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CLIMATE

NOTES

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Sakai Ando, Chenxu Fu, Francisco Roch, and Ursula Wiriadinata

IMF STAFF CLIMATE NOTE 2022/004

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Summary

Financial markets will play a catalytic role in financing the adaptation and mitigation to climate change. Catastrophe and green bonds in the private sector have become the most prominent innovations in the field of sustainable finance in the last 15 years. Yet the issuances at the sovereign level have been relatively recent and not well documented in the literature. This note discusses the benefits of issuing these instruments as well as practical implementation challenges impairing the scaling up of these markets. The issuance of these instruments could provide a wider source of stable financing with more favorable market access conditions, mitigate the stress of climate risks on public finances, and facilitate the transition to greener low-carbon economies. Emerging market and developing economies stand to benefit the most from these financial innovations.

Introduction

When it comes to dealing with climate change, fiscal policy is crucial. In addition to the essential carbon pricing that incentivizes low-carbon activities, fiscal policy can aid the transition to a greener low-carbon economy by investing in climate-smart infrastructures, such as renewable energy generation, and encouraging climate-smart technology research and development. Even though these policies would yield substantial long-term economic benefits, they require a substantial amount of financing. The prepandemic research by G20 Foundations Platform calculated that the world needs 2.2 percent of GDP invested annually to deliver commitments from the 2030 Sustainable Development Goals and the Paris Agreement. Furthermore, adapting to the consequences of climate change and minimizing damage from climate-related natural disasters usually necessitates an increase in government spending, among other things, which must be accommodated within a country's overall budgetary structure.

Financial innovation can then play a crucial role in financing these interventions. The development of green and catastrophe bonds has been one of the most important financial breakthroughs in the domain of sustainable finance during the last 15 years. Green bonds are often structured similarly to traditional “plain vanilla” bonds, with the distinction that the bond contains a “use of proceeds” clause stating that the funds would be utilized for green investments. A catastrophe bond is a debt instrument that allows the issuer to get funding from the capital market, if and only if catastrophic conditions, such as a hurricane, occur. Climate change is expected to increase the likelihood and severity of these extreme weather events. Although the two instruments are of different nature, this paper analyzes them together given that both of them can contribute to the resilience to climate risks and have been recently issued at the sovereign level. These innovative finance instruments allow policymakers to tap wider capital markets for the financing of Sustainable Development Goal–related projects (green bonds) and mitigate the stress on debt sustainability after natural disasters (catastrophe bonds). Thus the financial industry is becoming increasingly important in accelerating the transition to sustainability and carbon neutrality.

While green and catastrophe bonds have gained significant popularity, their markets remain fairly shallow at the sovereign level. For instance, sovereign green bonds make up about 0.2 percent of all government debt securities in the Organisation for Economic Co-operation and Development (OECD) area. In emerging market and developing economies (EMDEs), sovereign green bond issuances account for 12 percent of total green bond issuances (OECD 2021). However, the sovereign green bond market is likely to expand as more countries see green bond issuance as a vital tool for demonstrating moral leadership on climate change and sustainability, as well as funding commitments under the Paris Agreement. Similarly, a few countries have insured themselves against natural disasters, and even large catastrophe bonds only cover a small portion of the total possible damage.

The literature on sovereign green and catastrophe bonds is minimal. Since both green and catastrophe bonds issuances at the sovereign level are a recent development, most of the literature on sustainable finance has focused on the issuances by the corporate sector and local governments. This note fills this gap and studies the developing markets for sovereign green and catastrophe bonds, examines the characteristics of these instruments, and analyzes their costs and benefits. Our analysis contributes to the understanding of the markets for climate financing and the workstream of the Fund to help mobilize both public and private finance (see, for instance, IMF 2021a and IMF 2021b).

There are several potential benefits from tapping sovereign climate bond financing, but also limitations and challenges. First, the growing popularity of green bonds may allow governments to issue bonds with longer maturities (given the longer horizon of green projects) and at a lower borrowing cost relative to plain vanilla bonds (the "greenium"). However, there are still several obstacles impairing the further development of the green bond market: lack of an international set of guidelines of what constitutes a green bond, narrow investor base, the risk of fund mismanagement (greenwashing), and little issuances in emerging market and developing economies. Second, catastrophe bonds provide effective insurance against natural disasters and can be considered adaptation policies for the countries with exposure to climate change risks. Yet the note discusses significant barriers to the scale up of the catastrophe bond market: high transaction costs, the requirement of complicated underlying catastrophe models, and a narrow investor base (which could in turn be a consequence of the previous two factors).

The rest of the note is organized as follows. The next section analyzes the sovereign green bond market and estimates the greenium. The note then overviews the sovereign catastrophe bond market and discusses the associated benefits and challenges. A final section offers concluding remarks and policy lessons.

Green Bonds

A wide range of instruments is available for governments to finance green projects. For example, Rose (2021) discusses green bonds as well as other instruments, including green Sukuk, green loans, and green Schuldschein. World Wildlife Fund (2018) describes other examples including equity finance and debt for climate swaps. Among these instruments, the green bond is one of the fastest-growing segments. In this section, we overview sovereign green bonds, highlighting the recent development and policy issues.

What is a green bond?

Green bonds refer to debt securities issued to raise capital earmarked for green projects. The exact definition, however, varies depending on what constitutes green projects. For example, the Green Bond Principles (GBPs), which were established in 2014 and are maintained by the International Capital Market Association (ICMA), provide guidelines and green project categories (ICMA 2021). The Climate Bonds Standards (CBSs), built on top of the GBPs by the Climate Bonds Initiative (CBI), provide a sector-specific definition of "green" and are used for the certification of green bonds by CBI (Climate Bonds Initiative 2019).

For example, the CBSs categorize eligible projects into eight groups: energy, transport, water, buildings, land use and marine resources, industry, waste and pollution control, and information communications and technology.[1] Thus green bonds cover a wide range of environmental activities, some of which could be broader than climate objectives. As reporting requirements, the CBSs ask the issuers to document the use of proceeds, the process for evaluation and selection of projects and assets, and the management of proceeds, both before the issuance and annually after the issuance. A green bond issuer can obtain certification if the issuer pays fees to one of the verifier organizations and it confirms that the CBSs are met. This is, however, a private initiative, so compliance by bond issuers to the CBSs is voluntary.

Green bond data can differ across databases. ICMA (2017) explores four databases (Bloomberg, Environmental Finance, Dealogic, CBI) and discusses the difference in the definitions. For example, Bloomberg tags the "Green Bond" label when an issuer self-labels its bond as green or declares its compliance with the GBPs on the use of proceeds.[2] The Green Bond Database by Environmental Finance lists all bonds that are self-labeled as "Green." Eikon is another database that provides green bond data, whose definition is aligned with the CBSs; the data are reviewed by CBI. Thus the analysis of green bonds, in general, should be understood with caveats on the data. The analysis in this paper relies on Eikon as it is consistent with the CBSs and has been used extensively in the literature of the sovereign green bond (for example, Doronzo, Siracusa, and Antonelli 2021). For sovereign green bonds, Eikon and Bloomberg are comparable.

The public sector has accelerated its development of definition and regulatory framework following private initiatives. For example, the People's Bank of China issued guidelines in 2015 and a catalog in 2021, defining the projects that are eligible for green bond issuance (People's Bank of China 2021). The European Union adopted the regulation of EU taxonomy in 2020 that defines environmentally sustainable economic activities. In 2021, the European Commission proposed the legislation of the European green bond standard (European Commission 2021). Many other countries have issued green bond guidelines and frameworks as summarized by CBI (2022).[3]

Evolution of sovereign green bonds

Sovereign green bonds are a recent phenomenon, starting in 2016. The literature often cites the bond issued by the European Investment Bank in 2007 as the first green bond (Cortellini and Panetta 2021; OECD 2021).[4] Since 2007, international organizations, municipalities, and private sectors have increased the issuance. Until 2015, although the annual issuance of green bonds had reached $40 billion, no issuance by central governments was recorded. In 2016, building on the momentum of the Paris Agreement adopted in 2015, Poland became the first issuer of sovereign green bonds.

A wide range of sovereigns has issued green bonds since 2016. Figure 1, panel 2, shows the green bond in Eikon issued by the central government.[5] The list of green bonds used for the figure is provided in Annex 1. Poland was the first country to issue a sovereign green bond in 2016, followed by France in 2017, and the issuance recorded nearly $80 billion in 2021. Most issuance was by advanced economies until February 2022 (Figure 1, panel 1).[6] Geographically, the cumulative issuance from 2016 to 2021 is mostly concentrated in European countries ($161 billion), followed by Asian Pacific countries ($9 billion), Western hemisphere countries ($8 billion), the Middle East and Central Asian countries (less than $1 billion), and African countries (less than $1 billion).

[1] The high-level explanation of eligible projects in each group is summarized as Climate Bonds Taxonomy, and the detailed definitions are provided by the Sector Eligibility Criteria.

[2] In Bloomberg, green and blue bonds are separate categories.

[3] The details of individual countries' regulations can be found in the Green Finance Platform (2022).

[4] The World Bank issued the first labeled green bond in 2008 (World Bank 2015). Eikon includes older bonds, such as the bond issued by Danske Bank in 1985, as a green bond.

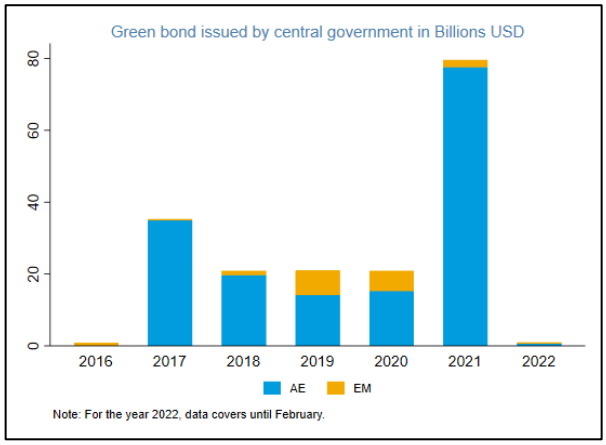
[5] The boundary is restricted to the central government for the calculation of greenium, as discussed later.

[6] Some emerging markets have alternative financing instruments. For example, Indonesia has issued Green Sukuk for a total of US$3.2 billion since 2018.

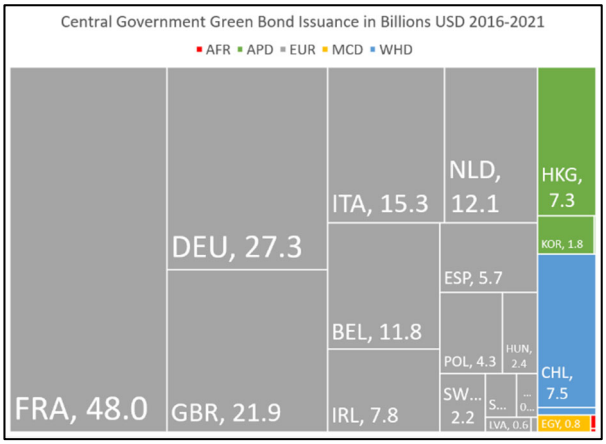
France has issued nearly $48 billion for green projects and is the largest issuer as of February 2022. In terms of cumulative green bond issuance relative to GDP at the country level, Chile has the highest ratio of 2.37 percent (relative to its GDP in 2021). Others are all below 2 percent as of February 2022. The average maturity as of issuance is 12.6 years with a standard deviation of 8.4 years. Although the holder's information is not available from Eikon, Doronzo, Siracusa, and Antonelli (2021) suggest that real money investors, such as pension funds, sovereign funds, and insurance companies, invest their money with a long-term perspective and a buy-and-hold strategy in Europe.

Figure 1. Green bonds issued by central government in billions of US dollars

1. Across years



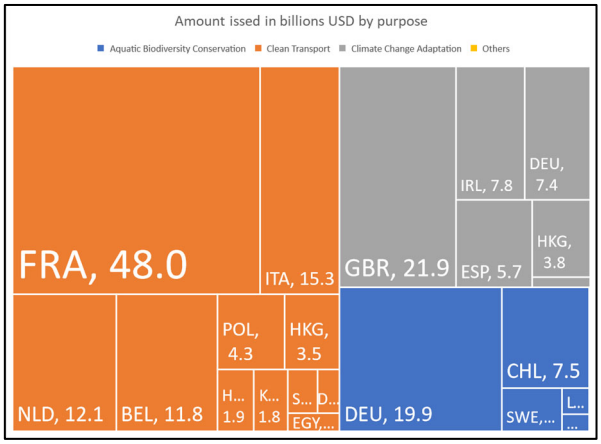
2. Cumulative from 2016-2021



Source: Eikon and IMF staff calculations.

The main purpose of issuing green bonds in the sample is clean transport (Figure 2). The classification of purpose is not necessarily mutually exclusive, but the available data in Eikon shows that clean transport is the main purpose of green bonds. The share of climate change adaptation and aquatic biodiversity conservation is also significant. One caveat is that the purpose of green bonds is classified by Eikon and may not reflect all purposes of each bond issued.

Figure 2. Green bond issued amount by purpose



Source: Eikon and IMF staff calculations.

Costs and benefits of sovereign green bond issuance

Several costs associated with sovereign green bond issuance have been discussed in the literature. For example, Doronzo, Siracusa, and Antonelli (2021) discusses three types of costs relative to the costs of the conventional bond:

1. Green bond requires more disclosure and tracking for the use of proceeds. For example, if a green bond issuer wants certification from CBI, documentation to show that the CBS is met and engagement with verifiers is needed. But more information provision could lead to less uncertainty for buyers, so the net impact is not clear.
2. The reputation of the issuer could be damaged if the green project that the green bonds finance fails or is perceived as greenwashing (falsely claiming that the financed investment is green). The net impact is again ambiguous since the green bond plays the role of a commitment device and thus can lower the probability of failure by motivating better planning and governance of the projects.
3. The issuance of green bonds can crowd out that of conventional bonds, resulting in lower liquidity and higher funding costs for both segments. Doronzo, Siracusa, and Antonelli (2021) summarize Danish and German techniques to mitigate the liquidity problems. For example, the Germany Finance Agency mitigates the impact on the liquidity of conventional bonds by increasing its stock of conventional bonds at the time it issues green bonds by the same amount. The additional own holdings in conventional bonds can be used on the secondary market for repo transactions or for lending activities.

OECD (2021) also points to gaps in supply constraints. A pipeline of green projects needs to be established to sustain the supply and liquidity of the green bonds. OECD (2021) argues that the supply constraints can be mitigated by utilizing technical assistance from experts and aggregation of small-scale projects with securitization.[7] Another obstacle to sovereign green bonds is that most sovereign debt legal frameworks do not allow the earmarking of proceeds.

The literature discusses a wide range of benefits. OECD (2017) points out their reputational benefits and their role as a commitment device, among other benefits. Unlike conventional bonds whose proceeds can be used for general purposes, the proceeds from green bonds need to finance green projects, tying the hands of the issuer. This commitment to finance green projects can send signals and improve the reputation of the issuer, leading to a higher price of the issuer's nongreen bonds (halo effect). For sovereign issuers, Doronzo, Siracusa, and Antonelli (2021) mention that the issuance of sovereign green bonds can encourage other issuers to enter the green bond market as it provides a market benchmark. Doronzo, Siracusa, and Antonelli (2021) also argue that green bonds tend to be issued with a long maturity, so the refinancing risk is lower, and the benefit could be larger for emerging or less-developed countries that have less stable demand for extra-long maturities.

A central benefit associated with green bonds has been labeled as the green premium (greenium). When a green bond exhibits a lower yield compared to a similar conventional bond without the green label, the green bond is said to exhibit positive greenium.

Greenium = yield of similar conventional bond - yield of green bond

A positive greenium implies that the price of the green bond is higher than that of a similar conventional bond.

Theoretically, the greenium can take either positive or negative signs. On one hand, the issuance amount and liquidity are smaller than the conventional bond, which could lead to a negative greenium. On the other hand, environmental, social, and governance investors' demand for green bonds and more information on the use of

[7] OECD (2021) also mentions subsidies for green bond issuing, but it is less relevant for sovereign issuance.

proceeds can justify a positive greenium.[8] Thus whether a green bond is traded at greenium is an empirical question.

The literature on sovereign green bond greenium is limited. Doronzo, Siracusa, and Antonelli (2021) discuss that the evidence of sovereign greenium reported by private financial institutions is mixed and estimate greenium in both the primary and secondary market using Eikon's data. They show that the greenium is negative in the primary market but is slightly positive (0.5 bps) in the secondary market. IMF (2021a, 2021b) shows that the greenium of 5- and 10-year green bonds are around 3 to 5 bps and that the greenium implied by swap spreads from 1 to 7 bps for six EU countries. In the context of the US municipal bonds, Karpf and Mandel (2018) find that the greenium was negative but has turned positive recently, suggesting that green bonds have become more attractive to investors in recent years. Baker and others (2021) also find that the greenium is positive except when it is issued simultaneously with ordinary bonds from the same issuer; in that case, a premium emerges over time on the secondary market.

How large is the sovereign greenium?

Since the literature on the sovereign green bond is scarce, this section provides greenium estimates. We first present the result of Germany since it issues twin bonds for the purpose of measuring greenium. For other countries, we impose additional assumptions and estimate the greenium.[9]

Germany

Germany has issued twin bonds since 2020 to provide a benchmark of greenium. Twin bonds consist of a conventional bond and a green bond that share the same maturity date and coupon. The main difference is that the use of proceeds from the green bond is limited to green projects. They are, however, also different in that the green bond's issuance volume is smaller and the issuance date is later. For example, in the twin bonds with maturity in 2030, the conventional bond was issued in August 2019 with a size of €30 billion, while the green bond was issued in May 2021 with a size of €6 billion. Through the issuance of twin bonds, Germany aims to establish the yields of green federal securities as the reference for the Euro green finance market (German Finance Agency 2022).

Germany's greenium oscillated between 2 to 5 basis points. As of February 2020, four twin bonds are on the market with maturity dates in 2025, 2030, 2031, and 2050. Coupons are zero for all bonds. Figure 3 shows that although the behavior of greenium differs across maturity dates and yields of the twin bonds can be positive or negative, the greenium is consistently positive.[10] The greenium does not seem to react much to large uncertainty shocks such as the Russian invasion of Ukraine in February 2022.

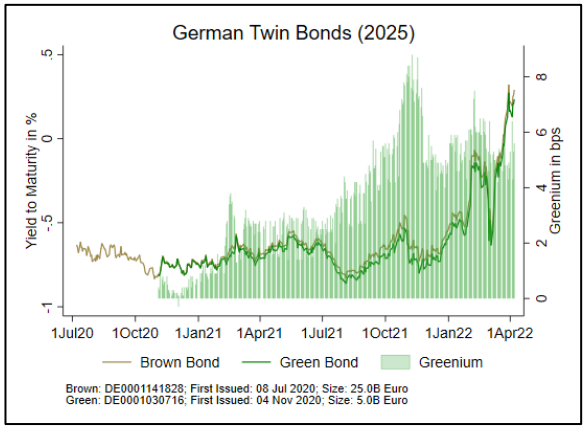
[8] Demand could be driven by the pure interest in Sustainable Development Goal investment or by regulations. In the former case, greenwashing is a concern that could reduce demand. The development of KPIs and penalties in the contract design can help mitigate the concern. In the latter case, the optimal level of market intervention becomes a policy issue. From an issuer perspective, the greenium should not exist given that the default probability is the same as conventional bonds.

[9] Note that the estimation could be subject to selection bias, as countries may not issue the green bonds if the greenium is expected to be negative.

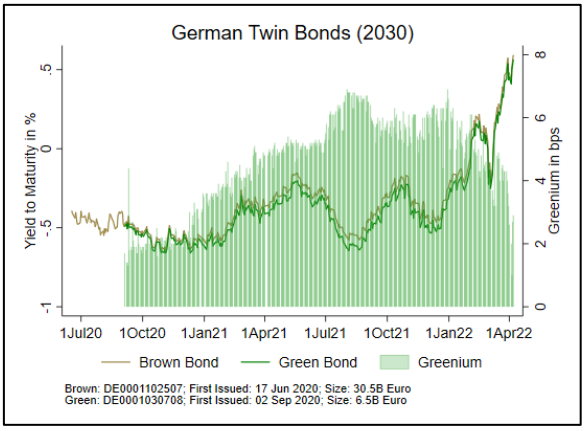
[10] The finance agency facilitates switch trades where investors can exchange their green bonds for the conventional twin.

Figure 3. Germany's Twin Bonds by Tenor

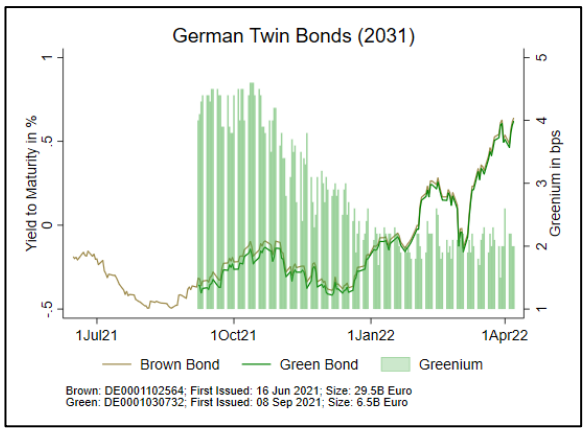
1. The greenium was small at issuance but has increased



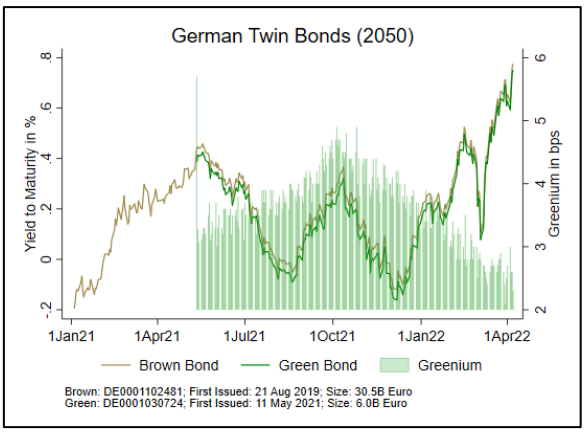
2. The greenium at issuance was high and is increasing



3. The greenium has been declining for 2031 maturity



4. The greenium increased first but has declined recently



Source: Eikon.

Other countries

Since twin bonds are not available in other countries, greenium needs to be estimated with a different approach. The rest of the section presents summary statistics of green versus conventional bonds, and greenium estimates using regression analysis.

Summary statistics of green versus conventional bonds. Annex Table 3.1 in Annex 3 shows the summary statistics of issuance size, yield-to-maturity, spread, and maturity of the green and conventional bonds in the sample, separately for advanced and emerging market and developing economies. Annex Tables 3.2 and 3.3 show the statistics for euro- and USD-denominated bonds, respectively.

- *Issuance size.* Green bond issuance is still relatively small, about 2.0 percent of the total issuance (2016–2022 average), but growing over time from 2.6 percent in 2018 to 3.2 percent in 2021. The share of green bond issuance and its growth are larger for emerging market and developing economies than advanced economies.

- *Maturity.* In the whole sample, the average maturity is 12.9 years for green bonds and 12.3 years for conventional bonds. This pattern is consistent with the idea that green bonds help countries extend their debt maturity profiles. The longer maturity of green bond debt is more pronounced in emerging market and developing countries; the difference is almost three years for EMDEs.
- *Yield.* The summary statistics already indicate a degree of greenium: the average yield of green bonds is lower than conventional bonds. The regression analysis will better estimate the size of the greenium, by controlling for relevant variables such as maturity and liquidity.

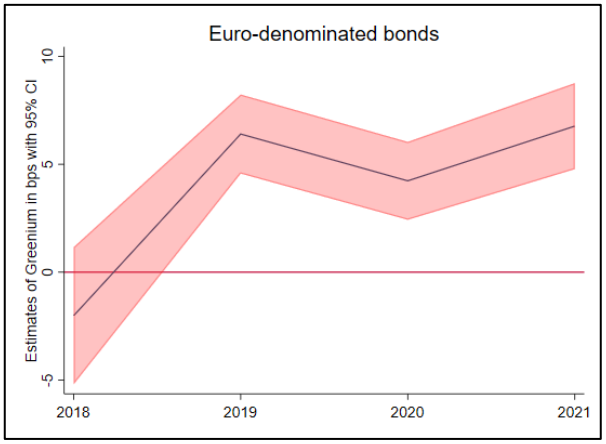
Greenium estimate. The average greenium is 3.7 and 30.4 basis points for euro- and USD-denominated bonds, respectively, as shown in Annex Table 3.4.[11] The difference is partly explained by the fact that a larger portion of USD-denominated green bonds is issued by emerging markets. Also note that the sample sizes of the two groups differ by around five folds.

Greenium is larger for emerging market and developing economies than advanced economies, for all currencies of debt denomination. Specifically, the greenium estimates for emerging markets are 49.3 and 12.5 basis points for the USD- and euro-denominated bonds, respectively, compared to 5 to 6 basis points for advanced economies as shown in Annex Table 3.5. There can be various reasons behind the difference, and formal analysis of the determinants with richer data is warranted and left for future research.

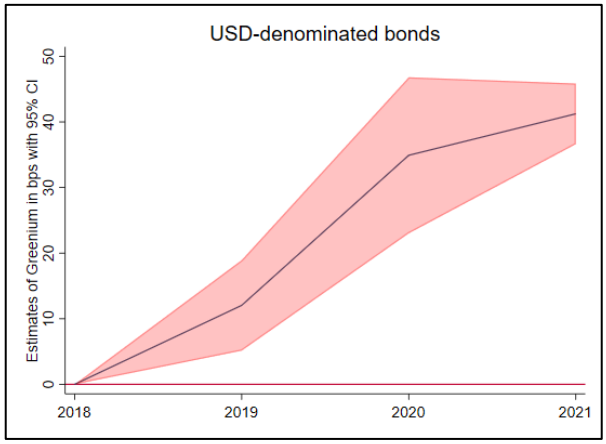
Time-series variation. Figure 4 plots the estimated greenium separately for euro-denominated and USD-denominated bonds in each year, from 2018 to 2021. The greenium of both USD- and euro-denominated bonds—though they started small—has been increasing over time. In the case of euro-denominated bonds, the greenium increased from on average –2.0 basis points in 2018 to 6.8 basis points on average in 2021.

Figure 4. Greenium Estimate

1. Estimated greenium of euro-denominated bonds



2. Estimated greenium of USD-denominated bonds



Sources: Eikon; and IMF staff calculations.

[11] The greenium estimates are robust to alternative estimation approaches (see Annex 3).

Catastrophe Bonds

Extreme weather is expected to be one of the consequences of climate change, and will result in both physical and fiscal damage. There are many ways to mitigate fiscal risks that originate from extreme weather events. For example, OECD and World Bank (2019) list both ex ante and ex post financing tools to mitigate the fiscal risks (Table 1).[12] Debt with maturity extension provisions such as hurricane clauses is another alternative.[13] A debt instrument with a unique structure is catastrophe bonds.

Table 1. Examples of Mitigation Tools for Residual Fiscal Risk

Ex Ante Financing	Ex Post Financing
Dedicated reserve fund	Budget reallocation
Contingency budget	Debt financing
Contingent financing (credit/grant)	Taxation
Sovereign risk transfer	Multilateral/international borrowing
Insurance of public assets	International aid
Catastrophe bonds	

Source: Organisation for Economic Co-operation and Development and World Bank (2019).

What is a catastrophe bond?

A catastrophe bond is a debt instrument that allows the cedent (the insured) to get funding from the capital market, if and only if catastrophic conditions, such as an earthquake or hurricane, occur. From an economic point of view, the instrument insures the cedent against the loss from catastrophic events (called peril) by shifting risks to the holders who bet on the nonoccurrence of catastrophic events. The insurance against natural disasters can be considered an adaptation policy for countries with exposure to climate change risks.[14]

The catastrophic conditions can be defined by various types of triggers. For example, a trigger based on actual monetary losses experienced by the cedent is called an indemnity trigger, the one based on industrywide losses is called an industry loss trigger, and the one based on noneconomic catastrophic conditions such as the magnitude of an earthquake or wind speed of a hurricane is referred to as parametric index trigger. The advantage of indemnity type is that it insures cedents against the actual loss, while a disadvantage is time-consuming loss verification since the damages need to be assessed. In contrast, the parametric type may not insure cedents against the amount of actual loss, but it has the advantage of speedy settlement since parameters such as wind speed and magnitude of an earthquake are easier to measure. The idea can be extended to noncatastrophic conditions, such as mortality rates, in which case the concept of catastrophe bonds is generalized to insurance-linked securities (ILS).

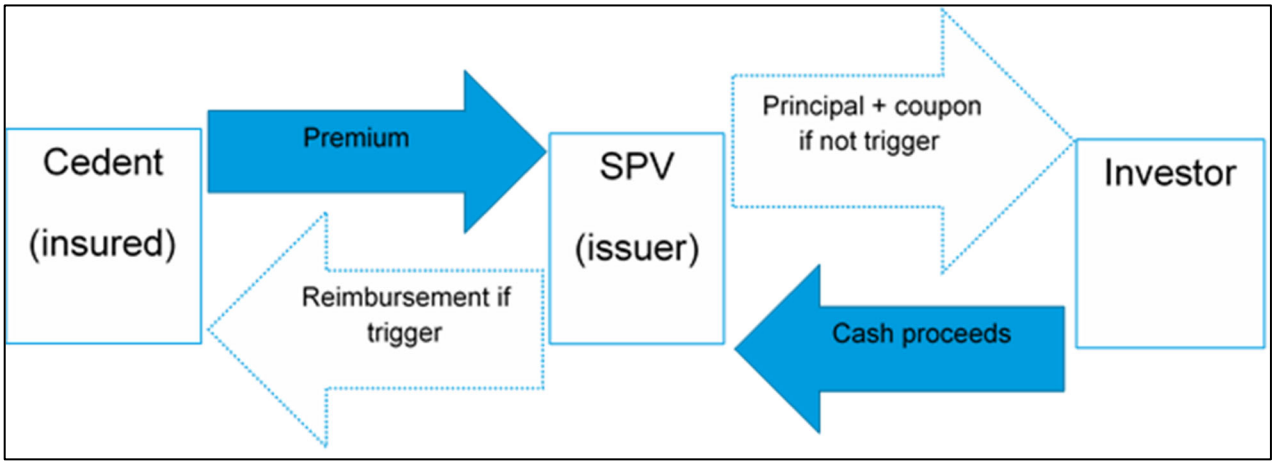
The legal structure of a typical catastrophe bond is designed to minimize counterparty risk. Specifically, a special purpose vehicle (SPV) is set up, and the cedent (often called the sponsor) enters an insurance agreement with the SPV. Cedents pay premiums upfront in exchange for future reimbursement conditional on catastrophic events. The SPV issues catastrophe bonds to the holders in exchange for cash, promising future principal and interest payments conditional on the nonoccurrence of catastrophic events. Thus, what an SPV does is to collect cash from cedent and investors, keep the cash typically in safe assets, and disburse it to either cedent or investors depending on the occurrence of catastrophic events. In this way, an SPV can secure the cash for later distribution, and who owns the bond does not affect the capacity to pay cedents, so the bond can be traded in the secondary market (Figure 5).

[12] IMF (2019) also discusses building resilience in developing countries vulnerable to large natural disasters.

[13] See Cohen and others (2020) for a discussion.

[14] Catastrophe bonds, however, are not considered green bonds by CBI. See https://www.climatebonds.net/cat-or-out.

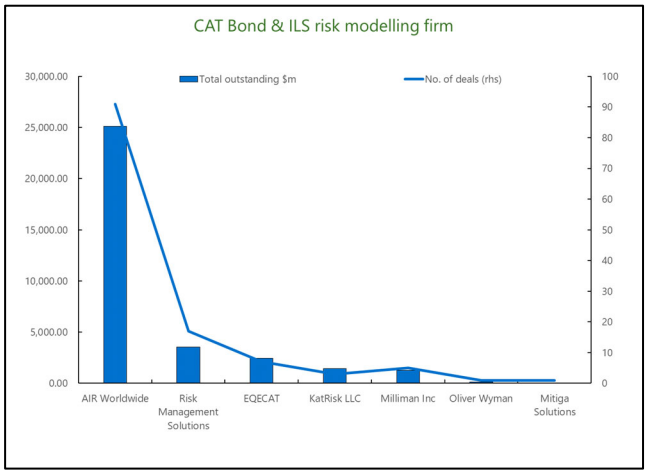
Figure 5. Legal structure of catastrophe bonds



Source: IMF staff.
Note: SPV = special purpose vehicle.

The legal structure has financial, statistical, and economic implications. Financially, the catastrophe bond is insulated from the cedent's financial condition, so the credit rating is different from that of the cedent. Statistically, the catastrophe bond is issued by the SPV and not by the cedent, so the cedent's debt does not increase. Economically, the cash proceeds are kept by the SPV, so they cannot be used by the cedent to spend on items including consumption, investment, etc., until triggered.

Figure 6. CAT bond and ILS risk modelling



Source: Artemis.

A notable difference from the traditional bond is the modeling of catastrophe risks (Figure 6). In addition to credit ratings, the risk modeling is prepared by a third-party risk modeler, such as AIR Worldwide (or Verisk), and the results including the expected loss are disclosed in the bond's offering documentation. Investors can ask questions to the modeler in the marketing process of the bond, and they often have their own modeling team to assess the risks. The modeler also calculates the actual loss after catastrophe events. The modeling often

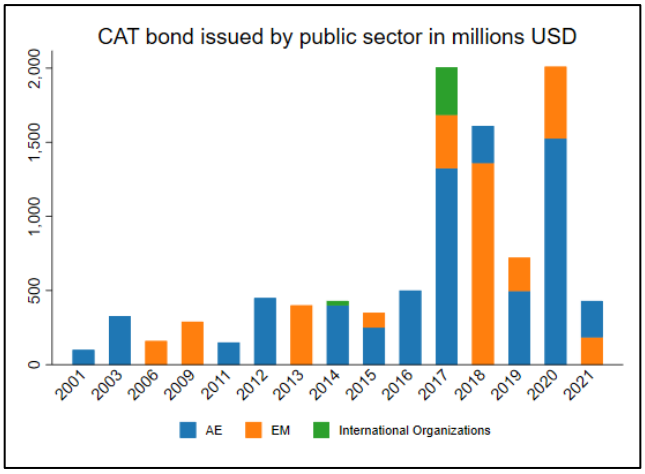
involves the assessment of extreme but nontail events since many catastrophe bonds are structured in the way that investors incur loss only if the loss from catastrophic events exceeds a certain threshold (attachment point), and the investors' loss is bounded by the principal (exhaustion point) (White 2020). The typical maturity is three to five years, so the long-term impact of climate change risks may not be fully reflected.[15]

Evolution of sovereign catastrophe bonds

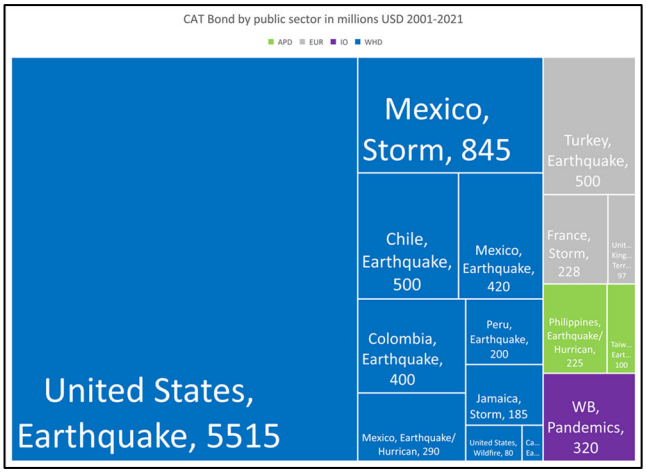
The catastrophe bond issuance by the public sector is increasing over time. Figure 7, panel 1, shows that the nominal amount of issuance is in an upward trend. This is also the case for the number of cedent countries. The largest player is the United States, accounting cumulatively for nearly $5.6 billion, followed by Mexico, Chile, Turkey, etc. Some of them, including the California Earthquake Authority, are local state agencies, but the central governments themselves can be the cedents, including the recent examples of Jamaica (2021), Mexico (2020), and the Philippines (2019). The list of the catastrophe bonds used in the analysis is provided in Annex 2.

Figure 7. CAT bond issued amount in millions of US dollars

1. Across years



2. Breakdown by purposes and countries



Source: Artemis.

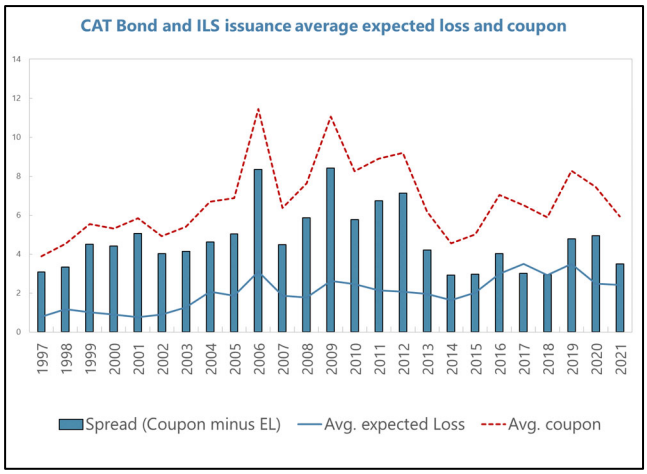
The perils covered by public sector catastrophe bonds have been mainly US earthquakes (Figure 7, panel 2). However, climate-related catastrophic events such as storms and hurricanes also constitute a significant share. Importantly, pandemics can be the perils: in 2017, the World Bank issued a five-year coverage, and then received payment for the COVID-19 pandemic.

Pricing of sovereign catastrophe bonds

Empirically, the cedents pay more than they receive in expectation. According to Artemis, from which only the aggregated data of private and public catastrophe bonds is available, the investors' average return to catastrophe bond in coupon is around 2 to 4 times the expected loss (Figure 8). Difiore, Drui, and Ware (2021) note that risk spreads have widened materially following major catastrophes in the past, such as 2006 following a US hurricane and 2012 following earthquakes in Japan and New Zealand.

[15] If innovation in climate models would allow for a longer forecast horizon, then maturities could potentially be longer.

Figure 8. CAT bond and ILS issuance average expected loss and coupon



Source: Artemis.

Whether the positive spread is expensive depends on the benchmark to compare. For example, self-insurance can save the coupon payment to investors, and thus can be an inexpensive alternative. The cash, however, needs to be stored in a dedicated fund and cannot be used for other illiquid purposes. Therefore, for countries with large opportunity costs, self-insurance can be more expensive than catastrophe bonds. A comparison can also be made with traditional reinsurance. Michael-Kerjan and others (2011) argue that the premiums that traditional reinsurance charges range from 3 to 5 times the expected loss, which is not very different from catastrophe bonds.[16]

Some literature argues that the catastrophe bond market is inefficient. In theory, the premium that cedents pay should be independent of the cedents' credit risks since the SPV stores and disburses cash. Chatoro, Pantelous, and Shao (2021) and Gotze and Gurtler (2020), however, argue that, in both the primary and secondary markets, the risk premium depends on the cedent's characteristics, such as the cedent's length of the time in the market, credit ratings, etc. Thus, new cedents can face challenges not only due to positive spread but also due to higher premiums than other experienced cedents.

Intermediation by the World Bank has mitigated the challenges that countries face in utilizing catastrophe bonds. Since 2016, all the sovereign catastrophe bonds in the data set compiled by Artemis have been intermediated by the World Bank. By providing the service of an SPV, the World Bank simplifies the procurement process as setting up an offshore SPV could be a legal barrier for countries. Anecdotally, the reputation and experience of the World Bank also contribute to narrowing the spread. Thus, catastrophe bond issuance through the World Bank offers an attractive venue for the countries that seek insurance against natural disasters. For example, a case study by the World Bank on its collaboration with Mexico can be found in World Bank (2020a).

[16] The problem may also not be specific to the ILS market. Cohen and others (2020) discuss that GDP-linked warrants, a variant of state-contingent debt based on the performance of GDP, are undervalued by investors.

Holder of sovereign catastrophe bonds

Although the holders' information is scarce, it is available for some catastrophe bonds intermediated by the World Bank. Table 2 summarizes the investor information from three recent issuances (World Bank 2019, 2020b, 2021). Most investors are in Europe, and the type of investors are concentrated on institutional investors with expertise such as ILS funds and insurance companies.

Table 2. Holders of Recent Sovereign Catastrophe Bonds

Cedent (issuance year)	By Geography	By Investor Type
Jamaica (2021)	Europe 60% North America 24% Bermuda 15% Asia 1%	ILS fund 66% Insurer/reinsurer 17% Asset management 14% Pension fund 3%
Mexico (2020)	Europe 52% North America 42% Bermuda 5% Asia 1%	ILS specialist fund 61% Asset management 16% Pension fund 15% Insurer/reinsurer 8%
Philippines (2019)	Europe 58% North America 25% Asia 13% Bermuda 4%	Asset management 50% ILS fund 29% Insurer/reinsurer 13% Pension fund 8%

Source: World Bank.
Note: ILS = insurance-linked securities.

Broadening the investor base to the public sector can help correct the market failure of climate change and improve crisis management. Since climate change has a heterogeneous impact on different regions on the earth, the cost of climate change in one region may not be internalized by other regions. Investing in catastrophe bonds can be an effective mechanism to internalize climate risks that are physically far away from the investors. In other words, by investing in catastrophe bonds, governments can show commitment by putting their "skin in the game" while earning a positive return on average. From a crisis management perspective, countries often pledge financial support after natural disasters in other regions, but aid pledges made while media attention is at its peak may not always be disbursed, could take a long time to arrive, or may replace previously pledged aid (Becerra, Cavallo, and Noy 2012). For example, the US Government Accountability Office (2011) reports that, 20 months after the 2010 Haiti earthquake, only 0.8 percent of the $412 million that the US government pledged for infrastructure construction activities was expensed. Catastrophe bonds offer an ex ante mechanism for countries to pledge financial support for natural disasters and timely disburse funds in catastrophic events.[17]

[17] Ex ante capacity building of the recipient countries is crucial to prevent corruption related to the disbursed funds.

Conclusions

Financial markets will play a catalytic role in financing the adaptation and mitigation to climate change. While catastrophe and green bonds in the private sector have become the most prominent innovations in the field of sustainable finance in the last 15 years, the issuances at the sovereign level have been relatively recent and not well documented in the literature. This note filled this gap by presenting an overview of the development of markets for these instruments, as well as discussing their benefits and the barriers for further development.

Sovereign green bonds can provide various benefits for issuers but also face several challenges. The demand for green instruments can potentially allow governments to issue bonds with a longer maturity (as green projects are long-term projects) and to borrow at lower costs. While the estimated greenium in this note is not large, it has been increasing over time alongside the level of sovereign green bond issuances. Whether the administrative costs associated with green bond issuance exceed the benefit is a country-specific question, but strengthening peer learning and climate information architecture could help reduce the costs and increase the benefits over time (Ferreira and others 2021). It remains an open question whether the purpose of the project associated with the green bond is a key determinant of the greenium, and whether green bonds have resulted in the climate outcomes they intended to achieve. The further development of the green bond market could be facilitated by improving transparency and creating clearer national guidelines and standards relating to eligibility and green definitions.

Sovereign catastrophe bonds are an effective tool to transfer risks to bond investors amid the increasing frequency of natural disasters due to climate change. However, this note has identified several obstacles to the more widespread use of catastrophe bonds. These challenges include their high transaction costs and limited investor base. Catastrophe bond issuance through the World Bank has mitigated some of these barriers and offers an attractive venue for the countries that seek insurance against natural disasters and could also help in broadening the investor base. Although fiscally constrained climate-vulnerable economies face the tradeoff between investing in resilience-enhancing adaptation and buying catastrophe bonds, one should note that the former could reduce the disaster risks, and thus the premium for the catastrophe bonds, and the latter could improve financial sustainability for the former. In this sense, green and catastrophe bonds can complement each other, and policymakers need to optimize their use.

Emerging and developing economies should work to foster larger sovereign issuances of these new instruments as they are the most susceptible to climate change. In the case of green bonds, a greater issuance (with appropriate institutions to prevent greenwashing) would facilitate the financing of climate-related projects and, hence, the transition to greener low-carbon economies. Moreover, increasing the size of the market could make the greenium more sizable, as observed in advanced economies. EMDEs usually face higher premiums and volatility in regular bond markets and thus stand to benefit greatly from green bond issuance by tapping the wider capital markets at reasonable rates. In turn, catastrophe bonds could be critical for EMDEs which face the highest climate risks but still feature low adaptive capacities. Strengthening countries' debt absorption capacity is an important necessary condition to leap the gains from these financial instruments given the large climate finance needs. Overall, the issuance of green bonds seems to be a potentially useful resource for EMDEs at high risk of climate change that need to undertake large green mitigation projects (which may be the reason behind the larger greenium for these countries), while catastrophe bonds seem more appropriate for countries which are already exposed to natural disasters or those in which climate change is expected to increase the likelihood and severity of these events (such as small islands). Finally, although these new instruments could contribute to deepening financial development, LICs and EMDEs with weak fundamentals tend to have limited access. For these countries, combining financial innovation with more traditional support from the international community in the form of grants and equity financing would be useful.

Annex 1. List of Green Bonds Used in the Analysis

From Eikon, there were 50 sovereign green bonds as of March 2022. One thing to note is that there might be two International Securities Identification Numbers for the same bond from Eikon since one International Securities Identification Number is under 144A and another is under Reg S in the United States, despite the same underlying security. There are seven cases in our sample (four for Hong Kong, one for Egypt, one for Serbia, and one for Sweden), which are excluded from Annex Table 1.1. Alternatively, one can filter them out by keeping only bonds that are not privately placed.

Annex Table 1.1. List of sovereign green bonds

	Issuer	Coupon	Maturity	Issue Date	International Securities Identification Number	Principal Currency	Amount Issued (USD million)
1	Belgium	1.25	4/22/2033	3/5/2018	BE0000346552	Euro	11,828
2	Chile	3.5	1/25/2050	6/25/2019	US168863DL94	US dollar	2,318
3	Chile	0.83	7/2/2031	7/2/2019	XS1843433639	Euro	2,231
4	Chile	2.55	1/27/2032	1/27/2020	US168863DN50	US dollar	1,500
5	Chile	1.25	1/29/2040	1/29/2020	XS2108987517	Euro	1,448
6	Colombia	7	3/26/2031	9/29/2021	COL17CT03797	Colombian peso	374
7	Denmark	0	11/15/2031	1/21/2022	DK0009924375	Danish krone	763
8	Egypt	5.25	10/6/2025	10/6/2020	US038461AS83	US dollar	750
9	Fiji	4	11/1/2022	11/1/2017	FJ0406990624	Fijian dollar	9
10	Fiji	6.3	11/1/2030	11/1/2017	FJ0406990632	Fijian dollar	38
11	France	1.75	6/25/2039	1/31/2017	FR0013234333	Euro	35,087
12	France	0.5	6/25/2044	3/23/2021	FR0014002JM6	Euro	12,930
13	Germany	0	8/15/2030	9/9/2020	DE0001030708	Euro	7,371
14	Germany	0	10/10/2025	11/6/2020	DE0001030716	Euro	5,707
15	Germany	0	8/15/2050	5/18/2021	DE0001030724	Euro	6,804
16	Germany	0	8/15/2031	9/10/2021	DE0001030732	Euro	7,371
17	Hong Kong	2.5	5/28/2024	5/28/2019	US43858AAB61	US dollar	1,000
18	Hong Kong	0.625	2/2/2026	2/2/2021	US43858AAC45	US dollar	1,000
19	Hong Kong	1.375	2/2/2031	2/2/2021	US43858AAD28	US dollar	1,000
20	Hong Kong	2.375	2/2/2051	2/2/2021	US43858AAE01	US dollar	500
21	Hong Kong	0	11/24/2026	11/24/2021	HK0000789849	Euro	1,427
22	Hong Kong	1	11/24/2041	11/24/2021	HK0000789856	Euro	571
23	Hong Kong	1.75	11/24/2031	11/24/2021	HK0000789823	US dollar	1,000
24	Hong Kong	2.8	11/30/2024	11/30/2021	HK0000789864	Chinese yuan	394
25	Hong Kong	3	11/30/2026	11/30/2021	HK0000789872	Chinese yuan	394
26	Hungary	1.75	6/5/2035	6/5/2020	XS2181689659	Euro	1,701
27	Hungary	1.03	9/17/2027	9/18/2020	JP534800CL92	Japanese yen	136
28	Hungary	1.29	9/18/2030	9/18/2020	JP534800DL91	Japanese yen	39
29	Hungary	4	4/28/2051	4/28/2021	HU0000404991	Hungarian forint	301
30	Hungary	3.28	12/16/2024	12/14/2021	CND10004QFJ7	Chinese yuan	157
31	Hungary	4.5	5/27/2032	1/26/2022	HU0000405535	Hungarian forint	66
32	Ireland	1.35	3/18/2031	10/17/2018	IE00BFZRQ242	Euro	7,816

33	Italy	1.5	4/30/2045	3/10/2021	IT0005438004	Euro	15,309
34	Korea	2.5	6/19/2029	6/19/2019	US50064FAQ72	US dollar	1,000
35	Korea	0	10/15/2026	10/15/2021	XS2376820259	Euro	799
36	Latvia		1/23/2030	12/13/2021		Euro	566
37	Lithuania	1.2	5/3/2028	5/3/2018	LT0000610305	Euro	78
38	Netherlands	0.5	1/15/2040	5/23/2019	NL0013552060	Euro	12,143
39	Nigeria	13.48	12/22/2022	12/22/2017	NGFGB2022S13	Nigerian naira	26
40	Nigeria	14.5	6/13/2026	6/13/2019	NGFGB2026S27	Nigerian naira	36
41	Poland	0.5	12/20/2021	12/20/2016	XS1536786939	Euro	851
42	Poland	1.125	8/7/2026	2/7/2018	XS1766612672	Euro	1,134
43	Poland	1	3/7/2029	3/7/2019	XS1958534528	Euro	1,701
44	Poland	2	3/8/2049	3/7/2019	XS1960361720	Euro	571
45	Serbia	1	9/23/2028	9/23/2021	XS2388558889	Euro	1,134
46	Seychelles	6.5	10/11/2028	10/11/2018	XS1885544236	US dollar	15
47	Spain	1	7/30/2042	9/14/2021	ES0000012J07	Euro	5,670
48	Sweden	0.125	9/9/2030	9/9/2020	XS2226974413	Swedish krona	2,218
49	United Kingdom	0.875	7/31/2033	9/22/2021	GB00BM8Z2S21	British pound	13,673
50	United Kingdom	1.5	7/31/2053	10/22/2021	GB00BM8Z2V59	British pound	8,204

Annex 2. List of Public Sector Catastrophe Bonds

Annex Table 2.1 summarizes the catastrophe bonds whose cedents belong to the public sector. We thank Artemis.bm for its generosity to allow us to use the data. The identification of public sector is based on reading the description one by one.

Annex Table 2.1. List of public sector catastrophe bonds

	Issuer	Cedent	Risks/Perils Covered	Size	Date	Cedent Country	Central Government
1	Western Capital Ltd.	California Earthquake Authority	California earthquake risks	$100m	Feb-01	United States	0
2	Formosa Re Ltd.	Taiwan Residential Earthquake Insurance Pool	Taiwan earthquake	$100m	Aug-03	Taiwan	0
3	Pylon Ltd.	Electricité de France (EDF)	European windstorm	$228m	Dec-03	France	0
4	CAT-Mex Ltd.	FONDEN	Mexico earthquake	$160m	May-06	Mexico	1
5	MultiCat Mexico 2009 Ltd.	FONDEN (Fund for Natural Disasters)	Mexico hurricane, Mexico earthquake	$290m	Oct-09	Mexico	1
6	Embarcadero Re Ltd. (Series 2011-1)	California Earthquake Authority	California earthquake	$150m	Aug-11	United States	0
7	Embarcadero Re Ltd. (Series 2012-1)	California Earthquake Authority	California earthquake	$150m	Jan-12	United States	0
8	Embarcadero Re Ltd. (Series 2012-2)	California Earthquake Authority	California earthquake	$300m	Jul-12	United States	0
9	Bosphorus 1 Re Ltd.	Turkish Catastrophe Insurance Pool	Turkey earthquake	$400m	Apr-13	Turkey	0
10	World Bank – CCRIF 2014-1	Caribbean Catastrophe Risk Insurance Facility (CCRIF)	Caribbean hurricane and earthquake	$30m	Jun-14	Caribbean	0
11	Ursa Re Ltd. (Series 2014-1)	California Earthquake Authority	California earthquake	$400m	Dec-14	United States	0
12	Bosphorus Ltd. (Series 2015-1)	Turkish Catastrophe Insurance Pool	Turkey earthquake	$100m	Aug-15	Turkey	0
13	Ursa Re Ltd. (Series 2015-1)	California Earthquake Authority	California earthquake	$250m	Sep-15	United States	0
14	Ursa Re Ltd. (Series 2016-1)	California Earthquake Authority	California earthquake	$500m	Nov-16	United States	0
15	Ursa Re Ltd. (Series 2017-1)	California Earthquake Authority	California earthquake	$925m	May-17	United States	0

16	IBRD CAR 111-112 – World Bank pandemic catastrophe bond	Pandemic Emergency Financing Facility (PEF)	Pandemics	$320m	Jul-17	WB	0
17	IBRD / FONDEN 2017	FONDEN / AGROASEMEX S.A	Mexico earthquakes, Mexico named storms	$360m	Aug-17	Mexico	1
18	Ursa Re Ltd. (Series 2017-2)	California Earthquake Authority	California earthquake	$400m	Nov-17	United States	0
19	IBRD CAR 117	Republic of Colombia	Colombia earthquake	$400m	Feb-18	Colombia	1
20	IBRD CAR 120	Republic of Peru	Peru earthquake	$200m	Feb-18	Peru	1
21	IBRD CAR 118-119	FONDEN / AGROASEMEX S.A.	Mexico earthquake	$260m	Feb-18	Mexico	1
22	IBRD CAR 116	Republic of Chile	Chile earthquake	$500m	Feb-18	Chile	1
23	Ursa Re Ltd. (Series 2018-1)	California Earthquake Authority	California earthquake	$250m	Sep-18	United States	0
24	Baltic PCC Limited (Series 2019)	Pool Re	Terrorism risk	$97m	Feb-19	United Kingdom	0
25	IBRD CAR 123-124	Republic of the Philippines	Philippine earthquakes and tropical cyclones	$225m	Nov-19	Philippines	1
26	Ursa Re Ltd. (Series 2019-1)	California Earthquake Authority	California earthquake	$400m	Nov-19	United States	0
27	IBRD / FONDEN 2020	FONDEN / AGROASEMEX S.A.	Mexico earthquakes, Mexico named storms	$485m	Mar-20	Mexico	1
28	Sutter Re Ltd. (Series 2020-1 & 2020-2)	California Earthquake Authority	California earthquake	$700m	May-20	United States	0
29	Ursa Re II Ltd. (Series 2020-1)	California Earthquake Authority	California earthquake	$775m	Oct-20	United States	0
30	Power Protective Re Ltd. (Series 2020-1)	Los Angeles Department of Water & Power	California wildfire	$50m	Dec-20	United States	0
31	Ursa Re II Ltd. (Series 2021-1)	California Earthquake Authority	California earthquake	$215m	Mar-21	United States	0
32	IBRD CAR 130	Government of Jamaica	Jamaica named storms	$185m	Jul-21	Jamaica	1
33	Power Protective Re Ltd. (Series 2021-1)	Los Angeles Department of Water & Power	California wildfire	$30m	Oct-21	United States	0

Annex 3. Summary Statistics and Greenium Estimation

Annex Table 3.1. Summary statistics for main variables

YTM		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	Mean	6.88	6.76	7.51	6.97	6.85	7.56	8.78	1.27	1.67	1.68	1.03	0.59	0.50	0.68
	SD	0.12	4.44	5.18	5.02	5.07	5.42	4.95	0.83	1.07	1.06	0.99	0.81	1.00	1.01
Green	Mean			4.91	3.82	2.09	2.48	2.83			1.20	0.90	0.37	0.62	1.08
	SD			5.88	4.78	2.16	2.59	2.31			0.06	0.81	0.69	0.92	1.02

Zspread in bps		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean	471.4	335.3	328.1	367.2	437.4	298	305.4	22.93	55.55	52.03	53.08	53.06	26.2	20.99
	sd	10.49	175.7	192	208.9	315.3	258	313.9	38.15	75.28	84.86	71.94	65.58	71.17	53.16
Green	mean			66.09	114.3	151.9	152.9	147.6			9.1	22.32	22.51	6.16	-3.78
	sd			104.2	124.5	144.1	191.8	176.2			19.27	31.64	38.13	47.39	68.27

Bid-ask spread		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean	0.14	0.12	0.15	0.12	0.17	0.2	0.24	0.04	0.06	0.07	0.07	0.07	0.06	0.07
	sd	0.02	0.08	0.09	0.06	0.1	0.12	0.13	0.01	0.04	0.04	0.04	0.04	0.04	0.05
Green	mean			0.04	0.05	0.07	0.09	0.1			0.06	0.04	0.04	0.04	0.05
	sd			0.02	0.02	0.05	0.1	0.11			0.04	0.04	0.04	0.03	0.05

Tenor		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean	10	12.83	11.7	11.37	10.59	9.32	8	8.25	16.38	15.3	15.23	14.78	14.93	13.51
	sd	2.01	8.28	7.69	7.9	8.13	8.57	8.38	2.22	12.04	12.2	12.8	14.54	16.61	16.98
Green	mean			8.12	14.06	14.94	14.35	14.15			12.79	12.28	11.77	13.81	13.02
	sd			1.8	9.34	8.59	8.73	8.77			2.32	4.49	4.81	7.94	8.07

Amount USD Billions	Panel A: EMs							Panel B: AEs						
	2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	5.28	53.49	82.14	86.54	138.3	230.3	19.85	47.99	798.4	706.2	881	1205	1584	238
Green		0.03	1.16	6.84	5.59	1.45	0.07			19.85	14.26	15.35	58.81	
Total	5.28	53.52	83.3	93.38	143.9	231.8	19.92	47.99	798.4	726.1	895.3	1220	1642	238

Source: Eikon and IMF staff calculations.

Note: AEs = advanced economies; EMs = emerging markets.

Annex Table 3.2. Euro-denominated Bonds

YTM in %		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	Mean		2.65	2.99	2.71	2.42	1.86	2.26	0.76	1.6	1.55	0.86	0.41	0.21	0.38
	SD		1.01	1.81	1.92	2.27	1.77	2.16	0.7	1.14	1.09	1.02	0.79	0.91	0.85
Green	Mean			1	0.62	0.74	0.73	1.2			1.2	0.49	-0.03	0.14	0.5
	SD			0.08	0.58	0.62	0.6	0.65			0.06	0.4	0.29	0.62	0.66

Zspread in bps		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean		213.3	236.7	271.4	270.8	201.3	214.2	21.84	62.72	61.02	63.48	60.78	31.46	26.64
	sd		103.6	171.4	184.9	225.5	171.3	219.7	49.03	76.09	89.48	76.49	68.27	71.63	57.97
Green	mean			25.62	39.64	82.8	63.91	78.61			9.1	12.83	6.72	1.66	5.74
	sd			6.58	25.92	50.74	42.85	56.4			19.27	29.9	27.1	46.5	55.5

Bid-ask spread		Panel A: EMs							Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean		0.22	0.18	0.14	0.15	0.13	0.14	0.04	0.06	0.07	0.07	0.07	0.06	0.07
	sd		0.11	0.11	0.07	0.06	0.07	0.09	0.01	0.04	0.04	0.04	0.04	0.04	0.05
Green	mean			0.03	0.04	0.05	0.05	0.07			0.06	0.04	0.04	0.02	0.04
	sd			0	0.01	0.02	0.02	0.06			0.04	0.04	0.04	0.03	0.05

Tenor		Panel A: EMs						Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean		8.27	8.67	8.83	8.92	10.04	9.8	8.67	17.5	16.13	15.94	15.75	16.11	15.11
	sd		3.28	3.11	3.1	3.94	5.85	5.87	1.9	12.44	12.33	12.64	15.02	17.38	18.02
Green	mean			9	15.25	16	15.59	14.71			12.79	13.87	13.86	15.37	15.04
	sd			0	8.85	7.53	7.31	7.42			2.32	3.77	4.43	7.29	7.66

Amount USD Billions	Panel A: EMs							Panel B: AEs						
	2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown		2.83	7	8.47	12.65	12.45	0.23	37.09	701.9	601.9	757.2	1007	1337	176.1
Green			1.14	4.53	3.17	1.14	0.07			19.85	12.26	13.16	54.52	
Total		2.83	8.14	13	15.82	13.59	0.3	37.09	701.9	621.8	769.5	1020	1391	176.1

Source: Eikon and IMF staff calculations.

Note: AEs = advanced economies; EMs = emerging markets.

Annex Table 3.3. USD-denominated Bonds

YTM in %		Panel A: EMs						Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	Mean	6.88	6.64	7.18	6.81	7.04	5.91	7.05		2.97	3.23	2.44	1.35	1.27	1.71
	SD	0.12	0.98	1.27	1.36	2.26	2.13	2.63		0.08	0.42	0.66	1.09	1.03	1.04
Green	Mean			6.19	4.67	3.62	4.58	5.16				2.18	1.32	1.53	2.04
	SD			0.14	1.1	1.59	2.3	2.1				0.23	0.37	0.69	0.54

Zspread in bps		Panel A: EMs						Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean	471.4	446.6	436.6	485.3	639.2	483.1	543.6		72.57	30.93	49.52	75.13	41.76	41.03
	sd	10.49	98.57	122.8	130.8	236.7	192.2	247.6		9.35	32.08	50.87	88.46	53.06	54
Green	mean			332.6	272.8	279.9	336.3	347.3				51.56	65.97	31.54	31.53
	sd			2.18	100.1	177.2	256.1	225.7				14.1	16.55	27.78	36.18

Bid-ask spread		Panel A: EMs						Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean	0.14	0.09	0.11	0.1	0.14	0.12	0.14		0.03	0.05	0.06	0.08	0.07	0.07
	sd	0.02	0.04	0.05	0.04	0.08	0.05	0.08		0.02	0.02	0.03	0.04	0.03	0.04
Green	mean			0.08	0.07	0.1	0.16	0.17				0.03	0.04	0.05	0.05
	sd			0	0.02	0.07	0.14	0.15				0.01	0.01	0.01	0.04

Tenor		Panel A: EMs						Panel B: AEs						
		2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	mean	10	15.34	15.7	15.37	15.58	16.05	16.53	10	8.7	9.67	9.26	10.68	12.64	
	sd	2.01	8.58	9	9.37	10.22	11.16	11.51	0	6.58	8.89	8.74	11.93	14.19	
Green	mean			10	16.95	16.86	14.52	14.38				7.35	7.5	11.96	11.68
	sd			0	9.89	9.85	9.87	9.87				2.5	2.5	9.11	8.55

Amount USD Billions	Panel A: EMs							Panel B: AEs						
	2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
Brown	5.28	19.84	25.88	12	14.16	40.98	4	37.09	1	7	11.5	15.63	5.2	176.1
Green			0.01	2.32	2.25						2		3.5	
Total		19.84	25.89	14.32	16.41	40.98	4	37.09	1	7	13.5	15.63	8.7	176.1

Source: Eikon and IMF staff calculations.

Note: AEs = advanced economies; EMs = emerging markets.

Baseline methodology. The following panel regression specification is estimated:

$$Y_{ijt} = \alpha_j + \beta \times green\ bond_{ij} + \gamma_1 \times tenor_{ijt} + \gamma_2 \times bid\ ask\ spread_{ijt} + e_{ijt}$$

where the dependent variable is either YTM or z-spread of bond i in country j at time t, beta is the coefficient on the green bond dummy variable. The control variables are remaining maturity and bid-ask spread to control for liquidity. We are interested in the estimate of beta coefficient—the greenium estimate—as it estimates the average difference in the yield of green versus conventional bonds, after controlling for maturity and liquidity. The country fixed effect controls time-invariant credit risks.

Annex Table 3.4. Baseline result by currency.

	(1) Euro Z-spread	(2) Euro YTM	(3) USD Z-spread	(4) USD YTM
Green Bond	-3.69***	-3.40***	-30.24***	-63.56***
	(0.62)	(0.82)	(2.73)	(2.54)
Tenor (Days)	0.01***	0.02***	0.02***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)
Bid-Ask Spread (Bps)	1.60***	2.40***	3.97***	1.95***
	(0.02)	(0.03)	(0.05)	(0.05)
Country FE	Y	Y	Y	Y
R^2	0.79	0.71	0.78	0.82
Bond-Day	323,127	328,746	65,521	66,043
Bonds	474	486	116	117
Green Bonds	21	22	15	15
Countries	16	16	11	11

Source: Eikon and IMF staff calculations.
Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Annex Table 3.5. Baseline result by currency and AEs/EMs.

Dependent variable: Z-spread	(1) Euro AEs	(2) Euro EMs	(3) USD AEs	(4) USD EMs
Green Bond	-5.61***	-12.45***	6.16***	-49.28***
	(0.72)	(1.37)	(1.34)	(3.52)
Tenor (Days)	0.01***	0.02***	0.01***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)
Bid-Ask Spread (Bps)	1.63***	1.96***	1.44***	4.28***
	(0.02)	(0.06)	(0.07)	(0.06)
Country FE	Y	Y	Y	Y
R^2	0.59	0.90	0.74	0.58
Bond-Day	290,246	32,881	13,405	52,116
Bonds	421	53	27	89
Green Bonds	14	7	10	5
Countries	11	5	5	6

Source: Eikon and IMF staff calculations.
Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. AEs = advanced economies; EMs = emerging markets.

Annex Table 3.6. Baseline result of Euro-denominated bonds over years.

Dependent variable: Z-spread	Euro 2018	2019	2020	2021
Green Bond	2.02	-6.40***	-4.23***	-6.77***
	(1.62)	(0.94)	(0.92)	(1.02)
Tenor (Days)	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)

Bid-Ask Spread (Bps)	1.76*** (0.04)	0.88*** (0.03)	1.72*** (0.03)	1.03*** (0.04)
Country FE	Y	Y	Y	Y
R^2	0.89	0.92	0.89	0.68
Bond-Day	48,372	70,407	90,928	113,420
Bonds	229	315	383	474
Green Bonds	4	8	12	21
Countries	14	14	15	16

Source: Eikon and IMF staff calculations.
Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Annex Table 3.7. Baseline result of US-denominated bonds over years

Dependent variable: Z-spread	USD 2018	2019	2020	2021
Green Bond	0.00 (.)	-12.04*** (3.52)	-34.92*** (6.07)	-41.24*** (2.36)
Tenor (Days)	0.02*** (0.00)	0.02*** (0.00)	0.02*** (0.00)	0.02*** (0.00)
Bid-Ask Spread (Bps)	0.83*** (0.20)	-5.74*** (0.12)	4.10*** (0.09)	-4.92*** (0.11)
Country FE	Y	Y	Y	Y
R^2	0.84	0.94	0.77	0.91
Bond-Day	7,567	13,786	18,491	25,677
Bonds	43	65	80	116
Green Bonds	1	5	8	15
Countries	6	8	10	11

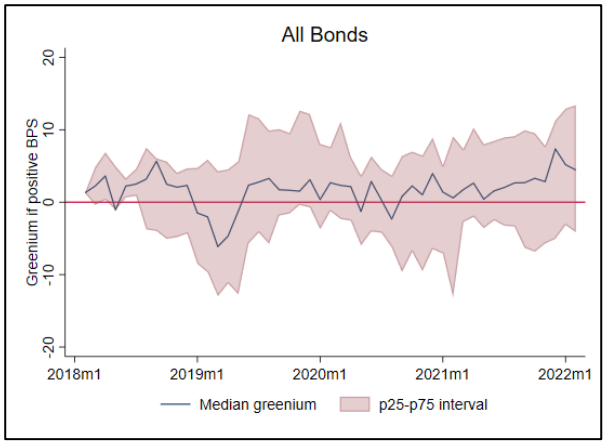
Source: Eikon and IMF staff calculations.
Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Synthetic estimation method. First, a regression of *z*-spread on tenor, bid-ask spread, amount issue, currency, country of issue, and weekly fixed effects using conventional bonds is run for each country. Afterward, the *z*-spread of the counterfactual conventional bond is predicted using the relevant information from the green bond and the coefficients obtained from the regressions.

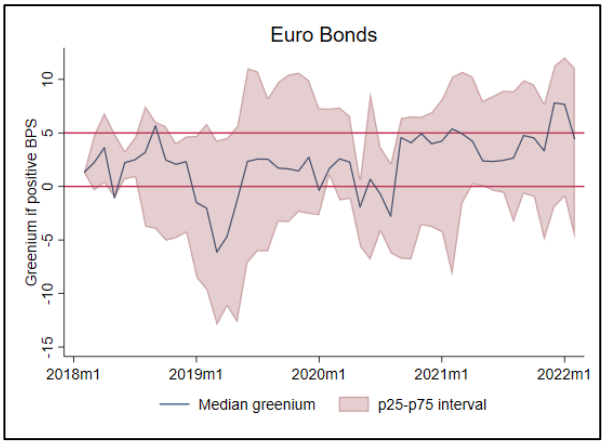
Greenium estimate using synthetic bond approach (Annex Figure 3.1). To find the counterfactual conventional bond that shares the same features as the green, this approach needs a country to issue at least one green bond and one conventional bond in the same currency. This restriction shrinks the sample size from 50 to 29 green bonds. Euro-denominated bonds show a median greenium of 0 to 5 basis points across time. The greenium on USD-denominated bonds are larger, although more volatile. The results from this method are in line with the baseline results. Over the entire time period, around two-thirds of synthetic estimations shows positive greenium.

Annex Figure 3.1. Greenium Estimate Based on the Synthetic Method

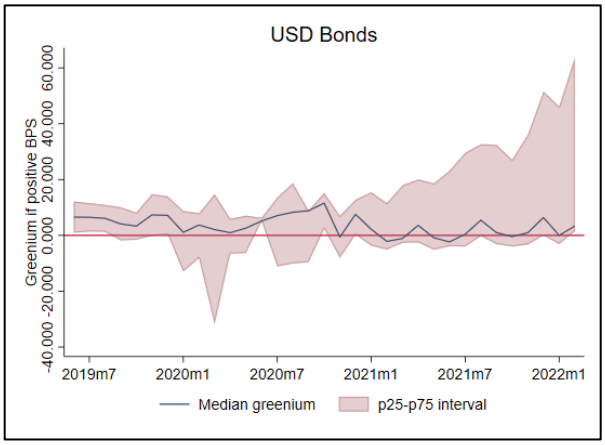
1. All 29 sovereign green bonds



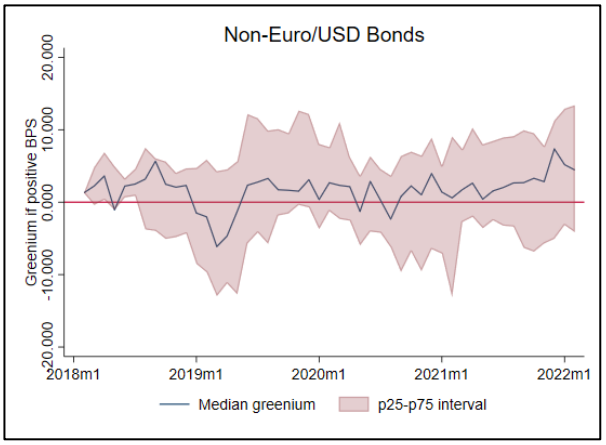
2. Using 19 sovereign green bonds denominated in euros



3. Using four sovereign green bonds denominated in US dollars



4. Using six sovereign green bonds denominated in other currencies



Sources: Eikon; and IMF staff calculations.

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