# The Road to Cheaper Debt: Sovereign Bond Yields and Infrastructure Investment


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**2021**

## CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.
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**Date:** 22nd November 2021

[1] I would like to express my gratitude to my supervisors – Kylie-Anne Richards, Kathy Walsh, Christina Nikitopoulos Sklibosios, and Deborah Cotton for their continued support and contributions throughout the thesis process. I am also appreciative of the feedback and support of Vitali Alexeev, our brilliant honours coordinator, and Laura Ryan, my industry mentor. Special thank you to Thomas Matthys for helpful comments.

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**Abstract**

The transition risks of climate change have been quickly incorporated into the risk premiums of assets. This paper challenges that the type of infrastructure that a country invests in can infer its vulnerability to climate change which has implications for sovereign bond markets. I find that the risks and costs associated with climate transition are not uniform across countries, and neither is the involvement in infrastructure as a means to facilitate change. This study addresses this problem by examining the impact of infrastructure investment in 40 countries on sovereign bond yields between 1995 and 2019. This paper uses a panel regression with fixed effects to examine key infrastructure variables, i.e. rail, transport, total infrastructure, and renewable energy. I find a negative relation between renewable energy contribution and both 3-year and 10-year sovereign bond yields. Advanced countries observe more significant impacts on sovereign cost of debt from transitioning towards renewable energy. If government cost of debt can be reduced by improving the emissions profiles of a country's infrastructure, then governments are going to be more likely to encourage substantial innovation and investment in low-carbon infrastructure. These results will benefit decision-makers in infrastructure funding and planning, participants in sovereign bond markets, and climate economists.

**Keywords:** climate change, transition risk, sovereign bond yields, infrastructure, renewables, transport

**JEL Classification:** F34, G15, H54, H63, O18, Q20, Q51

## 1. Introduction

Addressing the risks that climate change poses to countries is costly, but so is ignoring them altogether. There are two forms of climate risk discussed in the literature: physical risks and transitions risks (Carney, 2015). Physical risks include the natural ramifications of sustained global climate change, including the increased frequency of extreme weather events or natural disasters. Transition risks arise from the structural changes in an economy as it adjusts to a low carbon state and can be mitigated through investment into low carbon emitting infrastructure. However, country-level infrastructure landscapes are complex and some countries are better positioned to fund this type of infrastructure. The requirements for infrastructure investment and spending are in a global shortfall of USD 2.5 - 3 trillion annually, with these spending needs being misaligned with the prominent climate mitigation goals introduced in the Paris Agreement and Sustainable Development Goals (SDGs) (OECD et al., 2018). Climate change goals have the potential to be met through sustainable infrastructure investment which can be funded largely by the sovereign bond market. This warrants empirical analysis into the relationship between sovereign bond yields and the investment into infrastructure, forming the main question in this thesis. A nation's investment into climate resilient, low carbon emitting infrastructure reflects how seriously they are approaching the economic and environmental threat of climate change. The transition toward low-carbon infrastructure is further complicated in countries where existing shortfalls are large. As recent literature has revealed linkage between climate risks and sovereign risks (Beinre et al., 2020; Cevik & Jalles, 2020; Kling et al., 2018; Collender et al., 2020), infrastructure investment may provide further economic intuition behind the incorporation of climate risks into sovereign risk.

In 2015, the United Nations Framework Convention on Climate Change (UNFCCC) introduced the Paris Agreement, an international treaty on climate change, under which 196 parties agreed to regulate, monitor, and report emissions. The ultimate aim of the agreement is to limit global warming to 1.5°C ideally to reduce the impacts of climate change (UNFCCC, 2015). Prior to this, the United Nations General Assembly announced the 2030 Agenda for Sustainable Development consisting of 17 goals and 169 targets surrounding five broad themes of people, planet, prosperity, peace, and partnership (UN, 2015). The future outcomes of the Paris Agreement and SDGs are heavily ingrained in today's investment decisions around infrastructure. With approximately 60 percent of the world's carbon emissions coming from infrastructure, it is clear that there are strong ties between infrastructure and climate risks and it is therefore necessary to examine how infrastructure spending is being interpreted in financial markets (OECD et al., 2018).

Infrastructure investment and development has the ability to impact both physical and transition risks. As infrastructure is directly linked to emissions, the type of infrastructure being built can either mitigate or worsen the future physical risks of climate change, such as more frequent and severe natural disasters and climactic warming. For transition risks, the link to infrastructure is clear, as most economies will need to shift towards renewable energy, retire high emitting energy and transport assets, and absorb the costs of this. However, the costs associated with transition are not uniform across countries. In addition, significant investment into technology and research will be required to transition to low-carbon economies.

This research examines the effect of infrastructure spending by countries on sovereign bond yields and assesses the underlying issues around infrastructure and climate risk. In addition, I incorporate the following asymmetries: (i) Countries that still rely heavily on high carbon producing infrastructure have higher climate transition risk, and (ii) Countries that have high infrastructure investment shortfalls have further challenges in addressing low-carbon transitions[2].

To empirically investigate if investment into infrastructure is imputed into sovereign bond yields, I use a panel regression with both time and entity fixed effects and robust standard errors and measure effects on 10 and 3-year sovereign bond yields. The sample includes 40 countries between the years 1995 and 2015. I run each model on subsamples of the 29 advanced and 11 developing countries within the sample. Additionally, 19 out of the 40 countries are broken into two group by their investment shortfall in infrastructure, where countries with higher than a 20 percent shortfall are classified as having a "high" gap. This research places great emphasis on low-carbon infrastructure, which is defined as any infrastructure that reduces $CO_2$ emissions, reduce the use of traditional energy sources, and replace traditional technology with clean alternatives (Saha & Modi, 2017). In the World Bank's report on low-carbon infrastructure, Saha & Modi (2017) use infrastructure projects in renewable energy, rail, and urban public transport as appropriate examples of low-carbon infrastructure. Renewable energy is a clear choice and both rail and public transport have the potential to reduce the use of both cars and trucks which have higher aggregate emissions. I adopt the same definition but only estimate rail and renewables as examples of low-carbon infrastructure to examine if specific infrastructure sectors have ramifications on sovereign bond markets. In total, investment into rail, transport, and total infrastructure are examined alongside two renewable energy investment proxies: renewable contribution to total primary energy supply and renewable tonne of oil equivalent (TOE). I control for various macroeconomic factors and infrastructure-related variables which may have influence on sovereign bond yields outside of infrastructure.

I find that the contribution of renewable energy to total primary energy supply is negatively associated with sovereign bond yields. This implies that countries that have higher proportions of energy sourced from renewable technologies have lower cost of debt on average. For all countries in the sample, a 1 percent increase in 3-year sovereign bond yields corresponded to between 2.55 and 4.27 percent decrease in the use of renewable for energy on average between 1995 and 2019. For 10-year bond yields, this effect is more prominent, corresponding to a decrease of between 3.67 and 4.65 percent. Reflecting the transmission of climate transition risks into the wider economy, a country's shift towards low-carbon energy infrastructure has positive impacts on sovereign cost of debt, ceteris paribus. The same effects on yields are not observed in rail investment, the other form of low-carbon infrastructure.

[2] The Organisation for Economic Co-operation and Development (OECD) find that to build low-carbon, climate change mitigating infrastructure will required 10 percent additional investment per annum. Underlying economic conditions in countries will large shortfalls in existing infrastructure assets will have greater challenges meeting both economic and climate needs given the additional costs of this.

The effect of rail differs depending on bond maturity and the underlying sample of countries. For advanced and low investment gap countries, this relation is also negative but for developing and high investment gap countries the relation is positive. It is likely that the carbon emissions of rail infrastructure cannot be deciphered at an aggregate yearly investment level, though there is potential to re-examine rail investment at the project level to gain better understanding of sustainability criteria. Unlike the three infrastructure investment variables, the contribution of renewable energy has a consistently negative and significant relation with yields, as it provides insight into the transition of an economy's energy infrastructure. Renewable TOE, however, has a consistently positive and significant relation to yields. As the second variable measures absolute supply of renewable energy infrastructure, the positive relation likely arises as it captures not the relative landscape of energy infrastructure in an economy, but rather the overall energy intensity of a country. I also find that the benefits of relative increases in renewable energy are greater for advanced economies.

Analysis on the high investment gap countries proves that there are unique characteristics of countries when examining them on the basis of infrastructure shortfalls that differentiate them beyond advanced or developing status. It is difficult to formulate expectations around how infrastructure will interact with sovereign bond yields when countries have sufficiently sized shortfalls in existing infrastructure assets. I find mixed results for most variables amongst the high investment gap countries[3] across 3-year and 10-year bond yields. For these countries, the effect of renewable contribution on 10-year yields is negative, relatively smaller than other groups, and non-significant. However, the effect on 3-year bond yields is positive and significant at 1 percent in the low-carbon model[4]. For countries with large shortfalls, investment into infrastructure on the basis of climate risks or emissions levels may not be as critical as meeting economic needs.

Interesting findings arise from the introduction of infrastructure quality, a score between zero and seven capturing quality of all infrastructure assets, and maintenance investment in infrastructure. For high gap countries, there is a unique relationship between yields and quality score, where many of the variables that show significance for other groups fail to have any explanatory power amongst these six countries. Quality score is negative and significant at the 1 percent level across both maturities in the high investment gap results. The high gap countries are largely composed of developing economies, making sense of the relation that high yield countries have relatively lower quality of infrastructure. Despite this, it is likely that the models do not account for the complex characteristics of countries that underinvest into infrastructure, creating opportunity for omitted variable bias in all models. Maintenance into infrastructure also shows negative relation to bond yields, though only significant between 5 and 10 percent for developing countries. It is possible that the significance of this variable for developing countries alone signals the greater

[3] High-investment gap countries and their percent shortfall to 2030 include Mexico (55%), Russia (45%), Turkey (45%), United States (35%), Italy (28%), and Chile (22%).
[4] I use four models, a baseline model which includes only macroeconomic, and the remaining three models include both renewables variables, infrastructure controls, and iterate through each of three infrastructure variables. This is to account for high positive correlation between rail, transport, and infrastructure.

importance of existing infrastructure assets to operate normally. Higher yields may be associated with lower maintenance spend as a result of countries not having the ability to financially maintain existing assets by accessing debt markets as advanced countries would.

I conduct two checks on the robustness of my models. I test all models and groups using an alternative dependent variable, the sovereign bond yield spread. Results from these regressions show resounding and significant negative effect in the relation of 10 and 3-year bond yields with renewable contribution. Most variables observe the same or similar effects amongst yield spread results. I also test the sensitivity of the models when removing an influential country, in this case Portugal and Greece. Between 2010 and 2014, both countries were in the midst of financial crises, resulting in substantially higher bond yields across both 3 and 10-year maturities, as well as an inversion of their yield curves in 2011. When removing these from the sample of 40 countries, most variables have similar coefficients or experience slight increases both in value and significance. Overall, the results of the regression analysis with the exclusion of Portugal and Greece further confirm the negative relation between low-carbon infrastructure and sovereign bond yields, though with predominant effects within the renewable energy sector.

Infrastructure is an important pillar in the policy playbook of governments globally, with direct links to 72 percent of the SDG targets either directly or indirectly (Adshead et al., 2019). This research is an important contribution to the existing literature on climate goals and infrastructure and will be of great interest to climate economists. While many countries are already transitioning infrastructure towards low-carbon and efficient alternatives, the main implication of this paper is around how governments can lower their cost of debt through doing so. As the variables in this paper include investment measures composed of public and private funds, governments should further push for institutional participation in infrastructure in order to lower their own transition risk and cost of debt. The 29 advanced economies in the sample reflect that these benefits may be higher for advanced economies, with their greater access to debt markets. For developing countries, the outcomes of initiatives like the Group of Seven's Build Back Better World, which aims to provide infrastructure to low and middle-income countries, appear more critical than ever. Moving forward, governments need to recognise that the emissions profile of their infrastructure assets have wide ramifications on the wider economy, including their own cost of borrowing.

I contribute to a few key areas in this thesis, primarily in the nexus of climate risk and sovereign markets, as infrastructure and its implications has a more limited history in literature. Several recent papers have explored how climate risk factors are interpreted and imputed into sovereign securities, where this paper examines if there is a valid infrastructure narrative to these effects (Beinre et al., 2020; Cevik & Jalles, 2020; Collender et al., 2020; Kling et al., 2018). Collender et al. (2020) most closely resembles my work, as climate transition risks are examined in their effect on sovereign bond yields and yield spread. Using three indicators of climate transition risk, Collender et al. (2020) find similar results in the use of renewable consumption at a country level. By using an alternative measure for renewable energy, renewable contribution, I reaffirm the important assertions in Collender et al. (2020), that lower carbon emissions incur lesser sovereign cost of debt, with particular emphasis on the beneficial effects advanced economies may benefit from. Investment into low-carbon infrastructure, like renewable energy, provides an important transition opportunity for countries to address climate issues with wider economic benefits. This thesis is further related to the examination of climate vulnerability and cost of debt in Kling et al. (2018), examining a large sample of countries with emphasis on vulnerable[5] countries. Kling et al. (2018) control for similar macroeconomic factors that influence cost of debt, measured by bond yields, and find that countries that are at greater vulnerability to climate change exhibit on average 1.17 percent higher cost of debt. Highly relevant to this research question, Kling et al. (2018) also find a significant negative relation between infrastructure (as component of a wider social readiness index) and sovereign bond yields. This further corroborated my findings, which expand into the benefits of energy infrastructure on cost of debt. With regards to the body of literature in this area, I examine how other sectors of infrastructure may have meaningful impacts on cost of debt and the influence of climate risks on sovereign markets.

In this paper, Section 2 provides an overview of the surrounding literature on climate and sovereign risks, in addition to infrastructure and it's financing and climate ramifications. Section 3 describes the model specification and data, with descriptive statistics and diagnostics. Section 4 presents findings on the full sample, advanced, developing, high, and low gap countries in addition to robustness testing and a discussion of the limitations and implications of this research. Section 5 concludes.

[5] Vulnerable countries here refer to member nations of the Climate Vulnerable Forum, founded in 2009 with 20 nations countries who are highly vulnerable to global warming from climate change.

## 2. Literature Review

This review of research ties together several broad topics of relevance to the relationship between sovereign bonds and infrastructure. This section reviews the intersection of climate risk, financial markets, sovereign risk, and concludes with a section covering a wide variety of infrastructure related issues, including private participation in infrastructure, investment gaps, and the relation to climate goals.

### 2.1. Climate Risk & Financial Markets

The implications of climate risks on asset prices have been extensively explored in a variety of settings. In most cases, the risks of climate change negatively affect asset valuations. Bansal et al. (2016) find increases in global temperatures result in a positive risk premium in capital markets, with equity prices reflecting adverse wealth effects today despite the real effects of increased temperatures to be realised in the future. The IMF's (2020) Global Financial Stability report concluded that aggregate equity markets had not been reflective of physical climate risks in equity valuations during 2019, suggesting that climate risks may not be incorporated into investors short-term valuations. The report also documented that equity price reactions to climate disasters are highly contingent on country characteristics like sovereign financial position. This is highly relevant to this study, where it may be challenging to account for unobservable country characteristics that affect both infrastructure spending and sovereign debt markets. In real estate markets, incorporating climate risks into property pricing is heterogeneous among market participants, depending on individual investor characteristics (Baldauf, 2020). In bond markets, forward-looking climate risks have been examined in the pricing of both corporate and sovereign bond portfolios, with most studies focussing on physical climate risks (Kling et al., 2018; Beirne et al., 2020; Cevik & Jalles, 2020). The uncertainty around climate change-driven natural disasters, including type, severity, and frequency of occurrence, was found to create an underestimation of default probability in a bond portfolio ten-fold (Battiston & Monasterolo, 2019). As asset markets are inherently forward-looking, research needs to continue to examine the impacts of climate change. This is particularly important for fixed assets like infrastructure but may be more apparent today in the pricing of highly liquid assets like equities. This research investigates further the interaction of climate risks and sovereign bond markets by inferring transition risk from country-level investment in infrastructure.

Climate risk has been explored in many capacities beyond the incorporation into asset prices or returns (Hjort, 2016). The literature overview conducted by Hjort (2016) outlines keys topics within the areas of climate and finance, including climate change and financial loss, stranded assets, climate risk hedging, decarbonisation, and divestment. Covington and Thamotheram (2015) find that if climate damage results in overall global warming of 4°C or more by 2030 then the permanent losses to any diversified equity portfolios as a direct result of this will amount to between 5 and 20 percent, compared to zero warming scenarios. The recommendation of Covington and Thamotheram (2016) to long-term investors to remedy this downside risk was collective investor activism to promote transition towards renewable energy solutions and to vote on measures that align with decarbonisation – coining the term 'forceful stewardship'.

While only calculating climate damage in equity portfolios, they acknowledge that in the upper ranges of global warming that infrastructure and corporate bonds will likely be materially affected. If physical climate risks are not addressed and warming to the higher ranges of 3 and 4°C occurs, infrastructure asset lives will likely be shortened, aggravating any existing investment shortfalls. Stranded assets are another challenge to financial markets and may arise in the economy as a result from structural changes towards low-carbon solutions, including infrastructure. At-risk assets become "stranded" by losing significant value due to sudden, unforeseen changes in policy, markets, or technology. Robins (2014) identifies that non-renewable energy resources are at high risk of being stranded due to the need to transition to low-carbon alternatives. In 2013, the value at risk for the stock of European coal, gas, and oil were estimated to be between 40 and 60 percent (Robins et al., 2013). It was estimated that to reach the Paris Agreement goal of 2°C of warming that 80 percent of coal reserves, 50 percent of gas reserves, and a third of oil reserves would need to remain untouched (McGlade & Ekins, 2015). This paper explores the intersection of global energy sectors, financial risk, and climate change. The proportion of investment into renewables across countries will be explored as a treatment variable on sovereign bond yields, providing insight into how low-carbon alternatives are affecting sovereign cost of capital.

Estimations around the reserves of non-renewable natural resources and the real threats of stranded assets have sparked much of the research in climate hedging and divestment (Hjort, 2016). The Cambridge Institute for Sustainability Leadership (CISL) in 2015 conducted a study examining the potential to hedge climate risks in portfolios in the short term. Using the Oxford Economics' Global Economic Model, portfolios were stress-tested under various climate scenarios, finding that no hedging strategy can provide coverage of greater than 49 percent against climate risks (CISL, 2015). Additionally, they find that under a "no mitigation" climate policy scenario that a global recession will result where global growth shrinks 0.1 percent each quarter for at least three quarters. Engle et al. (2020) developed a strategy for dynamically hedging climate change news in equity portfolios by developing the Wall Street Journal Climate Change News Index and could overweight portfolios in stocks that react positively to climate news. This study concluded that hedging against climate news is possible, but did not take into account measures of transition risk in a portfolio, instead relying heavily on third-party ESG scores of firms to inform climate exposure (Engle et al., 2020). Divestment from high carbon emitting industries and firms seems the easiest way to limit exposure to climate risks, particularly for the average retail investor. Braungardt et al. (2019) explores the prominent financial and social arguments for and against divestment from the fossil fuel industries. Pro arguments made include that divestment can temper the financial risks of a "bubble" due to climate change, as forewarned by Covington and Thamotheram (2016), due to the generation of stranded assets. In addition, the divestment from fossil fuels may cause a shift towards low-carbon technologies (Braungardt et al., 2019). As for arguments against divestment, Braungardt et al. (2019) lists several societal reasons including the tendency for divestment to be symbolic and without any immediate effect on carbon emissions. Public investment in infrastructure, with a focus on energy and transport, needs to account for the risks of divestment and stranded assets to ensure new infrastructure assets remain cost effective throughout their asset lives.

## 2.2. Climate Risk & Sovereign Risk

The risks of climate change are quickly being explored as additional risk-based determinants of sovereign bond yields. In countries where high vulnerability and low resilience to climate risks was observed, the sovereign bond yields were higher (Beirne et al., 2020). The study examined both the impact of transition and physical risks and found that positive shocks to climate risk vulnerability resulted in sovereign bond yields reacting positively. The impact of climate risks on the sovereign bond market is significantly higher in developing countries, likely due to these countries having a strained ability to mitigate climate risks (Beinre et al., 2020; Cevik & Jalles, 2020; Kling et al., 2018). Concerning a country's cost of borrowing, Kling et al. (2018) also find that higher climate vulnerability results in a higher cost of sovereign debt on average. Using the Notre-Dame Global Adaptation Initiative Indices (ND-GAIN)(Chen et al., 2015) as a measure of climate vulnerability, alongside a dummy variable for countries in the Vulnerable 20 (V20)[6], vulnerable countries had a higher cost of debt by 1.174 percent (Kling et al., 2018). To ensure a wide sample in the cross-country analysis, this research collects any available infrastructure data on the developing countries that most climate-finance research emphasises. The sample includes 11 developing countries[7]. A vulnerable country analysis is critical in the knowledge that USD 4 trillion of the 6.3 trillion required annual infrastructure investment to 2030 is centred in developing regions (New Climate Economy, 2016). Following Kling et al. (2018), Cevik and Jalles (2020) carry forward the use of the ND-GAIN indices in their study of climate shocks and sovereign bonds, with a larger sample of countries and more robust estimation. The main result from Cevik and Jalles (2020) was that climate change vulnerability and the effect on 10-year government bond spreads was statistically significant and positive for all models, with the climate change coefficient being between 0.579 and 2.526. The results also displayed a relatively higher sovereign cost of debt for high vulnerability countries (Cevik and Jalles, 2020).

Clarvis et al. (2014) created the Environmental Risk in Sovereign Credit (E-RISC) framework for examining environmental risk in sovereign bond markets. The E-RISC framework was developed in collaboration with the United Nations Environment Programme Finance Initiative -and Global Footprint Network. Until this framework, there had been limited literature on the integration of environmental risk into sovereign credit ratings. The E-RISC framework consisted of three components: natural resource risks, economic significance of resource risks, and a country's economic resilience. Clarvis et al. (2014) acknowledges that the E-RISC framework was a "start" to hopefully further climate driven frameworks for sovereign credit risk analysis. Further research resulted in in the formulation of E-RISC II which refined

[6] Vulnerable 20 (V20) countries are a bloc of 20 nations formed out of the 2015 Climate Vulnerable Forum whose members are the most susceptible to the physical risks of climate change. Its membership now includes 48 countries of which most are developing economies (Volz & Ahmed, 2020).

[7] The developing country sample includes Bulgaria, Chile, China, Croatia, Hungary, India, Mexico, Poland, Romania, Russia, Turkey.

the original methodology with the intent to make a tool for markets to estimate environmental sovereign risk. Clarvis et al. (2014) motivated the analysis of the link between environmental performance and sovereign credit risk by Boyrie & Pavlova (2020). Using sovereign credit default swaps (CDS) for 50 countries, Boyrie & Pavlova (2020) examine whether the relation between environmental performance (measured by an index) and the credit risk of a country varies by maturity of the securities and fiscal performance. The results reflect a negative relationship between environmental performance and CDS spreads which Boyrie & Pavlova (2020) present as evidence of markets pricing the future consequences of poor environmental performance, measured by air pollution, water quality, etc. Related studies on the incorporation of "ESG" or Environmental, Social, and Governance factors and sovereign credit risk primarily focus on social and governance factors as these are less complex factors to measure (Drut, 2010; Margaretic & Pouget, 2018). This research will add the dimension of infrastructure investment, an important component of all economies, into the consideration of environmental risk and sovereign risk.

### 2.3. Climate Risk & Infrastructure Investment

In the climate-finance nexus, the interaction of infrastructure investment and the economic costs of climate risks has only recently been touched on in literature, primarily from large global organisations. It is likely that climate risks will pose an additional problem to the infrastructure investment process which Bak et al. (2017) find is already troubled by lacking investment. Across all infrastructure sectors the required investment over the next 10-15 years is estimated to be between USD $80-90 trillion, exceeding the value of the current global stock of infrastructure (Bak et al., 2017). Public infrastructure assets have long lifespans, so today's investment decisions have long-term consequences on emissions (OECD, 2020). These investment decisions are crucial considering the IPCC in the 2018 special report on global warming that CO2 emissions need to decline by 45 percent from 2010 levels by 2030 in order to have limited or nil overshoot from 1.5°C of warming (IPCC, 2018). Energy sector infrastructure projects often have long lead times which require even greater foresight of climate risks (Robins, 2014). Moreover, energy sectors are at high risk of being affected by stranded assets in resource sectors – namely coal, oil, and gas. Robins (2014) notes that without access to new pools of capital that there will be large shortages in investment for low-carbon infrastructure. Suppose increased investment gaps result in increased sovereign bond yields as markets perceive these countries will incur greater costs in adapting to climate risks. In that case, governments may too be inclined to encourage private sector investment in infrastructure to lower their cost of borrowing sooner, alleviating some of the funding shortages predicted by Robins (2014). Additional infrastructure issues arise from the physical vulnerability of existing assets. The costs to upgrade and maintain most existing infrastructure are high, creating pressures on the future investment to deliver reliable infrastructure (OECD et al., 2018). Climate change factors add to uncertainty around future infrastructure costs, both in maintaining and adding to the stock of fixed assets (Chester et al., 2020). Ratter et al. (2016) finds that the current impacts of climate change have already resulted in coastal erosion impacting local infrastructure and biodiversity in Comoros, Africa. Whilst there is a range of complexities in examining future investment in infrastructure, quantifying how these risks are incorporated into sovereign bond yields will cement that climate risks are already shaping current markets.

The challenges in meeting infrastructure investment requirements over the coming decades are clear. Low-carbon infrastructure funding will be an even greater challenge to countries. Many global organisations, including the World Bank, OECD, and Bank of International Settlements, have recognised this and simultaneously begun publishing reports that state private funding will be needed where countries are already experiencing funding bottlenecks (Ehlers, 2014). The OECD in 2020 published a report on accessing green infrastructure through private funding and institutional investment, highlighting private funding as a key source to remedy investment gaps worldwide. The report suggested that further securitised infrastructure products can attract investors that seek liquidity, among other incentives to promote investment (OECD, 2020). Globally, the share of public spending in infrastructure is between 87 and 91 percent of all investment, although this varies by region (Fay et al., 2019). In addition, the typical transmission of fiscal stimulus in private sectors is through infrastructure funding, but fiscal constraints and current debt levels in many countries are intensifying infrastructure investment gaps.

The OECD (2020) also examined the conflict between the need to conduct fiscal policy through infrastructure development and reduce climate funding to high carbon industries. When conducting fiscal budgeting towards infrastructure spending, already tightened budgets may not allow for future-proofing of infrastructure assets with climate risks in mind. This effect may be more pronounced with developing countries or countries with high cost of capital. These public policy issues when combined with the low returns on traditional investment vehicles may result in infrastructure projects becoming alternatives for institutional investors, simultaneously opening up private capital to traditionally publicly funded assets and projects (OECD, 2020). Melzter (2016) affirms this recommendation, stating that half of infrastructure investment needs can be met by the private sector. However, Meltzer recognises difficulties in funding low-carbon climate-resilient (LCR) infrastructure as the costs and benefits are realised by different parties at different periods – highlighting a key downside to public-private partnerships (PPPs). Sclar (2015) finds that due to a disconnect between private sector investment pursuits and public sector desire for increase social benefits from infrastructure, the use of PPPs should be restricted. The requirement for high private returns clashes with funding models that aim to maximise long-term sustainable social benefits, leading to inefficient and economically inequitable outcomes. The flow-on effects to the wider economy from private participation in infrastructure (PPI) are still being examined, with Fu & Liu (2018) finding that PPI promotes financial sector development, measured by both share of bank credit and the ratio of bank deposits to GDP. The promotion effect on financial sector was also found to be larger in emerging economies (Fu & Liu, 2018).

The advanced nations that form the Group of 20 (G20) account for 80 percent of global CO2 emissions and there are concerns around the distributional effects of climate policies that have the potential to curb growth in nations with lower levels of emissions (Bak et al., 2017). Bak et al. (2017) outline a set of measures that can combat some of these adverse distributional effects, including wide-spread carbon pricing, sustainable finance, and immensely scaling up the production of low-carbon, climate-resilient infrastructure. Future investments into infrastructure will require clear linkage to the UN's Sustainable Development Goals (SDGs) and with both the global carbon budget and longevity of infrastructure assets in the minds of policy makers. Investing in low-carbon infrastructure now also enables countries to avoid future costs of high carbon emissions and provides time to prepare for the future physical ramifications of climate change (Bak et al., 2017). Bak et al. (2017) identifies key problem areas for countries which hinder low-carbon infrastructure development. The prominent issues include a lack of long-term planning which internalises externalities, lack of established PPP frameworks, bias towards incumbent infrastructure solutions, and lack of ability to carry out efficient projects. Governments will need to address these challenges as a whole to provide efficient infrastructure assets. Using a framework structured around the Agenda for Sustainable Development, Adshead et al. (2019) created indicators that present the environmental performance of infrastructure investments. By using Curaçao to test the indicator, the results of performance indicated that failure to act on infrastructure demand and supply will result in a 28 percent decrease in SDG achievement across the targets to be met by 2030 in the island nation. Infrastructure-related solutions to climate change must also account for transition from a growth-centric economy to a more circular model due to the rare natural materials that are critical to many low-carbon infrastructure projects, primarily renewable energy assets (Jensen et al., 2020). It is evident that low-carbon infrastructure is going to be a major contributor to meeting the SDGs and managing climate risks in the coming decades. This research will attempt to isolate the low-carbon infrastructure investment for the 25 countries in the initial sample to determine if proportionally higher investment into climate change mitigating fixed assets has the effect of lowering a nation's cost of debt.

## 2.4. Hypotheses

The expected outcomes of this study focus on the level of low-carbon investment in an economy and the infrastructure investment gap. A hypothesis regarding the impact of overall infrastructure investment by a country cannot be made without first making a distinction on the nature of the environmental impact of that infrastructure (low-carbon or otherwise). Hence, the hypotheses have been guided by the country groupings and the emission classification of the underlying infrastructure. The three main hypotheses for this research are as follows and apply to both regressions on 10-year and 3-year sovereign bond yields (i.e. Equations 1 and 2 in Section 3.6):

**1.** Low-carbon infrastructure investment will be negatively associated with sovereign bond yields.

**1.1.** Countries investing in sustainable infrastructure will lower their transition risk and cost of debt to reflect this risk.

**2.** The effect of low-carbon infrastructure investment on sovereign bond yields will be greater for advanced countries.

**2.1.** Advanced countries have greater ability to access public debt markets in order to invest in high cost, sustainable infrastructure projects.

**3.** High investment gap countries will have a positive relation between transport and total infrastructure investment (non-low-carbon sectors) and sovereign bond yields.

**3.1.** Countries with higher needs for future infrastructure development may meet infrastructure requirements through traditional unsustainable methods (incurring higher transition costs), and these risks will be priced into sovereign yields.

## 3. Data & Empirical Design

In this section, I detail the data and methodology used to empirically analyse the relation between infrastructure investment and sovereign bond yields. In addition, I discuss descriptive statistics and limitations of the main sample. A complete list of variables can be found in Table A.1 of the Appendix.

### 3.1. Dependent Variables

To find the relation between infrastructure investment and bond yields, we need to select the right variables and proxies on both sides of the regression equation. To get a mix of long and short-term maturities, yearly panel data for 3-year and 10-year sovereign bond yields have been obtained from Bloomberg. Bond yields are taken as the year-end yield for the generic bond variants of each country, each denominated in local currency units. Prior literature has focussed largely on both yields and yield spreads of long-term sovereign bonds, most finding significant effects when examining climate variables (Beinre et al., 2020; Collender et al., 2021; Cevik & Jalles, 2020; Kling et al., 2018). By extending the analysis to include 3-year sovereign bond yields we can ascertain whether the key infrastructure variables, and their climate effects, are more relevant to long or short term markets. Given the short term costs associated with low-carbon infrastructure investment, it may be that there are differing effects depending on the bond maturity.

### 3.2. Independent Variables

Infrastructure investment may impact sovereign cost of debt, measured by bond yields, through the climate risks associated with each type or sector of infrastructure. There are two sets of explanatory variables as part of this research, infrastructure investment variables and proxies for investment into renewable infrastructure. Infrastructure investment is broken down into three variables, measuring total investment into rail, transport, as well as across *all* sectors of infrastructure[8]. The data for the investment variables is sourced from two publicly available datasets to ensure a wide sample of countries and periods are included in the study. The primary data comes from the OECD Infrastructure Indicators and is supplemented by data from the Global Infrastructure Hub (GIHUB) & Oxford Economics 2017 Infrastructure Outlook[9] dataset. The sample is 40 countries[10] between 1995 and 2019.

The initial sample from OECD data consists of all transport infrastructure investment data, collected and distributed annually, and includes roads, rail, air, sea, and inland water (i.e. river and canal transport) infrastructure. This dataset is supplemented using the GIHUB data which reports on further infrastructure sectors and has been used to account for water and information and communication

[8] Additional infrastructure sectors include both water and information and communication technology (ICT).

[9] The Global Infrastructure Outlook is a data tool for countries and businesses to analyse and predict infrastructure trends through to 2040. The tool consists of data compiled by GIHUB and Oxford Economics and includes detailed analysis on infrastructure investment gaps, including additional costs that will arise from the Sustainable Development Goals. Website: https://outlook.gihub.org

[10] The country cross-section includes Australia, Austria, Belgium, Bulgaria, Canada, Chile, China, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

technology (ICT) infrastructure investment data. GIHUB data was not used for all infrastructure sectors as it only accounts for annual data from 2007 to 2018, limiting the potential series. Instead, I use data for water treatment and ICT infrastructure was used to supplement the sample as the OECD does not include these sectors in its definition of infrastructure. Kling et al. (2018) show that ICT infrastructure has an impact on sovereign cost of debt, with ICT infrastructure forming part of the social-readiness index measured as one of the three subindices included in the ND-GAIN. For these reasons, the sample has included these sectors. To get a measure of total infrastructure investment in a country, I aggregate investment across all sectors by merging two datasets to create a best-case measure.

The low-carbon infrastructure investment is measured by the rail investment (mentioned above) and two measures of renewable energy investment. Renewable energy data must be separately sourced from the main infrastructure sample as the OECD does not currently collect energy investment data as a part of its infrastructure indicators. Public transit investment will be excluded from the investment in low-carbon infrastructure as this data is not widely collected by any global agency and reporting by individual countries is not consistent or without large gaps in data. For the purpose of consistency across the countries in the sample, indicators on renewable energy use are collected from the OECD. They include the percentage contribution of renewables to the total primary energy supply (TPES) and the actual measure of renewables contribution to the energy supply, measured in thousand toe (or tonne or oil equivalent). The types of renewable energy technologies reported by the OECD include hydro, solar, geothermal, wind, tide and wave generation. In addition, energy generated from biofuels[11], biogases, as well as the renewable portion of waste at the municipal level is included in the renewable contribution measures (OECD, 2021). These renewable energy indicators cover the full sample of countries provided in the OECD data used to source investment variables and will be used to create two proxies for investment into renewable energy.

Infrastructure is usually examined solely in the global energy sector, potentially due to the difficulties in accounting for the actual infrastructure spending across all sectors. This is particularly true for developing economies (Fay et al., 2019). Fay et al. (2019) developed the first consistent set of estimates for infrastructure spending for low and middle income countries, compiling four datasets to estimate values for 120 countries. Using proxies for actual investment including national accounts data, gross fixed capital formation, and the World Bank's BOOST database, Fay et al. (2019) triangulated succinct data for 2011 infrastructure spending. In this research, I have limited the sample of countries to those for which infrastructure investment is already readily available in one source or can be easily compiled from a few sources and for a suitable time period. This was to ensure the empirical research can be carried out within the time constraints but may result in the sample being biased towards countries whose underlying economic status means that reporting on such indicators is established. The hand-collection of the pooled dataset is another contribution of this research, where the individual datasets (OECD and GIHUB panels)

[11] Biofuels are defined as fuels derived from biomass, including wood, plant waste, ethanol, animal materials and waste, and sulphite lyes (OECD, 2021).

are limited either by country coverage or time-series length. Country-level fixed effects should account for unobservable characteristics.

### 3.3. Control Variables

The relation between infrastructure and sovereign bond yield is also impacted by country-level macroeconomic and infrastructure characteristics. The determinants of sovereign bond yields have been studied in depth in the literature on economic growth, trade, and sovereign risk over the years and these variables will be included in this study as important sources of endogenous variation in sovereign bond yields. The current control variables in this research include GDP (both as a measure of per capita and percentage growth), inflation, balance of trade, national debt (as a percentage of GDP), and the sovereign credit rating. The following paragraphs include a discussion of these controls, including their use in prior literature and their sources.

*i. GDP per capita*

Gross domestic product (GDP) measures the monetary value of all goods and services produced in an economy during a given time period, in this case a year. The per capita measure divides this value by the population level of the economy in the same year, generating a measure which represents the economic output for each person in an economy. Countries with a higher GDP per capita have a greater tax base on which to service debt and will likely result in a lower sovereign bond yield as this improves the credit worthiness of the country (Cantor & Packer, 1996). To account for these effects, I include control for GDP per capita with data sourced from the World Bank database and in local currency units to remain consistent with both yield and infrastructure investment data. Constant currency levels are used for GDP per capita, meaning all values are adjusted for the effects of price inflation with the base year at 2010.

*ii. Real GDP growth*

The real rate of GDP growth is the percentage change year-on-year in productivity that has been adjusted for inflation. Data on real GDP growth is also sourced from the World Bank database. According to Cantor & Packer (1996), higher real GDP growth corresponds to lower sovereign yield spreads as GDP growth indicates an economies future ability to service debt.

*iii. Inflation*

Inflation is represented in this research as the percent change in the Consumer Price Index (CPI), or the change in price of a basket of goods and services. Inflation data is sourced from the World Bank database. Based on a study conducted by Poghosyan (2014), the expected coefficient on inflation should be negative, where a change in inflation results in a deviation from the long-term equilibrium where bond yields react negatively. Differing results across studies on yields and yield spreads mean that the coefficient on inflation in this study may depend on the underlying characteristics of sample countries, i.e. whether they are developing or advanced (Nickel et al., 2011).

*iv. Debt-to-GDP*

Is the ratio of a country's gross central government debt as a percentage of total GDP. Data on Debt-to-GDP is sourced from the International Monetary Fund Global Economic Outlook database. Like inflation, Poghosyan (2014) finds that government bond yields positively react to an increase in debt-to-GDP, specifically a 1 percent increase in debt-to-GDP corresponded to a 2 basis point increase in yields. Laubach (2009) also reports statistically significant effects of debt-to-GDP on government bond yields. As a result, the expected coefficient on debt-to-GDP in this research should also be positive.

*v. Trade Openness Index*

Trade openness is calculated as the sum total of all exports and imports in an economy, taken as a percent of GDP. It is used as a measure of the relative importance of trade to an economy's productivity. Data for Trade Openness across the sample has been sourced from the World Bank database. Trade openness is a particularly relevant variable for developing countries, and has been found to positively economic growth (Keho, 2017). Given the positive growth connotations usually tied to trade outcomes, it is likely that greater trade openness in turn corresponds with lower sovereign bond yields. Countries that have harnessed trade advantages will have relatively higher growth and ability to service debt.

*vi. Current Account Balance*

Like trade openness, the current account balance is taken as a percent of GDP. It measures the sum of the balance of trade (net exports of goods and services), net income from overseas, and net current transfers. It reflects whether a country is a net creditor to the global economy. In relation to sovereign cost of debt, it is expected that current account balance will negatively affect yields as it indicates a country's relative competitiveness and debt servicing capacity. Advanced economies are more likely to have current account surpluses and vice versa for developing countries.

*vii. Sovereign Credit Ratings*

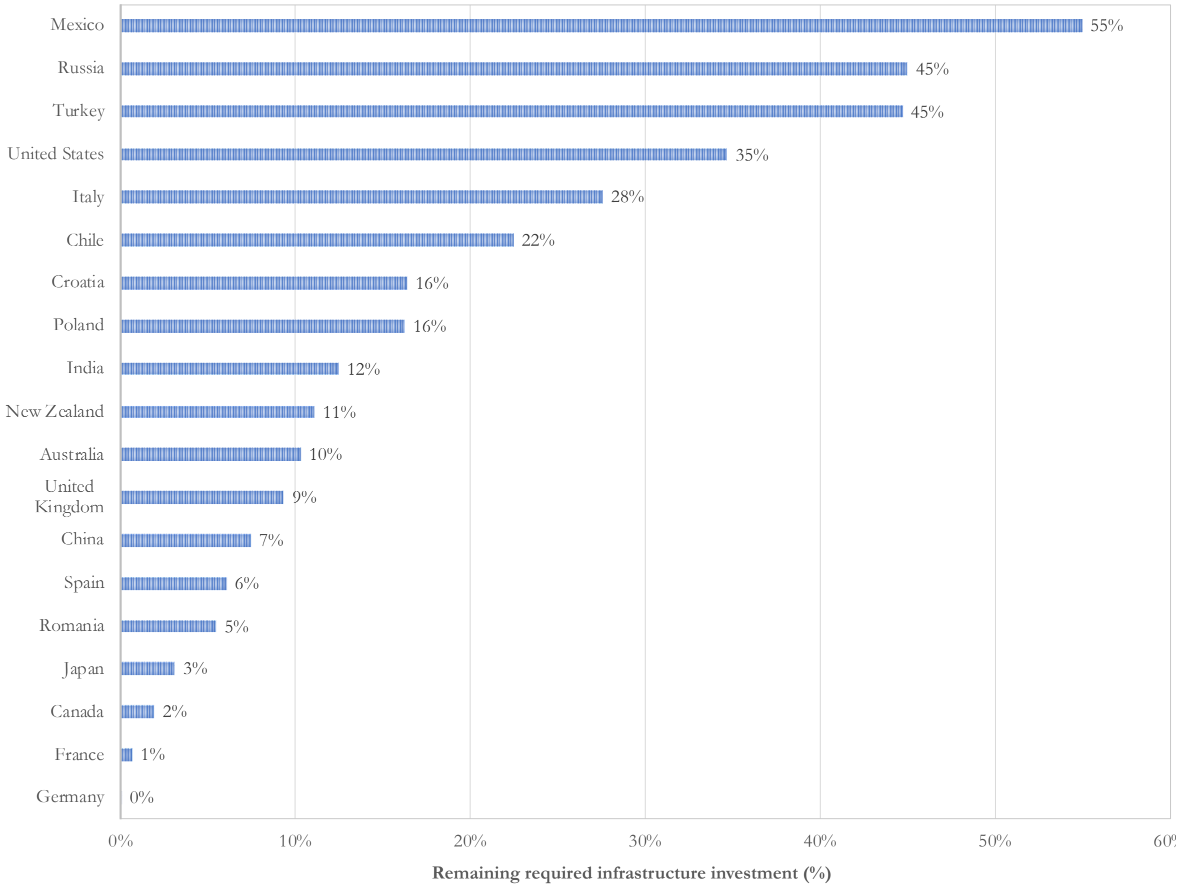
Panel data on credit ratings from Moody's are used as these ratings, compared with those of other agencies like Standard & Poor's and Fitch, include measures of climate transition risk in their methodology. Additional climate risk factors were include as a response to the signing of the Paris Agreement in 2015, and as such these factors are only included in the later part of the series. Cantor & Packer (1996) in an event study show that sovereign credit ratings have significant impacts on bond yield movements, where credit upgrades result in downward pressure and vice versa. In the same manner as Safiullah et al. (2021), a numerical transformation is applied to the yields, whereby 21 translates to a sovereign credit rating of A, descending to 1 which translates to a rating of C. Table A.2 in the Appendix shows all transformations and the labels for each rating (prime, investment grade, and high yield).

In addition to these macroeconomic controls, variables that may influence the existing stock of infrastructure within a country are controlled for in the model, including infrastructure maintenance investment and infrastructure quality. An economy with higher quality infrastructure and regular investment into maintaining existing infrastructure assets has better opportunities to generate income through greater tourism and liveability offerings and better transport networks through which to support trade. As bond yields are partially dependent on economic growth and trade characteristics to control for these effects. Infrastructure maintenance is reported by the OECD alongside other infrastructure indicators, though only for the sectors of infrastructure that is covered in the data. Appropriate data on water and ICT infrastructure maintenance investment could not be sourced as a complement to the OECD data. Quality scores for infrastructure are reported on by the World Economic Forum as part of the wider Global Competitiveness Index. The score refers to overall infrastructure quality, of which includes roads, rail, port, and air transport infrastructure. These variables have not been extensively researched in prior literature, though it is expected that both infrastructure quality and maintenance investment will have a negative relation to yields as it indicates a country is ensuring the full useful life of the existing stock of infrastructure, though this may depend on the country groupings.

### 3.4. Infrastructure Investment Gap

The costs associated with a low-carbon transition in an economy may be further affected by the underlying shortfalls in current infrastructure investment. If a country is only meeting a fraction of its current and future expected requirements of infrastructure based on economic need then it is going to be at a disadvantage when implementing low-carbon alternatives. I use the infrastructure investment gaps (or shortfall) of countries as a means of splicing the sample into two groups, the high and low investment gap countries. The investment gap to 2030 for each country is sourced from data collected by the GIHUB and Oxford Economics (2017) as part of the 2017 Infrastructure Outlook analysis. I implement investment gap data to separate countries into groups, indicating whether a country has a high or low investment gap and run the main panel regression model on both groups. The infrastructure investment gap to 2030 will cover 19 of the 40 countries in the sample (Figure 1). Countries have been separated into high and low groupings if their investment gap to 2030 was greater or less than 20 percent, resulting in 13 countries classified as having a 'low' gap and a further 6 as 'high' gap. The use of a 20 percent cut-off was determined as being a natural separation in the data marking this threshold. This allows for a reasonable spread of countries in each group. The percentage investment gap and classification of each country can be found in Table A.3 in the Appendix. Originally intended as an additional explanatory variable, the infrastructure investment gap (or shortfall) in a country is included as a means to group countries as it is a forecasted measure and not available as a time-series which would have reflected updates to the forecasting inputs.

**Figure 1: Infrastructure Investment Gaps to 2030 by Country**




*Notes:* Figure 1 displays the percentage investment shortfall for the 18 countries in the subsample analysis on investment gaps (Oxford Economics, 2017).

### 3.5. Descriptive Statistics

There are five groups of countries that this analysis will focus on, including advanced and developing countries, high and low infrastructure investment gap countries, and the full sample of 40 countries. Details of the countries contained in each can be found in Table A.4 in the Appendix. As the impact of climate risks on the sovereign bond market is significantly higher in developing countries due to these countries having a limited ability to mitigate climate risks, it will be beneficial to include as many developing economies in this analysis as possible (Beinre et al., 2020; Cevik & Jalles, 2020; Kling et al., 2018). As infrastructure spending data is only available for a select number developing countries in the population, there will be possible selection bias towards advanced economies. Of the 40 countries that form the initial sample in this research, 29 are advanced and 11 are developing (UN, 2020).

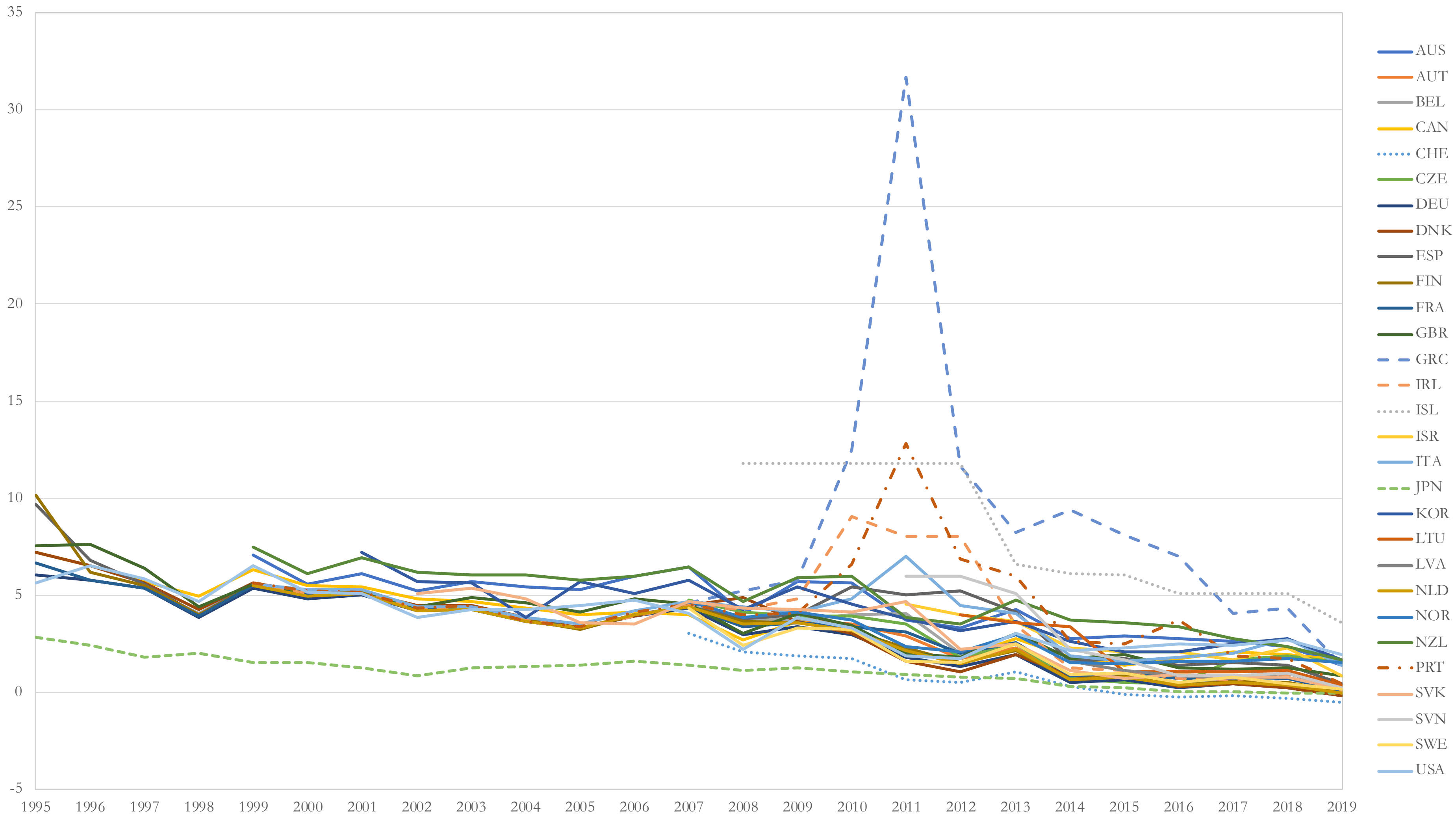
Figures 2 and 3 reflect the 10-year sovereign bond yields for the advanced and developing countries respectively. The availability of sovereign bond yield data is dependent on both when country issuance of sovereign debt commences and when data from Bloomberg became available. As a result the yields of many developing countries commence towards the end of the 1995-2019 series, most around the period surrounding the Global Financial Crisis of 2008-09. Sovereign yields have followed the general trend towards a zero prevalent in many interest rate markets[12] in the 2010's, particularly within the advanced country group. For the purpose of this study, any yields that reach negative values will be removed in order to conduct appropriate transformations to the data. Less than 1% of observations were removed from 10-year yields and less than 10% for 3-year yields, as short-term rates are more affected by monetary policy.

The yields of the advanced group generally remained within an upper bound of 10%, but between 2010 and 2014 yields for many countries spiked, with Greece's yields reaching near 33%. This anomaly clearly illustrates the Greek government debt crisis during this period whereby at its worst, Greece's GDP shrunk 6.9% in 2011 and unemployment grew to 23.1% in 2012. Government debt-to-GDP ballooned to 177% and as a result sovereign bond yields sharply rose for all bond maturities. Portugal experience similar economic conditions during this period. Between 2010 – 2014, Portugal's 10 and 3-year yields spiked due to a financial crisis related to a wider economic downturn. Poor economic conditions commencing in the early 2000's culminated in an economic bailout of Portugal by the European Commission, Eurogroup, and International Monetary Fund in 2011. The same year 10-year yields peaked at nearly 13% and 3-year yields exceeded this at 16%. For the stark contrast of Greece and Portugal's bond yield behaviour, the proposed panel regressions will be tested both including and excluding Greece and Portugal in order to conduct robustness checks.

The 10-year yields for the developing country group show different dynamics to the advanced, primarily in the variance of yields displayed over the series. Firstly, many countries do not have reportable government bond yields until around 2009, in line with the Global Financial Crisis, and the range of yields across the series is between 0.25% and 18%. The general trend of yields is downward, with the exception of Russia and Turkey, but with greater volatility than the observed in the advanced countries. China, Romania, and Croatia's yields reflect trends most consistent with the total sample of countries.

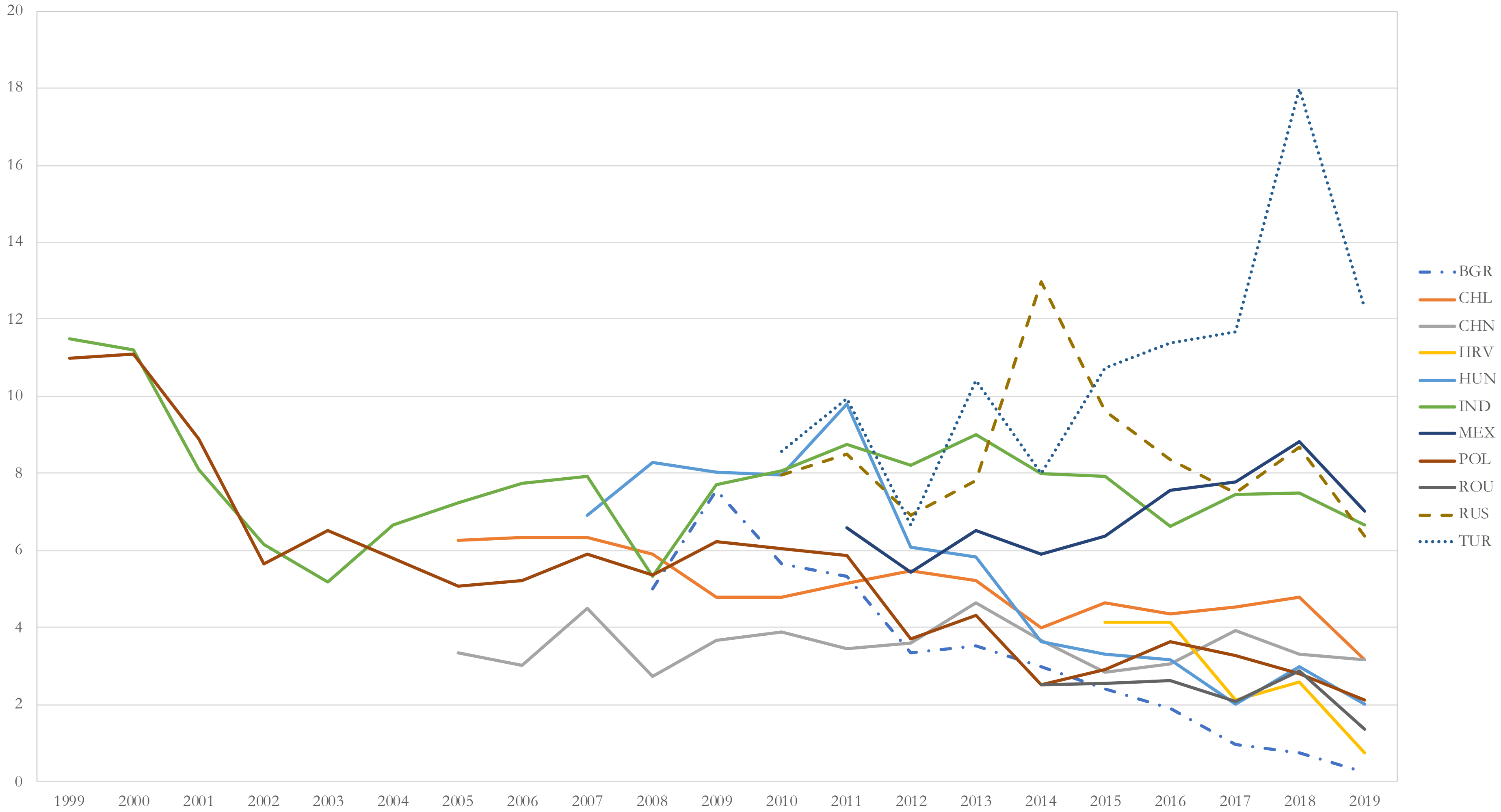
[12] Consecutive accommodative monetary policy decisions by central banks in many advanced markets, particularly European markets, have resulted in zero and sub-zero interest rates over the last 10 years. The desired growth effects on GDP and inflation have failed to realise from these rate cuts, reflecting stagnating inflation and real GDP growth which feed through into sovereign cost of debt.

**Figure 2: 10-Year Sovereign Bond Yields for Advanced Countries, 1995-2019**




*Notes:* Figure 2 presents the 10-year sovereign bond yields for the 29 advanced economies between 1995 and 2019. The left axis reflects the percentage value of the yields. The legend identifies each country according to its country code.

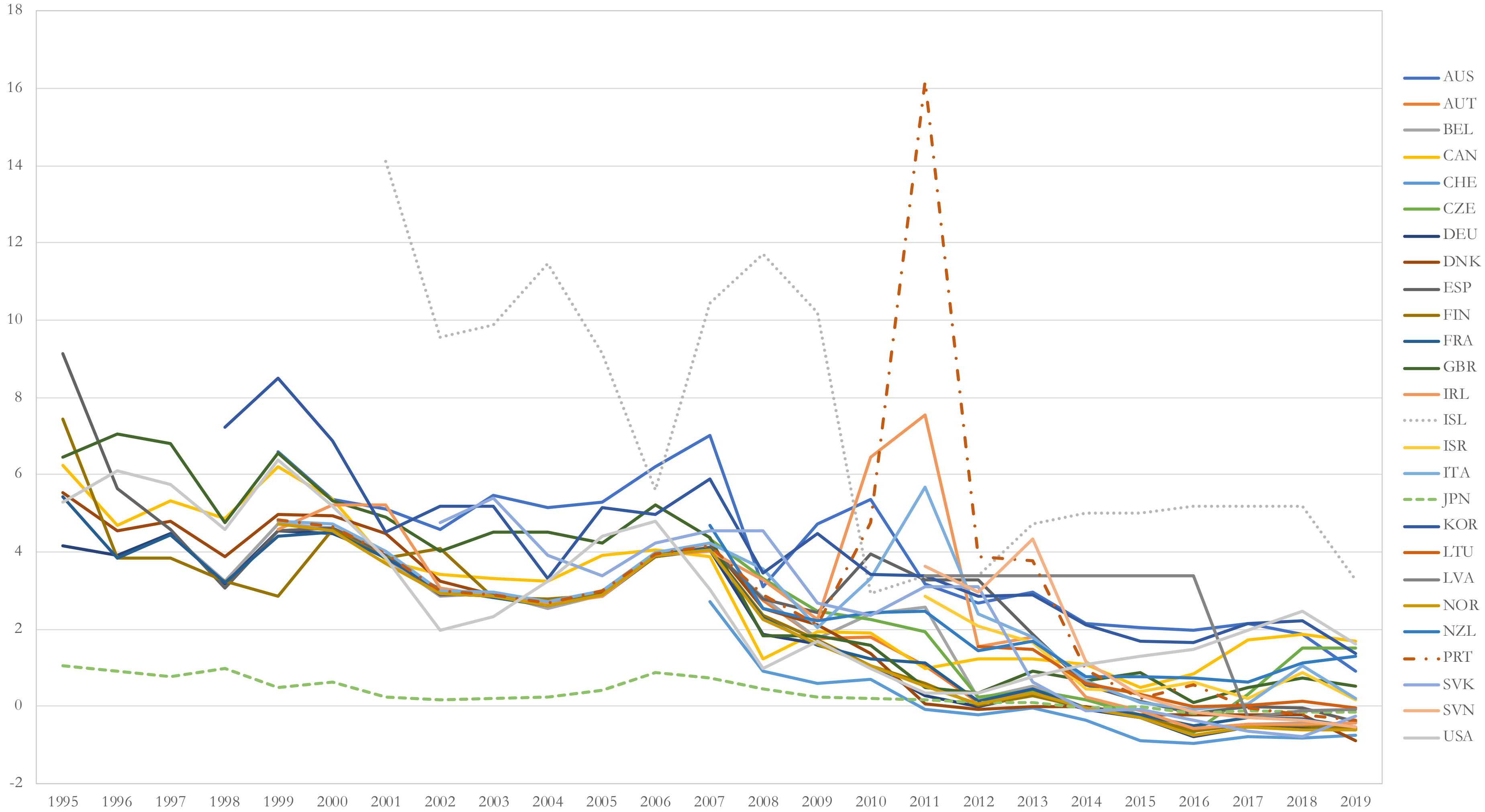
**Figure 3: 10-Year Sovereign Bond Yields for Developing Countries, 1995-2019**




*Notes:* Figure 3 presents the 10-year sovereign bond yields for the 11 developing economies between 1995 and 2019. The left axis reflects the percentage value of the yields. The legend identifies each country according to its country code.

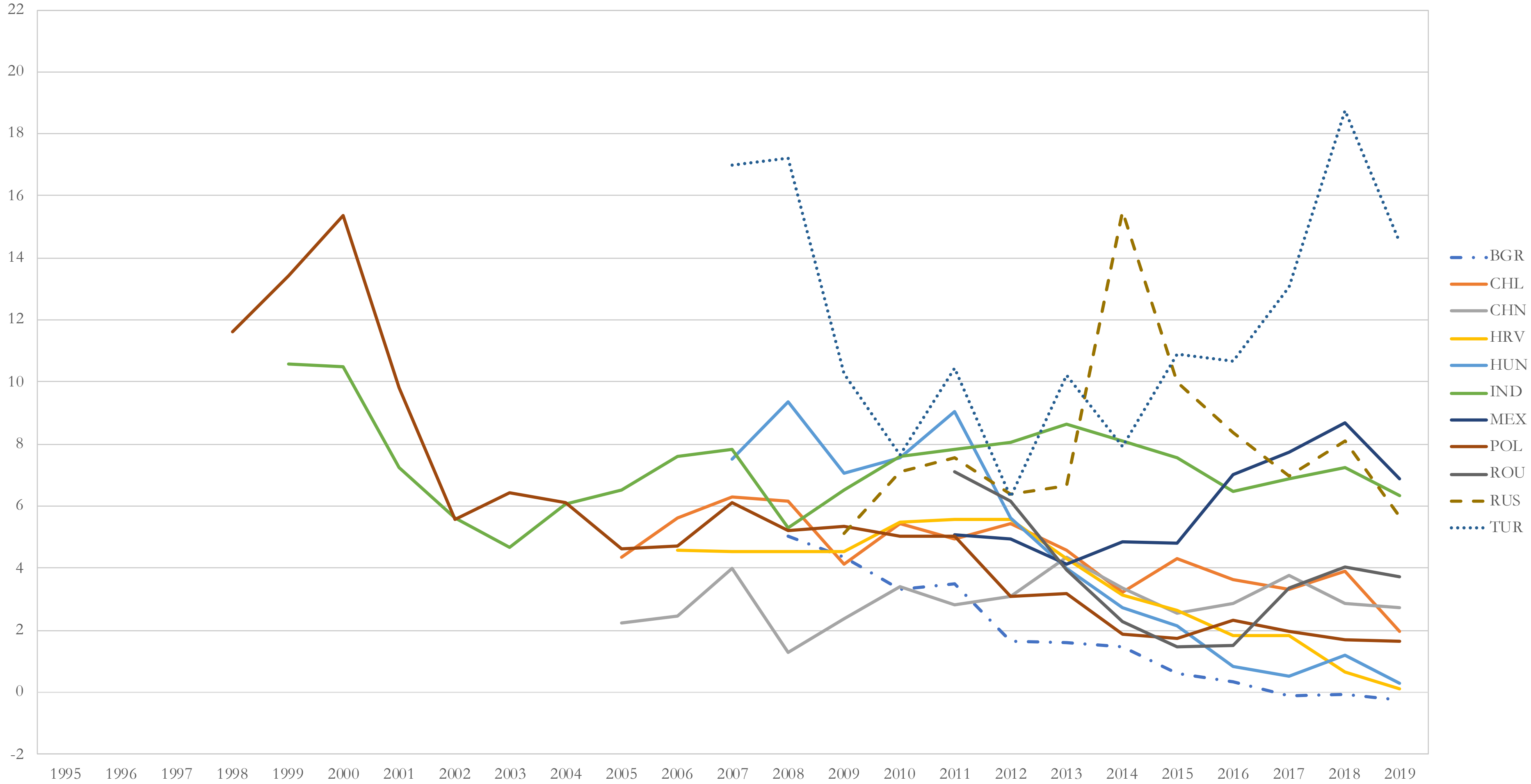
The second dependent variable, 3-year sovereign bond yields, is presented in Figures 4 and 5. Figure 4 presents the 3-year bond yields for advanced countries, where Greece has been excluded due to unusual bond yield spikes from economic crises and this will more accurately illustrate the dynamics of the rest of the advanced group counties. Much like the 10-year yields, Greece's 3-year bond yields across the 2010 to 2014 period rose drastically, peaking in 2012 at 107%. A comparison of the 10 and 3-year yields for advanced countries (Figures 2 & 4) shows a similar pattern of decline, again with a clear spike in 2011 to 2012 for Portugal at just over 16%, due to the aforementioned economic crisis during this time, and Iceland slightly before this between 2006 and 2008.. The breaching of the sub-zero yields occurs sooner for the 3-year yields, commencing with Denmark in 2011. Most 3-year yields for the advanced group remain within an upper bound of 8%. For the developing country group (Figure 5), 3-year yields have greater variance, reflecting the lesser maturity of the emerging debt markets in comparison to those in advanced countries. Again, the developing yields exist towards the end of the 1995 to 2019 time series as issuance arises from these countries. Many countries began issuing their own debt securities in the wake of the Global Financial Crisis, with the final countries to issue 3-year government bond being Romania and Mexico in 2011. The highly dispersed yields of the 11 countries in this group exist between a range between -0.1% and 18.7%. Across both the 10 and 3-year bond yields series, yields in the advanced group are significantly lower particularly in recent years.

**Figure 4: 3-Year Sovereign Bond Yields for Advanced Countries, 1995-2019**




*Notes:* Figure 4 presents the 3-year sovereign bond yields for the 29 advanced economies between 1995 and 2019. The left axis reflects the percentage value of the yields. The legend identifies each country according to its country code.

**Figure 5: 3-Year Sovereign Bond Yields for Developing Countries, 1995-2019**

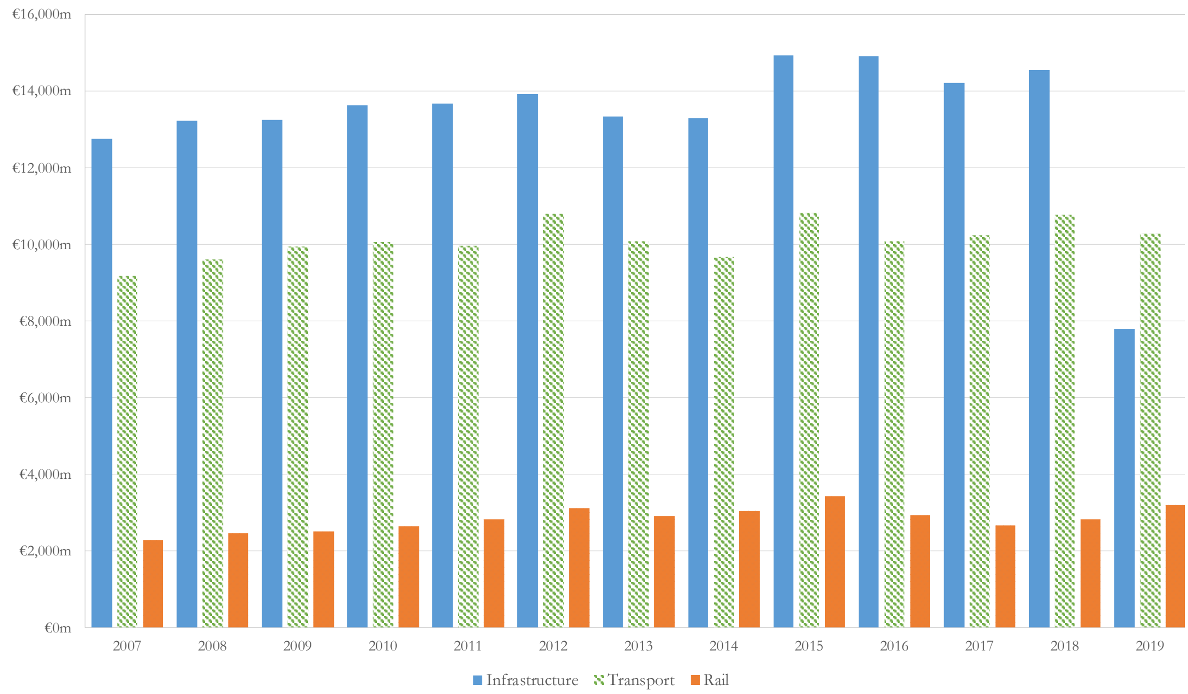



*Notes:* Figure 5 presents the 3-year sovereign bond yields for the 11 developing economies between 1995 and 2019. The left axis reflects the percentage value of the yields. The legend identifies each country according to its country code.

Figure 6 and 7 show the mean levels of infrastructure, transport, rail, and maintenance investment for the advanced and developing countries, between the years 2007 and 2019[13]. All investment values are represented in Euro, the original currency in which the available OECD data is denominated, to illustrate the various investment levels across countries. The advanced countries represented in Figure 6 display relatively stable levels of investment, both in the absolute terms and relative to the individual sectors. The decline in total infrastructure investment between 2018 and 2019 is due to underlying data. The Global Infrastructure Hub data on water and ICT infrastructure has not been updated for 2019 and hence mean levels will be lower than previous years for 2019.

Overall, total infrastructure shows a slight increase over 2007 to 2018, suggesting that most advanced economies have stable infrastructure portfolios. This enables higher income nations to stagger their redevelopment of older transport, water, and ICT infrastructure assets. Figure 6 also represents that rail investment makes up around one quarter to a third at most of total transport investment. As many of the advanced economies in the sample are still heavily reliant on road transport, which is a relatively higher emitter, it is evident that the additional investments into infrastructure are not entirely low-carbon alternatives.

**Figure 6: Mean Infrastructure Investment for Advanced Countries, 2007-2019**

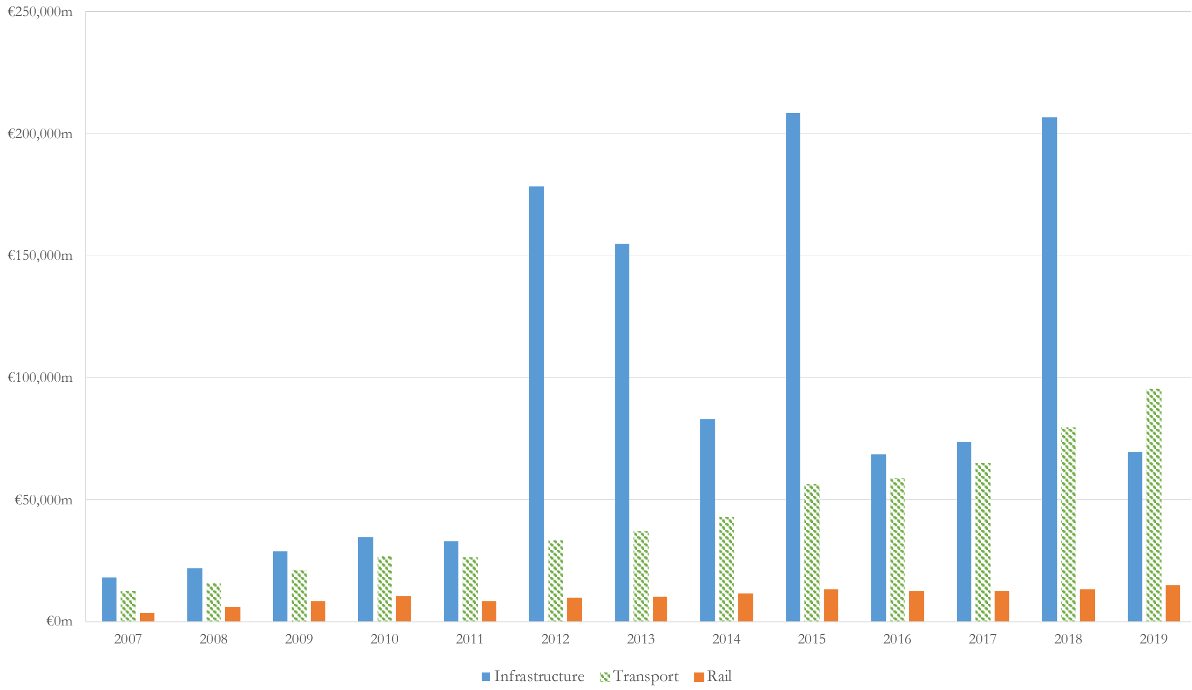



*Notes:* Figure 6 presents the average infrastructure investment by total, transport, and rail for the 29 advanced economies between 1995 and 2019. The left axis reflects the value of investments denominated in Euro.

13 While the full series is from 1995 to 2019, sector-level investment data for water and ICT infrastructure is only available from 2007, creating a spike in the total infrastructure investment for subsequent years.

Figure 7 shows a dispersion between average transport and total infrastructure 2012 and 2018. During these years large sums were invested by China, Russia, and India into the ICT and water infrastructure, a common trait likely due to their status as major emerging economies. The sharp decline in mean total infrastructure investment in 2019 is a result of a delay in certain countries reporting their annual infrastructure figures.

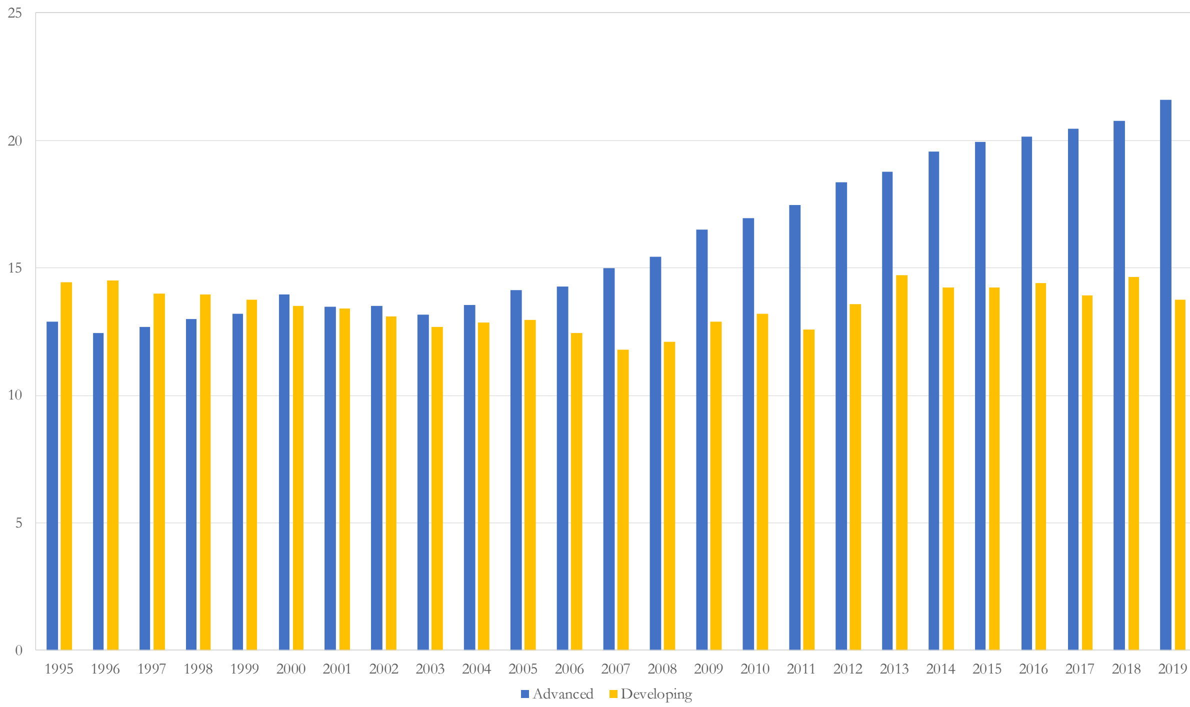
**Figure 7: Mean Infrastructure Investment for Developing Countries, 2007-2019**




*Notes:* Figure 7 presents the average infrastructure investment by total, transport, and rail for the 11 developing economies between 1995 and 2019. The left axis reflects the value of investments denominated in Euro.

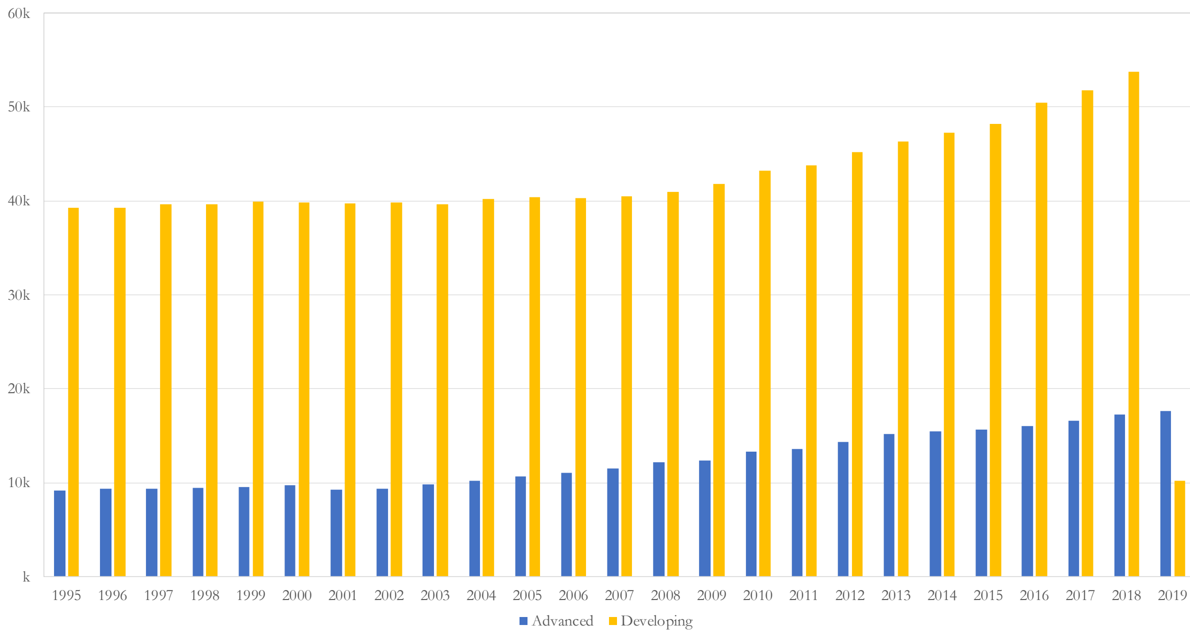
Figure 8 shows the mean level of renewables contribution, measured as the percent contribution of renewable energy generation to total primary energy supply. Developing nations lead the utilisation of renewable technology in the mid to late 1990's, but after this advanced economies show steady increasing mean renewables contribution. The 2019 mean level of renewables contribution was 21.6% and 13.7%, for advanced and developing countries respectively. This shows a clear shift by advanced economies to meet national energy requirements using renewable technologies. Developing countries have mostly maintained their stock of renewable infrastructure, with no clear trend either way in contribution over the series.

**Figure 8: Mean Renewables Contribution (%), 2007-2019**




*Notes:* Figure 8 presents the average infrastructure investment by total, transport, and rail for the 11 developing economies between 1995 and 2019. The left axis reflects the value of investments denominated in Euro.

**Figure 9: Mean Renewables Contribution (tonne of oil equivalent), 2007-2019**




*Notes:* Figure 9 presents the average infrastructure investment by total, transport, and rail for the 11 developing economies between 1995 and 2019. The left axis reflects the value of investments denominated in Euro.

Descriptive statistics for all variables are displayed in Table 1, including for the full sample and by advanced and developing country groupings, being the centre and right panels respectively. The mean bond yields are higher for the developing group, signifying that these countries cannot access cheap public debt markets due to credit worthiness and other factors. The mean credit rating for advanced countries is 19.39 (approx. Aa2) and 13.94 for developing economies (approx. Baa1), confirming the effects observed in the bond yields. Other interesting statistics include mean levels of infrastructure quality scores, which are 5.5 and 4.0 (on a scale of zero to seven), for advanced and developing countries, respectively. Across macroeconomic factors, the advanced country group on average has higher debt-to-GDP, trade openness, and current account balance and lower inflation. Due to the developing sample containing some emerging economies, like Russia and China, the GDP per capita and real GDP growth of these countries are higher.

Several transformations have been applied to the data in this research both to account for the statistical properties of the data and to match different data sources. Initially, in order to reconcile any exchange rate returns between the yield variables (denominated in local currency units) and the investment variables (denominated in both USD and EUR), all investment values needed to be converted to their local currency. Exchange rate data was collected from Bloomberg where the last weekday of each year in the series was used to convert the annual investment data. This was applied to rail, transport, total infrastructure, and infrastructure maintenance data in order to create complete local currency unit-based panel dataset.

## Table 1: Descriptive Statistics of Variables

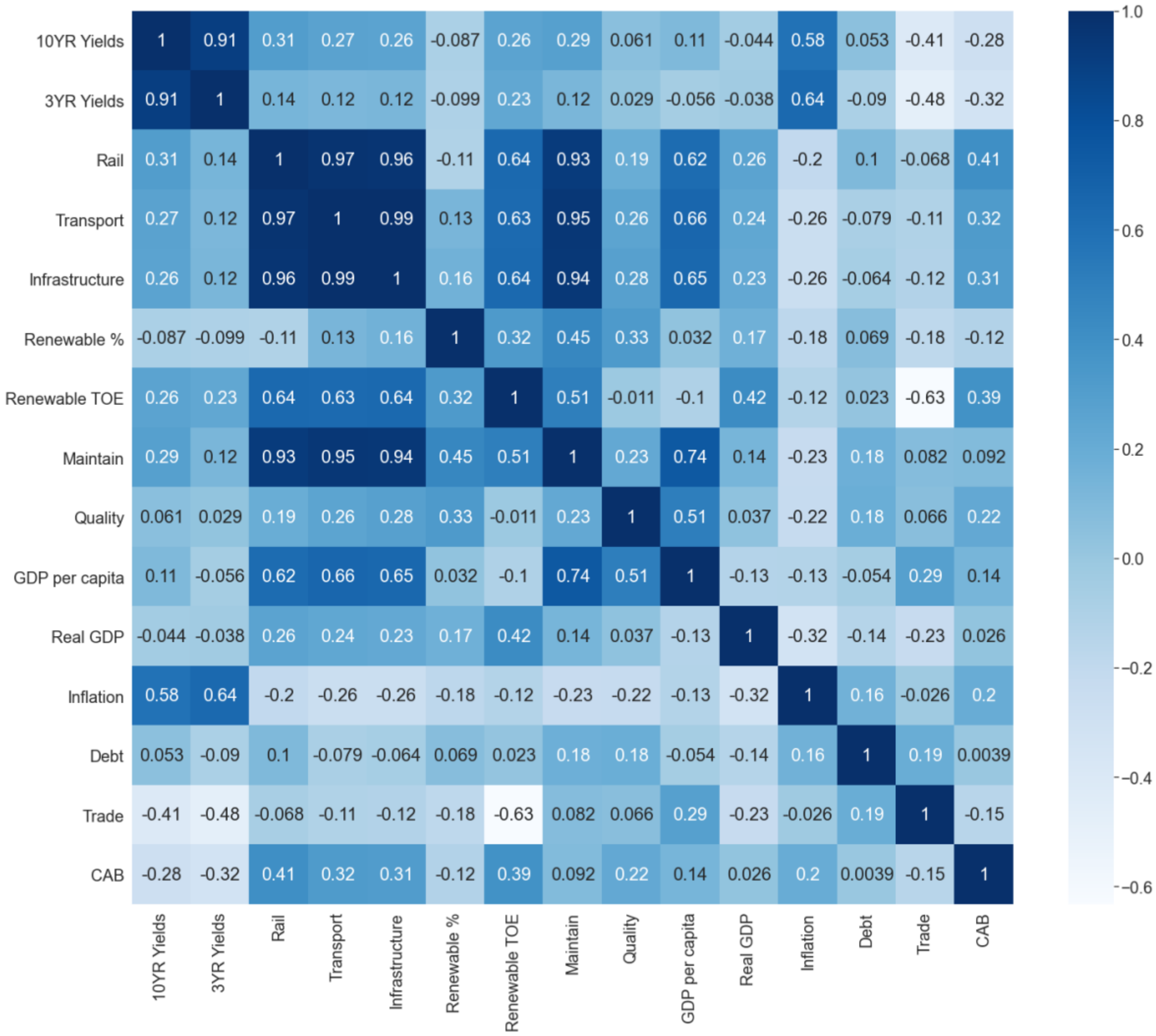
| | All Countries | | | | | | Advanced Countries | | | | | | Developing Countries | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Obs. | Min. | Max. | Mean | Median | St. Dev. | Obs. | Min. | Max. | Mean | Median | St. Dev. | Obs. | Min. | Max. | Mean | Median | St. Dev. |
| 10-year bond yield | 1,000 | (4.135) | 3.456 | 1.101 | 1.363 | 0.919 | 725 | (4.135) | 3.456 | 0.969 | 1.302 | 0.939 | 275 | (1.359) | 2.890 | 1.611 | 1.734 | 0.614 |
| 3-year bond yield | 1,000 | (3.863) | 4.677 | 0.976 | 1.214 | 1.091 | 725 | (3.863) | 4.677 | 0.796 | 1.072 | 1.126 | 275 | (2.010) | 2.930 | 1.488 | 1.619 | 0.789 |
| Rail investment | 1,000 | 14.509 | 30.032 | 21.606 | 21.479 | 2.758 | 725 | 14.509 | 30.032 | 21.332 | 21.417 | 2.577 | 275 | 17.005 | 27.432 | 22.336 | 21.762 | 3.077 |
| Transport investment | 1,000 | 16.118 | 31.032 | 23.124 | 22.957 | 2.673 | 725 | 16.118 | 31.032 | 22.700 | 22.781 | 2.514 | 275 | 17.104 | 29.381 | 24.290 | 24.110 | 2.755 |
| Infrastructure investment | 1,000 | 16.118 | 31.032 | 23.246 | 23.075 | 2.744 | 725 | 16.118 | 31.032 | 22.779 | 22.819 | 2.557 | 275 | 17.104 | 29.399 | 24.518 | 24.497 | 2.836 |
| Renewable contribution | 1,000 | (1.214) | 4.501 | 2.271 | 2.313 | 1.031 | 725 | (1.214) | 4.501 | 2.242 | 2.258 | 1.114 | 275 | 0.548 | 3.674 | 2.350 | 2.398 | 0.757 |
| Renewable TOE | 1,000 | 5.041 | 12.596 | 8.652 | 8.613 | 1.504 | 725 | 5.041 | 12.069 | 8.452 | 8.488 | 1.382 | 275 | 5.989 | 12.596 | 9.184 | 9.061 | 1.679 |
| Maintenance | 1,000 | 13.809 | 29.228 | 22.074 | 21.913 | 2.708 | 725 | 14.787 | 29.228 | 21.809 | 21.824 | 2.586 | 275 | 13.809 | 28.364 | 22.871 | 22.223 | 2.912 |
| Quality score* | 1,000 | 2.305 | 6.772 | 5.045 | 5.128 | 1.034 | 725 | 3.450 | 6.772 | 5.452 | 5.600 | 0.784 | 275 | 2.305 | 5.713 | 3.972 | 3.986 | 0.826 |
| GDP per capita | 1,000 | 8.397 | 17.392 | 11.331 | 10.630 | 1.987 | 725 | 8.397 | 17.392 | 11.268 | 10.598 | 1.938 | 275 | 8.724 | 15.917 | 11.495 | 10.947 | 2.107 |
| Real GDP growth^ | 1,000 | (14.839) | 25.176 | 2.972 | 2.883 | 3.304 | 725 | (14.839) | 25.176 | 2.561 | 2.552 | 2.960 | 275 | (14.193) | 14.231 | 4.050 | 4.304 | 3.871 |
| Inflation^ | 1,000 | (4.478) | 1,058.374 | 5.842 | 2.336 | 35.493 | 725 | (4.478) | 39.648 | 2.394 | 1.954 | 2.864 | 275 | (1.545) | 1,058.374 | 14.932 | 4.670 | 66.760 |
| Debt-to-GDP^ | 1,000 | 3.879 | 234.859 | 59.105 | 51.182 | 37.631 | 725 | 8.080 | 234.859 | 65.102 | 56.852 | 40.113 | 275 | 3.879 | 135.193 | 42.521 | 40.313 | 22.602 |
| Trade openness index^ | 1,000 | 16.679 | 239.837 | 80.520 | 70.629 | 37.672 | 725 | 16.679 | 239.837 | 84.237 | 74.337 | 39.123 | 275 | 21.929 | 168.243 | 70.723 | 60.869 | 31.578 |
| Current account balance^ | 1,000 | (23.907) | 16.309 | (0.370) | (0.639) | 5.339 | 725 | (22.711) | 16.124 | 0.062 | 0.086 | 5.474 | 275 | (23.907) | 16.309 | (1.517) | (1.514) | 4.785 |
| Sovereign credit rating* | 1,000 | 6.000 | 21.000 | 17.573 | 19.000 | 3.753 | 725 | 9.000 | 21.000 | 19.390 | 21.000 | 2.549 | 275 | 6.000 | 18.000 | 13.940 | 14.000 | 3.075 |

*Notes:* The descriptive statistics in the above table cover all variables in the panel data of 40 countries between 1995 and 2019. The advanced country group includes a subsample of 29 countries and the developing sample contains 11 countries. The statistics are broken down into advanced and developing countries. All variables are taken as a logarithmic tranfsormation of their original units, except where notations denote otherwise. * denotes a score formate, taking a numerical value of between 1 and 7 for quality score and between 1 and 21 for sovereign credit rating. ^ indicates a variable is in percentage form. These variables are taken in the presented forms in all regressions.

In order to test for stationarity in the panel data, both Augmented Dickey-Fuller (ADF) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests are used to identify if a unit root is present in any variables in the series. For simplicity, two countries from the advanced and developing countries were selected and the unit root tested on each variable. Austria and Denmark were selected from the advanced sample and Poland and India from the developing sample. Due to the strongly positive skew in all the investment variables I have taken the logarithm of these, including rail, transport, total infrastructure, and maintenance. Large positive values and skew also affect both the two renewables proxy variables as well as GDP per capita, warranting a logarithmic transformation of these variables also. Aside from the variables that require a log transformation based on normality, the ADF and KPSS tests show that that debt-to-GDP, trade openness, and current account balance indicate the presence of a unit root and non-stationarity. Baltagi (2021) show that under panel conditions where N>T and T is small (T<30) both the ADF and KPSS tests have misleading results. As these conditions fit the panel data I am testing (N=40, T=25), I do not conduct transformations to variables based on stationarity or the presence of a unit root.

Figure 10 depicts the correlation of all variables in the form of a heatmap. As expected, there exists strong positive correlation (0.91) between 10-year and 3-year yields as many of their determinants are the same and their primary difference being maturity. Strong positive correlation also exists between the each of the three infrastructure investment variables (0.96 to 0.99) and in addition each of these with infrastructure maintenance (0.93 to 0.95). This implies that a country that is investing highly into any form of infrastructure also invests highly into the maintenance of its existing stock of infrastructure assets. The correlation between rail, transport, and total infrastructure is nearly perfectly positive as the majority of total infrastructure is made up of transport sectors and of these roads and rail are the most important asset types. The correlation between each of the infrastructure investment variables and 10-year sovereign yields (0.26 to 0.31) is greater than the correlation with 3-year yields (0.12 to 0.14), likely showing that the climate risk implications of infrastructure are more relevant in the long-term and are imputed into yields accordingly. Negative correlation exists between renewables contribution and 10-year (-0.09) and 3-year (-0.10) bond yields, showing that an increase in renewables results in a slight decrease in yields. This is reaffirmed by the positive correlation between renewables tonne of oil equivalent and both 10-year (0.26) and 3-year (0.23) yields. GDP per capita and the level of infrastructure investment is moderately positively correlated, indicating that high income countries, or advanced countries, invest more into infrastructure. Moderately positive correlation between GDP per capita and both infrastructure maintenance (0.74) and infrastructure quality (0.51) also indicate that higher income countries are better equipped to build high quality infrastructure and preserve it to ensure full utilisation of the assets.

**Figure 10: Correlation Heatmap for All Countries**

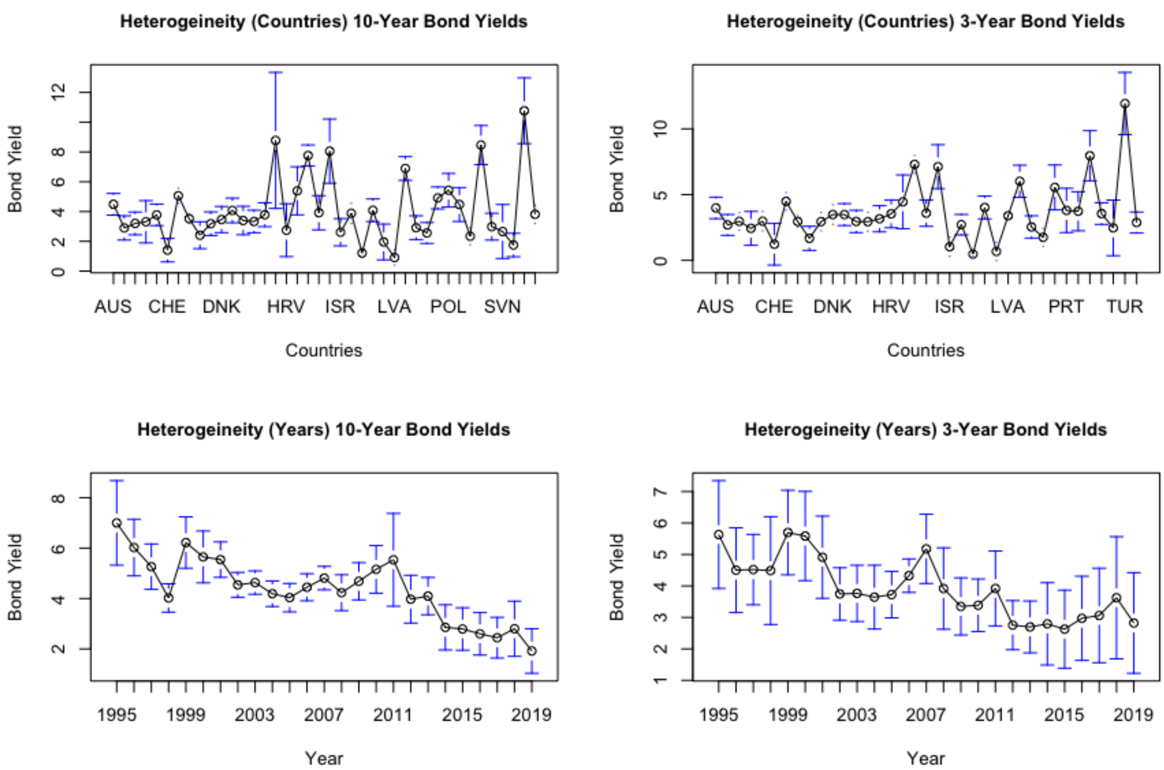



*Notes:* Figure 10 presents the correlation heatmap for all variables, covering 40 countries between 1995 and 2019. The calculation of correlation was based on post-transformation variables and therefore the natural logarithm of both bond yields, all infrastructure variables, and all renewables variables, along with GDP per capita has been used here.

### 3.6. Methodology

I expect that investment into infrastructure, alongside more traditional macroeconomic and credit controls, will have a relation to sovereign cost of debt through the transition risks associated with infrastructure. The effect of infrastructure spending on sovereign bond yields can be measured using a panel regression with fixed effects, both time and country level, and robust standard errors. Fixed effects can account for the unobservable characteristics across countries that are not accounted for in the control variables and is consistent with similar research on sovereign bond yields and climate risks, namely Collender et al. (2021). Examination of heterogeneity across country and year affirms the model choice. Figure 11 shows clear heterogeneity in the 10 and 3-year bond yields across both countries and years[14]. There is clear dispersion in the bond yields across the countries, where the different maturities display similar dynamics amongst countries. Turkey and Portugal can be identified from their prominent yield spikes across both the 10 and 3-year yields in Figure 11. The bottom subplots of Figure 11 reflects the trend of yields towards zero over the series.

**Figure 11: Heterogeneity of 10-Year and 3-Year Bond Yields, by Country and Year**




*Notes:* Figure 11 presents the heterogeneity of the 10-year and 3-year bond yields over the 40 countries and across time (between 1995 and 2019).

[14] Greece has been excluded from the 3-year bond yield heterogeneity plots in Figure 11 due to unusual bond yield spikes from economic crises and this will more accurately illustrate the dynamics of the rest of the advanced group counties.

The primary models for this research are shown in Equations (1) and (2) where the dependent variables in the analysis are either 10 or 3-year government bond yields to capture medium-term and long-term impacts of the transition risks associated with infrastructure. Sovereign bond yields, $yield\_10_{i,t}$ and $yield\_3_{i,t}$, are modelled on infrastructure investment, $infrasinvest_{i,t}$, renewable contribution (percent), $renewablepercent_{i,t}$, renewable contribution (tonne of oil equivalent), $renewableTOE_{i,t}$, maintenance investment, $maintain_{i,t}$, quality score, $qualityscore_{i,t}$, GDP per capita, $GDP_{i,t}$ , real GDP growth, $GDPgrowth_{i,t}$, inflation, $inflation_{i,t}$, debt-to-GDP, $debt_{i,t}$, trade openness, $trade_{i,t}$, current account balance, $CAB_{i,t}$ , and the Moody's sovereign credit rating, $creditrating_{i,t}$,

$$\begin{aligned} yield\_10_{i,t} = \beta_0 &+ \beta_1 infrasinvest_{i,t} + \beta_2 renewablepercent_{i,t} + \beta_3 renewableTOE_{i,t} \\ &+ \beta_4 maintain_{i,t} + \beta_5 qualityscore_{i,t} + \beta_6 GDP_{i,t} + \beta_7 GDPgrowth_{i,t} \\ &+ \beta_8 inflation_{i,t} + \beta_9 debt_{i,t} + \beta_{10} trade_{i,t} + \beta_{11} CAB_{i,t} \\ &+ \beta_{12} creditrating_{i,t} + \gamma_i + \theta_t + \varepsilon_{i,t} \end{aligned} \tag{1}$$

$$\begin{aligned} yield\_3_{i,t} = \beta_0 &+ \beta_1 infrasinvest_{i,t} + \beta_2 renewablepercent_{i,t} + \beta_3 renewableTOE_{i,t} \\ &+ \beta_4 maintain_{i,t} + \beta_5 qualityscore_{i,t} + \beta_6 GDP_{i,t} + \beta_7 GDPgrowth_{i,t} \\ &+ \beta_8 inflation_{i,t} + \beta_9 debt_{i,t} + \beta_{10} trade_{i,t} + \beta_{11} CAB_{i,t} \\ &+ \beta_{12} creditrating_{i,t} + \gamma_i + \theta_t + \varepsilon_{i,t} \end{aligned} \tag{2}$$

where *i* and *t* denote country and time in years, respectively. Country specific effects are denoted by $\gamma_i$ and time effects by $\theta_t$. The three infrastructure investment variables captured by $infrasinvest_{i,t}$ are each regressed in separate regressions, where the inclusion of rail, transport, and total infrastructure occur in different iterations of Equations (1) and (2). These are introduced into the model one at a time due to their near-perfect positive correlation. Model 1 denotes a fixed effects regression where only the macroeconomic control variables, including GDP per capita, real GDP growth, inflation, debt-to-GDP, trade openness, current account balance, and credit rating are regressed on 10 and 3-year bond yields. Models 2, 3, and 4 include each iteration of Equations (1) and (2), where rail, transport, and total infrastructure are included, respectively.

Lagged dependent variables are a common trait of models in the area of sovereign bond yield spreads, due to the persistence in their levels over time (Gerlach et al., 2010). Nickell (1981) warns of potential omitted variable bias arising from the omission of a lagged dependent variable, Nickell also finds upward bias introduced by correlation between the fixed effects and lagged variable. Baltagi & Chang (1994) also find that lagged dependent variables are at risk of being serially correlated with errors terms. Furthermore, whilst Gerlach et al. (2010) highlight the persistence in bond yield spreads, I focus on the underlying bond yields which demonstrate different effects. For these reasons, and consistent with the analysis of sovereign bonds in Collender et al. (2021), I do not include a lagged dependent variable in any of the models.

i. *Model diagnostics*

I conduct several diagnostic tests on the models to account for common issues in panel regressions. Testing is estimated at the broad level of 40 countries. A Hausman test is necessary to determine whether fixed or random effects are suited to the underlying panel data (Hausman, 1978). Results of the Hausman test confirm that fixed effects is preferred for all models as all p-values < 0.05. Likewise, the Lagrange Multiplier (Breusch-Pagan) test and F-test for individual effects both suggest that time-fixed effects are required in the regression models (Breusch & Pagan, 1980). Full results from these tests can be found in the Table A.5 in the Appendix.

Under the panel conditions (T = 25, N = 40) there are challenges in measuring country cross-sectional dependence amongst countries. Baltagi et al. (2012) show there may exist asymptotic bias in the measurement of cross-sectional dependence using common tests like the Breusch-Pagan LM and Pesaran CD tests (Breusch & Pagan, 1980; Pesaran, 2021). Results of these tests show presence of cross-sectional dependence in most models (see Table A.6 in the Appendix). Where the independent variable is 3-year bond yields the Pesaran CD test rejects failed to reject the null hypothesis of independence across N. Given the issues surrounding asymptotic bias in measuring cross-sectional dependence related to the size of T and N, I do not consider the results of the tests in making further amendments to the models.

A Breusch-Godfrey/Wooldridge test for serial correlation in panel models detected serial correlation in all models run on the full sample of 40 countries (Breusch, 1978; Godfrey, 1978). Additionally, the Breusch-Pagan test for heteroskedasticity shows presence of heteroskedasticity in the panel data. In order to address these issues, I implement robust (or clustered) standard errors into the model. Specifically, I apply heteroskedasticity-consistent robust standard errors using "Arellano" estimators which address both serial correlation and heteroskedasticity (Arellano, 1987). Again, the full results of the Breusch-Godfrey autocorrelation and Breusch-Pagan heteroskedasticity test can be found in Table A.7 and Table A.8 in the Appendix, respectively.

ii. *Model limitations*

The impact of climate risks on the sovereign bond market is significantly higher in developing countries due to these countries having a limited ability to mitigate climate risks (Beinre et al., 2020; Cevik & Jalles, 2020; Kling et al., 2018). As such, it is beneficial to include as many developing economies in this analysis as possible. As infrastructure spending data can only be collected for a few developing countries in the population, there will be possible selection bias towards advanced economies. This has implications for the results of this research as advanced economies are already better equipped to handle the risks of climate change. Of the 40 countries that form the initial sample in this research, 29 are advanced and 11 are developing (UN, 2020). Further limitations of the wider paper are discussed in section 4.7.

## 4. Main Results

The results of the main model are presented and discussed in Section 4.1 for the full sample of countries. Results for the advanced countries, developing countries, high, and low investment gap countries are contained in Section 4.2 to 4.5, respectively. I have conducted robustness[15] checks in support of the main results in Section 4.6, including both a sensitivity analysis and alternative dependent variable regressions. Section 4.7 will discuss the limitations of this research and Section 4.8 will outline the implications of these results on future research.

### 4.1. All Countries

Table 2 presents the regression results for the full sample of 40 countries, showing the model effects on both 3-year and 10-year sovereign bond yields. All regression models have been performed using a panel regression with time and entity fixed effects. The results of the initial model are presented in Table 9 and include only macroeconomic control variables to be used as a baseline model and includes GDP per capita, real GDP growth, inflation, debt-to-GDP, trade openness, current account balance, and sovereign credit rating. The adjusted R-squared of the baseline model is 24% for Panel A and 27% for Panel B, suggesting that the macroeconomic variables are better predictors of long-term yields. Two of the macroeconomic variables are significant when regressed on 3-year bond yields and five when regressed on 10-year bond yields. This is consistent with relevant literature, which predominantly focusses on 10-year yields and other long-term maturity bonds. Columns (2) to (3) in each panel reflect the results of the main models, where the three infrastructure investment variables are introduced into the model separately and alongside the two renewable investment proxy variables. The inclusion of rail, transport, and renewables occur in columns (2), (3), and (4), respectively. There is consistency in the direction of the coefficients of the macroeconomic control variables with the exception of real GDP growth and current account balance. For Panel B, the coefficients on infrastructure maintenance is negative across each model and the coefficient on quality score is positive and significant at the 1% level in column (2). For Panel A, these non-macroeconomic controls behave differently in the models, suggesting they are poor predictors of 3-year bond yields.

Column (2) in each panel is the relevant model to determine the outcome of the first hypothesis, relating to low-carbon infrastructure investment, as this model includes both rail and renewables contribution. We can ascertain the explanatory power of the model from the adjusted R-squared. For column (2), the adjusted R-squared of Panel A is approximately 26% and Panel B is 39%, indicating that the model may be a better predictor of longer maturity bond yields. In Panel A, the effect on 3-year yields of investment into rail and renewables are consistent with each other as both have negative coefficients. Despite this, the coefficient on rail investment is not significant where renewable contribution is statistically significant at 5%. The negative direction in the coefficients provides evidence that higher sovereign bond

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[15] Any models using alternative dependent variables and sensitivity analysis used to determine robustness of models will be conducted on the full sample of 40 countries.

yields are associated with a decrease in investment into low-carbon infrastructure. The log-log interpretation of column (2) in Panel A reflects that a 1% increase in 3-year sovereign bond yields is associated with a 0.16% decrease in rail investment and a 2.55% decrease in renewables contribution. The second renewables variable, which represents the absolute energy output from renewable sources in a county, has a positive coefficient of 1.35%. The positive sign on this secondary renewables variable likely arises as it does not capture the relative landscape of energy infrastructure in an economy but the overall energy intensity of a country. Hence, an increase in yields is associated with an increase in the energy intensity of an economy, on average.

**Table 2: Results for All Countries**

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | | (B) 10-Year Sovereign Bond Yield | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | -0.156<br>(0.181) | | | | 0.070<br>(0.112) | | |
| Transport investment | | | -0.089<br>(0.142) | | | | 0.176<br>(0.115) | |
| Infrastructure investment | | | | -0.186<br>(0.199) | | | | 0.138<br>(0.122) |
| Renewable contribution | | -2.546**<br>(0.991) | -4.271***<br>(1.283) | -4.110***<br>(1.344) | | -3.674***<br>(1.165) | -4.526***<br>(1.215) | -4.649***<br>(1.225) |
| Renewable TOE | | 1.351<br>(1.152) | 2.878**<br>(1.248) | 2.740**<br>(1.313) | | 3.057**<br>(1.229) | 3.707***<br>(1.232) | 3.839***<br>(1.246) |
| Infrastructure maintenance | | -0.135<br>(0.106) | -0.025<br>(0.094) | 0.012<br>(0.100) | | -0.179<br>(0.123) | -0.194<br>(0.120) | -0.174<br>(0.112) |
| Quality score | | -0.037<br>(0.268) | -0.138<br>(0.257) | -0.154<br>(0.261) | | 0.453***<br>(0.160) | 0.281<br>(0.173) | 0.277<br>(0.175) |
| GDP per capita | -0.720<br>(0.526) | -0.752<br>(2.005) | -2.120<br>(1.932) | -1.877<br>(2.059) | -1.330**<br>(0.612) | -4.143***<br>(1.252) | -4.570***<br>(1.179) | -4.610***<br>(1.176) |
| Real GDP growth | -0.012<br>(0.023) | 0.002<br>(0.023) | -0.008<br>(0.018) | -0.010<br>(0.019) | -0.025***<br>(0.009) | -0.012<br>(0.012) | -0.010<br>(0.009) | -0.010<br>(0.009) |
| Inflation | 0.080***<br>(0.025) | 0.100**<br>(0.041) | 0.046<br>(0.031) | 0.042<br>(0.031) | 0.063***<br>(0.020) | 0.059*<br>(0.035) | 0.027<br>(0.029) | 0.026<br>(0.030) |
| Debt-to-GDP | -0.019***<br>(0.005) | -0.013<br>(0.008) | -0.009<br>(0.008) | -0.010<br>(0.008) | -0.009**<br>(0.004) | -0.003<br>(0.005) | -0.001<br>(0.005) | -0.001<br>(0.005) |
| Trade openness | -0.013<br>(0.009) | -0.022**<br>(0.010) | -0.007<br>(0.010) | -0.006<br>(0.010) | -0.022***<br>(0.006) | -0.019***<br>(0.007) | -0.006<br>(0.007) | -0.007<br>(0.007) |
| Current account balance | -0.020<br>(0.023) | 0.038*<br>(0.021) | 0.022<br>(0.018) | 0.021<br>(0.018) | 0.003<br>(0.015) | 0.027<br>(0.016) | 0.019<br>(0.013) | 0.018<br>(0.013) |
| Sovereign credit rating | -0.019<br>(0.072) | 0.041<br>(0.093) | -0.042<br>(0.089) | -0.042<br>(0.087) | -0.020<br>(0.044) | 0.038<br>(0.043) | -0.019<br>(0.043) | -0.018<br>(0.043) |
| $R^2$ | 0.305 | 0.401 | 0.379 | 0.382 | 0.329 | 0.490 | 0.511 | 0.508 |
| Adj. $R^2$ | 0.241 | 0.263 | 0.249 | 0.252 | 0.276 | 0.393 | 0.425 | 0.422 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

For Panel B, the results from each model regressing on 10-year bond yields, the outcome of the first hypothesis around low-carbon infrastructure differs to Panel A. Interpreting the results from column (2), a 1% increase in 10-year sovereign bond yields is associated with a 3.67% decrease in renewable contribution but an increase of 0.07% in rail investment in all countries between 1995 and 2019. The coefficient on renewable contribution is statistically significant at all levels while rail investment is not significant and minor in magnitude. For this reason, across both panels find limited evidence that all low-carbon infrastructure corresponds to lower sovereign bond yields. When delving into individual infrastructure sectors, i.e. rail and renewables, only then can we confirm the hypothesis when pertaining to renewable energy infrastructure. This signals that aggregate rail investment as a variable doesn't provide the adequate carbon emissions information from this type of infrastructure to be imputed into sovereign yields in the same manner as renewable energy.

The remaining results in columns (3) and (4) in Panel A show consistency across variables. The direction and significance of the coefficients for renewable contribution and tonne of oil equivalent also remain the same across columns (2) through (4). For Panel B, columns (3) and (4) reflect similar dynamics, where the variables are consistent across models, yet infrastructure variables have a positive relation with 10-year bond yields in this instance. The most significant and large coefficients are again the renewables variables when regressing on 10-year bond yields. Renewable contribution in particular is highly informative with 1% statistical significance and a negative relation in all models across in Panel B.

Panels A and B display inconsistent results for infrastructure maintenance. In Panel A, the coefficient is negative in columns (2) and (3) yet positive in (4), though all coefficients are not significant. For Panel B, these results are negative across all models and a 1% increase in yields corresponds to a decrease in maintenance investment of between 0.17 and 0.19%. The coefficient on quality score also demonstrates varying effects depending on bond maturity. For Panel A, the relation between quality score and 3-year bond yields is negative and non-significant. Panel B shows that the effect of quality score is positive for 10-year bond yields, ranging from 0.28 and 0.45%. Quality score is only significant within the low-carbon model (Column 2) at the 1% level. Specific to Panel A only, the coefficients of quality score when compared to those of rail, transport, and infrastructure imply that the underlying stock of infrastructure in an economy may be more important than the additional annual investment into any given sector of infrastructure.

Overall, the coefficients on renewable contribution and renewable tonne of oil equivalent are significantly larger for the regressions on 10-year sovereign bond yields. This indicates that the longer term climate risks associated with infrastructure are less relevant to short-term government cost of debt. Higher adjusted R-squared for the regression on 10-year bond yields also indicate that these variables are more relevant to higher maturity bond yields. Adjusted R-squared for 10-year bond yield results ranges from 39 and 43% but only 25 to 26% for 3-year bond yields (columns 2 to 4).

Examination of the macroeconomic control variables are consistent with the prior underlying economic rationale from prior literature. Consistent across both panels, GDP per capita is negative associated with sovereign bond yields as high income countries will have lower sovereign bond yields. A 1% increase in 3-year bond yields is consistent with between a 0.72 and 2.12% decrease in GDP per capita, though these results are not significant. For 10-year bond  yields, all coefficients are significant and range from -1.33 and -4.61%. The coefficient on real GDP growth is mostly negative across 10 and 3-year sovereign bond yields, with the exception of column (2) of Panel A where the coefficient is positive and non-significant. Panel B shows consistency in the direction of the coefficient on real GDP growth as well as 1% significance in the baseline model.

The differential effects between the panels display the relative importance of the macroeconomic variables to 10-year bond yields as these long-term securities are usually the subject of research in the area of sovereign yield and yield spread determinants. The sign of the coefficient on inflation may differ depending on the country group, though it is expected to positively affect yields as high inflation infers economic instability which may impact the country's ability to repay debt (Min, 1998). Despite the ambiguity around the effects of inflation, a positive relation can be observed in the results of Panels A and B, and is statistically significant at the 1% level in the baseline models, columns (1). Trade openness also demonstrates the expected negative relation to yields, where as a countries have greater trade as a proportion of GDP they are better equipped to service debt and access cheaper debt markets.

Interestingly, both debt-to-GDP and current account balance demonstrate opposite effects to those expected. In the context of sovereign yield spreads[16], debt-to-GDP is expected to be positively related and current account balance is expected to be negatively related. This is because a higher debt-to-GDP is considered to indicate lower creditworthiness, in turn limiting the ability of countries to access cheaper debt markets. For current account balance, an increase is reflected as an improvement in global competitiveness measured through income generated, signalling improved debt serviceability. As the dependent variable is sovereign bond yields, there may be some alternative effects from these variables. As these results persist in most of the models presented in Table XX, it is uncertain that the introduction of infrastructure and renewables variables are causing these effects. In order to ensure this, the results from use of sovereign yield spreads as an alternative dependent variable are presented in Section 4.6. Finally, the observed effect of sovereign credit rating is negative, as expected, with the exception of column (2) in both panels. Sovereign credit ratings improve  with an increase with the creditworthiness of the country and in turn, reduce cost of debt.

[16] As sovereign bond yield spreads are the difference between each sovereign bond yield and the generic United States bond yield of the same maturity, a sample of sovereign bond yield spreads would exclude the United States. Both the influence of the United States in the sample and the differences between bond yield and yield spread behaviour may results in some coefficients flipping directions in results.

## 4.2. Advanced Country Group

The results of the regressions specific to the 29 countries in the advanced country sample are presented in Table 3, where the dependent variables are 3-year (Panel A) and 10-year sovereign bond yields (Panel B). Results from the advanced country sample regression enable the examination of both the first and second hypotheses. With regards to the first hypotheses, that low-carbon infrastructure investment will be negatively associated with sovereign bond yields, I find limited evidence of this effect with the exception of renewable contribution.

**Table 3: Results for Advanced Country Group**

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | | (B) 10-Year Sovereign Bond Yield | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | -0.589<br>(0.374) | | | | -0.099<br>(0.190) | | |
| Transport investment | | | 0.067<br>(0.384) | | | | 0.067<br>(0.237) | |
| Infrastructure investment | | | | -0.267<br>(0.481) | | | | -0.110<br>(0.275) |
| Renewable contribution | | -2.304<br>(1.915) | -5.380*<br>(2.785) | -4.869*<br>(2.697) | | -3.984**<br>(1.768) | -4.932***<br>(1.588) | -4.892***<br>(1.538) |
| Renewable TOE | | 0.793<br>(1.974) | 3.247<br>(2.884) | 2.853<br>(2.713) | | 3.828**<br>(1.842) | 4.366***<br>(1.652) | 4.395***<br>(1.612) |
| Infrastructure maintenance | | -0.060<br>(0.064) | 0.042<br>(0.141) | 0.170<br>(0.168) | | -0.182<br>(0.130) | -0.177<br>(0.168) | -0.105<br>(0.156) |
| Quality score | | -0.096<br>(0.341) | -0.580<br>(0.372) | -0.626<br>(0.403) | | 0.416**<br>(0.210) | 0.246<br>(0.252) | 0.249<br>(0.260) |
| GDP per capita | -2.101*<br>(1.106) | 8.649***<br>(3.032) | 4.035<br>(3.595) | 3.703<br>(3.702) | -4.451***<br>(0.953) | -7.487***<br>(2.779) | -6.889***<br>(2.258) | -7.266***<br>(2.349) |
| Real GDP growth | -0.008<br>(0.033) | 0.014<br>(0.037) | 0.005<br>(0.032) | 0.005<br>(0.032) | -0.015<br>(0.016) | 0.004<br>(0.017) | 0.008<br>(0.014) | 0.009<br>(0.014) |
| Inflation | 0.093<br>(0.068) | 0.103<br>(0.119) | -0.030<br>(0.057) | -0.033<br>(0.056) | 0.064<br>(0.047) | 0.126**<br>(0.060) | 0.040<br>(0.038) | 0.041<br>(0.038) |
| Debt-to-GDP | -0.020***<br>(0.006) | -0.018***<br>(0.006) | -0.010<br>(0.007) | -0.013*<br>(0.007) | -0.006<br>(0.004) | -0.003<br>(0.005) | -0.004<br>(0.006) | -0.005<br>(0.006) |
| Trade openness | -0.007<br>(0.014) | -0.055**<br>(0.027) | -0.024*<br>(0.014) | -0.020<br>(0.015) | -0.015**<br>(0.008) | -0.026**<br>(0.010) | -0.003<br>(0.008) | -0.003<br>(0.008) |
| Current account balance | -0.002<br>(0.033) | 0.017<br>(0.031) | 0.024<br>(0.040) | 0.007<br>(0.042) | 0.010<br>(0.020) | 0.028<br>(0.025) | 0.012<br>(0.028) | 0.004<br>(0.031) |
| Sovereign credit rating | -0.016<br>(0.078) | -0.096<br>(0.078) | -0.232**<br>(0.099) | -0.221**<br>(0.097) | 0.006<br>(0.057) | 0.067<br>(0.067) | -0.015<br>(0.062) | -0.007<br>(0.060) |
| $R^2$ | 0.318 | 0.467 | 0.418 | 0.422 | 0.432 | 0.532 | 0.533 | 0.534 |
| Adj. $R^2$ | 0.253 | 0.304 | 0.257 | 0.261 | 0.387 | 0.429 | 0.439 | 0.440 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

Panel A reflects that a 1% increase in 3-year bond yields corresponds to a 2.30% decrease in renewable contribution to total energy supply. Panel B similarly reflects that a 1% increase in 10-year yields corresponds to a 3.98% decrease in renewable contribution. The negative relation supports the hypothesis that higher low-carbon infrastructure investment corresponds to lower sovereign bond yields. Countries that are investing into sustainable and climate resilient infrastructure have lowered their climate transition risk and this should reflect a lowered cost of debt (Collender et al., 2020). As only renewable contribution in column (2) of Panel B is significant at 5%, we cannot reject that low-carbon infrastructure is negatively associated with bond yields. Adjusted R-squared values of 43% and 30% for 10-year and 3-year bond yields, respectively, show a satisfactory fit of the low-carbon models (column 2). Renewable contribution has is larger and more significant in columns (3) and (4) of both panels, at 10% for 3-year bond yields and 1% for 10-year bond yields.

Maintenance investment has a mostly negative relation to bond yields, with the exception of Panel A columns (2) and (3). The quality score of infrastructure has opposing signs between the panels, as seen in the full sample analysis, which may further allude to the lower predictive power of the models for 3-year bond yields, suggested by the lower adjusted R-squared when comparing the panels. Additionally, the negative relation of quality score and 3-year bonds is inconsistent with the results from the sample of all countries. Quality score is significant at 5% in column (2) of Panel B, the low-carbon model, and this remains consistent with the results in Table 2. The macroeconomic control variables all remain consistent with varying degrees of statistical significance for columns (1) to (4) across the 10-year results in Panel B. Inconsistency among the effects of GDP per capita and real GDP growth vary between the baseline and infrastructure models of Panel A. Again, this may allude to the lower predictive power of the for the 3-year bond yields. The adjusted R-squared of the baseline model (column 2) for approximately 25% for 3-year bond yields and 39% for 10-year bond yields amongst advanced economies.

In order to confirm whether the relationship between renewable contribution and the 3-year and 10-year sovereign bond yield is significantly different for advanced and developing countries (Hypothesis 2), I add an interaction term and repeat each of the infrastructure models again. Equation (3) presents the updated model tod equation to reflect the addition of $AdvXRenewable_{i,t}$, where all other variables maintain the same meaning outlined in Section 3.6.

$$\begin{aligned} yield\_10_{i,t} = {} & \beta_0 + \beta_1 infrasinvest_{i,t} + \beta_2 AdvXRenewable_{i,t} + \beta_3 renewablepercent_{i,t} \\ & + \beta_4 renewableTOE_{i,t} + \beta_5 maintain_{i,t} + \beta_6 qualityscore_{i,t} + \beta_7 GDP_{i,t} \\ & + \beta_8 GDPgrowth_{i,t} + \beta_9 inflation_{i,t} + \beta_{10} debt_{i,t} + \beta_{11} trade_{i,t} \\ & + \beta_{12} CAB_{i,t} + \beta_{13} creditrating_{i,t} + \gamma_i + \theta_t + \varepsilon_{i,t} \end{aligned} \tag{3}$$

The results of this are presented in Table 4. For 10-year bond yields, I can confirm that there is a significant difference between advanced and developing countries in the effects of low-carbon infrastructure, here renewable energy, on bond yields. The interaction term, 'Adv x Renewable contribution' is significant at the 5% level for columns (2) and (4) and significant at 1% for column (3). The additional negative association of renewable contribution on 10-year bond yields for advanced countries is between -

0.07 and -0.08%. Hypothesis 2 can be rejected in the effects of renewable contribution on 3-year bond yields, with none of the interaction terms having statistical significance.

**Table 4: Results for All Countries (incl. Interaction Term)**

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | (B) 10-Year Sovereign Bond Yield | | |
|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 2 | 3 | 4 |
| Rail investment | -0.088<br>(0.19) | | | 0.091<br>(0.099) | | |
| Transport investment | | -0.026<br>(0.151) | | | 0.208*<br>(0.109) | |
| Infrastructure investment | | | -0.122<br>(0.204) | | | 0.162<br>(0.115) |
| Adv x Renewable contribution | -0.109<br>(0.075) | -0.026<br>(0.151) | -0.122<br>(0.204) | -0.070**<br>(0.027) | -0.076***<br>(0.029) | -0.074**<br>(0.030) |
| Renewable contribution | -1.237<br>(1.337) | -0.127<br>(0.084) | -0.124<br>(0.084) | -3.139***<br>(1.209) | -3.726***<br>(1.298) | -3.888***<br>(1.301) |
| Renewable TOE | 0.463<br>(1.467) | -2.658*<br>(1.375) | -2.590*<br>(1.388) | 2.874**<br>(1.276) | 3.274**<br>(1.311) | 3.440***<br>(1.318) |
| Infrastructure maintenance | -0.178*<br>(0.104) | 1.765<br>(1.409) | 1.711<br>(1.435) | -0.184*<br>(0.108) | -0.208**<br>(0.105) | -0.184*<br>(0.097) |
| Quality score | 0.002<br>(0.262) | -0.084<br>(0.095) | -0.045<br>(0.104) | 0.452***<br>(0.154) | 0.273<br>(0.171) | 0.268<br>(0.173) |
| GDP per capita | -0.291<br>(2.119) | -0.102<br>(0.251) | -0.116<br>(0.255) | -3.938***<br>(1.290) | -4.248***<br>(1.248) | -4.302***<br>(1.240) |
| Real GDP growth | 0.005<br>(0.021) | -1.565<br>(2.053) | -1.375<br>(2.157) | -0.005<br>(0.010) | -0.004<br>(0.007) | -0.004<br>(0.007) |
| Inflation | 0.104**<br>(0.041) | -0.003<br>(0.018) | -0.004<br>(0.018) | 0.051<br>(0.033) | 0.021<br>(0.029) | 0.019<br>(0.030) |
| Debt-to-GDP | -0.013<br>(0.008) | 0.047<br>(0.034) | 0.043<br>(0.034) | -0.003<br>(0.005) | -0.002<br>(0.005) | -0.002<br>(0.005) |
| Trade openness | -0.026**<br>(0.010) | -0.010<br>(0.008) | -0.011<br>(0.008) | -0.022***<br>(0.007) | -0.009<br>(0.007) | -0.009<br>(0.007) |
| Current account balance | 0.020<br>(0.023) | -0.011<br>(0.009) | -0.010<br>(0.010) | 0.014<br>(0.015) | 0.006<br>(0.012) | 0.005<br>(0.012) |
| Sovereign credit rating | -0.006<br>(0.104) | 0.002<br>(0.020) | 0.001<br>(0.020) | 0.003<br>(0.048) | -0.051<br>(0.047) | -0.049<br>(0.047) |
| $R^2$ | 0.423 | 0.408 | 0.410 | 0.522 | 0.541 | 0.537 |
| Adj. $R^2$ | 0.285 | 0.280 | 0.282 | 0.428 | 0.459 | 0.453 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

In Table 4, transport and infrastructure investment have conflicting coefficients. Across both panels, the coefficient on transport is positive and infrastructure is negative, though only the effect of transport on 10-year bond yields is significant. The fit for both models, measured by the adjusted R-squared is approximately 26% (Panel A, columns 3 & 4). A positive coefficient observed on transport investment for advanced countries may relate to urban expansion as transport is dominated by road investment. Road infrastructure has a positive relation to climate risks, whereby greenhouse gas emissions are produced from each process of the project lifecycle though predominantly during the construction period (Chen et al., 2017). Hence, these climate risks are imputed into bond yields resulting in the positive relation with road infrastructure investment.

### 4.3. Developing Country Group

Results from the regression analysis specific to the 11 countries in the developing country sample can be seen in Table 5. Comparison of the advanced and developing country results show similar effects for the renewable variables but differences amongst infrastructure investment variables. All coefficients on infrastructure investment variables are positive and the effect of rail investment is statistically significant at the 10% level within the 10-year bond yield results.

**Table 5: Results for Developing Country Group**

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | | (B) 10-Year Sovereign Bond Yield | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | 0.099<br>(0.114) | | | | 0.15*<br>(0.086) | | |
| Transport investment | | | 0.075<br>(0.115) | | | | 0.167<br>(0.128) | |
| Infrastructure investment | | | | 0.103<br>(0.134) | | | | 0.212<br>(0.138) |
| Renewable contribution | | -4.539***<br>(1.628) | -4.054**<br>(1.593) | -4.123***<br>(1.466) | | -3.038***<br>(1.095) | -2.297*<br>(1.285) | -2.492**<br>(1.112) |
| Renewable TOE | | 3.527**<br>(1.535) | 2.848*<br>(1.559) | 2.901**<br>(1.406) | | 3.211***<br>(1.179) | 1.914<br>(1.308) | 2.076*<br>(1.150) |
| Infrastructure maintenance | | -0.638**<br>(0.278) | -0.586**<br>(0.225) | -0.575**<br>(0.229) | | -0.289*<br>(0.148) | -0.269**<br>(0.125) | -0.230*<br>(0.125) |
| Quality score | | -0.168<br>(0.224) | -0.041<br>(0.230) | -0.020<br>(0.231) | | -0.080<br>(0.168) | 0.027<br>(0.132) | 0.074<br>(0.112) |
| GDP per capita | -0.809<br>(0.507) | -2.490<br>(1.863) | -2.919<br>(1.856) | -3.051*<br>(1.716) | -0.702*<br>(0.361) | -2.452*<br>(1.229) | -2.304**<br>(1.138) | -2.605***<br>(0.917) |
| Real GDP growth | -0.023<br>(0.021) | -0.026<br>(0.023) | -0.025*<br>(0.014) | -0.025*<br>(0.014) | -0.047*<br>(0.027) | -0.022<br>(0.024) | -0.020<br>(0.015) | -0.019<br>(0.015) |
| Inflation | 0.081***<br>(0.026) | 0.045**<br>(0.017) | 0.047**<br>(0.022) | 0.048**<br>(0.022) | 0.022<br>(0.025) | -0.005<br>(0.020) | 0.017<br>(0.014) | 0.020<br>(0.013) |
| Debt-to-GDP | 0.002<br>(0.021) | 0.028<br>(0.031) | 0.010<br>(0.023) | 0.011<br>(0.022) | -0.008<br>(0.011) | 0.008<br>(0.017) | 0.000<br>(0.014) | 0.001<br>(0.013) |
| Trade openness | -0.014***<br>(0.005) | -0.007<br>(0.004) | -0.001<br>(0.008) | -0.002<br>(0.007) | -0.005<br>(0.004) | -0.012*<br>(0.006) | -0.006<br>(0.008) | -0.008<br>(0.008) |
| Current account balance | -0.029***<br>(0.010) | -0.029*<br>(0.016) | -0.020<br>(0.02) | -0.020<br>(0.019) | -0.034*<br>(0.020) | -0.033**<br>(0.015) | -0.011<br>(0.017) | -0.009<br>(0.016) |
| Sovereign credit rating | 0.169<br>(0.130) | 0.266***<br>(0.072) | 0.225**<br>(0.085) | 0.221**<br>(0.085) | 0.049<br>(0.049) | 0.114***<br>(0.036) | 0.073*<br>(0.043) | 0.066<br>(0.046) |
| $R^2$ | 0.445 | 0.681 | 0.638 | 0.639 | 0.369 | 0.657 | 0.575 | 0.581 |
| Adj. $R^2$ | 0.369 | 0.548 | 0.510 | 0.511 | 0.280 | 0.508 | 0.419 | 0.427 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

Column (2) in Panel A finds evidence in support of the first hypothesis though only in relation to renewable contribution, unlike the results from the full sample analysis in Section 4.1. The lack of a negative coefficient on rail investment in column (2) of both panels may relate to the underlying characteristics of developing countries, whereby to implement low-carbon rail alternatives is not fiscally possible or the sustainability information from aggregate rail investment is not distilled enough to indicate a low-carbon purity. Renewable energy technologies show little difference in their relation to sovereign bond yields between the full sample, advanced, and developing countries. A 1% increase in 3-year yields reflect, on average, a 4.54% decrease in the contribution of renewable energy sources to total energy supply in column (2). The fit of the low-carbon infrastructure models depicted in column (2) are particularly high relative to other models, at approximately 55% for 3-year bond yields and 51% for 10-year bond yields amongst developing countries.

Results surrounding low-carbon infrastructure are similar within the 10-year bond yields. A 1% increase in yields corresponds to a 0.15% increase in rail investment, statistically significant at the 10% level. For renewable contribution, I observe a negative relation amounting to 3.04% and significant at the 1%. Interestingly, the coefficient on renewable contribution is larger in the 3-year bond yield regressions. This effect only persists amongst the developing country group suggesting that for developing countries that short-term outcomes have greater returns to scale. This may imply that an investment into energy infrastructure has more meaningful economic growth effects from additional investment in the short-term than for an advanced economy explaining the greater effect on short-term bonds.

The effects of transport and total infrastructure investment in columns (3) and (4) in Panel A reflect a positive relation to 3-year bond yields. The corresponding columns in Panel B are similarly positive and non-significant, though with larger coefficients. Across all three investment variables, larger effects can be observed in Panel B which relates to the long construction lead times and asset lives tied to infrastructure. Renewable TOE, or the absolute output from renewables, has positive effects on the bond yields of developing countries, regardless of maturity. Despite the negative relation with the first renewable variable, absolute energy output from renewables is again proven to be an indicator of a country's energy intensity and not the environmental and economic benefits from a greater proportion of renewable energy infrastructure.

The developing country sample reacts to maintenance investment in the same fashion as advanced economies, where higher yields are associated with a decrease of between 0.58% and 0.64% for 3-year bond yields and 0.23% and 0.29% for 10-year bond yields. The coefficient on infrastructure maintenance is significant at between 5% and 10%, depending on the maturity of the bond and underlying model, in contrast with the advanced and full samples which showed no significance. This implies that the underlying stock of infrastructure in a developing economic is more critical to bond yields than other variables, like additional investment. Quality score has mixed effects that are inconsistent and mostly non-significant across both panels for developing countries.

## 4.4. High Investment Gap Group

The results from the regression estimation on high investment gap countries are presented in Table 6. Countries within this group have estimated infrastructure investment shortfalls[17] to 2030 that are in excess of 20 percent. Results are substantially different from previous groups, particularly within renewable variables which demonstrate opposite signs from prior results and are inconsistent across the 3-year and 10-year results. Due to the unique characteristics of the infrastructure landscape in high investment gap countries, I do not discuss the outcome of low-carbon infrastructure investment from these results.

The third hypothesis states that high investment gap countries will have a positive relation between bond yields and infrastructure investment variables, specifically transport and total infrastructure. The results find no evidence of these effects for both long and short maturity sovereign bond yields, with negative coefficients persisting across both models (though non-significant). In Panel A, a 1% increase in bond yields are associated with a 0.59% decrease in transport investment and a 0.33% decrease in overall infrastructure investment. For countries with large shortfalls, investment into infrastructure on the basis of climate risks or emissions levels may not be as critical as meeting economic needs. Also, it could simply be that these countries historically underinvest into infrastructure and so this results in the negative relation. The inability of the infrastructure variables to explain bond yields for high gap countries is represented in the adjusted R-squared which are almost double in value for the corresponding models for the low-gap countries (column (3) and (4), in Panel A of Table 7) further suggesting some unique characteristics of the high gap countries compared to the rest of the sample. For instance, the adjusted R-squared for Panel A, column (3) is 23% and the equivalent model when regressing on a low-gap sample has an adjusted R-squared of 50%. This may imply that there are loose ties between non-energy infrastructure and the environmental performance for this sample of countries. Panel B shows similar effects amongst the regression on 10-year bond yields. Neither the 3 or 10-year bond yield regression results have significant coefficients on rail, transport, or infrastructure.

Unlike other country groups or the full sample, quality score demonstrates the expected negative relation to bond yields in the high investment gap group. Statistically significant at the 1% level for columns (2) to (4), Panel A reflects that a 1% increase in yields coincides with a decrease in the quality of total infrastructure of between 0.82% and 1.11%. For Panel B, quality score is statistically significant in all models at the 1%. The coefficient on quality score on 10-year bond yields ranges from a decrease of 0.34% and 0.38% on average for countries with high investment gaps. Economically, this shows that countries with higher sovereign bond yields and high shortfalls in infrastructure required, on average demonstrate lower quality of existing infrastructure assets. Despite the unique effect of infrastructure quality score on bond yields for the results on high investment gap countries, all models (1) through (4) for both panels suffer

[17] The infrastructure investment gap (or shortfall) for each country is sourced from data collected by the GIHUB and Oxford Economics (2017) as part of the 2017 Infrastructure Outlook analysis. It is calculated as the anticipated infrastructure investment need based on economic and population growth statistics.

from relatively lower r-squared and adjusted r-squared levels, undermining the suitability of the predictive power of the models. It is likely that the model does not account for the complex characteristics of countries that underinvest into infrastructure, creating opportunity for omitted variable bias in the models. The unreliability of the expected effect on GDP per capita and real GDP growth amongst these countries furthers the likelihood that further research is required to make adequate assumptions on the relation between sovereign cost of debt and the climate effects of infrastructure in an economy.

### Table 6: Results for High Investment Gap Country Group

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | | (B) 10-Year Sovereign Bond Yield | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | 0.463<br>(0.419) | | | | 0.140<br>(0.154) | | |
| Transport investment | | | -0.592<br>(0.587) | | | | -0.313<br>(0.469) | |
| Infrastructure investment | | | | -0.332<br>(0.482) | | | | -0.076<br>(0.474) |
| Renewable contribution | | 4.784***<br>(1.200) | 0.748<br>(2.819) | 1.289<br>(2.874) | | -0.131<br>(2.395) | -1.242<br>(1.298) | -1.055<br>(1.008) |
| Renewable TOE | | -5.657***<br>(0.636) | -1.087<br>(2.446) | -1.702<br>(2.482) | | -0.065<br>(1.816) | 1.039<br>(0.896) | 0.801<br>(0.683) |
| Infrastructure maintenance | | 0.816<br>(0.709) | 0.515<br>(0.805) | 0.343<br>(0.702) | | -0.035<br>(0.079) | -0.011<br>(0.152) | -0.082<br>(0.077) |
| Quality score | | -1.114***<br>(0.093) | -0.834***<br>(0.190) | -0.854***<br>(0.182) | | -0.349***<br>(0.088) | -0.379***<br>(0.091) | -0.347***<br>(0.114) |
| GDP per capita | 0.228<br>(1.135) | 10.576***<br>(1.341) | 4.125<br>(3.010) | 3.854<br>(3.184) | 0.098<br>(0.396) | 2.758<br>(2.196) | 1.270<br>(1.326) | 0.641<br>(1.848) |
| Real GDP growth | -0.010<br>(0.025) | -0.076***<br>(0.009) | -0.019<br>(0.029) | -0.022<br>(0.033) | -0.008<br>(0.013) | -0.035***<br>(0.009) | -0.018<br>(0.024) | -0.019<br>(0.026) |
| Inflation | 0.063**<br>(0.029) | -0.050<br>(0.068) | -0.101<br>(0.069) | -0.104<br>(0.068) | 0.034**<br>(0.013) | -0.049<br>(0.048) | -0.059**<br>(0.026) | -0.055**<br>(0.022) |
| Debt-to-GDP | -0.023***<br>(0.003) | -0.035***<br>(0.011) | -0.047***<br>(0.015) | -0.045***<br>(0.015) | -0.013***<br>(0.001) | -0.007<br>(0.011) | -0.013**<br>(0.006) | -0.011**<br>(0.005) |
| Trade openness | 0.002<br>(0.014) | -0.074**<br>(0.034) | 0.034***<br>(0.010) | 0.037***<br>(0.011) | 0.008<br>(0.005) | -0.007<br>(0.007) | 0.026***<br>(0.005) | 0.026***<br>(0.009) |
| Current account balance | -0.031<br>(0.042) | -0.327***<br>(0.084) | -0.087*<br>(0.044) | -0.096**<br>(0.042) | -0.012<br>(0.021) | -0.133**<br>(0.056) | -0.041<br>(0.027) | -0.044<br>(0.030) |
| Sovereign credit rating | 0.154***<br>(0.043) | -0.268*<br>(0.139) | 0.052<br>(0.055) | 0.028<br>(0.045) | 0.040***<br>(0.015) | -0.095*<br>(0.052) | -0.006<br>(0.022) | -0.014<br>(0.029) |
| $R^2$ | 0.433 | 0.664 | 0.489 | 0.482 | 0.522 | 0.614 | 0.497 | 0.482 |
| Adj. $R^2$ | 0.340 | 0.436 | 0.234 | 0.223 | 0.440 | 0.324 | 0.228 | 0.206 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

## 4.5. Low Investment Gap Group

Results from the fixed effects models for low investment gap countries are more promising than those of the high investment gap sample and are presented in Table 7. The third hypothesis rejected in Section 4.4 is further challenged by these results, given the positive relation to transport in both panels, statistically significant at 1% for 10-year yields . For low gap countries, it is likely that additional investments are more critical to support traditional assets in transition and hence we observe the effects expected from the high gap countries here instead. For all infrastructure variables amongst the 10-year results (Panel B), their coefficients are positive, with rail and transport both being significant. A 1% increase in 10-year yields corresponds to, on average, greater investment into these sectors of infrastructure.

**Table 7: Results for Low Investment Gap Country Group**

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | | (B) 10-Year Sovereign Bond Yield | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | -0.194<br>(0.250) | | | | 0.126**<br>(0.062) | | |
| Transport investment | | | 0.064<br>(0.214) | | | | 0.615***<br>(0.223) | |
| Infrastructure investment | | | | -0.789*<br>(0.400) | | | | 0.300<br>(0.395) |
| Renewable contribution | | -2.647<br>(2.296) | -2.066<br>(2.319) | -1.452<br>(2.278) | | -1.443<br>(1.246) | -2.114*<br>(1.156) | -2.659*<br>(1.485) |
| Renewable TOE | | 2.669<br>(2.175) | 2.014<br>(2.220) | 1.717<br>(2.192) | | 1.994<br>(1.374) | 2.375**<br>(1.140) | 3.188**<br>(1.430) |
| Infrastructure maintenance | | 0.071<br>(0.157) | -0.057<br>(0.179) | 0.228<br>(0.158) | | -0.021<br>(0.144) | -0.373<br>(0.225) | -0.186<br>(0.233) |
| Quality score | | 0.030<br>(0.170) | 0.043<br>(0.150) | 0.073<br>(0.139) | | 0.108<br>(0.121) | -0.059<br>(0.123) | 0.002<br>(0.154) |
| GDP per capita | -0.246<br>(0.349) | -2.351<br>(2.022) | -2.338<br>(2.089) | -0.503<br>(2.043) | -1.102**<br>(0.472) | -2.594**<br>(1.096) | -3.495***<br>(1.219) | -3.600**<br>(1.734) |
| Real GDP growth | 0.005<br>(0.022) | 0.040<br>(0.026) | 0.039<br>(0.023) | 0.029<br>(0.024) | -0.024*<br>(0.013) | 0.015<br>(0.016) | 0.020<br>(0.016) | 0.015<br>(0.019) |
| Inflation | 0.082**<br>(0.032) | -0.001<br>(0.039) | -0.009<br>(0.034) | 0.022<br>(0.032) | 0.022<br>(0.020) | -0.019<br>(0.019) | -0.057*<br>(0.030) | -0.040<br>(0.033) |
| Debt-to-GDP | -0.027***<br>(0.006) | -0.035***<br>(0.013) | -0.037***<br>(0.013) | -0.039***<br>(0.013) | -0.017***<br>(0.004) | -0.025***<br>(0.002) | -0.024***<br>(0.003) | -0.025***<br>(0.004) |
| Trade openness | -0.025***<br>(0.008) | -0.029***<br>(0.010) | -0.024**<br>(0.011) | -0.041***<br>(0.012) | -0.015<br>(0.011) | -0.004<br>(0.012) | 0.017<br>(0.019) | 0.004<br>(0.019) |
| Current account balance | 0.025<br>(0.030) | -0.008<br>(0.060) | -0.006<br>(0.061) | -0.005<br>(0.061) | -0.017<br>(0.029) | -0.055<br>(0.047) | -0.064<br>(0.051) | -0.079<br>(0.057) |
| Sovereign credit rating | 0.132**<br>(0.051) | 0.043<br>(0.442) | 0.093<br>(0.451) | 0.073<br>(0.438) | 0.254***<br>(0.093) | 0.449***<br>(0.072) | 0.481***<br>(0.074) | 0.459***<br>(0.073) |
| $R^2$ | 0.535 | 0.657 | 0.650 | 0.667 | 0.492 | 0.667 | 0.694 | 0.670 |
| Adj. $R^2$ | 0.487 | 0.507 | 0.498 | 0.522 | 0.447 | 0.560 | 0.597 | 0.566 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; $p < 0.1$ *, $p < 0.05$ **, $p < 0.01$ ***

As discussed in Section 4.1 and 4.2, it is likely that aggregate rail investment doesn't provide the adequate carbon emissions information from this type of infrastructure to be imputed into sovereign yields in the same manner as renewable energy. Hence, these factors may result in rail, transport, and total infrastructure having positive relations with 10-year bond yields. The measured fit of the models (2) through (4) are reasonable, at 56%, 60%, and 57%, respectively. These are higher than the counterpart results for 3-year yields, though this is to be expected given the lesser predictive power of all variables, macroeconomic controls included, on short-term bond yields. Rail and infrastructure have a negative relation to 3-year bond yields for low investment gap countries. An increase of 1% in 3-year yields is associated with a decrease of 0.79% for total infrastructure investment, which is significant at the 5% level.

The most influential variable in the full sample, advanced, and developing country samples, renewables contribution, has a similar effect in the low investment gap sample, though with lower levels of significance. For 3-year bond yields, the coefficient on renewables is between -1.45% and -2.65%, though it is not statistically significant. The effect on renewable contribution is greater for 10-year yields, ranging from -1.44 to -2.66%, where in columns (3) and (4) it is significant the 10% level. Renewable tonne of oil equivalent (TOE) also has the expected coefficient signs. These results indicate that the characteristics of countries with lower investment gaps in infrastructure are likely similar to the sample of all countries which is biased towards advanced countries. Low investment gap countries have close to full infrastructure requirements based on economic need, so any future investments must be addressing alternative factors, like lowering a country's climate transition risk or restructuring the emissions profile of existing infrastructure assets towards low-carbon solutions. It is possible that renewables contribution, measuring the percent makeup of renewables in total energy supply, is more static amongst these countries given this limited shortfall and results in the lesser significance on yields than observed in earlier samples.

## 4.6. Robustness Check and Sensitivity Analysis

In order to legitimise the results from Tables 2 through 7, I conduct two forms of sensitivity analysis. Firstly, I conduct a sensitivity analysis on models for 3-year and 10-year bond yields the results of which are presented in Table 8. Secondly, I implement an alternative dependent variable, the corresponding bond yield spreads for the sample of all 40 countries. The alternative measure results are available in Table 9. I find that most of the observed effects in Sections 4.1 to 4.5 persist.

### *viii. Sensitivity Analysis - Influential Country Exclusion*

Congruent to testing conducted in Collender et al. (2020), I have selected Portugal as one of the countries to be removed from the full sample of countries in order to determine if the results presented in the main results are heavily influenced by countries whose bond yields demonstrate unique behaviours. I also select Greece for removal as a country unique to my sample and whose yields were also demonstrably high in the late 2000's.

Between 2010 – 2014, Portugal's 10 and 3-year yields spiked due to a financial crisis related to a wider economic downturn. Poor economic conditions commencing in the early 2000's culminated in an economic bailout of Portugal by the European Commission, Eurogroup, and International Monetary Fund in 2011. The same year 10-year yields peaked at 12.79% and 3-year yields exceeded this at 16.18%. Removal of Portugal from the full sample will ensure no upward bias is placed on coefficients resulting from these outliers. Greece posed another outlier in the bond yield samples, where between 2010 and 2014 Greece's 10-year bond yields reached nearly 33% and 3-year yields 107%. This anomaly clearly illustrates the Greek government debt crisis during this period whereby at its worst, Greece's GDP shrunk 6.9% in 2011 and unemployment grew to 23.1% in 2012. Government debt-to-GDP ballooned to 177% and as a result sovereign bond yields sharply rose for all bond maturities.

Regarding Panel A of Table 15, the results of the sample excluding Portugal and Greece look promisingly similar to the full sample results in Table 9. Panel A confirms the expectations set out in the first hypothesis, with both negative relation between rail and renewables contribution on 3-year bond yields as set out in column (2). The coefficient on rail is -0.23% and non-significant. For renewable contribution, this effect is -2.09% and significant at the 10% level. The removal of the two countries results in a slight increase in the renewable contribution coefficients from the corresponding results in of Section 4.1, though not for the low-carbon results in column (2). Again, the coefficients on all infrastructure investment variables mirror the dynamics of the primary results, remaining negative across rail, transport and infrastructure for 3-year bond yields results and positive for 10-year bond yields. Maintenance investment remains negatively related to bond yields and an observed improvement in the significance of the coefficients within the 10-year bond panel, changing from 10% to 1% (Column 2) and 5% (Columns 3 & 4) statistical significance with the exclusion of Portugal and Greece. Overall, the results of the regression analysis with the exclusion of Portugal and Greece further confirm the negative relation between low-carbon infrastructure and sovereign bond yields, though with predominant effects within the renewable energy sector. The overall fit of the model suffers with the exclusion of Portugal and Greece from the sample, as measured in the changes in adjusted R-squared between Table 15 and Table 9. Using the low-carbon model as an example (Column 2), amongst 3-year bond results the adjusted R-squared in the original model is 26% and under the sensitivity analysis is 34%. For 10-year results, the original adjusted R-squared is 39% and under the sensitivity analysis 44%, where both results allude that the presence of Greece and Portugal in the sample create a less powerful predictive model. This arises due to the unusual spikes in the bond yields of these countries.

**Table 8: Results for All Countries (Excluding Portugal & Greece)**

| Dependent Variable | (A) 3-Year Sovereign Bond Yield | | | | (B) 10-Year Sovereign Bond Yield | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | -0.227<br>(0.219) | | | | 0.087<br>(0.140) | | |
| Transport investment | | | -0.084<br>(0.171) | | | | 0.246*<br>(0.144) | |
| Infrastructure investment | | | | -0.193<br>(0.226) | | | | 0.201<br>(0.148) |
| Renewable contribution | | -2.094*<br>(1.122) | -4.315***<br>(1.319) | -4.141***<br>(1.401) | | -3.749***<br>(1.021) | -4.662***<br>(1.187) | -4.817***<br>(1.212) |
| Renewable TOE | | 1.244<br>(1.278) | 2.908**<br>(1.239) | 2.757**<br>(1.328) | | 3.292***<br>(1.086) | 3.794***<br>(1.208) | 3.968***<br>(1.235) |
| Infrastructure maintenance | | -0.115<br>(0.221) | -0.061<br>(0.151) | -0.005<br>(0.175) | | -0.392***<br>(0.136) | -0.360**<br>(0.146) | -0.322**<br>(0.137) |
| Quality score | | -0.194<br>(0.222) | -0.209<br>(0.239) | -0.224<br>(0.243) | | 0.381***<br>(0.135) | 0.238<br>(0.160) | 0.234<br>(0.163) |
| GDP per capita | -0.840<br>(0.549) | -1.167<br>(2.009) | -2.297<br>(1.894) | -2.036<br>(2.038) | -1.380**<br>(0.596) | -4.282***<br>(1.120) | -4.659***<br>(1.198) | -4.732***<br>(1.201) |
| Real GDP growth | -0.008<br>(0.023) | 0.013<br>(0.022) | -0.003<br>(0.018) | -0.006<br>(0.019) | -0.022**<br>(0.009) | -0.003<br>(0.011) | -0.007<br>(0.009) | -0.007<br>(0.008) |
| Inflation | 0.072***<br>(0.022) | 0.052<br>(0.034) | 0.028<br>(0.024) | 0.025<br>(0.025) | 0.058***<br>(0.018) | 0.044<br>(0.031) | 0.022<br>(0.027) | 0.020<br>(0.028) |
| Debt-to-GDP | -0.020***<br>(0.006) | -0.021**<br>(0.008) | -0.009<br>(0.009) | -0.010<br>(0.009) | -0.009**<br>(0.005) | -0.005<br>(0.006) | 0.000<br>(0.005) | 0.000<br>(0.005) |
| Trade openness | -0.011<br>(0.009) | -0.017*<br>(0.009) | -0.003<br>(0.009) | -0.002<br>(0.009) | -0.020***<br>(0.006) | -0.018**<br>(0.007) | -0.005<br>(0.006) | -0.005<br>(0.006) |
| Current account balance | -0.025<br>(0.023) | 0.015<br>(0.024) | 0.018<br>(0.021) | 0.018<br>(0.020) | 0.000<br>(0.015) | 0.018<br>(0.020) | 0.017<br>(0.015) | 0.016<br>(0.015) |
| Sovereign credit rating | 0.025<br>(0.095) | 0.173***<br>(0.061) | -0.004<br>(0.103) | -0.005<br>(0.101) | 0.012<br>(0.069) | 0.092**<br>(0.036) | -0.007<br>(0.051) | -0.004<br>(0.051) |
| $R^2$ | 0.318 | 0.465 | 0.395 | 0.398 | 0.333 | 0.527 | 0.530 | 0.525 |
| Adj. $R^2$ | 0.256 | 0.340 | 0.267 | 0.271 | 0.279 | 0.436 | 0.448 | 0.442 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

*ix. Alternative Dependent Variable*

Running the same models and alternating in a new dependent variable, sovereign bond yield spreads, and removing the United States from the sample results in consistency in the direction and significance of key variables across both Panels A and B (see Table 9). I observe resounding and significant negative effect in the relation of 10 and 3-year bond yields with renewable contribution. Renewable TOE is slightly more significant in columns (3) and (4), now significant at 5%. Contrasting the main results, infrastructure maintenance investment is not statistically significant when examining its effect on yield spreads. Amongst the macroeconomic variables, all have the expected association with yield spreads and we can confirm that these variables may interact slightly differently for the underlying bond yields, as discussed in Section 4.1. Reasonable adjusted r-squared measures are present across most models in the bond yields spread regressions, ranging from 24% to 28% for 3-year spreads and 27% and 44% for 10-year spreads. The measured fit of these models are comparable to those in Table 2 in the results from the full sample, suggesting that the presence of the United States does not substantially change the observed effects.

## Table 9: Results for All Countries (Bond Yield Spreads)

| Dependent Variable | (A) 3-Year Sovereign Bond Yield Spreads | | | | (B) 10-Year Sovereign Bond Yield Spreads | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Rail investment | | -0.160 | | | | 0.064 | | |
| | | (0.181) | | | | (0.115) | | |
| Transport investment | | | -0.079 | | | | 0.175 | |
| | | | (0.141) | | | | (0.116) | |
| Infrastructure investment | | | | -0.181 | | | | 0.134 |
| | | | | (0.197) | | | | (0.123) |
| Renewable contribution | | -2.651** | -4.456*** | -4.301*** | | -3.716*** | -4.622*** | -4.743*** |
| | | (1.037) | (1.321) | (1.389) | | (1.119) | (1.198) | (1.209) |
| Renewable TOE | | 1.502 | 3.090** | 2.961** | | 3.169*** | 3.849*** | 3.982*** |
| | | (1.193) | (1.285) | (1.353) | | (1.167) | (1.202) | (1.216) |
| Infrastructure maintenance | | -0.150 | -0.039 | 0.000 | | -0.194 | -0.203 | -0.183 |
| | | (0.113) | (0.097) | (0.103) | | (0.128) | (0.124) | (0.116) |
| Quality score | | -0.006 | -0.122 | -0.138 | | 0.497*** | 0.313* | 0.309* |
| | | (0.271) | (0.263) | (0.267) | | (0.161) | (0.177) | (0.179) |
| GDP per capita | -0.783 | -1.093 | -2.470 | -2.227 | -1.336** | -4.316*** | -4.745*** | -4.782*** |
| | (0.543) | (2.033) | (1.954) | (2.085) | (0.617) | (1.235) | (1.172) | (1.171) |
| Real GDP growth | -0.016 | 0.000 | -0.009 | -0.011 | -0.026*** | -0.015 | -0.012 | -0.012 |
| | (0.023) | (0.023) | (0.018) | (0.018) | (0.010) | (0.012) | (0.010) | (0.009) |
| Inflation | 0.080*** | 0.113*** | 0.056* | 0.052* | 0.064*** | 0.063* | 0.030 | 0.029 |
| | (0.025) | (0.041) | (0.030) | (0.030) | (0.020) | (0.035) | (0.029) | (0.030) |
| Debt-to-GDP | -0.019*** | -0.014* | -0.009 | -0.011 | -0.009* | -0.006 | -0.003 | -0.003 |
| | (0.006) | (0.008) | (0.008) | (0.008) | (0.005) | (0.005) | (0.005) | (0.005) |
| Trade openness | -0.011 | -0.021** | -0.006 | -0.004 | -0.022*** | -0.019*** | -0.006 | -0.006 |
| | (0.009) | (0.010) | (0.009) | (0.010) | (0.006) | (0.007) | (0.007) | (0.007) |
| Current account balance | -0.021 | 0.039* | 0.024 | 0.022 | 0.003 | 0.024 | 0.017 | 0.016 |
| | (0.023) | (0.022) | (0.018) | (0.018) | (0.015) | (0.016) | (0.013) | (0.013) |
| Sovereign credit rating | -0.019 | 0.045 | -0.039 | -0.039 | -0.021 | 0.031 | -0.027 | -0.026 |
| | (0.074) | (0.091) | (0.089) | (0.087) | (0.044) | (0.043) | (0.043) | (0.043) |
| $R^2$ | 0.303 | 0.418 | 0.393 | 0.396 | 0.327 | 0.506 | 0.521 | 0.518 |
| Adj. $R^2$ | 0.239 | 0.280 | 0.262 | 0.266 | 0.272 | 0.409 | 0.436 | 0.432 |

*Notes:* Country fixed effects and year fixed effects have been used in all regressions. Robust standard errors in parentheses; p < 0.1 *, p < 0.05 **, p < 0.01 ***

## 4.7. Limitations

There are a few key limitations with the methodology and underlying data. The full sample is dominated by advanced and low-investment gap countries, leading to bias in the estimation of results for the developing and high gap countries. And secondly, there are data limitations for variables on both sides of the regression. For infrastructure, the issue presented has been data frequency as most countries only report metrics in this area on an annual basis and with some lags in reporting. Unfortunately, this is standard practice for infrastructure related data. To address issues with infrastructure reporting, infrastructure project data as opposed to investment amounts may provide better data quality as well as improve the information on the sustainability of individual projects. With regards to bond yield data, further issues persist for developing countries, as many of these did not start issuing sovereign bonds until the late 2000's around the Global Financial Crisis. As a result, the bias in the sample towards advanced economies is further aggravated. Finally, the introduction of the infrastructure investment gap as a fairly novel variable could benefit from greater coverage of the wider sample of countries.

Other limitations are model-specific and more difficult to address. The first is reverse causality, which may be present in the models. There is potential for the cost of debt within an economy to determine the fiscal ability to invest into often-costly infrastructure assets. The level of debt within an economy is addressed through the inclusion of debt-to-GDP as a key macroeconomic control and bond yield determinant, which should address some of the issues of debt availability influencing infrastructure investment levels. The dollar investment variables used in this paper (rail, transport, infrastructure, and maintenance) are measures of combined public and private investment. Without knowing the exact proportions of public and private funds in the pool, I cannot be certain of how reverse causality may persist in the model, though it warrants a discussion regardless. The second concern is the comparative size of bond markets in a country, and their levels of liquidity will influence the bond yields and bond yield spreads. In the case of large sovereign bond markets like those in the United States, this may have a substantial influence on bond yields. Global low interest rate environments also pose a challenge to the model. As interest rates fall from expansionary monetary policy enables countries to borrow at cheaper interest rates and this will affect the ability to outlay funds into infrastructure projects. The downside of implementing additional controls beyond what this paper has already covered, is the potential for overfitting. The variables included have been chosen either on the basis of having a clear influence on infrastructure landscapes in an economy, or being previously studied determinants of sovereign bond yields.

### 4.8. Implications for Future Research

The intersection of climate risk and infrastructure and how this affects the wider economy is critical, and to examine how this is interpreted by sovereign markets is an important step into a developing area of research. Further studies could foray into project-level infrastructure data, as suggested in Section 4.7, to better leverage the climate risks of individual projects when making assumptions on broad sectors of infrastructure. Project-level data would allow for more frequent data and the potential to implement a panel vector autoregressive model may be more appropriate. Greater implications lie in including data that captures the type of funding involved in infrastructure development. Utilising Private Participation in Infrastructure (PPI) data to examine how private funds impact markets that are affected by climate transition risk, including sovereign debt markets may offer governments solutions to infrastructure shortfalls that cannot be met within fiscal limits. With the results for advanced economies in particular, this may push governments to further encourage private participation by institutional investors into infrastructure. The appetite for institutional participation infrastructure funding is evident with Macquarie Asset Management closing sixth Americas infrastructure fund with $6.9 billion in commitments in August of 2021. If government cost of debt can be reduced by improving the emissions profiles of a country's infrastructure, then governments are going to be more likely to encourage all kinds of innovation and investment in low-carbon infrastructure.

## 5. Conclusion

During the 26th Conference of Parties (COP) summit in Glasgow in November, 2021, world leaders failed to agree on eliminating coal and toughening emissions targets to 2030. At the "Build Back Better World" roundtable at COP26, United States President Joe Biden, stated that "*every infrastructure project started, we should think about from the perspective of climate*". The Build Back Better World initiative was formed out of the Group of Seven (G7) countries in an effort to provide infrastructure to low and middle-income countries. Infrastructure is a key component of a country's emissions profile. I specifically investigate how several forms of infrastructure investment (renewable energy, transport, total) impact a countries cost of debt when controlling for other macroeconomic and credit factors. I find that advanced economies can improve their cost of debt through meaningful investments into low-carbon, climate-resilient infrastructure and developing economies have underlying infrastructure needs that must be met on the basis of economic requirements and climate transition planning simultaneously. The intermingling effects of investment shortfalls in infrastructure, the emissions profiles of existing infrastructure assets, and the climate implications of future investments have mixed effects on global sovereign debt markets. I address some of the questions and expectations around infrastructure, climate risk, and sovereign bond markets using a sample of 40 countries over 25 years to 2019.

The most prominent effect from infrastructure variables comes from the renewable energy investment proxies, particularly the percent renewable contribution towards total energy supply. I find a resounding negative relation between renewable contribution and 3-year and 10-year bond yields. As rail investment showed no significance or consistency, I find limited evidence on the hypothesis that higher low-carbon infrastructure investment corresponds to lower sovereign bond yields. For advanced economies, the negative relation between renewable contribution, a critical form of low-carbon infrastructure supporting climate transition, is larger than developing economies. These effects of renewable contribution are not as strong for 3-year bond yields, which indicates that the longer term climate risks associated with infrastructure are less relevant to short-term government cost of debt. Nonetheless, both bond yield maturities demonstrate that higher renewables contribution corresponds to lower sovereign bond yields. For developing countries, the effects of renewable contribution is larger in the 3-year bond yield regressions, and as this effect only persists amongst the developing country group suggesting that for developing countries that short-term outcomes have greater returns to scale. It is possible that an investment into energy infrastructure has more meaningful economic growth effects from additional investment in the short-term than for an advanced economy explaining the greater effect on short-term bonds. Mixed results amongst high and low investment gap countries signify that, particularly high gap countries, require further study to evaluate the underlying infrastructure characteristics in these countries. Finally, control measures around infrastructure quality and maintenance leave questions around whether infrastructure is an indicator of physical climate risk. Variables that provide insight on the existing infrastructure portfolios of countries show significance in country groupings where investment may be required on the basis of non-climate requirements, like meeting basic population and growth needs.

There are several key implications for these results, primarily for policymakers in infrastructure funding decisions and those dealing in climate transition planning. Ideally, policymakers of advanced countries will identify the strategic benefits of transitioning their infrastructure towards climate-robust alternatives, potentially enjoying a reduced cost of debt as a result. Encouragement of institutional investor participation in infrastructure funding would enable developing and high investment gap countries to alleviate the strain on existing and high-emitting assets to reduce global emissions from all infrastructure sectors. Energy policy should continue or commence to improve the relative contribution of renewables to total energy supply at national levels. Future studies in this area could examine whether the benefits in cost of debt from implementing low-carbon energy are constant or with decreasing returns to scale. Improvements in technology should allow for these transitions to occur with reduced costs, though policymakers will need to make a trade-off between the current higher costs of low-carbon alternatives and the long-term benefits observed in bond yields and yield spreads. Equally important, will be ensuring the years ahead see meaningful transformation of all infrastructure sectors in order to meet the climate promises made my nations and the complex economic and environmental needs of future generations.

**References**


Adshead, D., Thacker, S., Fuldauer, L. I., & Hall, J. W. (2019). Delivering on the Sustainable Development Goals through long-term infrastructure planning. *Global Environmental*

Bak, C., Bhattacharya, A., Edenhofer, O., & Knopf, B. (2017). Towards a comprehensive approach to climate policy, sustainable infrastructure, and finance. *Economics*, *11*(1). https://doi.org/10.5018/economics-ejournal.ja.2017-33

Baldauf, M., Garlappi, L., & Yannelis, C. (2020). Does climate change affect real estate prices? Only if you believe in it. The Review of Financial Studies, 33(3), 1256-1295.

Baltagi, B. H. (2021). *Econometric Analysis of Panel Data*. Springer International Publishing. https://doi.org/10.1007/978-3-030-53953-5

Baltagi, B. H., & Chang, Y.-J. (1994). Incomplete panels: A comparative study of alternative estimators for the unbalanced one-way error component regression model. *Journal of Econometrics*, *62*(2), 67–89. https://doi.org/10.1016/0304-4076(94)90017-5

Baltagi, B. H., Feng, Q., & Kao, C. (2012). A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model. *Journal of Econometrics*, *170*(1), 164–177. https://doi.org/10.1016/j.jeconom.2012.04.004

Bansal, R., Kiku, D., & Ochoa, M. (2016). Price of long-run temperature shifts in capital markets (No. w22529). National Bureau of Economic Research.

Battiston, S., & Monasterolo, I. (2019). A climate risk assessment of sovereign bonds. Available at SSRN 3376218.

Beirne, J., Renzhi, N., & Volz, U. (2020). Feeling the heat: Climate risks and the cost of sovereign borrowing. ADBI Working Paper 1160, Available at SSRN 3657114 or http://dx.doi.org/10.2139/ssrn.3657114

Boyrie, M. E. de, & Pavlova, I. (2020). Analysing the link between environmental performance and sovereign credit risk. *Applied Economics*, *52*(54), 5949–5966. https://doi.org/10.1080/00036846.2020.1781772

Braungardt, S., van den Bergh, J., & Dunlop, T. (2019). Fossil fuel divestment and climate change: Reviewing contested arguments. *Energy Research & Social Science*, *50*, 191–200. https://doi.org/10.1016/j.erss.2018.12.004

Breusch, T. S. (1978). Testing for Autocorrelation in Dynamic Linear Models*. *Australian Economic Papers*, *17*(31), 334–355. https://doi.org/10.1111/j.1467-8454.1978.tb00635.x

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics. *The Review of Economic Studies*, *47*(1), 239–253. https://doi.org/10.2307/2297111

Cantor, R., & Packer, F. (1996). *Determinants and Impact of Sovereign Credit Ratings*. 18.

Carney, M. (2015). Breaking the tragedy of the horizon–climate change and financial stability. *Speech given at Lloyd's of London*, *29*, 220–230.

Cevik, S., & Jalles, J. T. (2020). This changes everything: climate shocks and sovereign bonds. IMF Working Paper No. 20/79.

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., & Chawla, N. (2015). University of Notre Dame Global Adaptation Index Country Index Technical Report.

Chen, J., Zhao, F., Liu, Z., Ou, X., & Hao, H. (2017). Greenhouse gas emissions from road construction in China: A province-level analysis. Journal of Cleaner Production, 168, 1039–1047. https://doi.org/10.1016/j.jclepro.2017.08.243

Chester, M. V., Underwood, B. S., & Samaras, C. (2020). Keeping infrastructure reliable under climate uncertainty. Nature Climate Change, 10(6), 488–490. https://doi.org/10.1038/s41558-020-0741-0

CISL (2015). Unhedgeable risk: How climate change sentiment impacts investment. Report, Institute for Sustainability Leadership, University of Cambridge.

Clarvis, M. H., Halle, M., Mulder, I., & Yarime, M. (2014). Towards a new framework to account for environmental risk in sovereign credit risk analysis. *Journal of Sustainable Finance & Investment*. https://www-tandfonline-com.ezproxy.lib.uts.edu.au/doi/abs/10.1080/20430795.2013.837810

Collender, S., Sklibosios Nikitopoulos, C., Puente Moncayo, D., Richards, K.-A., & Ryan, L. S. (2021). Climate Change Transition Risk on Sovereign Bond Markets. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3861350

Covington, H., & Thamotheram, R. (2015). The Case for Forceful Stewardship (Part 1): The Financial Risk from Global Warming (SSRN Scholarly Paper ID 2551478). Social Science Research Network. https://doi.org/10.2139/ssrn.2551478

Drut, B. (2010). Sovereign Bonds and Socially Responsible Investment. *Journal of Business Ethics*, *92*(1), 131–145. https://doi.org/10.1007/s10551-010-0638-3

Ehlers, T. (2014). *Understanding the challenges for infrastructure finance*. https://www.bis.org/publ/work454.htm

Engle, R. F., Giglio, S., Kelly, B., Lee, H., & Stroebel, J. (2020). Hedging Climate Change News. *The Review of Financial Studies*, *33*(3), 1184–1216. https://doi.org/10.1093/rfs/hhz072

Fay, M., Han, S., Lee, H. I., Mastruzzi, M., & Cho, M. (2019). Hitting the trillion mark: a look at how much countries are spending on infrastructure. The World Bank.

Fu, T., & Liu, Y. (2018). Private Participation in Infrastructure and Financial Sector Development: Evidence from Developing Countries. *Emerging Markets Finance and Trade*, *54*(1), 203–218. https://doi.org/10.1080/1540496X.2017.1300882

Gerlach, S., Schulz, A., & Wolff, G. B. (2010). Banking and Sovereign Risk in the Euro Area (SSRN Scholarly Paper ID 2785373). Social Science Research Network. https://doi.org/10.2139/ssrn.2785373

Godfrey, L. G. (1978). Testing for Higher Order Serial Correlation in Regression Equations when the Regressors Include Lagged Dependent Variables. *Econometrica*, *46*(6), 1303–1310. https://doi.org/10.2307/1913830

Hausman, J. A. (1978). Specification Tests in Econometrics. *Econometrica*, *46*(6), 1251–1271. https://doi.org/10.2307/1913827

Hjort, I. (2016). Potential Climate Risks in Financial Markets: A Literature Overview. In *Memorandum* (No. 01/2016; Memorandum). Oslo University, Department of Economics. https://ideas.repec.org/p/hhs/osloec/2016_001.html https://dx.doi.org/10.1787/9789264273528-en.

International Monetary Fund. (2020). Physical Risk and Equity Prices. Global Financial Stability Report, Chapter 5 (Washington, DC: International Monetary Fund).

IPCC (2018). Global Warming of 1.5oC. An IPCC Special Report on the Impacts of Global Warming of 1.5oC Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. eds V. P. Masson-Delmotte et al. (Cambridge: Cambridge Univeristy Press).

Jensen, P. D., Purnell, P., & Velenturf, A. P. M. (2020). Highlighting the need to embed circular economy in low carbon infrastructure decommissioning: The case of offshore wind. *Sustainable Production and Consumption*, *24*, 266–280. https://doi.org/10.1016/j.spc.2020.07.012

Keho, Y. (2017). The impact of trade openness on economic growth: The case of Cote d'Ivoire. *Cogent Economics & Finance*, *5*(1), 1332820.

Kling, G., Lo, Y. C., Murinde, V., & Volz, U. (2018). Climate vulnerability and the cost of debt. Available at SSRN 3198093.

Laubach, T. (2009). New evidence on the interest rate effects of budget deficits and debt. *Journal of the European Economic Association*, *7*(4), 858–885.

Margaretic, P., & Pouget, S. (2018). Sovereign bond spreads and extra-financial performance: An empirical analysis of emerging markets. *International Review of Economics & Finance*, *58*, 340–355. https://doi.org/10.1016/j.iref.2018.04.005

McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature*, *517*(7533), 187–190. https://doi.org/10.1038/nature14016

Meltzer, J. P. (2016). Financing Low Carbon, Climate Resilient Infrastructure: The Role of Climate Finance and Green Financial Systems (SSRN Scholarly Paper ID 2841918). Social Science Research Network. https://doi.org/10.2139/ssrn.2841918

New Climate Economy (2016). The sustainable infrastructure imperative: financing for better growth and development. London, UK.

Nickel, C., Rother, P., & Ruelke, J.-C. (2011). Fiscal variables and bond spreads–evidence from Eastern European countries and Turkey. *Applied Financial Economics*, *21*(17), 1291–1307.

Nickell, S. (1981). Biases in Dynamic Models with Fixed Effects. *Econometrica*, *49*(6), 1417–1426. https://doi.org/10.2307/1911408

OECD (2017). *Investing in Climate, Investing in Growth*, OECD Publishing, Paris.

OECD (2020). Green Infrastructure in the Decade for Delivery: Assessing Institutional Investment, Green Finance and Investment. OECD Publishing, Paris. https://doi.org/10.1787/f51f9256-en.

OECD, The World Bank, & United Nations Environment Programme. (2018). Financing Climate Futures: Rethinking Infrastructure. OECD. https://doi.org/10.1787/9789264308114-en

Oxford Economics (2017). Global infrastructure outlook to 2040. GI Hub, London.

Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, *60*(1), 13–50. https://doi.org/10.1007/s00181-020-01875-7

Poghosyan, T. (2014). Long-run and short-run determinants of sovereign bond yields in advanced economies. *Economic Systems*, *38*(1), 100–114. https://doi.org/10.1016/j.ecosys.2013.07.008

Ratter, B. M. W., Petzold, J., & Sinane, K. (2016). Considering the locals: Coastal construction and destruction in times of climate change on Anjouan, Comoros. Natural Resources Forum, 40(3), 112–126. https://doi.org/10.1111/1477-8947.12102

Robins, N. (2014). *Integrating Environmental Risks into Asset Valuations:* 13.

Robins, N., Spedding, P., & Mehta, K. (2013). Oil & Carbon Revisited: Value at Risk from 'Unburnable' Reserves. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2220738

Safiullah, M., Kabir, M. N., & Miah, M. D. (2021). Carbon emissions and credit ratings. *Energy Economics*, *100*(C). https://ideas.repec.org/a/eee/eneeco/v100y2021ics014098832100236x.html

Saha, D., & Modi, A. (2017). *Low-carbon infrastructure private participation in infrastructure (PPI): 2002 to H1 2017*. The World Bank.

Sclar, E. (2015). The political economics of investment Utopia: Public–private partnerships for urban infrastructure finance. Journal of Economic Policy Reform, 18(1), 1–15. https://doi.org/10.1080/17487870.2014.950857

UN (2015). Transforming our world: the 2030 agenda for sustainable development. United Nations, New York.

UN. (2020). *World Economic Situation and Prospects 2020*. 41.

UNFCCC. (2015). *Adoption of the Paris Agreement, FCCC/CP/2015/10/Add. 1.*

## Appendix

**Table A.10: Variable Definitions**

| Variable | Data Source | Definition |
|---|---|---|
| 10-year bond yield | Bloomberg | A country's generic 10-year bond yield |
| 3-year bond yield | Bloomberg | A country's generic 3-year bond yield |
| Rail investment | OECD | Annual investment into rail infrastructure |
| Transport investment | OECD | Annual investment into rail, roads, airports, ports, and inland waterway infrastructure |
| Infrastructure investment | OECD & GIHUB | Annual investment into transport, water, and ICT infrastructure |
| Renewable contribution | OECD | Contribution of renewable energy to total primary energy supply (TPES) |
| Renewable TOE | OECD | Renewable contribution energy measured in thousand TOE (tonne of oil equivalent) |
| Infrastructure maintenance | GIHUB | Annual investment into maintenance of current stock of infrastructure |
| Quality score | GIHUB | Score from 1 - 7 measuring infrastructure quality (also a component of the Global Compeitiveness Index) |
| GDP per capita | World Bank | Gross domestic product over total population |
| Real GDP growth | World Bank | Annual percentage change in real gross domestic product |
| Inflation | World Bank | Percent change in Consumer Price Index over a year |
| Debt-to-GDP | IMF World Economic Outlook Database | Gross government debt over gross domestic product |
| Trade openness | World Bank national accounts data, and OECD National Accounts data files. | Sum of exports and imports over gross domestic product |
| Current account balance | IMF World Economic Outlook Database | Sum of the balance of trade, net income from overseas, and net current transfers over gross domestic product |
| Sovereign credit rating | Moody's | Credit rating converted to a number between 1 and 21 (i.e. Aaa = 21) |

## Table A.11: Sovereign Credit Rating Transformations

| Moody's Ratings | Numerical Score | Bond Classification |
|---|---|---|
| Aaa | 21 | Prime |
| Aa1 | 20 | |
| Aa2 | 19 | |
| Aa3 | 18 | |
| A1 | 17 | |
| A2 | 16 | Investment Grade |
| A3 | 15 | |
| Baa1 | 14 | |
| Baa2 | 13 | |
| Baa3 | 12 | |
| Ba1 | 11 | |
| Ba2 | 10 | |
| Ba3 | 9 | |
| B1 | 8 | |
| B2 | 7 | |
| B3 | 6 | High Yield |
| Caa1 | 5 | |
| Caa2 | 4 | |
| Caa3 | 3 | |
| Ca | 2 | |
| C | 1 | |

*Notes:* Credit ratings from Moody's are transformed where the highest rating (Aaa) converts to 21 and the lowest credit rating (C) converts to 1. This transformation is applied as higher credit ratings are associated with lower sovereign bond yields and is congruent to the application of credit rating sin Safiullah et al. (2021).

## Table A.12: Countries by Investment Gap Classification

| Country | Investment Gap to 2030 | Classification |
|---|---|---|
| Australia | 10.32% | Low |
| Canada | 1.96% | Low |
| China | 7.47% | Low |
| Croatia | 16.40% | Low |
| France | 0.70% | Low |
| Germany | 0.06% | Low |
| India | 12.49% | Low |
| Japan | 3.13% | Low |
| New Zealand | 11.12% | Low |
| Poland | 16.27% | Low |
| Romania | 5.49% | Low |
| Spain | 6.07% | Low |
| United Kingdom | 9.37% | Low |
| Chile | 22.48% | High |
| Italy | 27.59% | High |
| Mexico | 54.98% | High |
| Russia | 45.01% | High |
| Turkey | 44.72% | High |
| United States | 34.70% | High |

**Table A.13: Country Groupings**

| Advanced (29) | Developing (11) | High Gap (6) | Low Gap (13) |
|---|---|---|---|
| Australia | Bulgaria | Chile | Australia |
| Austria | Chile | Italy | Canada |
| Belgium | China | Mexico | China |
| Canada | Croatia | Russia | Croatia |
| Czech Republic | Hungary | Turkey | France |
| Denmark | India | United States | Germany |
| Finland | Mexico | | India |
| France | Poland | | Japan |
| Germany | Romania | | New Zealand |
| Greece | Russia | | Poland |
| Iceland | Turkey | | Romania |
| Ireland | | | Spain |
| Israel | | | United Kingdom |
| Italy | | | |
| Japan | | | |
| Latvia | | | |
| Lithuania | | | |
| Netherlands | | | |
| New Zealand | | | |
| Norway | | | |
| Portugal | | | |
| Slovakia | | | |
| Slovenia | | | |
| South Korea | | | |
| Spain | | | |
| Sweden | | | |
| Switzerland | | | |
| United Kingdom | | | |
| United States | | | |

## Table A.14: Hausman Test, Lagrange Multiplier Test, and F-test

The table shows the results from the Hauman Test, Breusch-Pagan Lagrange Multiplier test, and F-test for time-fixed effects. The models on which these tests are run include only macroeconomic control variables (1), rail, renewables, and all control variables (2), transport, renewables, and all control variables (3) , and infrastructure, renewables and all control variables (4). These models are each run with both 10 and 3-year bond yields as the dependent variable. The sample includes all 40 countries.

| | **Hausman Test**<br>Chi-square (p-value) | **Lagrange Multiplier Test**<br>Chi-square (p-value) | **F-test**<br>F-stat (p-value) |
|---|---|---|---|
| **10-Year Bond Yields** | | | |
| Model 1 | 82.213 (1.246e-15) | 975.420 (2.2e-16) | 29.734 (2.2e-16) |
| Model 2 | 210.420 (2.2e-16) | 177.410 (2.2e-16) | 16.352 (2.2e-16) |
| Model 3 | 628.940 (2.2e-16) | 277.950 (2.2e-16) | 14.957 (2.2e-16) |
| Model 4 | 1122.100 (2.2e-16) | 903.210 (2.2e-16) | 15.375 (2.2e-16) |
| **3-Year Bond Yields** | | | |
| Model 1 | 215.480 (2.2e-16) | 143.790 (2.2e-16) | 11.242 (2.2e-16) |
| Model 2 | 62.746 (2.853e-09) | 25.308 (4.887e-07) | 5.024 (2.087e-06) |
| Model 3 | 82.456 (4.934e-13) | 30.717 (2.986e-08) | 5.374 (4.928e-07) |
| Model 4 | 102.050 (2.2e-16) | 33.203 (8.301e-09) | 5.347 (5.387e-07) |

## Table 15: Breusch-Pagan LM Test of Independence & Pesaran CD Test

The table shows the results from the Breusch-Pagan LM and Pesaran CD tests for cross-sectional dependence. The models on which these tests are run include only macroeconomic control variables (1), rail, renewables, and all control variables (2), transport, renewables, and all control variables (3) , and infrastructure, renewables and all control variables (4). These models are run with 10 and 3-year bond yields as the dependent variable. The sample includes all 40 countries.

| | **Breusch-Pagan LM Test**<br>Chi-square (p-value) | **Pesaran CD Test**<br>Z-stat (p-value) |
|---|---|---|
| **10-Year Bond Yields** | | |
| Model 1 | 3547.500 (2.2e-16) | 29.261 (2.2e-16) |
| Model 2 | 706.600 (2.2e-16) | 6.359 (2.03e-10) |
| Model 3 | 896.470 (2.2e-16) | 5.248 (1.534e-07) |
| Model 4 | 903.210 (2.2e-16) | 5.331 (9.784e-08) |
| **3-Year Bond Yields** | | |
| Model 1 | 1873.700 (2.2e-16) | 7.858 (3.892e-15) |
| Model 2 | 578.360 (9.457e-15) | 1.781 (0.07484) |
| Model 3 | 750.570 (2.2e-16) | 1.616 (0.1061) |
| Model 4 | 749.660 (2.2e-16) | 1.598 (0.1101) |

**Table A.16: Breusch-Godfrey Test of Serial Correlation in Panel Models**

The models on which these tests are run include only macroeconomic control variables (1), rail, renewables, and all control variables (2), transport, renewables, and all control variables (3) , and infrastructure, renewables and all control variables (4). These models are run with 10 and 3-year bond yields as the dependent variable. The sample includes all 40 countries.

| | **Breusch-Godfrey Test**<br>Chi-square (p-value) |
|---|---|
| **10-Year Bond Yields** | |
| Model 1 | 189.940 (2.2e-16) |
| Model 2 | 20.416 (6.23e-06) |
| Model 3 | 44.938 (9.539e-10) |
| Model 4 | 45.906 (5.939e-10) |
| **3-Year Bond Yields** | |
| Model 1 | 137.690 (2.2e-16) |
| Model 2 | 13.665 (0.0002185) |
| Model 3 | 33.142 (1.117e-06) |
| Model 4 | 33.545 (9.236e-07) |

**Table 17: Breusch-Pagan Test of Heteroskedasticity**

The models on which these tests are run include only macroeconomic control variables (1), rail, renewables, and all control variables (2), transport, renewables, and all control variables (3) , and infrastructure, renewables and all control variables (4). These models are each run with both 10 and 3-year bond yields as the dependent variable. The sample includes all 40 countries.

| | **Breusch-Pagan Test**<br>Test stat (p-value) |
|---|---|
| **10-Year Bond Yields** | |
| Model 1 | 304.220 (2.2e-16) |
| Model 2 | 113.480 (5.872e-09) |
| Model 3 | 149.700 (5.29e-14) |
| Model 4 | 151.460 (2.763e-14) |
| **3-Year Bond Yields** | |
| Model 1 | 303.270 (2.2e-16) |
| Model 2 | 167.640 (2.2e-16) |
| Model 3 | 189.520 (2.2e-16) |
| Model 4 | 187.960 (2.2e-16) |