496	51.942	6.07	196.699	31.845	31.536	45.065	63.865
Fiscal deficit	%	478	.685	-20.341	9.93	4.354	-.839	1.428	3.293
Current account balance	%	564	1.547	-9.74	27.143	5.94	-2.581	.013	4.485
Terms of trade	%	536	101.92	49.285	169.938	16.719	95.05	100.087	105.925
VIX	%	565	19.592	11.09	32.693	6.05	14.23	17.536	24.203
Financial development	%	536	.609	.126	1	.224	.403	.675	.787
Govt stability	Index (0-12)	536	8.239	4.667	11.5	1.561	7	8.208	9.333

Table A4: Countries by Development Status

Advanced Economies (13)	**Emerging Market and Developing Economies (EMDEs) (12)**
Australia	Argentina
Canada	Bangladesh
Denmark	Brazil
France	Colombia
Germany	India
Italy	Indonesia
Japan	Kenya
Norway	Mexico
Singapore	Morocco
Sweden	Russia
Switzerland	South Africa
United Kingdom	Turkey
United States	