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Bracing for the Typhoon: Climate change and sovereign risk in Southeast Asia

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Abstract
This article investigates and empirically tests the link between climate change and sovereign risk in Southeast Asia. Southeast Asian countries are among those most heavily affected by climate change. The number and intensity of extreme weather events in the region have been increasing markedly, causing severe social and economic damage. Southeast Asian economies are also exposed to gradual effects of global warming as well as transition risks stemming from policies aimed at mitigating climate change. To empirically examine the effect of climate change on the sovereign risk of Southeast Asian countries, we employ indices for vulnerability and resilience to climate change and estimate country-specific OLS models for six countries and a fixed effects panel using monthly data for the period 2002–2018. Both the country-specific and the panel results show that greater climate vulnerability appears to have a sizable positive effect on sovereign bond yields, while greater resilience to climate change has an offsetting effect, albeit to a lesser extent. A higher cost of debt holds back much-needed investment in public infrastructure and climate adaptation, increases the risk of debt sustainability problems, and diminishes the development prospects of Southeast Asian countries.

KEYWORDS
climate change, climate resilience, climate vulnerability, Southeast Asia, sovereign risk

1 | INTRODUCTION

Southeast Asian countries are among those most heavily affected by climate change. The number and intensity of extreme weather events in the region have been increasing markedly, often leading to the loss of life, homes, and livelihoods and causing severe economic damage. Southeast Asian economies are also exposed to gradual effects of global warming as well as transition risks stemming from policies aimed at mitigating climate change, the development of more climate-friendly technologies, and changes in consumer preferences.

To date, there is still very little analysis on the impacts of climate change on financial and macroeconomic stability in Southeast Asian countries. Moreover, there has been no systematic analysis thus far on the nexus between climate change and sovereign risk in Southeast Asia, even though it has become increasingly clear that the macroeconomic impacts of climate change and hence also the implications for public finances, will be substantial in this region. Understanding the implications of climate change for sovereign risk is of crucial importance at the current juncture as urgent action is needed to better mitigate and manage associated risks and climate-proof public finances, which are already under considerable strain due to the COVID-19 pandemic. Indeed, the pandemic has highlighted the pressing need to build resilience into our social, economic, and financial systems, and strong and sustainable public finances are crucial for this.

Against this backdrop, this article discusses the macrofinancial and sovereign risks stemming from climate change for Southeast Asian countries. To the best of our knowledge, this study is the first to examine climate change dynamics and fiscal transmission channels in Southeast Asian economies with an empirical focus on country-specific implications. To empirically examine the effect of climate change on the sovereign risk of the member countries of the Association of Southeast Asian Nations (ASEAN),[1] we estimate country-specific OLS models and a fixed effects panel over the period 2002M1 to 2018M12, using indices for climate change vulnerability and resilience to climate change. The country-specific models are estimated for six ASEAN countries: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Viet Nam. The results indicate that greater vulnerability to climate change has a sizable positive effect on sovereign bond yields, while greater resilience to climate change has an offsetting effect. The climate change risk premium is the highest for Viet Nam, the Philippines, Indonesia, and Thailand. The effect of resilience to risks from climate change has a substantially lower effect on bond yields across all ASEAN economies in our sample.

Our findings indicate that those ASEAN countries that are particularly exposed to climate change and have the greatest need to scale up resilience investment face the highest climate change risk premium on their sovereign debt. An increase in sovereign risk worsens the financing conditions of countries and can weaken their development prospects as it constrains fiscal space for investment, not only in crucial areas such as health and education, but also in adaptation measures which are urgently needed to cope with the effects of climate change. With climate change accelerating, and both physical and transition impacts becoming ever more pronounced, climate-related risk premia on sovereign bonds are bound to increase further for climate vulnerable countries, undermining debt sustainability and much-needed investment in resilience.

The article is structured as follows. Section 2 discusses the nexus between climate change and sovereign risk. Section 3 provides an overview of climate impacts on the Southeast Asian economies and how these may affect sovereign risk. Section 4 presents an empirical analysis of the impact of vulnerability and resilience to climate change on the sovereign bond yields of Southeast Asian countries. Section 5 concludes by discussing the implications of this research for the development prospects of Southeast Asian countries and policy measures that could be taken to address the problem.

2 | CLIMATE CHANGE AND SOVEREIGN RISK

Testing the relationship between climate change and sovereign risk is a relatively new strand of the literature, with recent empirical work demonstrating that vulnerability and resilience to climate change are important factors driving the cost of sovereign borrowing at the global level (Beirne, Renzhi, & Volz, 2020; Kling, Lo, Murinde, & Volz, 2018).[2] Conceptually, climate change can impact on an economy and public finances—and thus debt sustainability—in several ways (Volz et al., 2020).[3] In particular, climate-related natural disasters may have direct fiscal impacts. Government finances and a country's debt sustainability are exposed to different fiscal risks related to natural disasters. The IMF classifies fiscal risk into two categories, namely macroeconomic risks and specific fiscal risks, which may "arise from the realization of contingent liabilities or other uncertain events, such as a natural disaster, the bailout of a troubled public corporation or subnational government by the central government, or the collapse of a bank" (IMF, 2018, p. 95). 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, Oliveira, Mele, & Antonio, 2019); changes to commodity prices that could affect revenue or increase spending via fossil fuel or food subsidies; effects on inflation and interest rates through supply or demand shocks; and exchange rate effects (e.g., Farhi & Gabaix, 2016).

There are several explicit and implicit contingent liabilities through which governments are exposed to fiscal risks (Hochrainer-Stigler, Keating, Handmer, & Ladds, 2018; Mitchell, Mechler, & Peters, 2014; Schuler et al., 2019). Physical government assets and public infrastructure may be damaged or destroyed. Governments may hence have to spend on damage repair or reconstruction. Natural disasters may also affect the assets or operations of state-owned enterprises (SOEs). This could diminish the asset value of SOEs or affect dividend payment to the government. Governments may also have to realize contingent liabilities and step in and bail out SOEs that have been hit hard by a disaster (see Bova, Ruiz-Arranz, Toscani, & Ture, 2019). There are also fiscal consequences related to adaptation and mitigation policies (e.g., Bachner, Bednar-Friedl, & Knittel, 2019). The Global Commission on the Economy and Climate (2016) estimates that globally until 2030, around US$ 90 trillion will have to be spent on infrastructure, including energy, all of which needs to be sustainable and climate resilient.

As regards to broader macroeconomic impacts of climate change, the physical and transition impacts of climate change can cause aggregate supply and demand shocks (Batten, Sowerbutts, & Tanaka, 2016). Supply and demand shocks from extreme weather events, although short-term in nature, can also have lasting impacts on growth (Acevedo, 2014; Klomp & Valckx, 2014) and public finances. Moreover, the supply and demand side effects of gradual global warming and transition impacts can cause fundamental, enduring structural changes to the economy. For many countries, climate change will have profound impacts on their long-run productive capacity and potential output. A country's long-term growth potential will inevitably have ramifications for public finances, including through effects on sovereign bond yields, and debt sustainability.

Climate-related risks can also impact upon sovereign risk through the negative effect on financial sector stability. Acute physical risks, such as extreme weather events, and chronic physical risks, such as worsening water stress or sea level rises, can result in direct damage to operating assets and reduce the production output of borrowers. The reduction in borrowers' operating margins and cash flows and the value of collateral assets can lead to credit downgrades, a higher probability of default, and a reduction in the secondary market value of loans held on bank balance sheets. In more severe situations, borrowers will not be able to meet their debt service obligations, resulting in a higher incidence of nonperforming loans and a higher loss given default due to the reduced value of collateral assets. Moreover, investors may suffer from stranded asset risk (Semieniuk, Campiglio, Mercure, Volz, & Edwards, 2021). Financial sector instability may require public bailouts that could affect the solvency of the government and trigger a "doom loop," where a worsening of the sovereign risk profile and a decline in the prices of government bonds further deteriorate banks' balance sheets.

The price of sovereign risk can also be affected by climate change through the effect on international trade and capital flows (e.g., Dellink, Hwang, Lanzi, & Chateau, 2017; UNCTAD, 2019; Wilbanks et al., 2007; WTO and UNEP, 2009). The potentially significant effects on countries' balance of payments positions, which are important determinants of sovereign bond yields (e.g., Beirne & Fratzscher, 2013), can have implications for sovereign risk. Impacts can be grouped in three categories: disruptions to trade from climate-related extreme events and disasters; long-term effects of global warming on endowments and production; and transition impacts on international trade.

Climate change can also exacerbate social tensions and resource conflicts and thereby undermine political stability, which in turn can detrimentally affect sovereign risk profiles. Notably, political instability can undermine the ability or willingness of a government to repay its debt. For instance, Clark (1997) emphasizes the potential impact of political events on the probability of sovereign default, while Cuadra and Sapriza (2008) maintain that countries that are politically unstable and more polarized have higher default rates and are as a result charged a higher default risk premium in international credit markets.

3 | CLIMATE CHANGE IN SOUTHEAST ASIA

Although the vulnerability to climate change varies significantly across Southeast Asian countries, the region constitutes one of the most climate-vulnerable regions in the world where economic impacts of global warming are predicted to be among the largest (Kompas, Pham, & Che, 2018; Yusuf & Francisco, 2009). In the widely used Climate Risk Index by Germanwatch, which ranks countries according to fatalities and economic losses due to weather-related loss events, four ASEAN countries—Myanmar, the Philippines, Viet Nam, and Thailand—are listed among the 10 countries most affected by climate-related disasters over the period 1999 to 2018, with Cambodia coming close in 12th place (Table 1). At the same time, Brunei Darussalam and Singapore rank among those countries with the fewest fatalities and least damage. Figure 1 shows a significant increase in the absolute number of extreme weather events in ASEAN since the start of the last century. The increase has been driven by a rapid growth in the number of floods, storms, and landslides.

Table 2 provides a breakdown of the average number of annual fatalities, people affected, absolute losses, and losses as share of GDP for the period 2000–2019, as well as the total number of events over this period. The average total annual losses amounted to 0.44% of GDP in Cambodia, 0.27% in the Lao PDR and Myanmar, and 0.19% in Thailand. These averages, however, conceal the damage that can be caused by single events. In 2008, Cyclone Nargis caused economic damage totaling an estimated 12.6% of GDP in Myanmar. The damages caused by the 2011 flood in Thailand are estimated at 10.9% of GDP. Over the period 1993–2018, the 10 ASEAN countries and their combined population of 622 million experienced direct economic losses from weather-related events worth US$ 124 billion, which equates to an annual loss of US$ 5.2 billion (Table 3). Of these, only 14% were insured. However, this

TABLE 1 Climate Risk Index for 1999–2018

CRI rank	Country	CRI score	Fatalities 1999–2018 (rank)	Fatalities per 100,000 inhabitants 1999–2018 (rank)	Losses in million US$ (PPP) 1999–2018 (rank)	Losses per unit GDP in % 1999–2018 (rank)
175	Brunei Darussalam	169.17	168	154	179	180
12	Cambodia	35.33	40	34	52	26
77	Indonesia	76.83	16	92	21	120
76	Lao PDR	76.33	86	77	92	63
114	Malaysia	103.33	64	102	66	143
2	Myanmar	10.33	1	1	19	20
4	Philippines	17.67	7	16	9	29
180	Singapore	172.17	172	172	163	177
8	Thailand	31.00	22	62	4	18
6	Viet Nam	29.83	14	42	13	34

Note: The CRI score is calculated as a weighted average of the individual scores. For instance, with Viet Nam ranking 14th in fatalities among all countries, 42nd in fatalities per 100,000 inhabitants, 13th in losses, and 34th in losses per unit GDP, Viet Nam's CRI score is calculated as follows: 14x1/6 + 42x1/3 + 13x1/6 + 34x1/3 = 29.83.
Source: Compiled with data from Germanwatch (Eckstein, Künzel, Schäfer, & Winges, 2019).

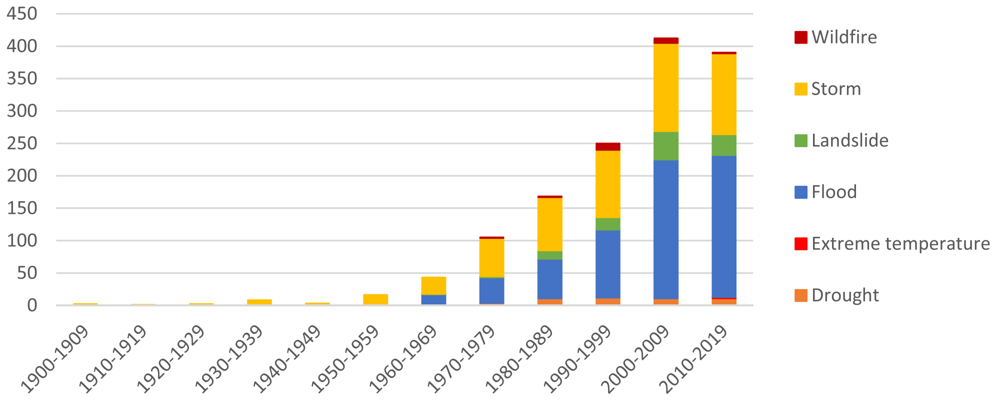

FIGURE 1 Historical occurrences of extreme weather events in ASEAN, 1900–2019. *Source:* Compiled with data from EM-DAT (2020) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Impacts of climate-related natural disasters in ASEAN countries, 2000–2019

Country	Total deaths (average 2000–2019)	Total people affected (average 2000–2019)	Total losses in million US$ (average 2000–2019)	Total losses as share of GDP in % (average 2000–2019)[a]	Number of events (total 2000–2019)
Cambodia	42	646,601	54.46	0.44	24
Indonesia	30	37,010	44.78	0.01	189
Lao PDR	14	177,989	22.85	0.27	20
Malaysia	4	65,377	30.19	0.01	47
Myanmar	3,489	158,644	104.62	0.27	40
Philippines	83	522,994	76.23	0.04	273
Thailand	31	941,647	574.33	0.19	82
Viet Nam	34	268,182	135.4	0.11	142

Note: No events were reported for Brunei Darussalam or Singapore between 2000 and 2019. Numbers for total deaths and people affected are rounded.
[a]These numbers are not weighted by GDP/year but by the average of total losses in million US$ by the GDP average between 2000 and 2019.
Source: Compiled with data from EM-DAT (2020), WDI, and IMF.

TABLE 3 Losses from weather-related events, 1993–2018

	Overall losses (2018 values in million US$)	Insured losses (2018 values in US$)	Fatalities
Brunei Darussalam	3.1	—	2
Cambodia	2,200	2.3	1,221
Indonesia	15,000	1,200	5,960
Lao PDR	460	—	188
Malaysia	2,300	330	974
Myanmar	5,500	—	143,070
Philippines	24,000	1,200	20,617
Singapore	42	4.4	2
Thailand	55,000	15,000	3,681
Viet Nam	19,600	43	9,247

Source: Compiled with data from NatCatSERVICE, https://natcatservice.munichre.com.

figure is due to a relatively high insurance coverage in Thailand, where 27% of losses were insured. In the Lao PDR, Myanmar, Viet Nam, and Cambodia, hardly any losses were insured, while insurance covered only 5% of losses in the Philippines, 8% in Indonesia, 11% in Singapore, and 14% in Malaysia.

The expected annual fiscal burden arising as a consequence of natural disasters (including recovery and reconstruction liabilities) as a percentage of government expenditure has been estimated at 2.5% for Myanmar, 1.5% for the Philippines, 1.0% for Cambodia, 0.9% for the Lao PDR, 0.7% for Viet Nam, 0.3% for Indonesia, and 0.1% for Thailand and Malaysia (World Bank and GFDRR, 2012). However, the estimated probable fiscal burden arising as a consequence of a 1-in-200-year probable maximum economic loss event as a percentage of annual government expenditure is significantly

TABLE 4 Percentage loss in GDP per capita in Southeast Asian countries by 2030, 2050, and 2100 under the RCP2.6 and RCP8.5 scenarios

	RCP 2.6 scenario			RCP 8.5 scenario		
	2030	2050	2100	2030	2050	2100
Brunei Darussalam	−0.15	−0.07	1.41	0.16	0.50	1.65
Cambodia	−0.36	−0.38	1.84	0.10	0.26	0.74
Indonesia	0.19	0.61	1.92	0.91	2.79	7.51
Lao PDR	−0.09	−0.07	0.78	0.19	0.65	2.34
Malaysia	−0.15	−0.31	−0.34	0.53	1.51	4.12
Myanmar	−0.34	−0.61	0.25	0.29	0.80	2.24
Philippines	0.29	0.98	3.05	0.98	3.09	8.46
Thailand	−0.03	−0.05	0.06	0.29	1.12	3.98
Viet Nam	0.00	0.01	0.02	0.38	1.51	5.15

Note: No data available for Singapore.
Source: Compiled with data from Kahn et al. (2019), Table A2).

higher: The World Bank and GFDRR (2012) estimate this at 23% for the Lao PDR, 19.5% for the Philippines, 18% for Cambodia, 5% for Viet Nam, 4% for Indonesia, and 1.5% for Malaysia and Thailand, respectively. With global warming accelerating, the chances are that disaster losses will rise further, unless investment in adaptation and resilience is scaled up substantially, which would also increase direct fiscal burdens.

Southeast Asian countries will not only be exposed to an increase in the frequency and intensity of extreme weather events, but large parts of the region will also suffer from chronic physical impacts such as worsening heat and water stress and sea level rises, which are expected to have a significant impact on economic activity. For instance, as much as 7% of Viet Nam's agricultural land may be lost in the case of a 1-m sea level rise (Dasgupta, Laplante, Meisner, Wheeler, & Yan, 2009).

Estimations of climate change impacts on economic growth are inexorably based on a host of assumptions on climatic trends, tipping points, technological innovation, adaptive capacity, and the effects of all these on human well-being and economic activity. Long-term growth projections hence need to be taken cautiously. Nevertheless, they do provide a useful indication of growth trends under different climate scenarios. Most projections suggest that the economic cost of inaction is immense. Raitzer et al. (2015) estimate that under a business-as-usual scenario, Southeast Asian GDP will decline by 11% by 2100. Table 4 displays recent country-by-country projections by Kahn et al. (2019) on losses in GDP per capita by the years 2030, 2050, and 2100 under two different representative concentration pathway (RCP) scenarios, RCP2.6 and RCP8.5. RCPs are greenhouse gas concentration trajectories used by the Intergovernmental Panel on Climate Change (IPCC). The RCP2.6 pathway is a relatively optimistic scenario under which the increase of global warming is limited to 0.01°C per annum, in line with the Paris Agreement. RCP8.5 is commonly referred to as the high emission or business-as-usual-scenario. Under the RCP2.6-scenario, sea levels are projected to rise between 29 and 59 cm, while the likely range under RCP8.5 would be between 61 and 110 cm, relative to 1986–2005 (Oppenheimer et al., 2019). Kahn et al.'s (2019:7) estimations suggest that the world's real GDP per capita would be 7.22% lower in 2100 under RCP8.5, compared to an output loss of 1.7% under RCP2.6. According to Kahn et al.'s (2019) estimates, under RCP8.5, real GDP per capita would be 8.46% lower in 2100 in the Philippines, 7.51% in Indonesia, 5.15% in Viet Nam, 4.12% in Malaysia, and 3.98% in Thailand.

Projections by Burke, Hsiang, and Miguel (2015) are even bleaker (Table 5). Their estimates suggest that because of global warming, global average incomes will be 23% lower in 2100 under a RCP8.5 emissions scenario compared to a nonclimate change scenario. According to their estimates, climate change will not only hold back the economic growth of Southeast Asian countries but even reverse their economic development in the second half of the century.[4]

A low-carbon or even zero-carbon transition would inevitably have to involve a phasing out of fossil fuels. This could cause trouble for governments that currently rely to a high degree on revenues from fossil fuels. Some governments rely heavily on revenues from the extraction of oil, natural gas, and coal resources. In Indonesia, revenues from fossil fuel accounted for 22.6% of total government revenues in the period 2011–2016 (OECD, World Bank, & UN Environment, 2018). A rough estimation for Indonesia, for instance, suggests that the introduction of a US$75 per ton carbon tax (+1.8%/GDP), the loss of fossil fuel revenues (−3.3%/GDP for 2011–2016), and the saving of fossil fuel subsidies (0.7%/GDP in 2017) would worsen the fiscal balance by 0.8% of GDP.[5]

A decarbonization of the world economy would inexorably also affect Southeast Asian countries' external trade. Figure 2 shows the carbon footprint of exports (t CO_2e/US$) plotted against the exports of goods and services as share of GDP for ASEAN countries as well as the OECD average for the year 2015. It clearly shows that the carbon intensity of exports of ASEAN countries is much larger for all ASEAN countries, compared to the OECD average. The exports of Viet Nam, Malaysia, Thailand, and Indonesia have a particularly large carbon footprint. Moreover, the figure also shows that most ASEAN economies are very export dependent. This

TABLE 5 Impacts of global warming (3°C) on the GDP of Southeast Asian countries

Country	Projected average temperature increase by 2100 (in °C)	Peak of positive growth rate over time with climate change (approximately)	Peak of GDP per capita over time with climate change (in USD)	GDP per capita without climate change in 2099 (in USD)	Change in GDP per capita, 2040–2059	Change in GDP per capita, 2080–2099
Brunei Darussalam	3.25	2044	41,737.88	126,684.7	−34.16	−81.47
Cambodia	3.60	2075	3,740.398	24,706.32	−38.94	−81.57
Indonesia	3.32	2067	8,841.082	38,561.36	−31.44	−77.93
Lao PDR	3.84	2069	3,567.634	17,327.95	−32.31	−79.17
Malaysia	3.41	2058	11,768.98	48,048.28	−33.53	−80.70
Myanmar	3.85	/	/	/	/	/
Philippines	3.05	2074	6,785.432	32,200.74	−30.61	−76.38
Singapore	3.23	/	/	/	/	/
Thailand	3.69	2058	8,341.051	40,265.12	−37.81	−84.70
Viet Nam	3.74	2066	3,593.551	17,668.67	−33.60	−80.82

Source: Compiled with data from Burke et al. (2015).

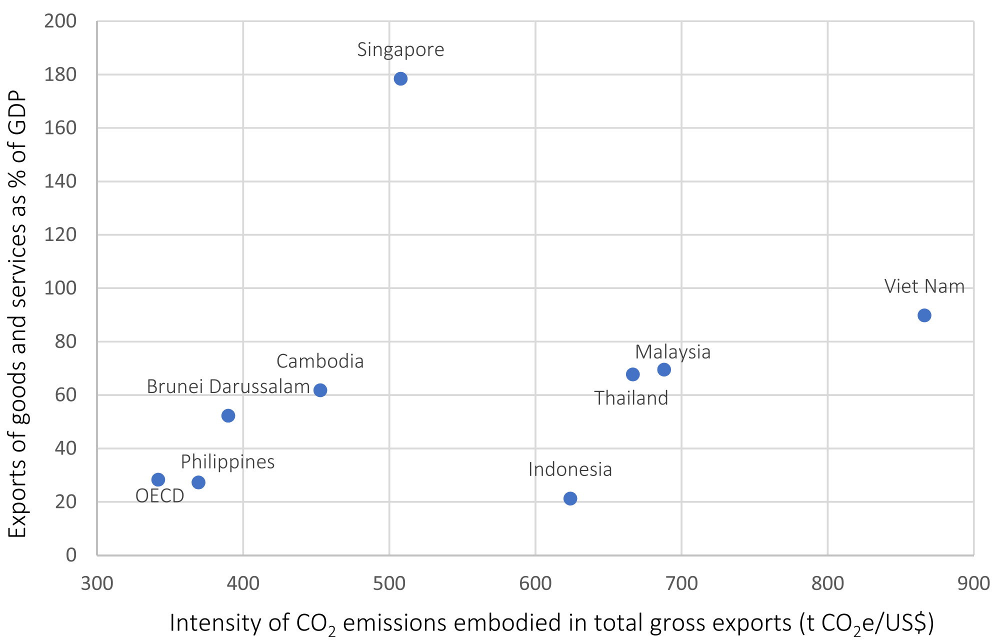

FIGURE 2 Carbon footprint of exports (t CO_2e/US$) vs. exports of goods and services as share of GDP (%) for ASEAN countries and OECD in 2015 [Colour figure can be viewed at wileyonlinelibrary.com]

implies that they are facing large transition risks. For instance, carbon border tariffs, as they are currently being discussed in the European Union, could have a significant impact on export revenue and domestic employment and by implication also on public finances.

Sources: Compiled with data from World Development Indicators and OECD Statistics.

Note: Data on carbon footprint of exports were not available for Myanmar and the Lao PDR.

To date, a comprehensive analysis of the potential fiscal impacts of climate change in Southeast Asia is still lacking. Yet even this cursory overview of macroeconomic climate impacts suggests that the impacts on public finances and debt sustainability may be substantial. It is important to understand the extent to which this is being reflected in the pricing of sovereign debt.

4 | EMPIRICAL ANALYSIS OF THE IMPACT OF CLIMATE RISK ON SOVEREIGN BOND YIELDS

4.1 | Previous research

While there is a rich body of literature analyzing the drivers of the price of sovereign risk, studies have focused on macroeconomic fundamentals as well as international financial contagion. Only recently, a new strand of the literature has emerged that tries to empirically assess the link between climate change and sovereign risk. The first study to systematically analyze the impact of climate change on the cost of sovereign capital is Kling et al. (2018), who conducted a panel analysis with annual data for a sample of 46 countries over the period

1996–2016. Accounting for a set of macroeconomic controls, their results suggest that climate-vulnerable countries have to pay a risk premium on their sovereign debt because of their climate vulnerability, which is measured by indices from the Notre Dame Global Adaptation Initiative (ND-GAIN).[6]

Beirne et al. (2020) examine the relationship between the cost of sovereign borrowing and climate-related risk using quarterly data for 40 advanced and emerging economies. Building on fixed effects panel estimations on the effects of climate risk on bond yields, they employ a structural panel VAR to examine the response of sovereign bond yields to shocks to climate vulnerability and resilience. Their findings show that both vulnerability and resilience to climate change are important factors driving the cost of sovereign borrowing at the global level. Their 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. Building on Beirne et al. (2020), the purpose of the current article is to provide a much more comprehensive and granular assessment of climate change dynamics in Southeast Asia specifically, including at a country level.

Other related work includes that of Battiston and Monasterolo (2019), who focus on transition risk. Using a financial pricing model, they estimate the behavior of government bond yields of OECD countries under forward-looking climate transition scenarios aligned with the Paris Agreement. Their findings suggest that countries with a large exposure to carbon-intensive sectors face higher bond yields. Klusak et al. (2021) model the impact of climate change on sovereign credit ratings. Their findings suggest that climate change adversely affects sovereign credit ratings, with likely impacts on the sovereign cost of capital. Overall, the emerging literature suggests that climate-related risks have an impact on sovereign yields. In the following, we examine this relationship further through country-specific analysis of ASEAN countries.

4.2 | Data and methodology

To empirically examine the effect of climate change on sovereign risk in the ASEAN region, we estimate country-specific OLS models and a fixed effects panel using monthly data over the period 2002M1 to 2018M12.[7] The added value in the analysis undertaken relates to the focus on six ASEAN economies that are particularly exposed to climate change. The country-specific models are estimated for the following ASEAN economies: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Viet Nam, while the fixed effects panel includes all six countries. This selection of ASEAN countries was imposed by data availability. Our two baseline equations are as follows:

Country-specific:

$$y_t = \gamma' z_{t-1} + \beta x_{t-1} + \chi \omega_{t-1} + \varepsilon_t; t = 1, \ldots, T \tag{1}$$

Fixed effects panel:

$$y_{i,t} = \gamma' z_{i,t-1} + \beta x_{i,t-1} + \chi \omega_{t-1} + \delta_i + \varepsilon_{i,t}; i = 1, \ldots, N, t = 1, \ldots, T \tag{2}$$

where y_i is the sovereign bond yield; z_i represents two climate change indicators; x_i denotes a set of domestic factors; ω denotes global factors; δ_i are country fixed effects; and ε_i is the error term. In order to mitigate against endogeneity concerns, the variables are lagged by one period.[8] Clustered *SEs* are used in order to correct for residual problems relating to heteroskedasticity and autocorrelation.

Following Beirne et al. (2020), the two climate change indicators of interest comprise a measure of vulnerability to climate change and a measure of resilience to climate change. The former is based on a refined version of the ND-GAIN vulnerability index that was developed by Kling et al. (2021), comprising 20 indicators for vulnerability of food and water supply, health, ecosystems, habitat, and infrastructure (Table A2). It excludes components from the original ND-GAIN index developed by Chen et al. (2015) that are highly correlated with macroeconomic variables, so that this vulnerability index is less correlated with countries' financial or economic conditions, which might cause endogeneity.[9] For resilience to climate change, we use a measure developed by FTSE Russell comprising 23 indicators for institutional, social, economic, and ecological resilience to climate change (Table A3).[10]

For the domestic controls, we draw on the literature that examines the drivers of sovereign bond yields (e.g., Beirne & Fratzscher, 2013; Edwards, 1984). The vector of domestic factors in Equations (1) and (2) includes the current account/GDP, public debt/GDP, fiscal balance/GDP, GDP per capita, and GDP growth. In addition, to reflect more highly integrated financial markets at the global level vis-à-vis ASEAN, we also control for global factors. Specifically, we include US bond yields and the Chicago Board Options Exchange's Volatility Index (VIX) as a measure of global financial market volatility. Table A1 in Appendix A presents details of all variables used, including the sources.

4.3 | Results

Table 6 presents both the country-specific and panel results.[11] The results are very clear in that greater vulnerability to climate change appears to have a sizable positive effect on sovereign bond yields, while greater resilience to climate change has an offsetting effect. With the exception of the resilience coefficient in the case of the Philippines, which is also negative but statistically not significant at the 10% level, the country estimates are all significant, and most are highly significant. Likewise, the panel results for ASEAN as a group confirm that greater climate vulnerability raises the cost of sovereign borrowing. Also, greater resilience to climate change lowers the cost of sovereign borrowing. These results are in line with the findings of Kling et al. (2018) and Beirne et al. (2020).

The control variables are largely in line with expectations. A higher per capita income, more rapid GDP growth, and a stronger current account correspond with lower bond yields. A higher public debt-to-GDP ratio corresponds in most cases with a higher cost of debt, although the coefficient is negative in the cases of Thailand and Viet Nam. The results for fiscal balance are also mixed, which confirms the

TABLE 6 Regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	ASEAN	IDN	MYS	PHL	SGP	THA	VNM
Vulnerability	1.529***	4.681***	0.601*	5.410**	1.775***	2.665***	7.275***
	(0.204)	(1.171)	(0.350)	(2.641)	(0.219)	(0.672)	(2.620)
Resilience	−0.042***	−0.013***	−0.052***	−0.002	−0.059***	−0.037***	−0.280*
	(0.009)	(0.004)	(0.007)	(0.016)	(0.017)	(0.008)	(0.141)
Current account/GDP	−0.047***	−0.356***	0.002	−0.110***	−0.0113	−0.063***	−0.072*
	(0.008)	(0.084)	(0.008)	(0.027)	(0.007)	(0.010)	(0.038)
GDP per capita	−4.411***	−11.59***	−1.598*	−3.351*	−3.722***	−2.919***	0.197
	(0.540)	(2.196)	(0.886)	(1.978)	(0.822)	(0.712)	(2.246)
Public debt/GDP	0.032***	0.007	0.026***	0.089***	0.019***	−0.028***	−0.081***
	(0.003)	(0.016)	(0.006)	(0.010)	(0.005)	(0.008)	(0.022)
Fiscal balance/GDP	−0.0106	0.458***	−0.0176	−0.260***	0.0106**	−0.056***	0.171***
	(0.014)	(0.095)	(0.016)	(0.036)	(0.005)	(0.014)	(0.041)
GDP growth	−0.067***	−0.342*	−0.024**	0.054	0.009	−0.045**	−0.752***
	(0.017)	(0.187)	(0.012)	(0.036)	(0.007)	(0.011)	(0.212)
US bond yield	0.428***	1.494***	0.383***	0.869***	0.427***	0.463***	0.066
	(0.077)	(0.188)	(0.050)	(0.132)	(0.045)	(0.059)	(0.259)
VIX	0.015***	0.116***	0.011**	0.014*	−0.006	−0.019***	−0.042*
	(0.006)	(0.017)	(0.005)	(0.008)	(0.004)	(0.007)	(0.022)
Constant	−32.55***	−305.2***	12.65*	273.9*	134.6***	−95.25***	−349.2**
	(10.48)	(67.53)	(7.320)	(146.0)	(18.82)	(28.24)	(145.7)
Observations	1,009	174	189	189	130	189	138
R-squared	0.589	0.811	0.516	0.934	0.769	0.804	0.863
Number of countries	6	1	1	1	1	1	1
Country fixed effects	Yes	n/a	n/a	n/a	n/a	n/a	n/a

***$p < .01$, **$p < .05$, *$p < .1$.

notion that higher fiscal spending per se is not necessarily a problem for the debt sustainability of countries. With regard to the international control variables, higher US bond yields drive up the cost of sovereign debt across Southeast Asia, with the exception of Viet Nam, where the effect is statistically not significant. Last but not least, greater global financial market volatility, as measured by the VIX, increases sovereign bond yields in most cases, although the coefficients for Singapore, Thailand, and Viet Nam are negative and significant for the latter two. The significance of global risk aversion implies sensitivity in yields to financial crisis and heightened uncertainty in global financial markets. The relationship between bond yields and the VIX warrants some further discussion. Previous work by Rey (2015) on the global financial cycle notes that reductions in the VIX are strongly correlated with rises in capital flows to emerging market economies, and one can infer that the expected relationship between the VIX and bond yields in emerging market economies should be positive (i.e., lower global risk aversion leads to net bond inflows and a compression of yields). The direction of the relationship between global risk aversion and sovereign bond yields in emerging market economies lacks consensus in the empirical literature however. While the prior may be for a positive relationship, Gadanecz, Miyajima, and Shu (2018) note that rising global risk aversion can lead to declines in emerging market economy bond yields in multivariate models that incorporate domestic macroeconomic fundamentals. Differences in the direction of the effect can also be related to changes in the relationship across different phases of the business cycle (Duyvesteyn & Martens, 2014). This can help to explain the negative significant coefficients on the VIX in our bond yield equations for Thailand and Viet Nam. Over the sample period in our analysis, global risk aversion has reduced the cost of sovereign borrowing for Thailand and Viet Nam, with these bond markets taking on the characteristics of safe havens during periods of amplified global tensions, perhaps related to strong and improving domestic fundamentals over the sample period.

When comparing the results across six ASEAN countries, it is notable that the magnitude of the effect of vulnerability to climate change on bond yields is highest for Viet Nam, the Philippines, Indonesia, and Thailand. As discussed before, the Philippines, Viet Nam, and Thailand are among the 10 most vulnerable countries in the world. In particular, for Viet Nam, increased vulnerability to climate change equates to a 728-basis point premium on its sovereign bond yield. Interestingly, the effect has been the smallest in Malaysia, whose coefficient estimate is even lower than that of Singapore, generally considered one of the least vulnerable countries.

The effect of resilience to climate change has a substantially lower effect on bond yields across all ASEAN economies in our sample. The coefficients are negative and significant in all cases except for the Philippines, where we find no significant effect. As in the case of vulnerability, the highest effect is evident in the case of Viet Nam, with higher resilience to climate change equating to a dampening effect on bond yields of around 28 basis points. The effect of resilience on the bond yields of the other ASEAN economies amounts to a reduction in yields of less than 10 basis points.

Overall, the findings indicate that those countries 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. With climate change accelerating, and both physical and transition impacts becoming ever more pronounced, the risk is that climate risk premia are bound to increase further for climate-vulnerable countries, undermining debt sustainability and constraining fiscal space for investment in much-needed adaptation and resilience.

5 | CONCLUSION AND DISCUSSION OF POLICY IMPLICATIONS

This article is a first attempt at investigating the impact of climate vulnerability on public finances and sovereign risk in Southeast Asia, one of the regions that is most affected by climate change. Using measures for vulnerability and resilience to climate change, our econometric analysis of six country-specific models as well as a panel regression for all ASEAN countries in our sample reveal that greater vulnerability to climate change has a sizable positive effect on sovereign bond yields, suggesting that ASEAN countries are already having to pay a climate-related risk premium on sovereign bonds now. With a worsening of climate change, and a greater awareness of investors to climate change impacts, this risk premium is likely to increase in the future. The implication is that countries like Viet Nam, the Philippines, Indonesia, and Thailand, which are among those countries with the greatest need for adaptation and resilience investment, will face greater constraints in financing those. It should be noted that due to data constraints, it was not possible to conduct this analysis for Cambodia, the Lao PDR, or Myanmar, the poorest ASEAN countries.[12] Cambodia and Myanmar in particular are both extremely climate vulnerable. For these countries, climate change poses a substantial threat to future development.

There is a risk of a vicious circle facing climate-vulnerable countries, where an acceleration of global climate change will make the developing countries of Southeast Asia ever more vulnerable, with adverse effects on their sovereign credit profile and a resulting higher cost of debt. A higher cost of capital will, in turn, hold back public investment in growth and development, including crucial investment in climate-resilient infrastructure and other adaptation measures. Over time, there is a risk that a worsening of climate change and associated macroeconomic impacts will further undermine public finances. Moreover, greater climate vulnerability is also holding back the development of the private sector (Kling et al., 2021). The poorer countries in the region face the risk of not being able to finance necessary adaptation measures and, without external support, ending up in this vicious circle of greater vulnerability and worsening public finances and perpetual debt crises.

On the upside, we also find that greater resilience to climate change can partially offset the effect of climate vulnerability on the cost of capital. While the estimated effect of resilience to climate change is substantially lower than that of vulnerability, the analysis provides a very strong rationale for scaling up investment in climate adaptation and resilience. However, with the exception of Brunei Darussalam and Singapore, Southeast Asian countries will need international support to substantially scale up adaptation and resilience investment.

Besides the need to enhance investment in resilience and adaptation, our findings also underscore the need to mainstream climate risk analysis in public financial management. Governments need to consider the potential impacts of climate change on the medium- to long-term quality and sustainability of public finances and seek to mitigate risks. For instance, budget planning should build in fiscal buffers for climate-related risks and develop contingency savings funds. The Philippines, for example, have established a National Disaster Risk Reduction and Management Fund, an example that could be replicated in other countries in the region.

ASEAN countries should also seek to develop regional and international disaster financing mechanisms and risk-pooling arrangements. The establishment of the Southeast Asia Disaster Risk Insurance Facility—a regional catastrophe risk insurance pool for the Lao PDR and Myanmar—with financial support from Japan, Singapore, and the World Bank in 2018 is a step in the right direction. However, a more ambitious scheme for the whole of developing Southeast Asia will be needed. ASEAN countries should also discuss with China, Japan, and the Republic of Korea—with whom they form the ASEAN+3 grouping—to mandate the ASEAN+3 Macroeconomic Research Office to developing a surveillance mechanism for climate-related macrofinancial risk for all countries in the region (Volz, 2021). The ASEAN+3 group should also consider to develop an emergency financing facility that would provide support for countries hit by a disaster. Last but not least, ASEAN countries should also work with institutions like the Asian Development Bank, the Asian Infrastructure and Investment Bank, and the World Bank on strengthening adaptation and resilience across the region and on developing risk transfer mechanisms.

Climate change poses a serious threat to development across Southeast Asia. Concerted efforts in adapting to climate change are needed to reduce the vulnerability to, and impacts of, climate change. The amounts needed to invest in adaptation and resilience will be substantial for all countries of Southeast Asia. However, a failure to make these investments in the near future is likely to result in much greater costs in the future—including in the form of a higher cost of sovereign borrowing.

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ENDNOTES

[1] The 10 member countries of ASEAN are Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

[2] Klusak, Agarwala, Burke, Kraemer, and Mohaddes (2021) establish a direct link between macroeconomic impacts of climate change and sovereign credit ratings.

[3] For further details on the transmission channels discussed in this section, see Volz et al. (2020).

[4] Projections by Kompas et al. (2018) paint a similarly bleak picture.

[5] Estimates for carbon tax revenues and data on fossil fuel revenues are from OECD, World Bank, and UN Environment (2018), while data on fossil fuel subsidies are from the International Energy Agency's Energy Subsidies database (2019).

[6] In a related study, Kling, Volz, Murinde, and Ayas (2021) use firm-level data and find that climate change vulnerability also affects the cost of corporate financing and access to finance, controlling for various firm-specific and macroeconomic factors.

[7] The use of a fixed effects as opposed to a random effects model for the panel has been justified on the basis of the results of a Hausman test, which rejected the null hypothesis at below the 1% level with a test statistic chi-squared value of 436.51.

[8] Other approaches based on instrumental variables could have been applied, although these are fraught with difficulty given the problems of identifying suitable instruments. As regards preliminary analysis, a correlation matrix of the independent variables indicates no concerns about multicollinearity (see Table A4 in Appendix A). Furthermore, stationarity tests based on the ADF test for the country-specific models and the Choi (2001) test for the panel (which corrects for cross-sectional dependence) reject the null hypothesis of a unit root for the variables used in our analysis. Given the large volume of results, these are not provided but are available from the authors upon request. Descriptive statistics are provided in Table A5 in Appendix A, while the dynamics of bond yields and our climate indicators over time are shown in Figure A1 in Appendix A.

[9] The original ND-GAIN vulnerability index comprises three core measures: (a) the extent to which an economy is exposed to significant climate change from a biophysical perspective; (b) the degree to which an economy is dependent upon sectors that are particularly sensitive to climate change; and (c) the extent of an economy's capacity to adapt to climate change. This measure can be interpreted as an overall measure reflecting both physical and transition risks.

[10] As can be seen from Tables A2 and A3, the component indicators of the resilience and vulnerability measures overlap in only one component, the freshwater withdrawal rate.

[11] As shown in Figure A2 in Appendix A, the actual and fitted values from the models indicate that the models explain the sovereign bond yields of the ASEAN economies well.

[12] There were also no data available for Brunei Darussalam, which, along with Singapore, is one of the countries considered least climate vulnerable (cf. Table 1).

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APPENDIX A

TABLE A1 Sources and definition 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. (2021)	The refined vulnerability measure by Kling et al. (2021) 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.
US bond yield	Bloomberg	US 10-year government bond yield.
VIX	Bloomberg	VIX stands for the Chicago Board Options Exchange (CBOE)'s Volatility Index, a measure of global risk aversion.

TABLE A2 Components of Kling et al.'s (2021) climate vulnerability measure

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
	Freshwater 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 5 m above sea level

Source: Compiled by authors drawing from Kling et al. (2021).

TABLE A3 Components of FTSE Russell's resilience index

Sub-index	Indicators
Institutional	Intended country $C0_2$ 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 A4 Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Resilience	1.000								
(2) Vulnerability	0.182	1.000							
(3) Current account/GDP	0.496	0.158	1.000						
(4) GDP per capita	0.641	0.151	0.785	1.000					
(5) Public debt/GDP	0.531	0.550	0.661	0.728	1.000				
(6) Fiscal balance/GDP	−0.178	−0.006	−0.087	−0.032	0.058	1.000			
(7) GDP growth	−0.175	0.408	−0.249	−0.378	−0.106	−0.188	1.000		
(8) US bond yield	−0.171	0.004	0.012	−0.120	−0.008	0.210	0.125	1.000	
(9) VIX	0.028	0.005	−0.064	−0.031	−0.008	−0.104	−0.127	−0.003	1.000

TABLE A5 Descriptive statistics

Variables	Obs	Mean	*SD*	Min	Max
Sovereign bond yield	1,018	5.99	3.32	1.29	17.26
Vulnerability	1,152	48.05	3.74	41.78	53.40
Resilience	1,152	26.66	14.20	0	47.20
Current account/GDP	1,152	5.29	9.17	−22.73	31.75
GDP per capita	1,152	8.49	1.18	6.67	10.92
Public debt/GDP	1,152	107.38	45.47	45.38	221.62
Fiscal balance/GDP	1,152	−0.20	4.82	−13.19	9.74
GDP growth	1,152	6.49	3.97	−8.27	19.49
US bond yield	1,152	3.26	1.08	1.45	5.40
VIX	1,152	19.37	8.33	9.51	59.89

FIGURE A1 Sovereign bond yield and climate risk.

Note: The red line represents government bond yield in percentage. The blue line represents resilience. The green line represents vulnerability [Colour figure can be viewed at wileyonlinelibrary.com]

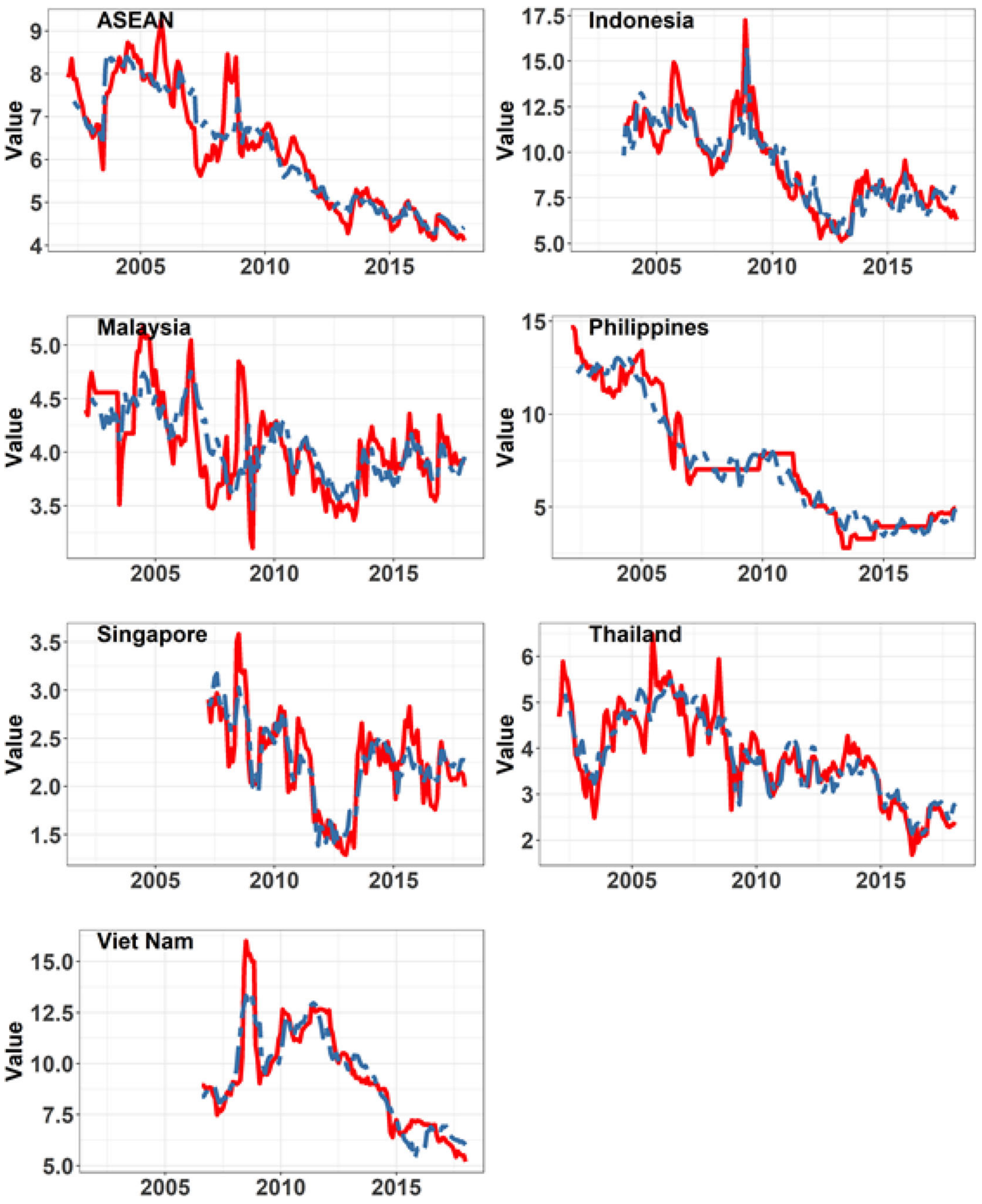

FIGURE A2 Actual and fitted values of government bond yields.
Note: The red line represents the actual value of government bond yield in percentage. The dark blue dashed line represents its fitted value [Colour figure can be viewed at wileyonlinelibrary.com]