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# FEELING THE HEAT: CLIMATE RISKS AND THE COST OF SOVEREIGN BORROWING

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**Abstract**

This paper empirically examines the link between the cost of sovereign borrowing and climate risk for 40 advanced and emerging economies. Controlling for a large set of domestic and global factors, the paper shows that both vulnerability and resilience to climate risk are important factors driving the cost of sovereign borrowing at the global level. Overall, we find that vulnerability to the direct effects of climate change matter substantially more than climate risk resilience in terms of the implications for sovereign borrowing costs. Moreover, the magnitude of the effect on bond yields is progressively higher for countries deemed highly vulnerable to climate change. Impulse response analysis from a set of panel structural VAR models indicates that the reaction of bond yields to shocks imposed on climate vulnerability and resilience become permanent after around 12 quarters, with high risk economies experiencing larger permanent effects on yields than other country groups.

**Keywords:** climate risk, cost of sovereign borrowing

**JEL Classification:** F32, F41, F62

# Contents

# 1. INTRODUCTION

Climate risks can have material impact on the sustainability of public finances. In climate-vulnerable countries, fiscal health is under threat by potential output losses related to climate hazards and disaster recovery costs, as well as transition risks that may hit specific sectors or the economy at large. For example, Koetsier (2017) finds a considerable increase in government debt for most damaging and deadliest disasters. While a growing body of research has studied the macroeconomic impacts of climate change (Hochrainer 2009; von Peter, von Dahlen, and Saxena 2012; Cabezon et al. 2015; Batten 2018; Mercure et al. 2018; Cantelmo, Melina, and Papageorgiou 2019; Batten, Sowerbutts, and Tanaka 2020), relatively little research has been conducted on the nexus between climate risk and sovereign risk. That said, recent research by Kling et al. (2018) on the relationship between climate vulnerability, sovereign credit profiles, and the cost of capital in climate-vulnerable developing countries shows that these countries incur a risk premium on their sovereign debt, reducing their fiscal capacity for investments in climate adaptation and resilience.[1] Although this is an area that is increasingly receiving attention from rating agencies, to date there has been little systematic research to investigate this deeper.[2]

Our paper builds upon the work carried out by Kling et al. (2018), primarily through the use of a series of structural panel VARs that allow us to examine the response of bond yields to shocks imposed on climate risk and resilience. The regression analysis conducted in the first stage of our approach is largely consistent with the findings of Kling et al. (2018) in terms of the extent of the effect of climate risk on bond yields, although our paper employs alternative measures of climate risk and a higher data frequency. However, the main added value of our approach is the examination of how bond yields react to climate risk and resilience shocks which, crucially, control a large set of domestic and global factors.

Our findings confirm that climate vulnerability has significant implications for sovereign borrowing costs, and that the direct effects of climate change matter substantially more than climate risk resilience. Furthermore, the magnitude of the effect on bond yields is larger for countries deemed highly vulnerable to climate change. Impulse response analysis suggests that the reaction of bond yields to shocks imposed on climate vulnerability and resilience become permanent after around 12 quarters, and that high risk economies experience larger permanent effects on yields than other country groups. The remainder of the paper is organized as follows. The next section provides an overview of the related literature. Section 3 lays out our empirical methodology and the data that we use. Section 4 presents the empirical results. Section 5 concludes.

# 2. RELATED LITERATURE

This paper contributes to the literature on the determinants of the price of sovereign risk, with early work by Edwards (1984) finding a strong role for domestic macroeconomic fundamentals to play in driving government bond spreads, particularly public debt, foreign reserves, the current account balance, and inflation. More recently, work on sovereign risk has been set against the context of the European sovereign debt crisis. Beirne and Fratzscher (2013) find in a study of 31 advanced and emerging economies

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[1] See also Buhr et al. (2018).

[2] Credit ratings agencies are increasingly incorporating climate risk into their assessment of sovereign risk and risk across other asset classes (e.g., Mathiesen 2018).

that worsening economic fundamentals are the main driver of the price of sovereign risk. However, in crisis times, a further important issue was found to be ‘fundamentals contagion’—i.e., an abrupt increase in financial market sensitivity to fundamentals. Other work by Aizenman, Hutchison, and Jinjarak (2013), studying 60 economies, find evidence that credit default swap (CDS) spreads for euro area periphery countries were mispriced based on a set of macroeconomic fundamentals (see also Amato 2005; Packer and Zhu 2005; Cecchetti, Mohanty, and Zampolli 2010). D’Agostino and Ehrmann (2014) focus on the G7 economies, showing that sovereign risk appears to have been mispriced both before and after the crisis. Favero and Missale (2012) make the point that when global risk aversion is high, this can increase the role played by fiscal fundamentals in driving the price of sovereign risk. The issue of contagion has also been a feature of the literature on government bond yields. Some of this work has focused on spillovers and contagion between sovereigns and banks. For example, Alter and Beyer (2014) test the effect on sovereign risk and bank CDS from unexpected shocks imposed on sovereign creditworthiness and country-specific bank indices. Other work has taken a financial integration perspective, with Baldacci and Kumar (2010) noting that price discovery in government bond markets and the more efficient pricing of sovereign risk are associated with the ongoing integration of government bond markets at the global level.

There is a range of channels through which the cost of sovereign borrowing may be affected by climate change, and these are important to consider in the context of the current paper. One way that this may occur is through the depletion of natural capital, and implications for fiscal sustainability and the price of sovereign risk (e.g., Pinzón et al. 2020). Climate risk can also affect sovereign risk due to the fiscal impact of climate-related natural disasters. For example, macroeconomic risks related to natural disasters and extreme weather include risks of a disruption of economic activity, which may adversely affect tax income and other public revenues and increase social transfer payments (e.g., Schuler et al. 2019). A further channel relates to the fiscal consequences of adaptation and mitigation policies for climate change. Public adaptation to climate change affects public budgets directly on the expenditure side (e.g., Bachner, Bednar-Friedl, and Knittel 2019). Likewise, investment in mitigation—for example, clean energy investment—can strain public finances, while climate mitigation policies such as carbon taxes can affect the revenue side. United Nations Conference on Trade and Development (2019) estimations for a group of 31 developing countries suggest that public debt-to-GDP ratios would have to rise from 47% to 185% to finance basic investments to meet the Sustainable Development Goals in poverty, nutrition, health, and education if these investments had to be financed through debt. Many of these investments are linked to adaptation and mitigation. Less developed economies especially tend to have a relatively low debt servicing capacity and are vulnerable to the build-up of external debt. Since these are the countries with the greatest need for adaptation finance, it will be important to develop robust debt management frameworks and limit risk exposure to international debt financing.

Climate change can also affect the cost of sovereign borrowing via broader macroeconomic implications. The first progress report of the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) stresses that climate risks can have negative side effects on macroeconomic conditions, leading to lower investment, financial losses, and disruption in asset valuations (NGFS 2018). On the macroeconomic impacts of climate change, our paper contributes to the strand of literature that examines the implications of climate change for long-run economic growth. Supply and demand shocks from extreme weather events, although short-term in nature, can have lasting impacts on growth (Acevedo 2014; Klomp and Valckx 2014; Botzen, Deschenes, and Sanders 2019) and public finances. Moreover, the supply and demand side effects of gradual global warming and transition impacts can cause fundamental and enduring structural changes to the economy, and adversely affect long-term output trajectories (Burke, Hsiang, and Miguel 2015a; Kahn et al. 2019). For many countries, climate change will have a profound impact on their long-run productive capacity and potential output. A country's long-term growth potential will inevitably have ramifications for public finances and debt sustainability. In addition, the extent to which climate change affects financial stability can have ramifications for the cost of sovereign borrowing and the price of sovereign risk. For example, physical risks related to extreme weather conditions can cause a rise in bank credit risk owing to damage to the operating assets and production output of borrowers. This may lead to an inability of borrowers to meet their debt service obligations, and a higher incidence of non-performing loans, with negative implications for the sovereign risk profile. Bolton et al. (2020) note that central banks need to seriously consider a possible role as a 'climate rescuer of last resort' in a systemic financial crisis by purchasing significant amounts of impaired financial sector assets. Empirical research on bailouts indicates that there can be negative implications for public debt ratios (e.g., Acharya, Drechsler, and Schnabl 2014; European Central Bank 2015). Also, it is important to consider how natural disasters may impact upon international capital flows (e.g., David 2010; Escaleras and Register 2011; Osberghaus 2019), affecting balance of payments positions and thus sovereign risk. Finally, climate risk could lead to a rise in sovereign default rates should it lead to political instability. The positive link between political instability and sovereign default has been widely researched (e.g., Clark 1997; Cuadra and Sapriza 2008). However, more recently, there has been some work to show that climate-related disasters can lead to migration within and between countries, which may induce political instability (e.g., Black et al. 2011; Burke, Hsiang, and Miguel 2015b).

While it is not the aim of our paper to test all of these transmission channels between climate risk and sovereign risk, we seek to empirically confirm the nexus between climate vulnerability and higher sovereign cost of debt identified by Kling et al. (2018). The latter study conducts a panel and principal component analysis with annual data for a sample of 46 countries over the period 1996–2016, and finds that countries with higher exposure to climate vulnerability, measured by indices from the Notre Dame Global Adaptation Initiative (ND-GAIN), exhibit higher cost of debt.[3] The present paper builds on this analysis, using higher frequency data and refined measures of climate vulnerability, risk, and resilience. Importantly, we also develop a set of structural panel VAR models to conduct an impulse response analysis and simulate shocks on climate vulnerability and resilience.

# 3. DATA AND EMPIRICAL METHODOLOGY

A twofold approach is implemented. First, using quarterly data frequency, we use a fixed effects panel model over the period from 2002Q1 to 2018Q4 across 40 countries, the sample of which includes advanced economies, emerging economies (EMEs), and the member countries of the Association of Southeast Asian Nations (ASEAN).[4] We also examine a sub-panel based on economies characterized as having high climate-related risks, defined as being in the top quartile for risk exposure. The first stage examines the drivers of sovereign bond yields, based on a large set of macroeconomic

[3] In a related paper using firm-level data, Kling et al. (2020) show that climate vulnerability also affects the cost of corporate financing and access to finance, controlling for various firm-specific and macroeconomic factors.

[4] See Table A1 in the Appendix for the full list of countries.

data and two climate-related indicators (climate risk vulnerability and climate risk resilience). Drawing on the literature that examines the drivers of sovereign bond yields and the price of sovereign risk, the macroeconomic controls include the current account balance, public debt/GDP, the fiscal balance, GDP per capita, and GDP growth. These variables have been attained from Bloomberg, the IMF International Financial Statistics, the OECD, and China Economic Database (CEIC).[5]

Regarding the climate vulnerability indicator, data for vulnerability to climate risk are taken from a refined version of the ND-GAIN vulnerability index developed by Kling et al. (2020). The refined vulnerability measure comprises all of the components from the ND-GAIN vulnerability index that are not highly related to economic variables in order to mitigate against endogeneity concerns.[6] Data for climate resilience are from FTSE Russell. This indicator refers to the extent to which an economy has measures in place to address exposure to climate risks. Details of the construction of these variables are shown in the Appendix (Tables A3 and A4).[7]

The following baseline equation is estimated:

$$y_{i,t} = \beta x_{i,t-1} + \gamma Z_{i,t-1} + \chi VIX_{t-1} + \tau USY_{t-1} + CRISIS_{i,t-1} + \delta_i + \varepsilon_{i,t} \quad i=1,\ldots,N,\ t=1,\ldots,T \qquad (1)$$

where $y_{i,t}$ represents the government bond yield; $x_{i,t}$ represents a set of domestic macroeconomic fundamentals; $Z_j$ denotes our climate vulnerability and resilience indicators; VIX stands for the Chicago Board Options Exchange (CBOE) Volatility Index, a measure of global risk aversion; USY are US long-term government bond yields; CRISIS represents the Laeven and Valencia (2018) indicator for the incidence of a crisis event for each country in the sample; $\delta i$ are country fixed effects; and $\varepsilon_{i,t}$ is the error term. The variables are lagged by one period to mitigate against endogeneity concerns.

Second, a structural panel VAR is used to examine the response of sovereign bond yields to shocks to climate vulnerability and resilience. Crucially, these shocks control for a range of macroeconomic fundamentals and global factors. The panel SVAR is implemented across the same 40 countries as in stage one, but over the period from 2007Q1 to 2017Q4 in a balanced set-up. The panel SVAR can be denoted as follows in its general specification, with structural shocks identified by a recursive restriction:

$$A(L)\Delta Y_{i,t} = \varepsilon_{i,t} \qquad (2)$$

where A(L) is the matrix of lag polynomial; $Y_{i,t}$ refers to the demeaned value of $X_t$ of country i to accommodate country-specific fixed effects; and $\varepsilon_{i,t}$ is a vector of structural disturbances. Following the setting of the previous SVAR model, we take a first-differencing form of $Y_{i,t}$ as $\Delta Y_{i,t}$. The ordering of the variables imposed in the recursive

5 See Table A2 in the Appendix for details of all variables used, including sources.

6 The original ND-GAIN vulnerability index (Chen et al. 2015) comprises three core measures: (i) the extent to which an economy is exposed to significant climate change from a biophysical perspective; (ii) the degree to which an economy is dependent upon sectors that are particularly sensitive to climate change; and (iii) the extent of an economy's adaptive capacity to climate change. This measure can therefore be interpreted as an overall measure reflecting both physical and transition climate-related risks. We use the refined measure by Kling et al. (2020) which strips out measures that are highly correlated with macroeconomic variables, so that the new vulnerability index is less correlated with countries' financial or economic conditions, which might cause endogeneity.

7 As can be seen from Tables A3 and A4 in the Appendix, there is largely no overlap in the components of the climate vulnerability and resilience indicators. The only overlap applies to just one component, namely the freshwater withdrawal rate.

form is the same as the previous SVAR model. The panel VAR includes two lags selected by the Akaike information criterion (AIC).

Our identification strategy is based on a block recursive restriction (Christiano, Eichenbaum, and Evans 1999), which results in the following matrix $A$ to fit a just-identified model:

$$A = \begin{bmatrix} a_{1,1} & 0 & \cdots & 0 \\ a_{2,1} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ a_{11,1} & \cdots & a_{11,10} & a_{11,11} \end{bmatrix} \quad (3)$$

The ordering of the variables imposed in the recursive form implies that the variables at the top (such as $a_{1,1}$) will not be affected by contemporaneous shocks to the lower variables (such as $a_{2,1}, a_{11,1}, \ldots$), while the lower variables will be affected by contemporaneous shocks to the upper variables. Usually, slower moving variables are better candidates to be ordered before fast-moving variables (Bruno and Shin 2015). It follows therefore that we place the climate vulnerability variable at the top in the ordering, which implies that it will only be affected by contemporaneous shock to itself. Following the vulnerability variable, we place the climate resilience variable second in the ordering, which implies that resilience will be affected by contemporaneous shocks to vulnerability and itself, but not by contemporaneous shocks to macroeconomic fundamentals or sovereign bond yields. Importantly, we put the sovereign yields in last place in the ordering, which is not only based on the assumption that climate risk will affect bond yields, but also on the consideration of our first-stage empirical results that imply the macroeconomic fundamentals that are driving bond yields. Last, we place our macroeconomic fundamentals in the middle of the ordering. The lag selection of the SVAR model is based on the AIC, which suggests that our model should be with two lags.

# 4. EMPIRICAL RESULTS

The results from the estimation of equation (1) are provided in Table 1.[8] The coefficients on the domestic and global factors accord largely with priors, and are also in alignment with the findings in the related literature. The results are presented across four main country groups: advanced economies, emerging markets, ASEAN, and a high risk group.[9] Across all countries as a whole, controlling for domestic and global factors, it is clear that vulnerability to climate risk and resilience to climate risk have significant effects on sovereign bond yields. Increases in vulnerability and lower resilience to climate risks lead to rises in bond yields.[10] The premium on sovereign bond yields from rising climate risk vulnerability is highest for the high risk group at 275 basis points, compared to 155 basis points for ASEAN and 113 basis points for other EMEs.

8 As shown in Figure A5 in the Appendix, the models estimated across all the country groups appear to explain sovereign bond yields well based on a comparison of actual yields and the yields implied by the models—i.e., the fitted values.

9 The high risk group is defined as economies that are in the top quartile for climate risk exposure based on the refined ND-GAIN vulnerability index (Kling et al. 2020). This group comprises the following countries: Japan, the Netherlands, the Republic of Korea, Sri Lanka, Singapore, the Philippines, Viet Nam, Thailand, Indonesia, and India.

10 The direction of the effects is in line with intuition and also reflects the pattern that can be observed from raw plots of sovereign bond yields against our climate risk indicators (see Figures A1 to A4 in the Appendix).

The effect of vulnerability on bond yields for advanced economies is not statistically significant. As regards climate risk resilience, the magnitude of the effect on bond yields is substantially lower than that of climate risk vulnerability, with higher resilience associated with declines in bond yields by fewer than 10 basis points across all country groups.[11]

**Table 1: The Determinants of Sovereign Bond Yields**

| | (1)<br>All | (2)<br>ADV | (3)<br>EME | (4)<br>ASEAN | (5)<br>HRSK |
|---|---|---|---|---|---|
| **Climate risk vulnerability and resilience** | | | | | |
| Vulnerability | 0.634*** | –0.001 | 1.134*** | 1.549*** | 2.753*** |
| | (0.150) | (0.164) | (0.434) | (0.328) | (0.388) |
| Resilience | –0.067*** | –0.084*** | –0.070*** | –0.057*** | –0.057*** |
| | (0.009) | (0.013) | (0.016) | (0.015) | (0.016) |
| **Domestic factors** | | | | | |
| Current account/GDP | –0.051*** | –0.019 | –0.127*** | –0.0650*** | –0.106*** |
| | (0.011) | (0.015) | (0.029) | (0.013) | (0.015) |
| GDP per capita | –0.748* | –9.181*** | –0.265 | –4.587*** | 1.049 |
| | (0.385) | (0.992) | (0.571) | (0.868) | (0.666) |
| Public debt/GDP | 0.016*** | 0.013*** | –0.0133* | 0.0294*** | 0.00991*** |
| | (0.001) | (0.002) | (0.008) | (0.005) | (0.003) |
| Fiscal balance/GDP | 0.008 | –0.014 | 0.172*** | –0.015 | –0.023 |
| | (0.008) | (0.008) | (0.035) | (0.022) | (0.020) |
| GDP growth | –0.180*** | –0.142*** | –0.242*** | –0.042 | –0.042* |
| | (0.014) | (0.019) | (0.027) | (0.027) | (0.023) |
| Crisis | 0.673*** | 1.325*** | –0.129 | n/a | 0.605 |
| | (0.203) | (0.226) | (0.377) | | (0.743) |
| **Global factors** | | | | | |
| US bond yield | 0.803*** | 0.832*** | 0.587*** | 0.282** | 0.861*** |
| | (0.052) | (0.072) | (0.092) | (0.129) | (0.101) |
| VIX | 0.049*** | 0.035*** | 0.059*** | 0.006 | 0.038*** |
| | (0.005) | (0.007) | (0.009) | (0.010) | (0.009) |
| Constant | –14.94** | 102.3*** | –36.96** | –30.90* | –142.3*** |
| | (7.242) | (13.16) | (17.67) | (17.54) | (20.95) |
| Observations | 2,399 | 1,088 | 949 | 362 | 600 |
| R-squared | 0.296 | 0.430 | 0.236 | 0.573 | 0.411 |
| Number of countries | 40 | 17 | 17 | 6 | 10 |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes |
| Time effects | No | No | No | No | No |

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors, based on estimation of equation (1).

The results are striking in two main ways. First, it is apparent that vulnerability to climate risk matters substantially more for the cost of sovereign borrowing than resilience to climate risk. In other words, exposure to the direct effects of climate change remains key, with a sizable and significant impact on the cost of sovereign debt for developing and emerging economies. Improving resilience efforts further may help to combat exposure to these direct effects and hence bring down the cost of sovereign financing. Second, it

[11] Interpretation of the coefficients on vulnerability and resilience applies to a unitary rise in the series' which are standardized between 0 and 1.

is clear that the magnitude of the effect on bond yields is notably higher for economies that are more exposed to climate risks. In particular, the effect on bond yields for the high risk group is higher than for EMEs as a whole by a factor of about three, and higher than for ASEAN by a factor of around two. Our findings therefore suggest that those economies that are particularly exposed to climate change and have the greatest need for resilience investment face the highest climate risk premium on their sovereign borrowing costs. Given that a significant share of the financing of adaptation and vulnerability reduction measures would have to be borne by the public sector, a higher cost of borrowing could severely hamper these crucial investments.[12]

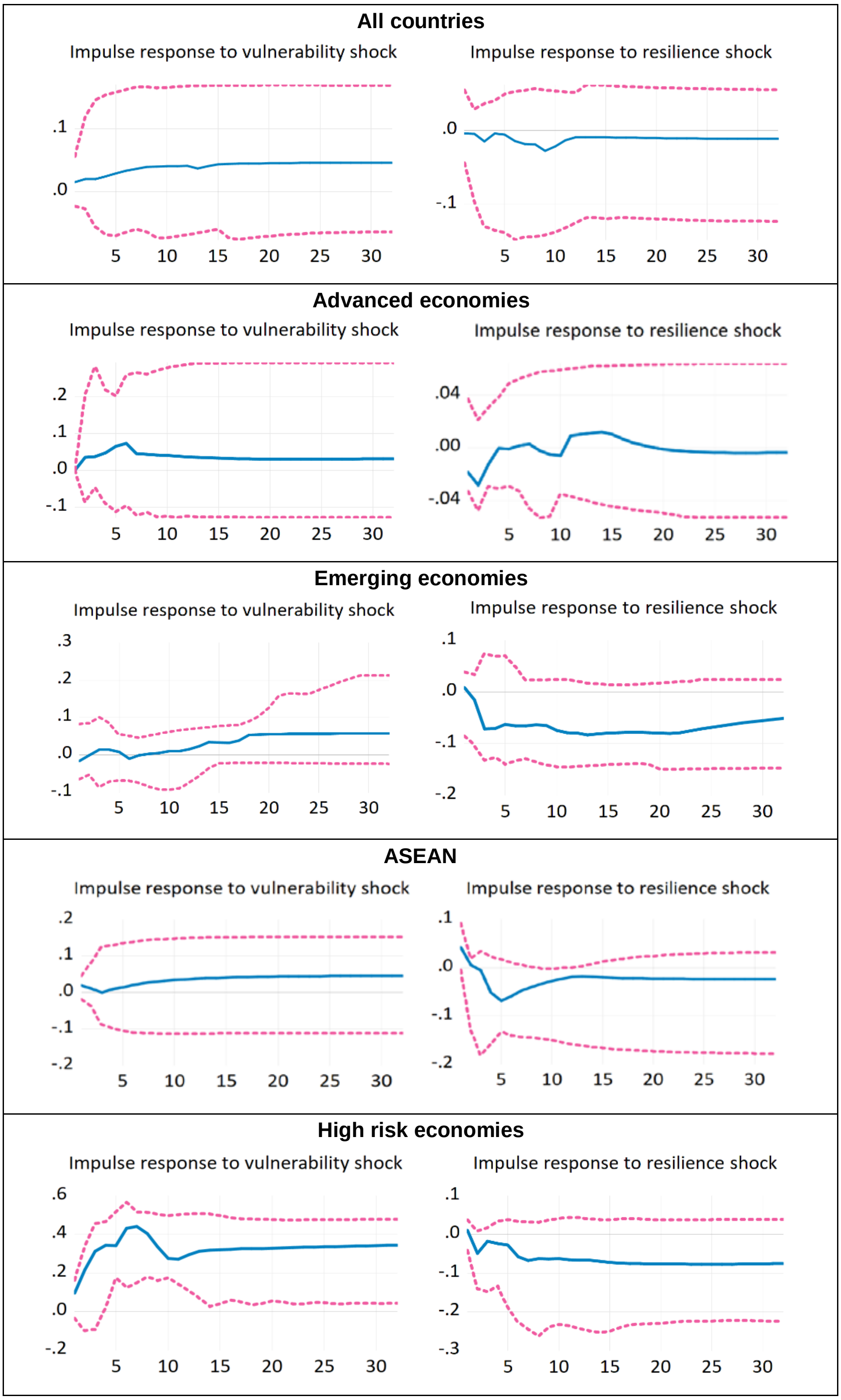
Turning to the domestic macroeconomic fundamentals, worsening current account positions, lower GDP per capita, and lower GDP growth have detrimental effects on the cost of sovereign borrowing, increasing yields as expected. Economies with weak net international investment positions tend to have higher bond yields. Moreover, lower levels of economic development and growth prospects can lead to investor flight, thereby increasing sovereign bond yields. Other important factors affecting bond yields include the public debt/GDP ratio and the fiscal balance. On global factors, positive spillovers from the US bond market are evident in the majority of cases as expected, similar to global risk aversion.

As a robustness check, we also examine alternative measures of climate risk vulnerability. These results are provided in Table A5 in the Appendix and are fully consistent with those from our baseline specification. Using measures of physical climate risks and transition risks taken from FTSE Russell (Table A6 in the Appendix), we find that both transition and physical risk are positively and significantly related to sovereign bond yields. On transition risks—i.e., risks related to shifting to a low-carbon economy—we find that the magnitudes of the effects on sovereign bond yields are lower on average across our sample of countries than for physical risks or resilience. This may be related to the fact that financial markets have not yet fully priced in these risks. Nonetheless, the effect that we find is certainly not trivial, in particular for higher risk-exposed groups. On physical risks, we find that the effect on sovereign bond yields is significant in all cases apart from advanced economies. Exposure to the physical effects of climate risk is clearly a factor that policymakers should be increasingly aware of. As in our baseline, and as expected, we find that the magnitude of the effect on yields from physical climate risks is large for economies deemed to be exposed due to their geographic location and propensity for the incidence of natural climate-related disasters. These include the ASEAN group of countries in our sample, as well as sub-panels deemed high risk (the top quartile of countries based on physical and transition risk exposure) and very high risk (the top decile of countries based on physical and transition risk exposure). Indeed, we find that the magnitude of the effect on yields is progressively higher as the degree of risk exposure rises, in line with economic intuition.

In order to understand better the relationship between sovereign bond yields and climate risk exposure and resilience, we delve into this issue further using a structural panel VAR approach. Across our full sample, as well as sub-panels, Figure 1 shows the effect on sovereign bond yields following a one standard deviation shock on climate risk vulnerability and resilience.

[12] Some have argued that adaptation measures should be conducted by the private sector and that the role of the government is limited to setting the right incentives (e.g., Tol 2005; Jones, Keen, and Strand 2013).

**Figure 1: Response of Sovereign Bond Yields to Climate Risk Vulnerability and Climate Risk Resilience Shocks**




Note: Pink line represents 95% confidence interval. Blue line represents the impulse response of government bond yield to shocks.

Source: Authors.

Figure 1 indicates that across the sample of 40 countries, sovereign bond yields respond positively to a positive shock imposed on climate risk vulnerability, and negatively to a positive shock on resilience, in line with economic intuition. The shock becomes permanent after around 12 quarters. The direction of the effect of the shocks on bond yields is consistent across each of our sub-panels. Moreover, and in line with our stage one analysis, the magnitude of the effect on bond yields is notably larger for economies in the high risk category.

For the high risk economies, the upward effect on yields of the vulnerability shock peaks at around six quarters, while for ASEAN and other EMEs, the peak is reached at a longer duration of around 15–18 quarters, albeit with lower magnitudes. The upward reaction of advanced economy bond yields also peaks after around six quarters. For shocks to climate risk resilience, the downward response of yields is most pronounced after around six quarters for EMEs, ASEAN, and the high risk group, with advanced economy bond yields peaking downwards much more quickly after around two quarters. Given that the effect of climate risk vulnerability and resilience to climate risk on sovereign bond yields is not transitory and does not subside over time, this underscores the importance for policymakers to ramp up efforts aimed at mitigating the effects of physical climate risks. Without such action, the negative ramifications for fiscal sustainability and, as a result, economic growth could be substantial.

# 5. CONCLUSIONS

This paper contributes to a better understanding of the effects of climate vulnerability on the price of sovereign risk and fiscal sustainability. Set against the a growing literature highlighting the impacts of climate risks on macroeconomic conditions, this paper tests empirically the link between climate vulnerability and resilience to climate risk and sovereign bond yields. This is also an important issue to consider in light of the increasing incorporation of climate risk by credit risk agencies in their sovereign rating methodologies. Using a diverse sample of 40 advanced and emerging economies, many of which are particularly vulnerable to climate risks due to their geographical location and susceptibility to natural disasters, our results provide evidence that climate risks and resilience to these risks have significant effects on the cost of sovereign borrowing. In particular, higher climate risk vulnerability and, to a lesser extent, lower climate risk resilience, lead to significant rises in the cost of sovereign borrowing. Given the material effects of climate change on the cost of sovereign borrowing, our analysis indicates that more attention needs to be paid to the incorporation of climate risk into the operational frameworks of central banks. Moreover, the issue warrants further consideration by financial supervisors from a financial stability perspective. Last but not least, our findings strongly suggest that adaptation investments that help to mitigate climate risks would contribute to a lowering of the cost of sovereign debt, and this would provide much-needed fiscal space to those countries particularly affected by climate change.

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# APPENDIX

### Table A1: List of Countries

| Advanced | Emerging | ASEAN | High Risk |
|---|---|---|---|
| Australia | Argentina | Indonesia | Indonesia |
| Belgium | Brazil | Malaysia | India |
| Denmark | Chile | Philippines | Japan |
| Finland | Columbia | Singapore | Netherlands |
| France | Czech Republic | Thailand | Philippines |
| Germany | Hungary | Viet Nam | Republic of Korea |
| Greece | India | | Singapore |
| Ireland | Israel | | Sri Lanka |
| Italy | Mexico | | Thailand |
| Japan | Nigeria | | Viet Nam |
| Netherlands | People’s Republic of China | | |
| New Zealand | Peru | | |
| Portugal | Poland | | |
| Spain | Republic of Korea | | |
| Sweden | Russian Federation | | |
| United Kingdom | South Africa | | |
| United States | Sri Lanka | | |

Source: Compiled by authors.

### Table A2: Overview of Variables Used in the Empirical Analysis

| Variable | Data Source | Definition |
|---|---|---|
| Sovereign bond yield | Bloomberg | 10-year government bond yield. |
| Vulnerability | ND-GAIN and Kling et al. (2020) | The refined vulnerability measure by Kling et al. (2020) comprises all of the components from the ND-GAIN vulnerability index that are not highly related to economic variables. |
| Resilience | FTSE Russell | Resilience refers to a country’s preparedness and actions to cope with climate change. |
| Current account/GDP | OECD and CEIC | The current account balance to GDP ratio. |
| GDP per capita | The World Bank | Real GDP per capita at constant 2010 US$. |
| Public debt/GDP | IMF International Financial Statistics | The public debt as a share of GDP, defined as general government gross debt to GDP ratio. |
| Fiscal balance/GDP | IMF International Financial Statistics | The fiscal balance as a share of GDP, defined as cyclically adjusted primary balance to GDP ratio. |
| GDP growth | OECD and CEIC | The real GDP growth rate. |
| Crisis | Laeven and Valencia (2018) | The Laeven and Valencia (2018) indicator for the incidence of a crisis event for each country in the sample. |
| US bond yield | Bloomberg | US 10-year government bond yield. |
| VIX | Bloomberg | VIX stands for the Chicago Board Options Exchange (CBOE) Volatility Index, a measure of global risk aversion. |
| Transition risk | FTSE Russell | Transition risk from mitigation encompassed by GHG emission requirements. |
| Physical risk | FTSE Russell | Fundamental climate-related risk to the country and its economy |

Source: Compiled by authors.

### Table A3: Measures for Climate Vulnerability

| Sector | Indicators |
|---|---|
| Food | Projected change of cereal yields |
| | Projected population change |
| | Food import dependency |
| Water | Projected change of annual runoff |
| | Projected change of annual groundwater recharge |
| | Fresh water withdrawal rate |
| | Water dependency ratio |
| Health | Projected change of deaths from climate-induced diseases |
| | Projected change in vector-borne diseases |
| Ecosystems | Projected change of biome distribution |
| | Projected change of marine biodiversity |
| | Ecological footprint |
| | Protected biome |
| | Engagement in international environmental conventions |
| Habitat | Projected change of warm periods |
| | Projected change of flood hazard |
| Infrastructure | Projected change of hydropower generation capacity |
| | Projected change of sea level rise impacts |
| | Dependency on imported energy |
| | Population living less than 5m above sea level |

Source: Compiled by authors drawing from Kling et al. (2020).

### Table A4: Resilience Index

| Sub-Index | Indicators |
|---|---|
| Institutional | Intended country C02 emissions in 2030 |
| | Government effectiveness |
| | Disaster preparedness index |
| | External debt as % of GDP |
| Social | Fuel subsidies |
| | GINI index |
| | Human Development Index |
| | Voice and accountability |
| | People using sanitation services (% of population) |
| | Access to electricity (% of population) |
| Economic | Country CDP performance ratio |
| | Insurance penetration index |
| | R&D expenses |
| | Logistics performance index |
| | Doing business |
| | Country green bonds performance ratio |
| | Water productivity |
| | Agricultural adaptive capacity |
| Ecological | Annual freshwater withdrawals |
| | Share of protected areas |
| | Share of biodiversity threatened |
| | Biodiversity stock |
| | Afforestation rate |

Source: Compiled by authors using data from FTSE Russell.

**Table A5: Robustness Using Alternative Climate Risk Variables: The Determinants of Sovereign Bond Yields**

| | (1) All | (2) ADV | (3) EME | (4) ASEAN | (5) HRSK | (6) VHRSK |
|---|---|---|---|---|---|---|
| **Climate risk and resilience** | | | | | | |
| Transition risk | 0.637*** | 0.408*** | 0.260* | –0.450 | 1.264*** | 0.968** |
| | (0.078) | (0.117) | (0.135) | (0.301) | (0.244) | (0.477) |
| Physical risk | 0.644*** | 0.115 | 0.782** | 2.780** | 4.346*** | 18.060*** |
| | (0.170) | (0.182) | (0.320) | (1.176) | (1.366) | (2.335) |
| Resilience | –3.768*** | –6.054*** | –4.026*** | –2.691*** | –4.127*** | –4.098*** |
| | (0.136) | (0.492) | (0.161) | (0.391) | (0.293) | (0.366) |
| **Domestic factors** | | | | | | |
| Current account/GDP | –0.109*** | –0.041*** | –0.156*** | –0.094*** | –0.253*** | –0.408*** |
| | (0.006) | (0.011) | (0.0167) | (0.023) | (0.021) | (0.068) |
| GDP per capita | –0.184** | 0.215 | –0.405*** | –1.438*** | 0.336 | 1.491** |
| | (0.0834) | (0.329) | (0.126) | (0.247) | (0.221) | (0.733) |
| Public debt/GDP | –0.004*** | –0.004*** | 0.033*** | 0.025*** | 0.026*** | 0.057*** |
| | (0.001) | (0.001) | (0.003) | (0.005) | (0.004) | (0.008) |
| Fiscal balance/GDP | 0.027** | 0.037** | 0.193*** | –0.115*** | –0.094*** | –0.143* |
| | (0.013) | (0.015) | (0.034) | (0.028) | (0.033) | (0.085) |
| GDP growth | –0.211*** | –0.236*** | –0.289*** | 0.0309 | 0.0349 | –0.145* |
| | (0.024) | (0.046) | (0.023) | (0.049) | (0.042) | (0.075) |
| Crisis | 1.126*** | 1.553** | 1.289*** | n/a | 2.873*** | 2.367** |
| | (0.393) | (0.665) | (0.359) | | (0.720) | (0.993) |
| **Global factors** | | | | | | |
| US bond yield | 1.332*** | 1.257*** | 1.777*** | 0.453 | 1.102* | 0.951 |
| | (0.212) | (0.171) | (0.474) | (0.656) | (0.655) | (0.628) |
| VIX | 0.124 | 0.148** | 0.108 | 0.056 | 0.054 | –0.022 |
| | (0.081) | (0.075) | (0.140) | (0.087) | (0.215) | (0.194) |
| Constant | 11.72*** | 19.59*** | 13.64*** | 14.11** | –10.22 | –73.38*** |
| | (1.819) | (3.112) | (3.013) | (6.527) | (7.818) | (14.84) |
| Observations | 2,459 | 1,139 | 1,006 | 314 | 535 | 350 |
| R-squared | 0.678 | 0.618 | 0.744 | 0.865 | 0.686 | 0.660 |
| Number of countries | 39 | 17 | 17 | 5 | 9 | 6 |
| Time effects | Yes | Yes | Yes | Yes | Yes | Yes |

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. The high risk group comprises Colombia, India, Indonesia, Malaysia, Singapore, Philippines, Sri Lanka, Peru, and Nigeria; the very high risk group comprises India, Indonesia, the Philippines, Sri Lanka, Peru, and Nigeria.

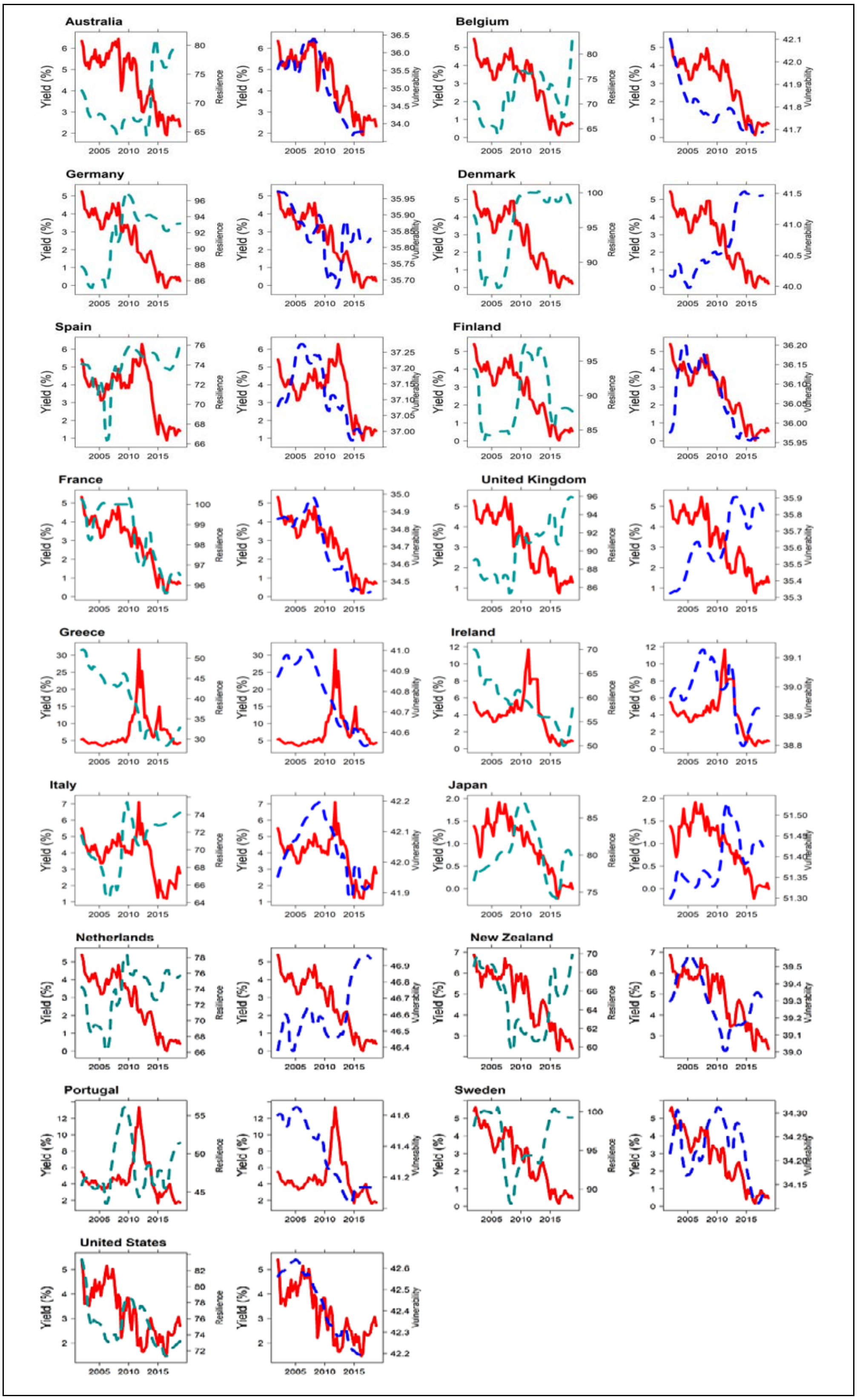
Source: Authors based on estimation of equation (1).

**Table A6: Physical Risk and Transition Risk Indices**

| Index | Components |
|---|---|
| Physical Risk Index | Death caused by climate extremes<br>Sensitivity of agriculture<br>Sea-level rise exposure |
| Transition Risk Index | Territorial distance to reach compliant emissions target of 2°C by 2050<br>Greenhouse gas emissions gap between trend and distance to target |

Source: Compiled by authors using data from FTSE Russell.

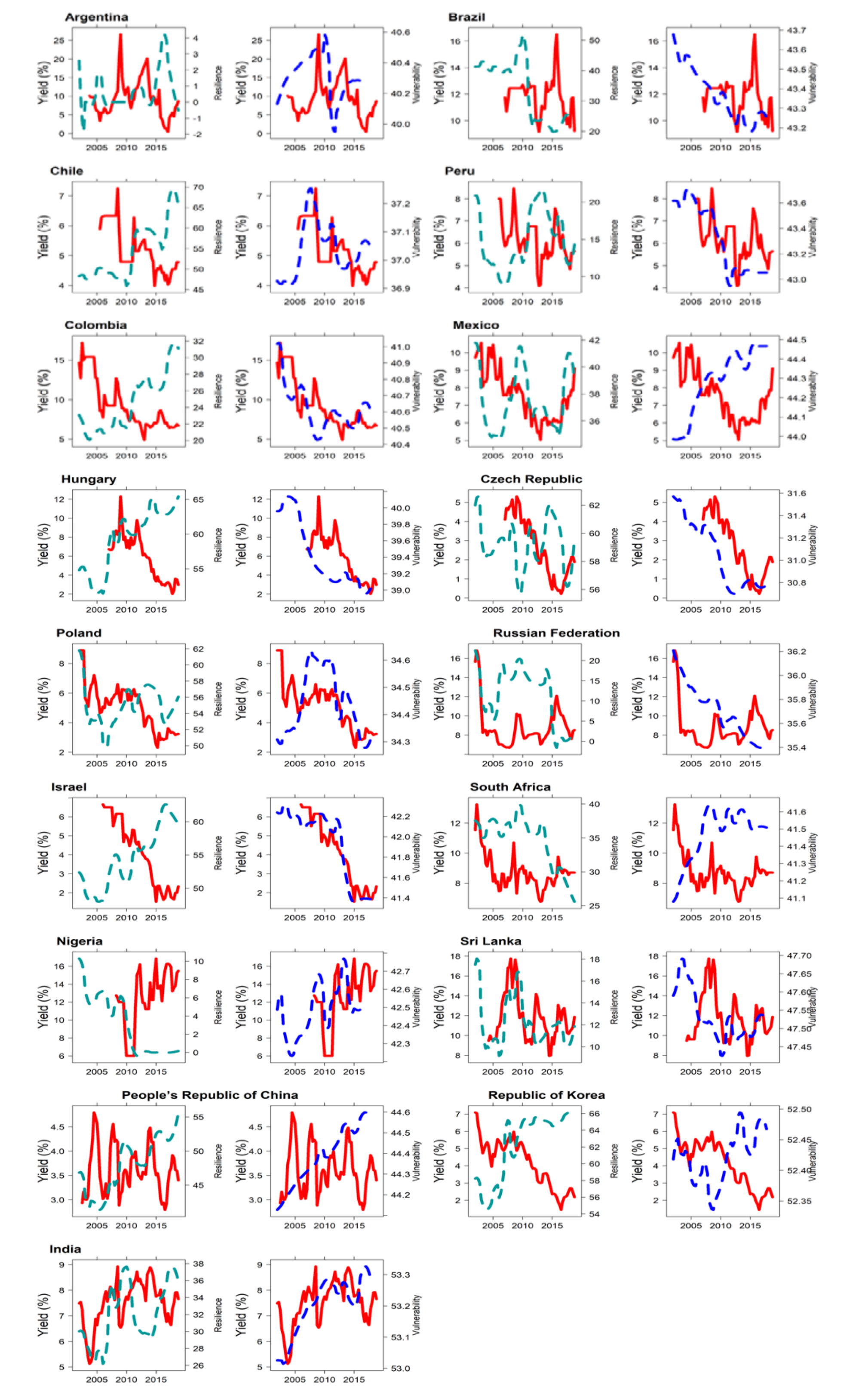
## Figure A1: Sovereign Bond Yield and Climate Risk: Advanced Economies




Note: Red line represents government bond yield in percentage. Blue dashed line represents vulnerability. Dark green dashed line represents resilience.

Source: Authors, with data from Bloomberg, FTSE Russell, ND-GAIN, and Kling et al. (2020).

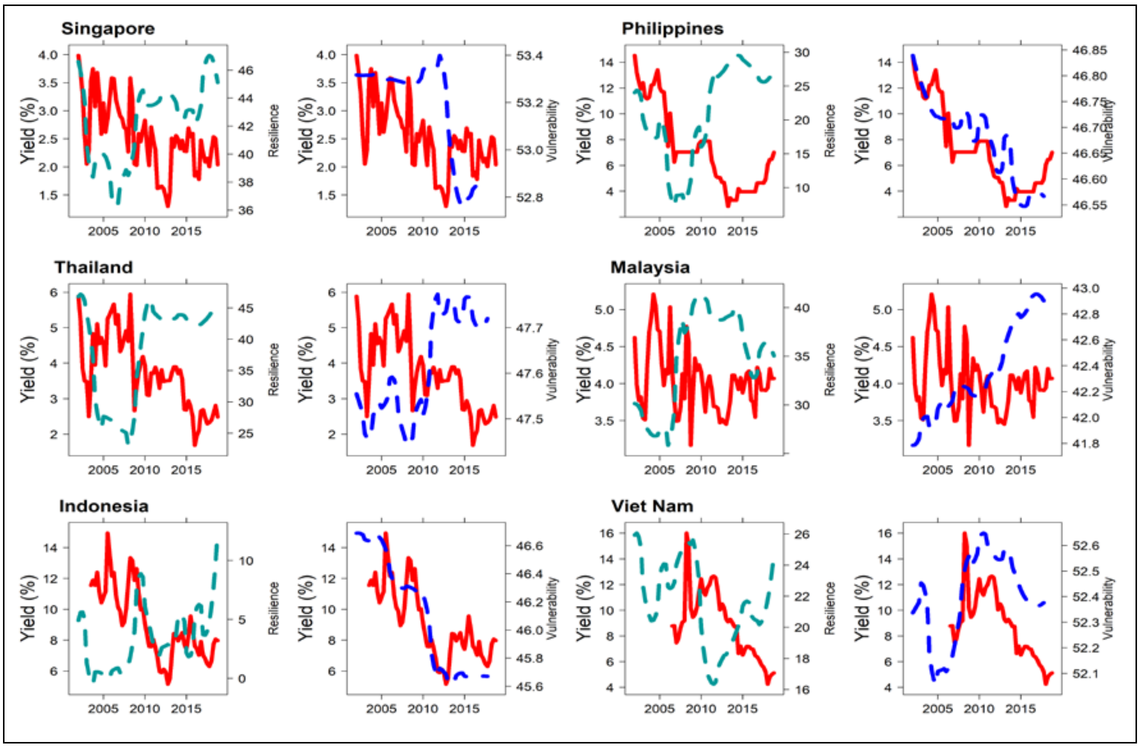
**Figure A2: Sovereign Bond Yield and Climate Risk: Emerging Economies**




Note: Red line represents government bond yield in percentage. Blue dashed line represents vulnerability. Dark green dashed line represents resilience.

Source: Authors, with data from Bloomberg, FTSE Russell, ND-GAIN, and Kling et al. (2020).

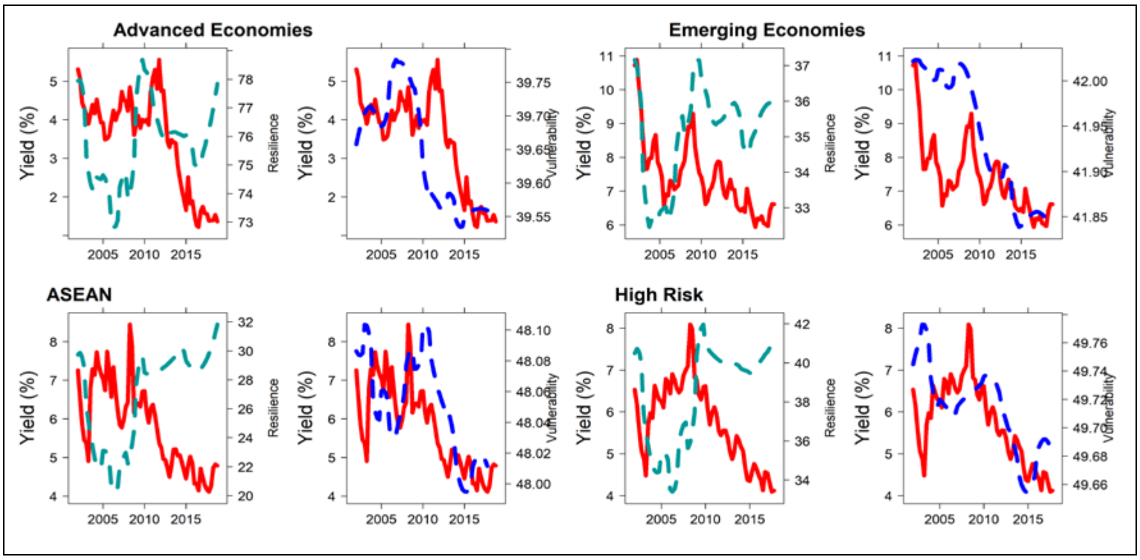
## Figure A3: Sovereign Bond Yield and Climate Risk: ASEAN




Note: Red line represents government bond yield in percentage. Blue dashed line represents vulnerability. Dark green dashed line represents resilience.

Source: Authors, with data from Bloomberg, FTSE Russell, ND-GAIN, and Kling et al. (2020).

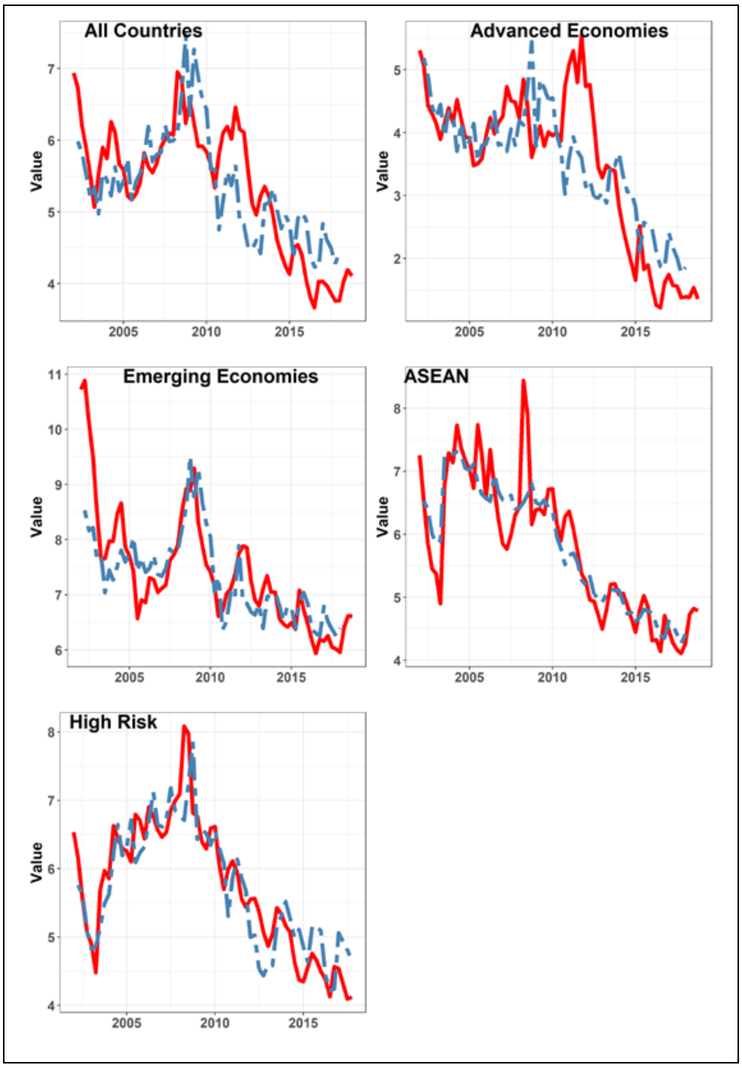
## Figure A4: Sovereign Bond Yield and Climate Risk: Regions




Note: Red line represents government bond yield in percentage. Blue dashed line represents vulnerability. Dark green dashed line represents resilience.

Source: Authors, with data from Bloomberg, FTSE Russell, ND-GAIN, and Kling et al. (2020).

**Figure A5: Actual and Fitted Values**




Note: Red line represents actual value of government bond yield in percentage. Dark blue dashed line represents its fitted value.

Source: Authors.