Climate Change Transition Risk on Sovereign Bond Markets

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Abstract

We challenge the narrative that climate change transition risk is not being priced into sovereign bond markets. Climate change transition risk, as measured by carbon dioxide emissions, natural resources rents and renewable energy consumption, are factored into sovereign bond yields (and spreads) by investors. Using a sample of data from 23 advanced and 16 developing markets from 2000-2019, we show countries with lower carbon emissions incur a lower risk premium on sovereign borrowing costs. Moreover, advanced countries willing to reduce their earnings from natural resources rents and to some extent, increase renewable energy consumption are associated with lower sovereign borrowing cost. In contrast, developing countries with strong dependence on natural resources, or restricted renewable energy consumption incur lower sovereign borrowing cost. Thus, advanced economies who perform poorly in managing their climate transition, may encounter increased sovereign borrowing costs, liquidity constraints, reduced capacity to effectively manage climate transition and the inability to finance economic recovery from severe climate shocks or natural disasters. The necessity to support developing countries to meet climate change targets also emerges.

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Given the threat climate change poses to the global economy, we hypothesise an increase in the significance of transition risk factors as determinants of sovereign bond yields.
Keywords: climate change, transition risk, sovereign bond yields, carbon dioxide, natural resources rents, renewables, GDP

JEL: F34, G15, H63, Q20, Q51

1. Introduction

Climate transition risks are the risks related to the process of adjustment towards a low carbon economy.[2] Many in the investing community, claim that climate change is not being factored into government bond markets[3] and therefore sovereign bond yields are not fully reflecting the impact of climate change and a country's effort to transition to a low-carbon economy in line with the 2015 Paris Agreement.[4] We challenge this narrative and show that transition risks are currently priced into sovereign bond yields (and spreads).

There are three main transmission channels of climate change risk affecting the financial stability of a country; physical risks, liability risks and transition risks. Bank of England (2015) define physical risks as the first-order risks which arise from weather related events with direct impacts, such as damage to the property and indirectly through disruption to global supply chains or resource scarcity. An extensive body of literature exists to explain the negative physical effects of climate change on economic growth and recovery (Nordhaus, 1991, Dell et al., 2012, Batten et al., 2020). More recently, finance literature has begun to explore the nexus between physical climate risk and sovereign risk (Kling et al., 2018, Beirne et al., 2020, Cevik and Jalles, 2020). Liability risks stem from parties who have suffered loss from the effects of climate change and seeking compensation from those responsible. This has led to widespread ramifications that extend to litigation's against companies and governments who now have an established duty of care.[5]

Transition risks arise due to a country's process of adjustment towards a greener economy. ClimateWise (2019) present both transition risks and opportunities, with transition risks including policy changes, reputational impacts, and shifts in market preferences, norms and technology. Transition opportunities include those driven by resource efficiency and

[2]Basel Committee on Banking Supervision: https://www.bis.org/bcbs/publ/d517.pdf

[3]See for example AFR: https://www.afr.com/policy/economy/investors-not-pricing-climate-change-into-government-bond-risks-20210118-p56uyk; CNBC: https://www.cnbc.com/2021/02/24/climate-risks-not-priced-in-bond-markets-a-risk-for-many-countries-.html

[4]The Paris Agreement's goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. This is a legally binding international treaty on climate change and adopted by 196 Parties at COP 21 in Paris, on 12 December 2015

[5]See, for example, ABC: https://www.abc.net.au/news/2021-05-27/climate-class-action-teenagers-vickery-coal-mine-legal-precedent/100169398; Bloomberg: https://www.bloomberg.com/news/articles/2020-07-22/australia-sued-for-not-disclosing-climate-risk-in-sovereign-debt

the development of new technologies and products and services, which could capture new markets and sources of funding.[6] Despite the significance of these risks/opportunities in preparing our economies for a successfully transition, existing literature is focused primarily on the aforementioned physical risk, with relatively little research investigating climate change transition risk indicators impact on sovereign bond yields and spreads.

Climate change transition risk variables are chosen for their ability to measure how well a country is transitioning towards a carbon-neutral economy, in line with the SDGs. Thus, we examine the impact of climate change transition risk on sovereign bond yields by employing climate change transition risk variables that can be mapped directly to specific SDGs. Specifically, we employ: *carbon dioxide emissions*, aligned with SDG Goal 13 Climate Action; *natural resources rents*, aligned with SDG Goal 12 Responsible Consumption and Production; and *renewable energy consumption*, aligned with SDG Goal 7 Affordable and Clean Energy. Carbon dioxide emissions and natural resources rents produce negative climate related effects, as an increase in either reflects a higher reliance on fossil fuels and therefore an increasingly difficult transition to a net zero economy. Renewable energy consumption has a positive-related climate effect, as an increase in renewable energy aligns with progression towards cleaner fuel sources and a more sustainable economic future. For countries with higher carbon emissions and natural resources rents, we hypothesise they will incur a risk premium on their sovereign borrowing cost. For renewable energy, we hypothesise countries with higher renewable energy consumption relative to total consumption will be rewarded with a discount on sovereign borrowing cost.

We further suggest that climate transition risk has two avenues via which it can impact yields; directly through the risk factors themselves, and indirectly through macroeconomic variables such as GDP. For example, with respect to the first avenue, countries with poor prospects of transitioning away from a reliance on fossil fuels will likely incur higher costs of funding as a result of investors penalising countries who are not seen to be pulling their weight with respect to tackling climate change.[7] The second and indirect avenue relates to

[6]These risks and opportunities vary across geographies, sectors, time horizons and government and business commitments to limit global temperature rises.

[7]https://www.smh.com.au/business/markets/swedendumps-aussie-bonds-as-country-not-known-for-good-climate-work-20191114-p53agw.html

how much investors think a country's future GDP prospects will suffer if their economy relies on a declining industry such as fossil fuels. It is expected the magnitude of both the direct and indirect influences will increase over the coming years as climate change intensifies its impact on economies globally. Of course, the physical risk of climate change is currently impacting GDP levels.[8] In which case, even if investors are not linking the decline in current levels of GDP to the physical risk of climate change, we can argue that climate change is being priced into yields and spreads to the extent that investors account for present GDP levels.

We test these hypotheses by employing 10-year bond yield data from 23 advanced countries and 16 developing countries over the period from 2000 to 2019. The estimation results are split by country group, under the assumption a country's transition efforts will be impacted by economic and financial characteristics, which implies the impact on sovereign bond yield spreads are best observed alongside countries with similar characteristics. In addition, in order to standarise yields across countries, we estimate yield spreads as a country's 10-year bond yield minus the United States yield of the same maturity. Seven macroeconomic and liquidity variables that are traditional determinants of bond yields are used to control for domestic-specific factors and mitigate against endogenous concerns.

Through a series of panel fixed effects regressions, with both time and country effects, we show that climate transition variables have a significant impact on sovereign yields and spreads. Carbon dioxide emissions are positively related to both sovereign bond yield and spreads, a relation that holds for both advanced and developing countries. Thus, carbon dioxide emissions play a dominant role in influencing worldwide the sovereign bond market, with reduced carbon dioxide emissions being associated to lower sovereign borrowing cost. Reductions on natural resources rents in advanced countries are related with lower sovereign borrowing cost, revealing a positive impact of climate change transition risk to sovereign bond yields and spreads. Interestingly, we find that developing countries with high dependence in natural resources are also associated with lower sovereign borrowing cost. Further, increase in renewable energy consumption is associated with reduced sovereign borrowing cost for the

[8] https://www.bloomberg.com/news/articles/2020-02-13/rba-s-lowesays-economic-implications-of-climate-change-profound

advanced country group, though is associated with increased sovereign borrowing cost for the developing country group.

A number of reasons can explain the differences in the effects between advanced and developing countries. Implementing emission reduction strategies such as technology advancement, moving to less-reliant on fossil fuels and consuming cleaner energy sources is far easier in advanced countries who have the capacity to borrow at a lower cost, have higher GDP per capital and are more resilient to economic shocks. Developing countries face a unique challenge in this regard, and partnership assistance, financial support and technology transfer from advanced countries will be critical in assisting them to successfully transition to cleaner economies. Clean energy adaption and integration have the potential to drive economic growth that would counteract the short-term financial losses arising from the transition away from high-carbon economies and the dependency on natural resources. But, given the future expected cost of transitioning may rely on external support which is highly uncertain, market participants may demand to be compensated for this uncertainty by way of higher yields. Further, developing countries yields are often more volatile and can be dominated by shorter term "noise" (for example geopolitical risk), and as such investors may be much more focused on a developing country's ability to repay debt as a function of shorter term factors. Finally, advanced countries have the advantage of favourable economic and political conditions to implement strategies to transition to a lower carbon economy. In contrast, if the high natural resource rents that developing countries command are much higher than the uncertain payoff from transitioning to a carbon neutral economy, and the cost of transitioning is prohibitive - then it makes sense that investors would not value increased renewable energy exposure favourably. A further explanation may be that investors consider transition risk a burden that developed economies may be required to bear - as supported by calls from leaders that partnership assistance and technology transfer will be necessary in order to meet Paris Agreement goals (United-Nations, 2019).

This research provides useful insights to investors and policy makers via analysis of key transition indicators and their impact on sovereign cost of borrowing in advanced and developing countries. By aligning the variables to SDGs, this paper provides a transparent and easily replicable way for governments, investors and businesses to evaluate climate change transition risk in relation to sovereign bond yields going forward. Policymakers will gain better understanding of how transition efforts, such as lowering carbon emissions and increasing investment in renewable energy, affect their cost of borrowing and access to financial markets. Further, the sovereign bond market serves a number of critical purposes: providing a benchmark from which every other asset class is priced, acting as a safe haven asset during market crises and providing liquidity and funding for the banking sector and governments. The global financial system is therefore dependent on a well functioning bond market. Understanding the impact transition risk has on a country's cost of borrowing is also critical for governments to effectively manage climate transition. This is particularly true if they are to align their policies and strategies with the United Nations Sustainable Development Goals (SDGs) - goals, which many governments appear to be at risk of not achieving.[9] The research is driven by growing recognition that there is need to investigate not only the physical risks of climate, but the transition risks countries face in trying to prepare for a more sustainable future.

This paper is organised as follows. Section 2 outlines the relevant literature on climate change transition risk factors and potential determinants of sovereign bond yields/spreads. Section 3 describes the data and the methodology used in this study, along with the preliminary analysis. Section 4 presents the empirical findings reporting the impact of climate change transition risk indicators to sovereign bond yields and spreads. Robustness and sensitivity analysis is included in Section 5. Section 6 concludes.

2. Literature Review

In recent years, the impact of climate change risk has attracted the attention of practitioners and academics as another potential determinant of government bond yields. Kling et al. (2018) use the Notre Dame Global Adaptation Initiative (ND-GAIN) indices for vulnerability[10] to climate change - specifically the sensitivity, capacity, and social readiness index - and confirm the importance of these indices in determining bond yields from 48 countries,

[9]United Nations SDGs: https://www.un.org/sustainabledevelopment/

[10]The definition of *vulnerability* according to the ND-GAIN is "Propensity or predisposition of human societies to be negatively impacted by climate hazards".

including countries from the V20[11] and G7[12] group. The analysis is challenged by the lack of variability of the ND-GAIN factors, multicollinearity, and low number of data points for some countries. Similarly, Cevik and Jalles (2020) and Beirne et al. (2020) focus on climate risk vulnerability and readiness[13] measures from the ND-GAIN indices and revealed that an increase in vulnerability and a decrease in readiness leads to rising sovereign bond yields with these effects being more pronounced in developing countries.

However, this body of literature conflates the potential negative effects climate change can have on society at large through more frequent or severe weather events (physical risk), with the negative economic impacts countries may experience from moving towards a less polluting, greener economies (transition risk).[14]

In a first attempt in the literature to separate physical from transition climate change risk, Beirne et al. (2020) show that transition risk has lower effects in the sovereign bond yields compared to the physical risk, underscoring the fact that transition risk is not well understood and most importantly priced in bond and financial markets. Furthermore, the market does not price climate risk for near-term maturities and bonds with low credit ratings attract higher issuance costs for climate risk coverage as shown by Painter (2020) using municipal bond offerings in US counties. Based on scenario analysis of banking sector sentiments, Dunz et al. (2021) show that government policies and financial regulation can facilitate the transition to a low-carbon economy.

At the firm-level, data from 71 advanced and emerging countries, Kling et al. (2021) have demonstrated that for firms in countries with high exposure to climate change risk, climate vulnerability increases the cost of debt directly and indirectly in the form of restricted access to finance (financial exclusion), while cost of capital is closely associated to the cost of debt. This enforces a climate vulnerability risk premium that leads to lower sovereign (and private)

[11]These are the top 20 nations that are most affected by the catastrophes rooted from climate change. The listed nations are Afghanistan, Bangladesh, Barbados, Bhutan, Costa Rica, Ethiopia, Ghana, Kenya, Kiribati, Madagascar, Maldives, Nepal, Philippines, Rwanda, Saint Lucia, Tanzania, Timor-Leste, Tuvalu, Vanuatu and Vietnam.

[12]Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.

[13]The definition of *readiness* according to the ND-GAIN is "Readiness to make effective use of investments for adaptation actions thanks to a safe and efficient business environment".

[14]For more detailed definitions of physical and transition risk, see https://www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability.

investment and a subsequent curtailing of economic development towards climate adaption of countries. Although Kling et al. (2021) construct an adjusted ND-GAIN climate vulnerability index to control for endogeneity from highly correlated macro-economic variables, the pressing matter of the transition climate change risk has not been addressed.

In this paper, we aim to identify determinants of transition climate change risk by avoiding the combined information of ND-GAIN sub-indices - and similar approaches - which may suffer from endogeneity and lack of time-series variation.[15] We focus on three key transition climate change risk indicators: carbon dioxide emissions, natural resources rents, and renewable energy consumption,[16] which are aligned with specific SDGs. These are variables a country can influence through appropriate climate policy and strategy. Unlike, the vulnerability and readiness that are important risk factors to the physical burden of climate change, we focus on carbon footprint and intensity indicators to understand how countries are currently transitioning to lower carbon economies.

2.1. Carbon dioxide emissions

Greenhouse gases (GHGs) are the primary contributor to climate change, by disturbing the earth's radiative balance and trapping heat in the atmosphere. Of the four main types of greenhouse gases,[17] carbon dioxide accounts for the largest share of radiative forcing – which is the heating effect caused by greenhouse gases in the atmosphere.[18] Literature concerning carbon dioxide emissions, has been well studied alongside economic growth and energy consumption (Sebri and Ben-Salha, 2014, Cowan et al., 2014). Sebri and Ben-Salha (2014) investigate the direction of causality between GDP, electricity consumption and carbon dioxide emissions in BRICS7[19] countries over a period between 1997 –2010. The findings show evidence of a feedback hypothesis for Russia, which has significant implications for energy

[15] ND-GAIN index for individual countries does not offer much variation over time and as such it does not capture neither countries' efforts to combat climate change nor the increase vulnerability as climate continues to change and evidence becomes more abundant.

[16] Climate change indicators are more informative and effective when they capture more detail and considered individually (Lisa et al., 2015).

[17] Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Fluorocarbons (FCs).

[18] Carbon emissions stem from the burning of fossil fuels such as coal, natural gas, and oil for energy use, burning wood and waste materials, and from the manufacturing of cement.

[19] Brazil, Russia, India, China, and South Africa (BRICS).

policies. For instance, in Russia, where electricity consumption causes carbon emissions, policymakers must invest in increasing the efficiency of electricity so emissions can be reduced without negatively effecting GDP. Omri et al. (2014) demonstrate that foreign direct investment (FDI) inflows, energy consumption and output are determinants of carbon dioxide emissions and as such could lead to environmental degradation (see also Marques and Caetano (2020)). These studies are particularly relevant for developing countries, suggesting that depending on the level of external investment, markets may be prioritising economic development through natural resources rather than through renewable energy technologies. According to the environmental transition theory, pollution in developed countries is driven by strong energy consumption associated with urbanization and industrialization (Sadorsky, 2014). Furthermore, the transition from pollution intensive industrial economies to environmentally cleaner economies due to trade liberation could lower carbon dioxide emissions (Kolcava et al., 2019), while harvesting, deforestation and the trade of agricultural products have a material impact on carbon dioxide emissions (Balogh and Jambor, 2017). Aller et al. (2021) identify robust determinants[20] of carbon dioxide emissions per capital using panel data from 92 countries over two decades and confirm the significance of economic and financial development, FDI, international trade and political stability in improving carbon dioxide emissions. Factors such as political stability, corruption control and rule of law on carbon dioxide emissions play an important role in improving environmental quality in terms of development and income and subsequently would attribute to the smoother transition to cleaner economies (Muhammad and Long, 2021).

2.2. Natural resource rents

The World-Bank (2003) defines the economic rent of a natural resource as equal to the value of capital services flows rendered by the natural resources, or their share in the gross operating surplus; its value is given by the value of extraction. Put another way, natural resource rents are the difference between the price at which an output from a resource can be sold and its respective extraction and production costs, including normal return, thus

[20]The determinants are: GDP per capital, the share of fossil fuels in energy consumption, urbanization, industrialization, democratization, the network effects of trade and political polarization. These determinants are typically positively associated with carbon dioxide emissions (except political polarization).

conceptualised as abnormal or super-normal profit (Scherzer and Sinner, 2006). Natural resources result in economic rents because they are not produced, differing from produced goods and services which have competitive forces expanding supply until economic profits are driven to zero.[21] Natural resources on the other hand have a fixed supply and typically generating returns that are well above the cost of production, at an expected increase in carbon emissions levels, as demonstrated by Danish (2020) who investigates the cointegration between natural resource rents, water productivity and international trade, finding all three variables increase carbon emissions levels.

Particular countries have significant earnings coming from economic rents, contributing to a sizable component of the country's GDP. Rents from nonrenewable resources, such as fossil fuels and mineral, over-harvesting forests is in effect borrowing against the future of that country (World-Bank, 2019). The liquidation of the country's capital stock to support current consumption presents an unsustainable component of GDP, demonstrating a tangible transition risk and therefore anticipated positive relation with sovereign bond yield spreads. Clarvis et al. (2014) put forward a framework to integrate natural resources and environmental risks into the sovereign bond market, recognising the financial materiality of these risks to a country's economy. Furthermore, Battison and Monasterolo (2020) introduce a financial pricing model that considers forward-looking climate risk in the valuation of sovereign bond yields. By applying a novel methodology to a portfolio, they find the introduction of climate policy does impact a country's financial stability. In particular, the earlier a country has aligned to climate transition targets, such as those outlined in the Paris Agreement, the lower the yields on their bonds. Conversely, countries who still derived a large portion of revenue from fossil fuel intense industries, had higher sovereign yields.

2.3. Renewable energy consumption

The global energy use in electricity, heat and transport accounts for 73% of the green house gas emissions with additional contribution from agriculture/forestry (18%) and industry (5%).[22] Indeed, global energy transformation and successful transition to clean energy

[21] https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS
[22] See https://ourworldindata.org/ghg-emissions-by-sector

is heavily relying on renewable electricity. Although, renewable energy should be complemented by energy efficiency deployed in industrial, buildings and transport sectors (IRENA, 2019). Along with energy efficiency and renewable energy, "deep" electrification[23] could reduce the energy-related carbon emission by 90% by 2050 (IRENA, 2017).

The transition to 100% renewable-powered economies has become a "near" target for many countries (mostly advanced countries) due to the technological innovations and reduced financial cost of renewable energy deployment. Further, many advanced economies have committed to financially assisting poorer countries with their renewable energy targets (IRENA, 2017). It is well understood that the key to a successful transition towards decarbonisation lies on reducing energy-related CO_2 emissions mainly sourced by renewable electricity. Thus the role of energy governance and energy security is critical on fostering the development and deployment of technology that will accelerate the transformation of the energy sector and increase the renewable electricity share in industry, transport and buildings (Wand et al., 2018, Arroyo and Miguel, 2020).

To quantify the challenges associated with the energy transition in terms of planning, policies and financing, the literature has employed scenario analysis tools[24] to assess the climate change transition risk. Fuss et al. (2012) recognise the importance of uncertainties associated with technological innovation, socio-economic and market conditions, policy implications, and climate sensitivity, on the investment decision making for biomass-based energy. By addressing population and climate change in a global energy mix scenario analysis, Jones and Warner (2016) show that renewable energy plays a vital role in meeting the 2^oC goal. Using a comprehensive scenario analysis, Gielen et al. (2019) demonstrate that growth in renewable energy and increased energy efficiency[25] would be able to provide up to 94% of the emissions reduction needed to meet the targets of the Paris Agreement. Thus, renewable energy consumption is an important indicator of how a country is accelerating the energy transition, while ensuring there is ample energy for economic growth.

[23]Electrification of heat and transport application such as deploying electric vehicles, heat pumps and renewable hydrogen.

[24]Forecast tools are more popular in assessing physical climate change risk, see Kim and Jehanzaib (2020).

[25]Energy efficiency refers to the goal of reducing the amount of energy required to produce the same goods and services (GDP).

We will gauge next the impact of these three climate change transition risk indicators on sovereign bond yields and spreads to support the notion that climate change transition risk serves as a determinant of sovereign borrowing cost.

3. Data and Methodology

3.1. Data

By employing data from 23 advanced countries and 16 developing countries over the period from 2000 to 2019, the relationship between climate transition indicators and sovereign bond yields and yield spreads is analysed. The main variables of interest are sovereign yield and yield spreads on 10-year government bonds. The widely accepted calculation of the yield spread is the difference between the interest rate paid by a country on its external US-denominated debt and the US Treasury bond rate offered on debt of a comparable maturity ((Hilscher and Nosbusch, 2010) and (Capelle-Blancard et al., 2019)). Within this research, the United States 10-year Treasury bond is treated as the 'benchmark' rate, with the yield spread being the difference between the respective country's yield and the benchmark rate. Sovereign yields are extracted from Bloomberg with a yearly frequency (values related to end-of-year).

The data on carbon dioxide emissions is extracted from the Our World in Data dataset and they are sourced from the Global Carbon Project. It is defined as the carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy and cement production where land use change is not included.[26] Using environmental economics data from the World Bank, the natural resources rents[27] variable is defined as the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents and forest rents relative to GDP (World-Bank, 2019). Renewable energy, computed as a percentage of primary energy, refers to the renewable energy technologies' share in the energy mix, whereby energy consumption represents the

[26]The unit is million tonnes of CO_2 (1 tonne of $CO_2 = 3.664\times$ tonnes of carbon)

[27]The World Bank estimates of natural resources rents are calculated as the difference between the price of a commodity and the average cost of producing it. This is done by estimating the price of units of specific commodities and subtracting estimates of average unit costs of extraction or harvesting costs. These unit rents are then multiplied by the physical quantities countries extract or harvest to determine the rents for each commodity as a share of gross domestic product (GDP).

sum of electricity, transport, and heating and is sourced from the Our World in Data.[28] In 2019, around 11% of global primary energy came from renewable technologies.

Consistent with literature on the determinants of sovereign bond yield and spreads, seven control variables are included in the analysis. We consider GDP per capita, Real GDP growth, inflation, Trade Openness and current account balance, which are extracted from the World Bank database. Debt-to-GDP ratio is extracted from the IMF World Economic Outlook database.[29]

3.2. Preliminary Analysis

To inform the selection of countries we consider a set of advanced and developing countries, with the majority becoming signatories of the Paris Agreement. Further, we look to the Germanwatch Climate Change Performance Index (CCPI)[30] to evenly select countries from all performance rating categories – i.e. very low, low, medium, and high climate performance. The full list of countries and their CCPI category rating is available in Table A.2.[31]

[28] Renewable technologies include a combination of hydropower, solar, wind, geothermal, wave, tidal and modern biofuels [traditional biomass – which can be an important energy source in lower-income settings is not included]. Note that this data is based on primary energy calculated by the 'substitution method' which attempts to correct for the inefficiencies in fossil fuel production, by taking all energy sources' energy normalised to EJ – this takes account of the inefficiencies in fossil fuel production and is a better approximation of "final energy" consumption. It does this by converting non-fossil fuel sources to their 'input equivalents': the amount of primary energy that would be required to produce the same amount of energy if it came from fossil fuels. https://ourworldindata.org/renewable-energy

[29] A large body of literature is dedicated in identifying and analysing the determinants of government bond yields and sovereign risk. An early contribution to the literature, Edwards (1983) finds a country's economic fundamentals impacts their ability to pay debt and thus, their cost of debt. Kinoshita (2006), Laubach (2009), Engen and Hubbard (2004) study liquidity and solvency to find a country's debt-to-GDP ratio is positively related to the real long-term government bond yield. Cantor and Packer (1996) find that high economic growth rates allow a country to service their debt easier, thus reducing their sovereign bond yield and credit ratings have an independent influence on yields, which is above their correlation with other macroeconomic variables. Also, inflation, seen as a proxy for how well a country manages its fiscal balances, typically increases bond yield spreads (Min, 1998). Similarly, Min (1998) finds a country's terms of trade has a negative effect on yield, as increased export earnings imply a better ability to repay debt. Since the Global Financial Crisis (GFC) and the European Debt Crisis, the relationship between macroeconomic fundamentals and yield spreads seem to have experienced a structural change. Afonso et al. (2015) study Eurozone bonds finding the relationship between European Monetary Union (EMU) sovereign bond yields and macroeconomic fundamentals appears to be time varying.

[30] Germanwatch aims to evaluate countries based on GHG emissions, renewable energy, energy use and climate policy. Using a weighted methodology, countries are ranked in relative terms, with very low indicating a country is managing its transition risk very poorly. More information is available at `https://germanwatch.org/en/CCPI.`

[31] The CCPI rating is compiled by the Country classification of the United Nations, Data sources, country classifications and aggregation, see `https://www.un.org/en/development/desa/policy/wesp/wesp_cur`

It is important to note, a handful of countries included in the developing country group are also referred to emerging economies depending on the source. To ease confusion, emerging countries are grouped into the same category as developing countries for this analysis. Data from 1990 to 2019 was originally collected as part of the sample. Though due to lack of consistency of both economic and climate data for many countries in the early 1990s, the sample period used is 2000 to 2019.[32]

Figure 1 presents the 10-year government bond yields for advanced countries over the span of 2000 to 2019. The bond data begins where it is available for each country. The overall trend for bond yields in the last 20 years is downward. In the early 2000's, most advanced government bonds were priced between 5—9%, compared to recent average yields of 2–4%. Some anomalies in the figure stand out, i.e. between 2010 and 2014, Portugal suffered an economic and financial crisis leading to high unemployment, falling GDP, rising government debt and not surprisingly, increased bond yields. This gives reason to exclude Portugal in robustness checks, as bond yields and economic fundamentals are not performing in the same pattern as the other countries over the same period.

Figure 2 presents the 10-year government bond yields for developing countries. Large variance in the yields can be depicted across all time periods, largely as the emerging country debt market is younger and less sophisticated than that of advanced nations. As the implementation of fiscal and monetary policies has grown, so too has the issuance from these countries. The figure shows where each bond yield starts from, with many countries only issuing their own bonds post 2005. While in the last three years advanced countries rarely yield a cost of borrowing higher than 6%, developing countries have a large dispersion of yields from 0.25% to 18% in the last two years. The difference in yields give reason to separate the results of developing countries and advanced countries for the study.

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rent/2014wesp_country_classification.pdf

[32] We also excluded some countries due to a very sample size such as Kenya, Croatia, Colombia having for example only 4 observations.

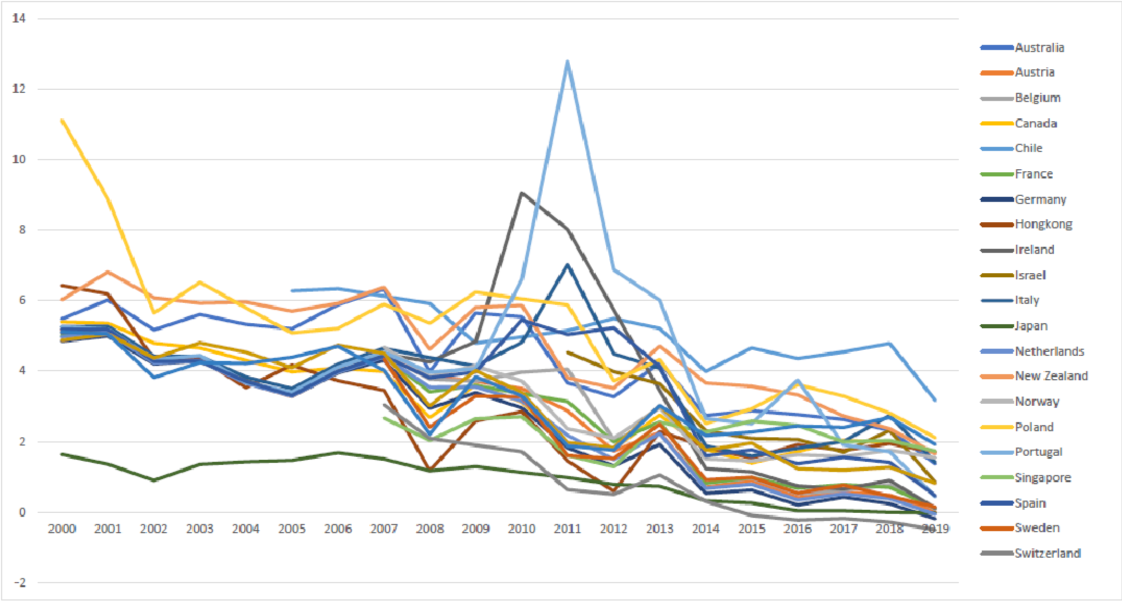


Figure 1: **Sovereign Bond Yields of Advanced Countries**
Figure 1 displays the sovereign bond yields for advanced countries between 2000 and 2019. On the left-axis, yields are in percentage form. The legend on the right-hand side displays the country codes for all countries in the sample.

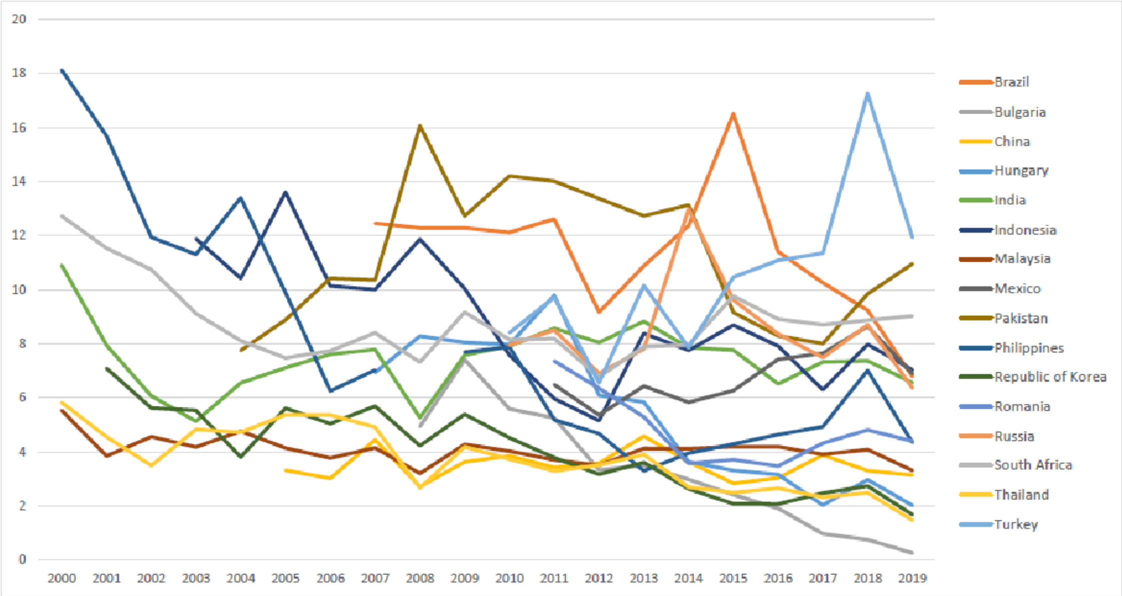


Figure 2: **Sovereign Bond Yields of Developing Countries**
Figure 2 displays the sovereign bond yields for developing countries between 2000 and 2019. On the left-axis, yields are in percentage form. The legend on the right-hand side displays the country codes for all countries in the sample. Many developing countries did not issue bonds prior to 2008, this has been accounted for in the analysis.

Figures 3.a, 3.b, and 3.c show the average carbon dioxide emissions, natural resources rents and renewable energy consumption over time for advanced and developing countries. Figure 3.a reveals developing countries emit significantly more carbon dioxide than advanced countries each year. Although, emissions have incrementally decreased over the sample period for the advanced countries, it is clear more government framework and policy are needed to reduce emissions to zero within this century, with the developing countries also displaying an alarming overall average increase in emissions. Figure 3.b illustrates that developing countries earn a higher percent of GDP from natural resources, averaging around 1–3% higher than advanced countries over the period. Figure 3.c displays the prominence of renewable energy consumption in advanced countries. This is likely due to greater ability to invest in technological innovation to increase the supply and consumption of renewable energy within their respective population.

Table 1 displays the descriptive statistics for sovereign bond yields (and spreads), climate change variables and control variables for all countries, split into country groups in the right two panels. An extended description of the control variables can be found in Appendix A.1.1. Assessment of the statistical properties of the variables warrants common transformations of a square root transform applied to carbon dioxide emissions and natural resources rents and a logarithmic transformation to GDP per capita. Given the country sample size is larger than the time series, i.e. $N > T$: $i \in \{1, \ldots, N\}$, where $N = 37$ and $t \in \{1, \ldots, T\}$, where $T = 20$, and in addition, the time series is not classified as sufficiently large ($T > 30$) a test for the presence of a unit root will be misleading (Baltagi, 2021).

Echoing the visual analysis of the climate change transition variables over time, we observe the comparison of the two country groups in Table 1, revealing expected disparities in macroeconomic characteristics. Developing countries on average have a lower GDP per capita, higher GDP growth rates, higher inflation, less trade openness, and a less favourable current account balance.

Table 1: **Descriptive Statistics of Variables**

The table shows the descriptive statistics for all variables between 2000 and 2019. The statistics are grouped together, then split into advanced and developing country groups. All figures are in percentage form, except GDP per capital which is in thousands of dollars. The square transformation of carbon dioxide emissions and natural resources rents and the log transformation of GDP per capita and trade openness are used in the analysis as explained in Appendix A.1.

	All Countries					Advanced Countries					Developing Countries				
Variables	Obs.	Mean	St.Dev.	Min.	Max.	Obs.	Mean	St.Dev.	Min.	Max.	Obs.	Mean	St.Dev.	Min.	Max.
Bond yields	780	4.46	3.06	-0.50	18.13	460	3.17	1.90	-0.50	12.79	320	6.72	3.37	0.26	18.13
Bond yield spreads	780	1.42	3.01	-3.69	14.57	460	0.01	1.60	-3.69	10.91	320	3.76	3.32	-1.93	14.57
Carbon dioxide emissions (sq)	780	19.20	17.15	5.50	100.87	460	16.66	14.97	5.50	78.31	320	22.85	19.32	6.48	100.87
Natural resources rents (sq)	780	1.18	1.08	0.01	4.62	460	0.80	0.97	0.01	4.62	320	1.74	0.99	0.11	4.53
Renewable energy consumption	780	12.41	14.26	0.02	71.13	460	15.18	16.26	0.02	71.13	320	8.51	9.55	0.23	45.02
GDP per capita (log)	780	10.05	0.78	7.65	11.53	460	10.53	0.38	9.16	11.53	320	9.35	0.67	7.65	10.69
Real GDP growth	780	3.19	2.97	-7.80	25.16	460	2.38	2.59	-5.69	25.16	320	4.36	3.08	-7.80	14.23
Inflation	780	3.49	4.81	-4.48	54.92	460	1.80	1.50	-4.48	9.90	320	5.91	6.58	-1.54	54.92
Debt-to-GDP	780	58.73	36.82	0.05	234.86	460	68.00	42.86	0.05	234.86	320	45.47	19.27	7.45	87.66
Trade openness	780	4.30	0.62	2.99	6.09	460	4.40	0.65	2.99	6.09	320	4.17	0.54	3.10	5.40
Current account balance	780	1.15	6.07	-25.76	27.14	460	1.92	6.44	-11.90	27.14	320	0.05	5.33	-25.76	17.47

To inspect the expected relationship between the 10-year bond yields and each of the transition variables, we calculate the Person's correlation for all countries, displayed in Figure 4. For the majority of the advanced countries carbon dioxide emissions have a positive coefficient in relation to 10-year yields, indicating higher carbon emissions are correlated with higher yields. A notable exception is Australia, which is heavily reliant on the fossil fuel industry and the leader in coal production per capita, producing 1,100% more than the second largest producer per capita (Poland) within our advanced countries universe.[33] Similarly, natural resource rents displays a negative relationship with 10-year bond yeilds with Australia. The expected positive correlation of natural resource rents with yields is observable for almost all other advanced countries. Renewable energy consumption, displays a negative relationship to yields for almost all advanced countries. Climate change transition risk variables exhibit the expected sign of their coefficient, with notable exceptions warranted based on economic drivers.

There is less consistency across the developing countries. A similar rationale for the negative association between carbon dioxide emissions and natural resource rents with 10 year bond yields applies to South Africa, producing 164% more coal per capita than the next largest producer with the developing countries universe considered in this study.[34] The

[33]Source: Our World in Data, BP Statistical Review of World Energy. Ranking of top coal production per capita advanced countries considered in this study, 2019: 1. Australia (144,912 kWh),2. Poland (13,711 kWh), 3. United States (12,072 kWh), 4. Canada (8,278Wh)

[34]Source: Our World in Data, BP Statistical Review of World Energy. Ranking of top coal production per

relationship between 10-year bond yields and renewable energy consumption is more consistent across developing countries compared with the other transition variables. However, the results are less consistent than what is observed in the advanced countries. The difference between the correlations of the two country groups implies that climate transition efforts will be more significant in determining the sovereign yield spreads of advanced countries than for developing countries.

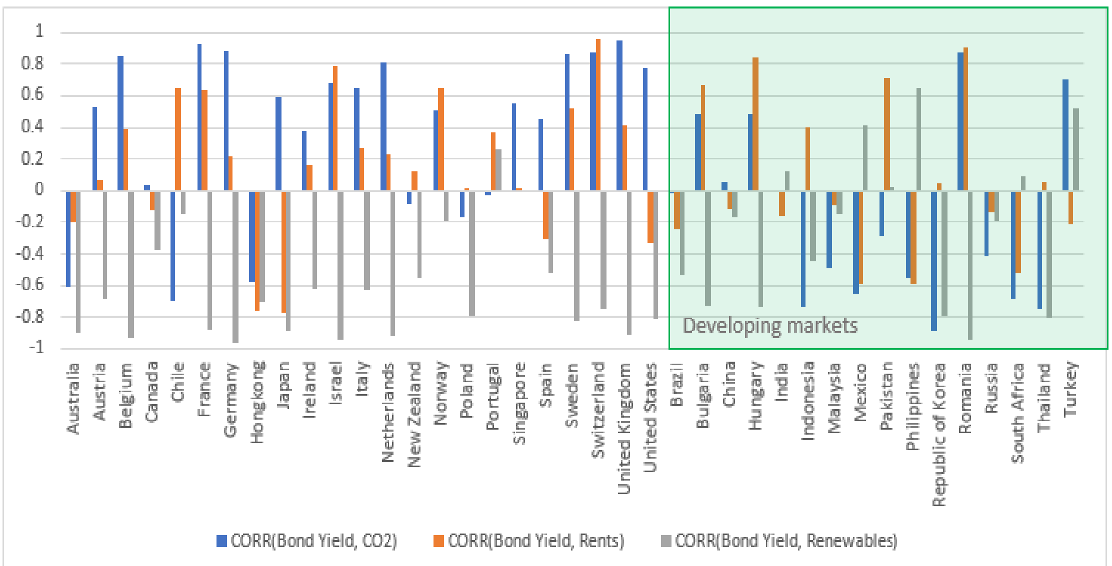
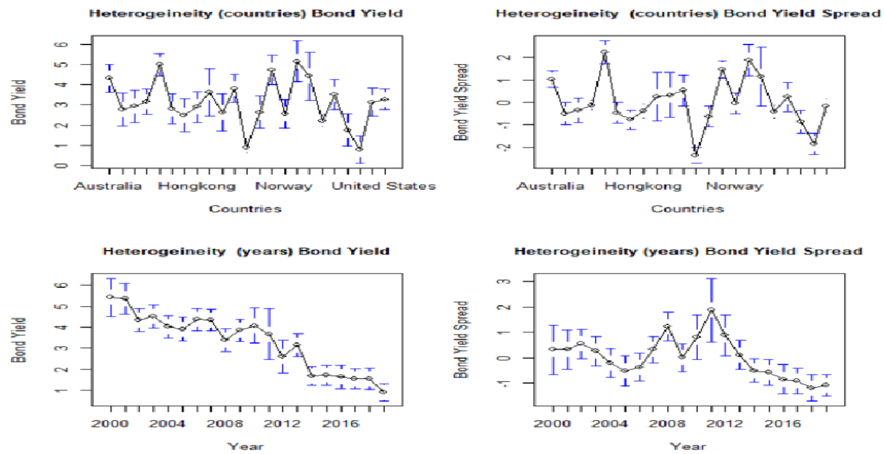


Figure 4: **Country Based Correlations of Bond Yields and Transition Risk Variables for All Countries**
This figure presents the Pearson correlations of the 10 year bond yield with each of the transition risk variables: carbon dioxide emissions, natural resource rents, renewable energy consumption for each country.

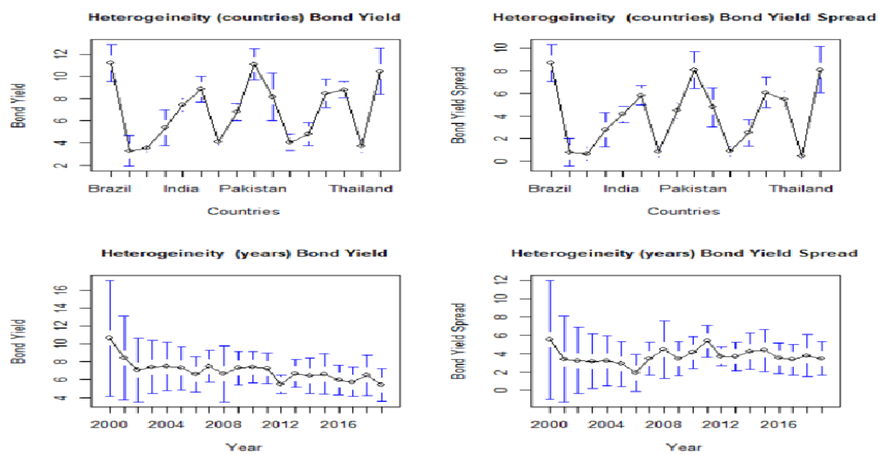
3.3. Methodology

The empirical investigation focuses on examining whether climate change transition risk affects the sovereign borrowing cost across countries and over time. Figure 5 demonstrates the heterogeneity of the sovereign bond yields and spreads over time and across the advanced and the developing country groups justifying the use of panel fixed effects regression as an estimation technique.

capita developing countries considered in this study, 2019: 1. South Africa (28,555 kWh),2. Russia (17,521 kWh), 3. China (15,464 kWh), 4. Indonesia (15,447Wh)



5.a: Advanced Countries



5.b: Developing Countries

Figure 5: **Heterogeneity the sovereign bond yields and spreads across countries and over time** The figure displays the heterogeneity of the sovereign bond yields and spreads for the advanced country group (top panels) and for the developing country group (bottom panels) between 2000 and 2019.

Equation (1) specifies the dependent variable as the 10-year government bond yield, $Y_{i,t}$, for the ith country, $i \in \{1, \dots, N\}$ and time, $t \in \{1, \dots, T\}$.

$$\begin{aligned} Y_{i,t} = &\gamma_1 CO2_{i,t-1} + \gamma_2 Rent_{i,t-1} + \gamma_3 Renewables_{i,t-1} + \beta_1 GDP_{i,t} + \beta_2 Growth_{i,t} + \\ &\beta_3 Inflation_{i,t} + \beta_4 Debt_{i,t} + \beta_5 Trade_{i,t} + \beta_6 Current_{i,t} + \mu_i + \nu_t + e_{i,t}, \end{aligned} \tag{1}$$

where the collection of transition risk variables are: carbon dioxide emissions, $CO2_{i,t-1}$; natural resources rents, $Rents_{i,t-1}$; and renewable energy consumption, $Renewables_{i,t-1}$. The control variables are: GDP per capita, $GDP_{i,t}$; real GDP growth, $Growth_{i,t}$; inflation rate, $Inflation_{i,t}$; debt-to-GDP ratio, $Debt_{i,t}$; trade openness, $Trade_{i,t}$; and the current account to GDP ratio, $Current_{i,t}$. The μ_i are the country-specific intercepts that capture heterogeneity's across countries. The ν_t are the yearly-specific intercepts that capture heterogeneity's across the years. $\epsilon_{i,t}$ are the idiosyncratic error terms.

Equation (2) specifies the dependent variable as the 10-year government bond yield spread, $YS_{i,t}$,

$$\begin{aligned} YS_{i,t} = &\gamma_1 CO2_{i,t-1} + \gamma_2 Rent_{i,t-1} + \gamma_3 Renewables_{i,t-1} + \beta_1 GDP_{i,t} + \beta_2 Growth_{i,t} + \\ &\beta_3 Inflation_{i,t} + \beta_4 Debt_{i,t} + \beta_5 Trade_{i,t} + \beta_6 Current_{i,t} + \mu_i + \nu_t + e_{i,t}. \end{aligned} \tag{2}$$

As specified in (1) and (2) the models are estimated with all transition risk variables included. Additional model estimations is undertaken, whereby the model estimation is performed with the incorporation of each transition risk variable in-turn (inclusive of the control variables).

The choice between fixed and random effects specifications is based on the Hausamn Test (Hausman, 1978). This test compares the two estimators under the null that the model is random effects. If the null hypothesis is rejected than the fixed effects estimator is chosen. The Lagrange Multiplier Test (Breusch-Pagan) (Breusch and Pagan, 1980) testing for time effects for unbalanced panels is also conducted. The results can be found in Appendix A.2.

Robustness of the models is assessed via several sensitivity analyses. This will be an assessment for both country groups, by using alternative dependant variables of the 10-year sovereign bond yields and bond yield spreads. In addition, bond yield spreads are prone to abnormal increases. Impact of countries that may demonstrate abnormal movements will be removed from the sample to assess the potential biases introduced into the results.

In similar empirical literature, it is common to include a lagged dependent variable on the right-hand side of the equation to account for persistence inherent in bond yield spread (Gerlach et al., 2010). However, a major concern with this inclusion is that the lagged dependent variable is serially correlated with the error terms, which makes the OLS estimators biased and inefficient (Baltagi and Chang, 1994). Nickell (1981) finds that while excluding the lagged dependent variable may create omitted variable bias, including it creates an upward bias of its own as the lagged dependent variable is correlated with the fixed effects of the regression. Beck and Katz (2004) find this bias can be reduced if the number of time periods is at least 20. As the sample period is 19 years, and climate data is only available at annual periods, there is neither theoretical nor empirical reason to include the lagged dependent variable, as it is likely highly correlated with the entity and time effects of the panel regressions.

4. Main Results

In this section, we evaluate the impact of carbon dioxide emissions, natural resources rents and renewable energy consumption, as measures of climate change transition risk, on the 10-year sovereign yields and spreads between 2000 and 2019. The estimation results of the models are presented and discussed for advanced and developing countries. We further conduct robustness checks to support the main results and discuss implications for future research.

4.1. Advanced Country Group

Table 2 presents the effects of the climate change transition indicators on the 10-year sovereign yields (left panel) and spreads (right panel) for the advanced country group. In column (1), all three climate change transition indicators are included into the regression, while to test the individual strength of these indicators, each of the climate variables are introduced one at a time in columns (2), (3) and (4). Note that the signs of all significant control variables remain consistent in each regression.

4.1.1. Impact on sovereign yields

We find that carbon dioxide emissions, natural resources rents and renewable energy consumption significantly affect the 10-year sovereign bond yields of advanced countries, see columns (1)-(4) of left panel.[35] More specifically, the coefficient of carbon dioxide emissions

[35] The explanatory power of these regressions is satisfactory with an adjusted R-squared ranging from approximately 55% to 60%.

Table 2: **Sovereign Bond Yields/Spreads and Climate Change Transition Risk - Advanced Countries**

The table reports the estimation results of the panel fixed effects regressions (1) and (2) between the sovereign bond yields and spreads, respectively, and the climate change transition indicators for the group of the developing countries. Country fixed effects and year fixed effects have been used in all regressions. Standard errors are displayed in parentheses; $p < 0.1^{*}$, $p < 0.05^{**}$, $p < 0.01^{***}$.

	Advanced countries							
Dependent variable	Sovereign bond yields				Sovereign bond yield spreads			
	1	2	3	4	1	2	3	4
Carbon dioxide emissions	0.261***	0.267***			0.283**	0.246***		
	(0.091)	(0.072)			(0.119)	(0.087)		
Natural resources rents	0.589**		0.740***		1.230***		1.345***	
	(0.258)		(0.257)		(0.269)		(0.267)	
Renewable energy consumption	-0.008			-0.069**	0.040			-0.041
	(0.036)			(0.029)	(0.040)			(0.030)
GDP per capita	-5.395***	-5.555***	-5.580***	-5.294***	-2.437***	-2.358***	-2.349***	-2.196***
	(0.416)	(0.330)	(0.356)	(0.392)	(0.436)	(0.349)	(0.366)	(0.413)
Real GDP growth	-0.052**	-0.057**	-0.048**	-0.050**	-0.107***	-0.116***	-0.104***	-0.106***
	(0.023)	(0.023)	(0.024)	(0.023)	(0.024)	(0.024)	(0.024)	(0.025)
Inflation	0.124***	0.134***	0.123***	0.121***	0.255***	0.270***	0.244***	0.265***
	(0.045)	(0.043)	(0.045)	(0.044)	(0.047)	(0.046)	(0.046)	(0.047)
Debt-to-GDP	0.016***	0.014***	0.009**	0.012***	0.033***	0.032***	0.029***	0.030***
	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.004)	(0.005)
Trade openness	-1.048	-0.802	-1.021	-0.625	-0.944	-0.522	-0.920	-0.514
	(0.682)	(0.642)	(0.687)	(0.654)	(0.709)	(0.688)	(0.710)	(0.698)
Current account balance	0.016	0.004	-0.003	0.015	-0.014	-0.011	-0.026	0.000
	(0.024)	(0.021)	(0.023)	(0.022)	(0.024)	(0.022)	(0.023)	(0.023)
R^2	0.589	0.630	0.581	0.613	0.349	0.335	0.339	0.318
Adj. R^2	0.552	0.601	0.547	0.583	0.290	0.283	0.285	0.263

ranges between 0.261 and 0.267 and remains highly significant for the two model specifications (see column (1) and (2)). The effect of natural resources rents is also statistically significant at the 1% level, with a positive coefficient ranging between 0.589 and 0.740 (compare columns (1) and (3)). This indicates that advanced countries experiencing an increase in carbon dioxide emissions and/or natural resources rents can expect on average an increase in their sovereign bond yields. In addition, renewable energy consumption (as a percentage of total consumption) is negatively affecting the sovereign bond yields and significant only in model (4) which assesses the individual impact of renewable energy consumption on yields. Thus an increase in renewable energy consumption reduces an advanced country's cost of borrowing by approximately 0.07% an impact that does not remain significant when accounting for the effects of carbon dioxide emissions and natural resources rents.

In an examination of the macroeconomic fundamentals, GDP per capita and real GDP growth display significantly negative coefficients for all models, which is in line with the literature and expected notion that countries with higher GDP and economic growth rates are better equipped to service their central government debt and thus reduce sovereign borrowing cost. Further, inflation is positively and significantly associated with sovereign bond yields, confirming that for advanced economies, changes in the consumer price index serve as strong indicators of sovereign yields. Debt-to-GDP also displays a positive and highly significant effect on yields, suggesting governments with higher debt levels do incur a risk premium on sovereign yields. The trade openness has a negative impact on yields, implying that trade is beneficial for country growth and sustainability thus having ample trade resources gives countries an ability to monetise their comparative advantage and leads to a decrease in yield spread. However, the effect is not significant for sovereign bond yields in advanced countries, the same as the effect of the current account balance on the sovereign bond yields.

These results provide evidence that in advanced economies, carbon dioxide emissions and earnings from natural resources directly increase a country's bond yields, while the negative effects from non-renewable energy also tends to increase sovereign bond yields. The results also support the findings of Chaudhry et al. (2020), that carbon emissions increase sovereign risk both economically and statistically. This allows us to draw a conclusion regarding transition risk - where countries experience an increase in emissions and natural resources rents, they are effectively borrowing against their future, which leads to an increase in sovereign borrowing cost as a result. Secondly, countries who prioritise consuming more renewable energy as part of their total energy mix, are rewarded with a lower cost of debt. Both conclusions align with the goals of the Paris Agreement, i.e. for countries to transition towards renewable technologies and to increase energy efficiency. It is clear from the three transition indicators, that while energy production may contribute to economic growth, it may also increase sovereign borrowing cost, depending on whether it is renewable or not. The findings support moving towards a climate-neutral world, suggesting that by implementing targets to cut emissions from current levels and improve the share of renewable energy in the total energy mix, countries may access fixed income financing at a lower cost. These findings are highly significant for policy makers and governments, as they advocate advanced countries that successfully take action in favour of climate targets, and invest in technological innovation, could in turn drive economic growth through the renewable energy sector.

4.1.2. Impact on sovereign yield spreads

Considering the sovereign bond yield spreads, as a measure of sovereign bond risk, we benchmark the sovereign bond yield of advanced countries against the US aiming to gauge the effects for countries whose yields may be directly or indirectly effected by the US yield curve, with not all countries experiencing this bellwether impact in the same way. The right panel of Table 2 displays the combined and the individual effect of the three climate risk indicators on sovereign yield spreads for the advanced country group.[36]

The carbon dioxide emissions and natural resources rents are positively and significantly related to sovereign bond yield spreads for advanced countries, which is consistent with the impact on sovereign bond yields. Where countries increase their carbon emissions and natural resources rents, they can expect an increase in their sovereign bond risk and borrowing cost. However, the impact of renewable energy consumption is not significant and conclusive, a result that may have been biased by the exclusion of the US dataset. Thus, countries that actively increase their renewable energy consumption (relative to total energy consumption) experience a decrease in the sovereign bond yield, with not a tangible impact on the yield spreads. Further, GDP per capita, real GDP growth inflation and debt-to-GDP are strong indicators of both sovereign bond yields and spreads. These results illustrate that transition efforts – i.e. those that are significant for a country shifting away from carbon-intense resources – do have an impact on sovereign yield and spread in advanced countries. A key implementation phase of the Paris Agreement has begun in 2020 – where countries are due to submit their Nationally Determined Contributions (NDCs).[37] In light of this, the way countries manage climate change transition risk during this time is likely to garner more interest from bondholders. As such we expect markets will price in key transition risks into the evaluation of sovereign yield and spread more significantly in the coming years.

[36]The explanatory power of the yield spreads regressions is lower compared to the regression for the sovereign bond yields, with an adjusted R-squared approximately at 33% compared to almost 60% for the yields. This may be caused by the mandatory exclusion of the US dataset from our sample in constructing the panel data for the bond yield spreads.

[37]Nationally Determined Contributions are a country's intended reduction in greenhouse gas emissions. For example, Switzerland was the first nation to submit their NDC to the Paris Agreement in 2015, with the goal of reducing their greenhouse gas emissions by 50% by 2030, see https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Switzerland.

Table 3: **Sovereign Bond Yields/Spreads and Climate Change Transition Risk - Developing Countries**

The table reports the estimation results of the panel fixed effects regressions (1) and (2) between the sovereign bond yields and spreads, respectively, and the climate change transition indicators for the group of the developing countries. Country fixed effects and year fixed effects have been used in all regressions. Standard errors are displayed in parentheses; $p < 0.1^{*}$, $p < 0.05^{**}$, $p < 0.01^{***}$.

	Developing countries							
Dependent variable	Sovereign bond yields				Sovereign bond yield spreads			
	1	2	3	4	1	2	3	4
Carbon dioxide emissions	0.200***	0.213***			0.183***	0.187***		
	(0.056)	(0.054)			(0.056)	(0.053)		
Natural resources rents	-1.266***		-1.441***		-0.637*		-0.721**	
	(0.342)		(0.346)		(0.344)		(0.344)	
Renewable energy consumption	0.133			0.163**	0.031			0.046
	(0.082)			(0.077)	(0.083)			(0.075)
GDP per capita	-5.916***	-5.480***	-3.846***	-3.870***	-2.517***	-2.443***	-0.751	-0.829*
	(0.706)	(0.655)	(0.479)	(0.467)	(0.710)	(0.634)	(0.476)	(0.453)
Real GDP growth	-0.132**	-0.155***	-0.161***	-0.187***	-0.174***	-0.189***	-0.202***	-0.219***
	(0.055)	(0.053)	(0.055)	(0.054)	(0.054)	(0.055)	(0.056)	(0.055)
Inflation	0.300***	0.262***	0.296***	0.271***	0.297***	0.278***	0.297***	0.282***
	(0.051)	(0.050)	(0.053)	(0.052)	(0.052)	(0.049)	(0.053)	(0.050)
Debt-to-GDP	0.006	0.033**	0.015	0.024	0.030*	0.038***	0.033**	0.038**
	(0.017)	(0.014)	(0.017)	(0.016)	(0.017)	(0.014)	(0.017)	(0.015)
Trade openness	2.519***	1.223	2.813***	1.210	2.286***	1.523*	2.437***	1.543*
	(0.867)	(0.820)	(0.890)	(0.840)	(0.872)	(0.793)	(0.884)	(0.816)
Current account balance	-0.052	-0.068*	-0.077**	-0.113***	-0.081**	-0.092***	-0.108***	-0.126***
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.035)	(0.037)	(0.036)
R^2	0.506	0.469	0.466	0.443	0.420	0.408	0.388	0.374
Adj. R^2	0.445	0.414	0.406	0.385	0.349	0.347	0.320	0.310

4.2. Developing Country Group

Table 3 presents the combined (in column (1)) and the individual effects (in columns (2)–(4)) of the climate change transition risk indicators on the 10-year sovereign yields (left panel) and spreads (right panel) for the developing country group between 2000 and 2019.[38] The results of developed countries are starkly different from advanced countries as explained next.

4.2.1. Impact on sovereign yields

All climate change transition risk indicators are significant in explaining sovereign bond yields in developing countries, but their impact differs to the impact observed in advanced countries. More explicitly, carbon dioxide emissions display a positive and significant coefficient around 0.200 in both specifications (see column (1) and (2)), implying that developing countries with an increase in carbon dioxide emissions, can expect on average an increase in

[38]The explanatory power of these regressions display an adjusted R-squared ranging from approximately 40% for yields and 35% for yield spreads.

their sovereign borrowing cost. Contrasting to advanced countries, natural resources rents is negatively affecting the sovereign bond yield in developing countries (see column (1) and (3)), a result that is statistically significant at the 1% level. Thus, an increase in earnings from natural resources tends to lead to a decline in sovereign bond yield. In a similar vein, renewable energy consumption is positively associated to the sovereign bond yield, and significant at the 5% level in the regression (4) assessing the individual impact. Thus even though natural resources rents and renewable energy consumption are priced in the sovereign bond yields of developing countries, their impact do not motivate alignment with the goals of the Paris Agreement. These results reveal that in developing economies, earnings from natural resources and non-renewable energy consumption tend to, on average, decrease the country's sovereign borrowing cost. Thus bondholders in developing countries consider the pursuit of economic growth and development via existing natural resources as a higher priority than focusing on climate change transition goals. This may also suggest that developing countries may be financially constrained in their capacity to invest in new technologies such as renewables, thus, bondholders consider earnings from natural resources as a sign of better ability to repay sovereign debt.

As expected, all macroeconomic fundamentals considered in the study are significant determinants of the sovereign bond yields in developing countries, including the GDP per capita, real GDP growth, inflation and debt-to-GDP. Contrary to the advanced countries, the trade openness and the current account balance play an important role in determining a country's sovereign borrowing cost. Indeed, trade openness positively effects yield spread, implying that trade in developing countries with substantial trade resources tends to increase their sovereign bond yields, potentially due to financial constrains that do not allow countries to explore the comparative advantage of trade. The effect of the current account balance on the sovereign bond yields is negative, stressing the challenge of developing countries which are more likely on current account deficits and may not have the funds to finance exports and this low balance in turn decreases their sovereign yield spread.

The results underscore the unique challenges faced by low socio-economic countries that experience a greater physical climate risk and vulnerability to natural disasters. In a recent study, Cevik and Jalles (2020) focus on this physical risk, finding higher climate vulnerability significantly increases the sovereign bond yield of developing countries. In comparison, we focus on three key indicators of transition efforts rather than physical environmental conditions. The three indicators selected are parameters a country may strive to change through committing to technology advancement, moving to be less-reliant on fossil-fuel intense industries and consuming cleaner fuel sources. These actions, together with stricter environmental policies can structurally change an economy (Sarkodie and Strezov, 2019). Though implementing these changes is far easier in advanced countries who have the capacity to borrow at a lower cost, have higher GDP per capita and are more resilient to economic shocks. At a UN General Assembly committee meeting, Botswana's delegate cited adverse climate change affects have severely hindered the country's efforts to meet Sustainable Development Goals. To address the changes, the country is developing a climate policy to reduce greenhouse gas emissions by 15% by 2030, though this will fail in its efforts if the country does not receive partnership assistance, financing support and technology transfers (United Nations , 2019). This example supports the results of this paper – the effects of climate change transition risk, with the except of carbon emissions, are not priced into the yield spreads of developing countries. We suggest a number of reasons for this. Firstly, given the future expected cost of transitioning depends on external support which is highly uncertain, market participants may demand to be compensated with higher yields. Further, developing countries yields are often more volatile and can be dominated by shorter term "noise" (for example geopolitical risk), and as such investors may be much more focused on a developing country's ability to repay debt as a function of shorter term factors. And finally, advanced countries have the advantage of favourable economic and political conditions to implement strategies to transition to a lower carbon economy. In contrast, if the high natural resource rents that developing countries command are much higher than the uncertain payoff from transitioning to a carbon neutral economy, and the cost of transitioning is prohibitive - then it makes sense that investors would not value transition risk exposure favourably.

4.2.2. Impact on sovereign yield spreads

The regression results of the combined (in column (1)) and the individual impact (in columns (2)–(4)) of climate change transition risk on sovereign bond yield spreads for developing countries are displayed in the right panel of Table 3. The significance of carbon dioxide emissions in determining sovereign bond yield spreads remains at the 1% level. Thus, carbon dioxide emissions constitute one of the key determinants of sovereign bond risk in both advanced and developing countries. Similarly to the sovereign bond yields, natural resources rents remain a statistically significant contributor to sovereign bond yield spreads with a negative impact. Potentially, investors in developing countries may be prioritising economic development through natural resources industries rather than other non-renewable energy sources. Furthermore, while renewable energy consumption is not significant for yield spreads (but significant for yields), it presents on average a positive coefficient. This suggests the financial constraint of new technology and renewable energy sources in the short term for developing countries, is a consistent finding within the study. Note that consistently with the results in yields, all macroeconomic control variables are significant and have similar (and stronger) effects on yield spreads. These conclusions are echoed by leaders from the developing countries citing resources may need to be transferred if ambitious Paris Agreement goals are to be achieved (United Nations, 2019). Ultimately, the results and conclusions drawn from the impact of climate change transition risk on developing countries is robust to measures of sovereign bond yields and spreads.

5. Robustness and Sensitivity Analysis

To validate the empirical regression results, several sensitivity analyses are performed.

5.1. All countries results

To make an aggregate assessment of the impact of climate change transition risk on sovereign bond yields and spreads, we also examine the regressions for the full sample of countries, 39 in total. These results are presented in Table 4.[39]

We find that for all countries, carbon dioxide emissions are statistically significant and positively related to both sovereign bond yield and spreads, a relation that also holds for

[39]The explanatory power of these regressions display an adjusted R-squared ranging from approximately 50% for yields and 30% for yield spreads.

Table 4: **Sovereign Bond Yields/Spreads and Climate Change Transition Risk - All Countries**

The table reports the estimation results of the panel fixed effects regressions (1) and (2) between the sovereign bond yields and spreads, respectively, and the climate change transition indicators for all countries. Country fixed effects and year fixed effects have been used in all regressions. Standard errors are displayed in parentheses; $p < 0.1^{*}$, $p < 0.05^{**}$, $p < 0.01^{***}$.

	All countries							
Dependent variable	Sovereign bond yields				Sovereign bond yield spreads			
	1	2	3	4	1	2	3	4
Carbon dioxide emissions	0.264***	0.255***			0.240**	0.221***		
	(0.034)	(0.030)			(0.035)	(0.030)		
Natural resources rents	-0.521***		-0.757***		0.100		-0.113	
	(0.197)		(0.202)		(0.198)		(0.202)	
Renewable energy consumption	0.042			-0.033	0.038			-0.043
	(0.033)			(0.031)	(0.034)			(0.031)
GDP per capita	-6.102***	-5.859***	-4.669***	-4.491***	-2.793***	-2.701***	-1.496***	-1.420***
	(0.360)	(0.284)	(0.285)	(0.297)	(0.366)	(0.285)	(0.284)	(0.291)
Real GDP growth	-0.093***	-0.097***	-0.106***	-0.107***	-0.136***	-0.140***	-0.148***	-0.147***
	(0.024)	(0.023)	(0.025)	(0.025)	(0.024)	(0.023)	(0.025)	(0.024)
Inflation	0.245***	0.234***	0.263***	0.257***	0.288***	0.289***	0.305***	0.308***
	(0.033)	(0.031)	(0.034)	(0.033)	(0.033)	(0.031)	(0.034)	(0.033)
Debt-to-GDP	0.013***	0.017***	0.005***	0.011**	0.032***	0.033***	0.025***	0.030***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
Trade openness	0.742	0.250	0.318	-0.521	0.617	0.621	0.198	-0.042
	(0.538)	(0.492)	(0.557)	(0.517)	(0.542)	(0.494)	(0.556)	(0.511)
Current account balance	-0.013	-0.021	-0.029	-0.031	-0.042**	-0.043**	-0.057***	-0.049**
	(0.021)	(0.019)	(0.021)	(0.021)	(0.021)	(0.019)	(0.021)	(0.020)
R^2	0.501	0.531	0.451	0.466	0.353	0.367	0.295	0.308
Adj. R^2	0.459	0.496	0.407	0.425	0.297	0.319	0.238	0.254

both advanced and developing countries. This underscores the dominant role of carbon dioxide emissions in determining the sovereign bond risk of countries and the positive impact of reduced carbon dioxide emissions in lowering the sovereign borrowing cost. The results for natural resources rents reveal a significant negative relation with the yields, but not with the spreads. Comparing this result with the results over the two country groups of advanced and developing countries, a compelling divergence emerges. Advanced countries reducing their earning from natural resources rents tend to be awarded with lower sovereign borrowing cost, while developing countries that increase their dependence in natural resources are awarded with lower sovereign borrowing cost. The results on renewable energy consumption in all countries level are inconclusive. Yet an increase in renewable energy consumption tends to reduce sovereign borrowing cost for the advanced country group but to increase sovereign borrowing cost for the developing country group. These results suggest an incapacity and unwillingness of developing countries (potentially due to social-economic conditions and financial constraints) to prioritize climate change transition targets and to forgo the short-term financial benefits of dependency on natural resources as well as to invest on new technology such as renewable energy projects.

Table 5: **Advanced Country Group Results – Excluding Portugal**

This table shows the estimation results of the panel fixed effects regression (1) for all advanced countries excluding Portugal. Country fixed effects and year fixed effects are included in the regressions. Standard errors are displayed in parentheses; $p < 0.1^{*}$, $p < 0.05^{**}$, $p < 0.01^{***}$.

Dependent variable	Sovereign bond yields	Sovereign bond yield spreads
Carbon dioxide emissions	0.166**	0.175*
	(0.081)	(0.105)
Natural resources rents	0.485**	1.140***
	(0.225)	(0.234)
Renewable energy consumption	-0.058*	-0.007***
	(0.032)	(0.036)
GDP per capita	-5.162***	-2.227***
	(0.367)	(0.382)
Real GDP growth	-0.039*	-0.092***
	(0.021)	(0.021)
Inflation	0.075*	0.199***
	(0.040)	(0.041)
Debt-to-GDP	0.009*	0.026***
	(0.004)	(0.004)
Trade openness	-0.568	-0.478
	(0.600)	(0.619)
Current account balance	0.012	-0.022
	(0.022)	(0.022)
R^2	0.666	0.373
Adj. R^2	0.635	0.316

5.2. Exclude Portugal

As a sensitivity check, Portugal is removed from the advanced country group results to account for the abnormal increase in bond yield spread during the period of 2010 – 2014. As previously noted in Section 3.2, Portugal faced a unique economic and financial crisis, making its yield curve an outlier compared to other countries over the same period. The regression results for sovereign bond yields and spreads is displayed in Table 5.[40]

We find that all three climate change transition risk indicators are statistically significant with carbon dioxide emissions and natural resources rents positively associated with yields and spreads (consistent with the result of the advanced country group). The impact of the renewable energy consumption is also significant and stronger in the new regressions. These results further substantiate the finding that transition efforts do impact sovereign yield and spread in advanced economies.

[40]The adjusted R^2 are higher at 63.5% in these regressions compared to the 55.2% when Portugal was included in the advanced country group regressions.

6. Conclusion and Policy Implications

Since the inauguration of the Paris Agreement, investors have become more focused on understanding the impact of climate change risks on sovereign debt markets. A limited body of literature has examined the impacts of physical climate risk, such as a country's vulnerability and resilience to climate shocks and its effect on sovereign bond yield (Beirne et al., 2020, Cevik and Jalles, 2020, Kling et al., 2018). As many of these physical risks are largely associated with geographic location and vulnerability to natural disasters, it is important to explore the impact of climate change transition risk, i.e. the short-term opportunity cost of decreasing reliance on fossil-fuel intense industries, and focusing on renewable energy supply and consumption, on sovereign bond yields as well.

This paper assesses the significance of carbon dioxide emissions, natural resources rents and renewable energy as a key component in sovereign bond yield and spreads. These variables are regressed, along with conventional macroeconomic fundamentals, on sovereign yield spread for a sample of 39 countries between 2000 and 2019. The sample includes both advanced and developing countries, with a diverse range of countries rated from poor to satisfactory climate performance. We find a strong positive association between carbon dioxide emissions and sovereign yields and spread in both country groups. Further for advanced markets, natural resource rents have a strong positive association, while renewable energy has a negative association with yields and spreads. In contrast, in developing markets natural resource rents are negatively associated and renewable energy positively associated with yields and spreads. Developing economies are less likely to have the resources to facilitate a transition from fossil fuel reliance to renewables, thus they seem to not prioritise climate change targets. The negative association between resource rents may be explained by the relatively high natural resource rents that developing markets earn when compared to the high cost of transitioning to a clean economy. Investors may be valuing the net present value of the payoff from a transition to renewables at less than that of natural resource rents (over the nearer term). In which case, it may be these countries who suffer greater transition opportunity costs over the longer term. This research supports the finding that investors in sovereign bond markets do price climate change transition risk factors in the evaluation of sovereign risk.

The evidence presented in this paper has clear implications for policymakers. The results provide support that prioritising renewable energy supply and consumption, while forgoing any short-term opportunity cost of decreased revenue from natural resources would have the benefit of lowering the cost to borrow in the sovereign debt market. Cheaper financing may counteract any short-term losses that industries may face from the revaluation of assets. Further, the savings made on funding could be invested into renewables technology and a just transition away from industries in decline such as the fossil fuel industry. While our analysis considers transition risk and macro fundamentals as drivers of yields, it may be that other non financial goals are also being considered by investors. For example, a country's reputation in climate risk management may impact demand for its debt. Swedish Central Bank is one of the first central banks to divest from government assets from issuers who have a high climate footprint, even if macroeconomic fundamentals are favourable. Looking to the future, governments who perform poorly in managing their climate change transition may encounter difficulty in finding investors to buy their sovereign debt. If this were the case, liquidity may become an issue, which would likely increase sovereign yield spread. In a scenario where a country may experience severe climate shocks or natural disasters, this increased yield spread, could have ripple effects on a country's ability to finance its economic recovery.

Furthermore, there is growing awareness that timely implementation of climate policies is necessary to achieve climate targets. The findings of this paper give sovereign bond market participants a clear case to request for greater government transparency regarding specific climate risk, strategy and policy that is inherently linked to the bonds they issue. For now, the approach used in this analysis gives bond fund managers, investors, and policy makers a way to assess a country's transition risk that aligns directly with the Sustainable Development Goals, with the advantage of using publicly available data sources.

Ultimately, when Mark Carney spoke the words "climate change is a tragedy of the horizon which imposes a cost on future generations that the current one has no direct incentive to fix"(Carney, 2015, page 3), he may not have realised that sovereign debt markets were already beginning to directly impose a cost for climate transition risk. In summary, carbon dioxide emissions and natural resources not only negatively effect the environment and inhibit progression towards climate goals, they also increase a country's cost to borrow in debt markets. Just as importantly, renewable energy is an economically and statistically significant mitigation strategy, as supply and consumption of clean fuel sources could drive economic growth counteracting any short-term financial losses from the non-renewable energy sector.

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Appendix A. Appendix

Appendix A.1. Variables

Table A.1: **Description of Variables**

The table lists the variables used in the study with a brief description of the variables and their data source.

Variable	Data Source	Definition
Sovereign bond yield	Bloomberg	A country's 10-year bond yield
Sovereign bond spread	Bloomberg	A country's 10-year bond yield minus the US treasury bond of the same maturity
Carbon dioxide emissions	Our World in Data	CO_2 emissions from the burning of fossil fuels for energy and cement production
Natural resources rents	World Bank	Sum of oil, natural gas, coal, mineral and forest rents, divided by GDP
Renewable energy consumption	Our World in Data	Renewable energy consumption (% of total final energy consumption)
GDP per capita	World Bank	the current international dollars GDP divided by the mid-year population.
Real GDP growth	World Bank	A country's growth rate based on real GDP figures
Inflation	World Bank	Year-on-year percentage change in Consumer Price Index
Debt-to-GDP IMF	World Economics Outlook Database	Central government gross debt divided by GDP
Trade openness	World Bank	Sum of Exports and Imports divided by GDP
Current account balance	World Bank	Current account balance divided by GDP

Appendix A.1.1. Extended description of control variables

Consistent with the literature on the determinants of sovereign bond yield and spread, seven control variables are included in the fixed effects regression analysis. This section provides, additional description of expected relation to sovereign yield spread. Control variables *GDP per capita*, *Real GDP growth*, *inflation*, *Trade Openness* and *current account balance* are extracted from the World Bank database. *Debt-to-GDP* ratio is extracted from the IMF World Economic Outlook database. For summarised definitions of the control variables please refer to Table A.1.

Gross Domestic Product (GDP), *GDP per capita*, measures the total monetary value of all goods and services produced in a country in each period and it is the current international dollars GDP divided by the mid-year population. It is converted by a purchasing power parity conversion factor that controls for price level differences between countries.[41] The coefficient of this estimator is expected to be negative, as a higher GDP per capita indicates a more favourable economic position, and as a result, a lower sovereign yield spread as the country is better able to service its debt.

Real GDP growth is the annual percentage growth rate of GDP at market prices based on constant local currency, which measures the year-on-year percent change in productivity across the sample countries. Constant series are used to measure the true growth of a series, i.e. adjusting for the effects of price inflation. In contrast, current series are influenced by the effect of price inflation. Higher GDP growth rates in countries are expected to have a negative association with sovereign yield spread, as as they are better equipped to service debt in the future (Cantor and Packer, 1996).

[41] The per capita values for gross domestic product (GDP) are expressed in current international dollars converted by purchasing power parity (PPP) conversion factor. The conversion factor is a spatial price deflator and currency converter that controls for price level differences between countries. Total population is a mid-year population based on the de facto definition of population, which counts all residents regardless of legal status or citizenship.

The *inflation* measure is calculated as the percent change in the Consumer Price Index (CPI), which measures price changes related to the spending pattern and consumption of households. The effect of inflation on bond yield spread remains somewhat ambiguous, as early studies identified inflation as a signal of how well a country can manage its fiscal balances (Min, 1998). The higher the inflation, typically the more economically in-stable the country is. Conversely, countries with higher inflation rates have a larger tax base of which to pay their debt in real terms, which would imply a negative association with yield spread (Nickel et al., 2011). Due to the ambiguity of this effect, the sign coefficient may be different depending on the country group.

The *Debt-to-GDP* ratio is calculated as central government gross debt relative to GDP. Laubach (2009) studies a 30-year sample of government debt and treasury yields, finding a debt-to-GDP has a statistically significant effect on government borrowing cost. The variable is expected to have a positive coefficient sign, as countries with higher debt levels proportional to their GDP are considered less creditworthy and likely to pay a higher cost of debt.

Trade Openness is calculated as the sum of exports plus imports of goods and services as a percent of gross GDP. It measures the scale of trade in an economy relative to the size of that country. Trade openness has a positive effect on economic growth both in the short and long run, particularly for developing countries ((You et al., 2015) and (Keho, 2017)). There is an argument that trade openness may have an effect on the sustainability of a country, as the higher the trade openness, the more a country captures comparative advantages with respect to its own resources. However, some very large economies exhibit low trade openness, e.g. the United States, which may suggest its significance in relation to advanced countries has diminished over time. If one assumes that trade is fundamentally beneficial for growth, which in turn allows countries to monetise their comparative advantages, the estimation of trade openness is expected to contribute to positive sustainability outcomes, thus having a negative association with sovereign yield spread. Signifying that an increase in trade openness, will lead to a decrease sovereign borrowing cost.

A country's *current account balance* is taken relative to GDP. The calculation of current account balance is the total of net exports from goods and services, net primary income, and net secondary income. This variable is expected to negatively affect yield spread, as it indicates a country's competitiveness in the global market and ability to raise money for debt servicing. A current account deficit is more likely to be observed in developing countries, as these countries may not receive enough funds from exports to finance its imports. Hence, a larger current account balance is more favourable, and a lower yield spread is expected to follow any increases to a country's current account.

Appendix A.1.2. Climate Change Performance Index (CCPI) of countries

Table A.2: **Full List of Countries with CCPI Rating**

The table presents a list of the countries used in the study and their Climate Change Performance Index (CCPI). The categorisation of countries as advanced or developing is informed by United Nations country classification. CCPI rating is based on 2019 rankings, as this is the final year of the sample dataset. Very low indicates poor climate performance relative to other countries, similarly very high are indicates high climate performance. NR indicates the country is not rated.

Advanced (23)	*CCPI* Rating	Developing (16)	*CCPI* Rating
Australia	Very low	Brazil	Medium
Austria	Low	Bulgaria	Low
Belgium	Medium	China	Medium
Canada	Very low	Hungary	Low
Chile	NR	India	High
France	High	Indonesia	Low
Germany	Medium	Malaysia	Very low
Hong Kong	NR	Mexico	Medium
Ireland	Very low	Pakistan	NR
Israel	NR	Philippines	NR
Italy	Medium	Republic of Korea	Very low
Japan	Very low	Romania	Medium
Netherlands	Medium	Russian Federation	Very Low
New Zealand	Low	South Africa	Low
Norway	High	Thailand	Low
Poland	Low	Turkey	Very low
Portugal	High		
Singapore	NA		
Spain	Low		
Sweden	High		
Switzerland	High		
United Kingdom	High		
United States	Very low		

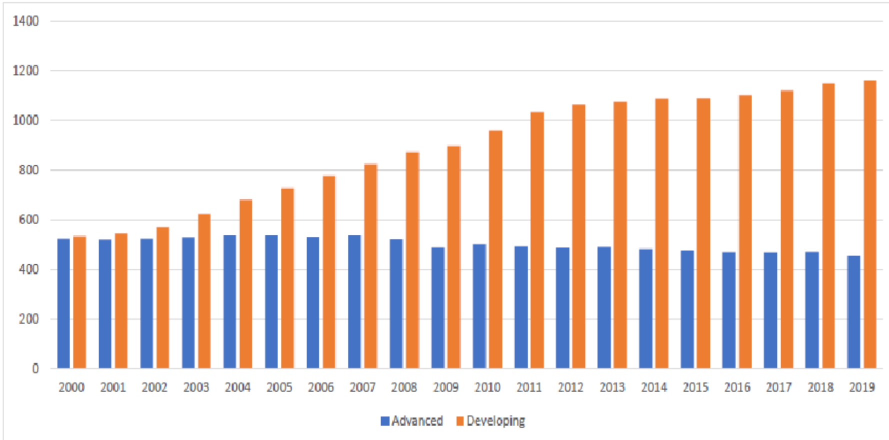
Appendix A.2. Additional Results

The choice between fixed and random effects specifications is based on the Hausamn Test (Hausman, 1978). The Hausman test is based on the comparison of two sets of estimates (Hausman, 1978) Specification testing in panel models in essence involves testing for poolability and for time unobserved effects. This test compares the two estimators under the null that the model is random effects. If the null hypothesis is rejected than the fixed effects estimator is chosen. The Lagrange Multiplier Test (Breusch-Pagan) (Breusch and Pagan, 1980) testing for time effects for unbalanced panels is conducted, along with the F test for individual effects. The results are presented in Table A.3

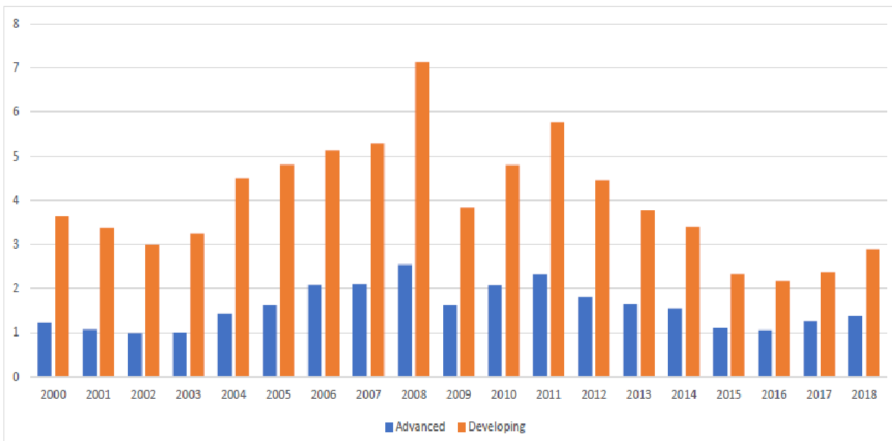
Table A.3: **Hausman Test and Lagrange Multiplier Test (Breusch-Pagan)**

The table displays the Hausman Test and Breusch-Pagan Lagrange multiplier statistics for the advanced and developing country models. We consider both the 10 year bond yield model (1) and 10 year bond yield spread model (2). For all cases the Hausman Test rejects the null hypothesis at the 5% level, therefore we use fixed effects. The Lagrange Multiplier Test (Breusch- Pagan) and likewise the F test rejects the null hypothesis that no time- fixed effects are needed for the advanced countries models and the developing country 10 year bond yield model. However, for the developing countries 10 year yield spread model (2), the Lagrange Multiplier Test fails to reject the null hypothesis, whereas the F-test rejects the null hypothesis. We proceed with using time-fixed effects for all models

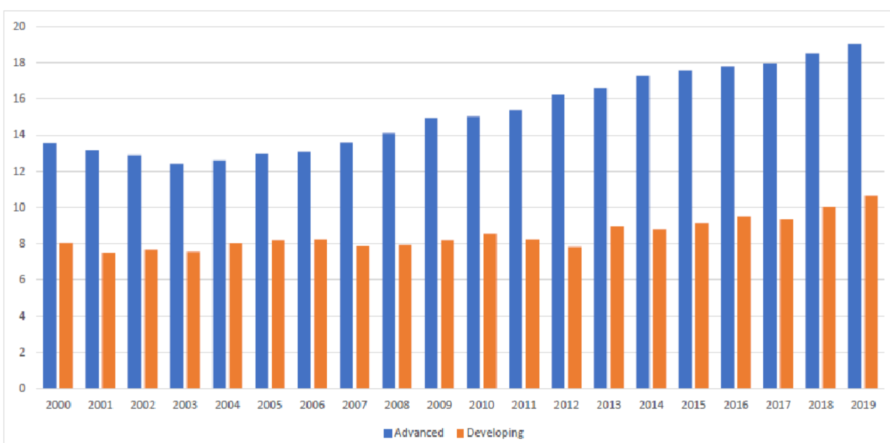
Country	Hausman Test χ^2 test-stat (p-value)	Lagrange Multiplier Test Cχ^2 test-stat (p-value)	F-test F-stat (p-value)
Advanced			
10 Year Bond Yield (full model)	167.52 (¡2.2e-16)	164.86 (¡2.2e-16)	10.009 (¡2.2e-16)
10 Year Bond Yield Spread (full model)	62.879 (3.724e-10)	759.26 (¡2.2e-16)	11.229 (¡2.2e-16)
Developing			
10 Year Bond Yield (full model)	111.69 (¡2.2e-16)	4.3771 (0.03643)	1.8091 (0.02716)
10 Year Bond Yield Spread (full model)	116.21 (2.2e-16)	1.7406 (0.187)	2.1759 (0.005318)



3.a: Mean carbon dioxide emissions



3.b: Mean natural resources rents



3.c: Mean renewable energy consumption

Figure 3: Climate Change Transition Risk Measures
The top panel displays the mean carbon dioxide emissions, the middle panel displays the mean natural resources rents and the bottom panel the the mean renewable energy consumption in advanced countries and in developing countries between 2000 and 2019.