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ESG and Sovereign Risk

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Abstract

In this paper, we examine the materiality of ESG on country creditworthiness from a credit risk analysis viewpoint. To address this, we consider a granular set of 269 indicators within the three ESG pillars to determine what the sovereign bond market is pricing in. From this set of ESG metrics covering the 2015-2020 period and 67 countries, we first determine the ESG indicators that are most relevant when it comes to explaining the sovereign bond yield, after controlling the effects of traditional variables such as economic strength and credit rating. We also emphasize the major themes that are directly useful for investors when assessing the country risk premium. At the global level, we notice that these themes mainly belong to the E and G pillars. Those results confirm that extra-financial criteria are integrated into bond pricing. However, we also identify a clear difference between high- and middle-income countries. Indeed, whereas the S pillar is lagging for the highest income countries, it is nearly as important as the G pillar for the middle-income ones. Second, we determine which ESG metrics are indirectly valuable for assessing a country's solvency. More precisely, we attempt to infer credit rating solely from extra-financial criteria, that is the ESG indicators that are priced in by credit rating agencies. We find that there is no overlap between the set of indicators that predict credit ratings and those that directly explain sovereign bond yields. The results also highlight the importance of the G and S pillars when predicting credit ratings. The E pillar is lagging, suggesting that credit rating agencies are undermining the impact of climate change and environmental topics on country creditworthiness. This is consistent with the traditional view that social and governance issues are the main drivers of the sovereign risk, because they are more specific and less global than environmental issues. Finally, taking these different results together, this research shows that opposing extra-financial and fundamental analysis does not make a lot of sense. On the contrary, it advocates for greater integration of ESG analysis and credit analysis when assessing sovereign risk.

Keywords: ESG, Sovereign risk, debt, bond yield, credit spread.

JEL classification: H63, Q5.

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1 Introduction

While ESG investing was still a niche market for some mindful investors a decade ago, it is now at the forefront of the financial industry, and all stakeholders have played a key role in the development of this paradigm. Consumer awareness has generally risen, and greater attention is being paid to the carbon footprint of human habits and behavior, but also to the social impact on various communities. International organizations have also pushed for legislation on ESG matters, for example the launch of the Sustainable Development Goals or the Paris Agreement on climate risk. Policymakers and regulators have joined the effort by developing new rules, such as the EU taxonomy for sustainable activities or the sustainable finance disclosure regulation. Asset managers, asset owners and investors have massively invested in ESG strategies, funds and securities. We could continue this list indefinitely.

However, the development of ESG investing would not have been possible without the emergence of extra-financial analysis. Whereas fundamental analysis is based on financial ratios, extra-financial analysis is dedicated to environmental, social and governance issues. Therefore, alternative data has been developed to analyze issuers from this new viewpoint. In this context, ESG rating agencies provide extra-financial information that might seem completely different from the financial information given by credit rating agencies. Nevertheless, the opposition between extra-financial and funadmental analysis, alternative and financial data or ESG and credit ratings is more complicated than it sounds:

> "*Since we observe a feedback loop between extra-financial risks and asset pricing, we may also wonder whether the term "extra" is relevant, because ultimately, we can anticipate that these risks may no longer be extra-financial, but simply financial*" (Bennani *et al.*, 2018).

Similarly, Ben Slimane *et al.* (2019) found that there is a positive correlation between ESG and credit ratings. This is normal since credit rating agencies also incorporate extra-financial risks into their default risk models.

Rather than opposing ESG analysis and credit analysis, we think that they are complementary. This is truer in the case of sovereign risk, and we can imagine that the two approaches will converge in the near future because the creditworthiness of a country is highly dependent on its economic growth, political environment, willingness to pay its debt, social stability, etc. We can easily relate these factors to ESG metrics. Indeed, there is a breadth of economic literature that studies the interconnectedness between sovereign credit risk, economic development, environmental resources, social welfare and governance (Persson and Tabellini, 1994; Mauro, 1995; Alesina *et al.*, 1996; Graf Lambsdorff, 2006). For example, country risk and sovereign credit risk are connected, and they are highly dependent on political risk, which can be measured by governance (and social) metrics. In the academic literature, many research articles have been written to compare the economic growth between two regions. Known under the name "*A Tale of Two Countries*", they generally highlight how big institutions, governance, and political uncertainties have an impact on economic development and financial situation (Lucas, 1993; Henry and Miller, 2009). Similarly, we can relate country risk to some social issues such as education (Abramovitz, 1993; Krueger and Lindahl, 2001), social infrastructure (Hall and Jones, 1999; Lora and Olivera, 2007), democratic institutions (Perotti, 1996), social inequality (Benabou, 1996; Galor and Moav, 2004), etc. Finally, the environmental pillar also plays an important role because of climate conditions (Masters and McMillan, 1966; Dell *et al.*, 2014; Burke *et al.*, 2015), natural resources (Sachs and Warner, 2001), water stress (Pimentel *et al.*, 1997) or climate change (Tol, 2009). Not only do these extra-financial risks have an effect on a country's economy, they also impact the financial markets and the asset pricing of securities. This result is particularly well-documented when it involves the political risk (Diamonte *et al.*, 1996; Erb *et al.*, 1996; Bernhard and Leblang, 2002; Pàstor and Veronesi, 2012; Bekaert *et al.*, 2016; Lehkonen and Heimonen, 2015; Pagliardi *et al.*, 2019).

As noted by Ben Slimane *et al.* (2019), the credit rating industry is beginning to integrate the ESG landscape in two directions. First, it has understood that ESG ratings have become competitors of credit ratings. Indeed, even though they pursue two different goals, ESG and credit ratings are correlated, meaning that there is some overlap between them. Second, the primary role of ESG rating agencies is to provide and produce data information, which is useful when assessing the comprehensive risk of corporates and countries. Nowadays, there is a race among investors (asset owners and managers) to obtain granular data rather than just a synthetic figure. The rise of machine learning and alternative data in finance is contributing to and amplifying this situation. The framework of our research encompasses these different aspects. Indeed, instead of studying the relationship between ESG ratings and sovereign risk in financial markets, we prefer to focus on raw ESG data, which are interesting to monitor from a credit analysis viewpoint. We know that there is some divergence between ESG ratings at the corporate level (Berg *et al.*, 2020), because the construction of ESG ratings is dependent on the list of selected indicators and the weighting system used by the provider. There is no reason to believe that divergence of ESG ratings would not be confirmed for sovereign issuers. Therefore, testing the impact of sovereign ESG ratings on sovereign risk is equivalent to testing the selection and the weighting of the rating provider. For a credit analyst or an investor, it is more interesting to know which ESG metrics are important to complement a traditional risk assessment based on credit ratings, economic indicators and financial ratios.

In what follows, the sovereign risk is measured by the bond yield spread. We consider the traditional approach that consists in explaining a country's bond yield spread by macroeconomic variables such as economic growth or inflation and creditworthiness indicators such as debt ratio or probability of default measured by credit rating. The goal is to build an alternative model by adding the most relevant ESG metrics to the traditional model. Therefore, we would like to identify those ESG indicators and measure their marginal effects to determine which ESG themes are **directly** priced in by the bond market. For instance, in the case of the environmental pillar, we would like to know whether transition or physical risks are important drivers of the bond yield spread. Nevertheless, to be as effective as possible, we also investigate the ESG themes that are **indirectly** priced in by the bond market through the control variables. We restrict our analysis to the credit rating, which is the key variable in credit risk analysis. For instance, in the case of the social pillar, we wonder whether education, health or inequality are important drivers of the credit rating. By considering both direct and indirect channels, we expect to identify the most relevant ESG indicators and themes for sovereign credit risk analysis.

The rest of the paper is organized as follows. Section 2 discusses the interconnectedness between ESG risk and sovereign debt risk. We distinguish financial and extra-financial analyses and detail the three pillars of ESG risk when we consider sovereign issuers. Section 3 presents a single-factor analysis, where we test the explanatory power of 269 ESG metrics on sovereign bond yields after controlling for the effect of macroeconomic variables and the credit rating. Then, the significant ESG indicators are used in Section 4 to perform a multi-factor analysis. The multi-dimensional selection procedure for the most relevant variables is done at the pillar and global levels, and by distinguishing high- and middle-income countries. Whereas the previous two sections consist in identifying the ESG metrics that are directly priced in by the bond market, Section 5 investigates the ESG metrics that may explain good and bad credit ratings, that is the ESG indicators that are indirectly priced in by the bond market via the credit rating channel. Finally, Section 6 concludes the paper.

2 Interconnectedness between ESG risk and sovereign debt risk

In this section, we study the relationship between ESG risk and country risk. In fact, environmental, social and governance pillars generally translate the level of a country's economic development. Beyond the information conveyed by a credit rating, some of these metrics may be priced in by the market and may be useful for investors to elaborate a more comprehensive country risk model.

2.1 From financial risk to extra-financial risk

The consensus for assessing the country risk is to use sovereign credit ratings (Cantor and Packer, 1996; Duffie and Singleton, 2003), which quantify the risk of non-payment by a country or its probability of default. By definition, sovereign credit ratings measure mainly the financial risk, even if they incorporate political risk (Reinhart, 2002; Bekaert *et al.*, 2014). Since the early 2000's, they gained prominence on asset allocation and debt issuance. This is particularly obvious with the importance of being rated AAA for developed countries and investment grade for emerging countries. Certainly, they actively participated in the European sovereign debt crisis (Gärtner *et al.*, 2011; Afonso *et al.*, 2012) and the management of the Greek crisis (De Santis, 2012).

Since a credit rating measures a probability of default, it is obvious that it is mainly driven by financial risks rather than extra-financial risks. This is particularly obvious for corporate firms. However, Ben Slimane *et al.* (2019) showed that credit and ESG ratings are correlated. In the case of countries, the relationships between financial and extra-financial risks are even more important. For instance, Mellios and Paget-Blanc (2006) demonstrated that sovereign credit ratings are explained by some traditional economic variables such as production, exchange rate, inflation and default history, but also by some governance variables such as the corruption perception index. Political risk is also another dimension that is priced into credit ratings (Bekaert *et al.*, 2014). The distinction between financial and extra-financial risks is then artificial when we consider sovereign credit risk. Indeed, economic performance, environmental situation, social risk and governance are highly interconnected at the country level. For instance, climate quality and environmental resources impact the economic growth through the agricultural production, natural resources such as water and energy resources, or natural hazards. "*Environmental dotations*" differ from one country to another and may explain the differences in economic performance. An extreme case concerns regions of the world that are hostile to life, and where there is no economic production. Social choices may also be critical for explaining the economic welfare. For example, education is a key variable for defining human capital in economic models (Barro, 1991; Benhabib and Spiegel, 1994). In endogenous growth theory, economic development is generated by technological progress, while technological progress is a function of the level of education or "*investment in humans*" (Nelson and Phelps, 1966; Romer, 1989). Governance is also related to economic development and the estimation of the probability of default. It also involves, of course, political risk (Henry and Miller, 2009), but other factors can play a role, for example national security or international relationships.

Since extra-financial risks can translate into financial risks or explain economic growth, ESG ratings are correlated with credit ratings. Nevertheless, an ESG rating or a credit rating cannot summarize all the environmental, social and governance information. In what follows, we consider which ESG metric has an impact on the cost of sovereign debt that is not already explained by the credit rating. Because there are many ESG metrics, it may be interesting to know which indicator is priced in by the market. In some sense, ESG can be viewed as an alternative risk assessment model of countries from an extra-financial viewpoint, whereas the selected ESG indicators can form a complementary alternative risk assessment model from a financial viewpoint.

2.2 The three pillars of ESG risk

2.2.1 Environmental pillar

Natural capital is key to the world economy. A country endowment in water, lands, forests or biodiversity is determinant not only for its industry and citizens, but also for its resistance to pollution and climate change. However, country's ability to benefit from these resources is tightly linked to its governance. To have a material and positive impact on a country's development, natural capital (oil, minerals, water, forests, etc.) must be efficiently managed to avoid the "*natural resource curse*". Indeed, natural capital's features but also its level of development will impact sovereign creditworthiness differently. For instance, Wang (2021) finds that countries with non-renewable assets (such as fossil fuels, oil, coal, natural and shale gas, etc.) typically face higher yields (potentially because of the natural resource curse) while the growth of renewable ones (such as forests or agricultural lands) generally reduces sovereign borrowing costs.

As a matter of fact, expanding such natural assets (reforestation, reintroducing species) or at least safeguarding them is crucial for the environment and in-fine for the country creditworthiness. Indeed, biodiversity is vital for human basic needs and their health. Ecosystem disruptions and biodiversity loss can deteriorate water and soil quality, lead to species extinction, reduce natural carbon absorption, etc. Eventually, such damages can jeopardize crops – therefore causing food shortage – and accelerate global warming. Additionally, the erosion of biodiversity notably caused by increased human's land use implies a greater proximity with wildlife, accelerating infectious diseases transmission and increasing pandemic likelihood. All these elements make land and ocean areas protection as well as air quality improvements crucial for governments to safeguard biodiversity. Similarly, sensible waste management and recycling are efficient solutions to reduce greenhouse effect and curb pollution. However, the link between high absolute level of pollution and economic progress is still questioning. For instance, He (2006) found that following a 1% rise in foreign direct investment (FDI) capital stock to China, industrial SO_2 emissions will rise by 0.099%. The study of Selden and Song (1994) suggests that per capita emissions of several important air pollutants exhibit inverted-U relationships with per capita GDP. This result is related to the Environmental Kuznet Curve (EKC) forming an inverted U-shaped relationship between environmental degradation and economic growth. Orubu and Omotor (2011) tried to test the presence of an EKC for air and water quality in African countries. The empirical results affirm the existence of an EKC for air pollution, but in the case of water pollution, the relationship with income per capita tends to be strictly positive.

As far as climate risk is concerned, the Paris Agreement, adopted during the COP21 in 2015, has been a cornerstone in climate change mitigation. The past years have indeed been marked by an increasing awareness, both from the public and governmental bodies, on the urgency to depart from our current CO_2 emissions path. Reduction of CO_2 emissions is now on many governments and companies' agenda. Indeed, CO_2 is the major contributor to earth temperature imbalances, followed by methane and nitrous oxide. Working on G7 countries, Chaudhry *et al.* (2020) argue that CO_2 emissions can actually increase sovereign risk, captured either by equity tail risk or government bond data. Global warming has devastating consequences on the planet and therefore exploitation of fossil fuel resources must be diminished in favor of renewable energies (from solar power stations or wind farms for instance). On climate transition, Battiston and Monasterolo (2020) showed that countries with a large share of their economy relying on low carbon resources have lower yield than those with an economy marked by high fossil fuel dependence. They also argued that carbon intensity and climate misalignment imply higher sovereign bond yields. Climate change can have a substantial impact on sovereign creditworthiness by physically entailing its assets. Indeed, extreme weather shocks (floods, drought, cyclones, etc.) but also more gradual events, such as sustained rise in temperatures, can destroy production apparatus and infrastructures, disrupt the economy, affect commodities and food prices but also harm citizens. For developed and resilient countries, such events generally imply large government spending (and thus translate into higher debt level), but for less developed countries, or those with poor governance, the loss may not be recovered. In any cases, the cost induced by adverse extreme events hinders sovereign creditworthiness.

How much a country borrowing cost will be impacted by climate change is then dependent on its exposure to adverse climate events, its vulnerability, its preparedness and its resilience. Beirne *et al.* (2020) showed that countries with high vulnerability to climate change face higher sovereign borrowing costs, the less resilient countries are also concerned but in a lesser extent. For a sample of developing countries, Buhr *et al.* (2018) reported that climate vulnerability raised the average debt cost by 117 bps. Departing from sudden adverse one-off climate event, Klusak *et al.* (2021) focused on the impact of rising temperature on sovereign creditworthiness at the 2030 horizon and concluded that it will lead to rating downgrades and rising interest debt expenses.

2.2.2 Social pillar

Unlike the two other pillars, the social dimension of ESG has been studied with less consideration at the sovereign level. Several reasons support this argument. The matter of social progress is generally unclear. Indeed, it encompasses human behavior, social standards and cultural heritage, where the human being is inevitably at the center, making its quantifiable measurement limited or irrelevant. The capacity of a country to establish a society, which improves and maintains the living standards of its citizens, cannot be reduced to one figure, especially when marginalized groups are out of scope. To be relevant, social metrics might be interpreted as social disturbances leading to inequality between individuals or groups regarding incomes, assets, access to essential services and control over resources. Inequality triggers discrimination, exclusion and in other extent poverty. The latter could be perceived as the final outcome following the mismanagement of social risk, but poverty is an absolute value that is hard to interpret when comparing different countries.

However, over the previous years, the social pillar seems to be more integrated into the ESG landscape. Results from the analysis of Drei *et al.* (2019) show that the social pillar is not anymore the lagging pillar in the equity market. This recent catch up comes with recent social outbreaks. For instance, the Covid-19 crisis revealed that efficient health system among other tools helps the conditional resilience of a country. Repealing the pandemic at the global level may foster health equity. As a footprint of this pandemic, long-lasting socioeconomic impacts will never fade away if health protection lacks universality (Wang and Tang, 2020). Lagging countries tried to offset this unmet requirement by increasing tax revenue or reforming the health care system. Recent tax initiative in Colombia led to inequality surges, that in turn triggered civil unrest. The pandemic did not only shed the light on health inequalities, but also unveiled failures in the education system. Indeed, the pressure of the pandemic on school closure has disrupted progress made in education over the past 25 years. The study of ILO and UNICEF (2020) estimates that globally, around 24 million of children will not go back to school. Among them, a majority of girls who are particularly at risk of household chores. As this example illustrates, social issues are interconnected and may push people towards social deprivation. This vicious circle puts pressure on the government and can become rapidly a country risk.

Profound disruptions originate from health insecurity. Social protection deriving from the health sector carries an important role in mitigating the impact of health insecurity, inequality and poverty. Inappropriate public spending in health triggers out-of-pocket healthcare expenditures that in turn, spark off vulnerability, inequality and poverty in the medium and long term. Consequently, health insecurity disrupts social and economic progress by increasing the health burden (reduced life expectancy, prevalence of obesity or undernourishment, as well as premature mortality) and hampering adults to work and children to study (Fentiman *et al.*, 2001). Improving social protection in the health sector has the potential to propel economic growth and becomes analogous to an investment rather than a cost. Nutrition is also a central aspect of the health system of a country, as both undernourishment and overweight testify food insecurity. The study of Ogden *et al.* (2017) shows that income growth and educational attainment tend to reduce the prevalence of obesity, especially among women, although this association can differ substantially between regions. Obesity raises the risk of non-communicable diseases (NCDs). Globally, NCDs are responsible for almost 41 million deaths each year from which 77% occur in middle- and low-income countries (World Health Organization, 2020). Economic progress cannot thrive without public health achievements.

Gender inequality is a central aspect of the social pillar covering diverse dimensions such as education, health, employment and pay. Gender discrimination lowers well-being and economic prospects in several ways. On the education front, low girls' school enrollment reduces the amount of human capital, future pool of skilled workers and thus caps the economic perspectives. As the workload is constrained to a fewer number of female workforce, the selection of talent is in turn reduced (Esteve-Volart, 2004). Additionally to the gap of work participation, Cavalcanti and Tavares (2016) found that inequality in education and employment might increase the fertility rate to levels that indirectly hamper future economic growth. These inequalities systematically lead to permanent discrimination in pay. Loss of bargaining power at the household levels, attributable to the pay gap between men and women, can reduce the health and education investment of children, and impact the next generation and future growth. Additional income in the hand of women tends to produce better impact than in the hand of men regarding survival rate and food security (King and Mason, 2001). On the economic participation and representation aspect, these authors suggested that equal participation in public life is associated with cleaner business and better governance in both companies and governments. The higher the influence of women in public life, the lower the level of corruption[1].

The social pillar is in fact, mainly a matter of human rights. The right to education, the freedom of opinion and assembly, the access to electricity and water, and the protection of the working conditions (including the right to strike, the right to establish and join a trade union, and the right to trade union activities) among other, form the basic needs citizens may own to live a decent life. Abuses of human rights condemn civil society, political stability and may hamper prosperous economic development. Beyond the fact that civil rights violation brave the Universal Declaration of Human Rights[2], trade relations between countries or between companies can also be affected. Since international trade standards and economic policies place human rights in the foreground, international relationships are deeply dependent of human rights abidance. Therefore, investors generally recognize the materiality of human rights abuses as a country risk that should integrate the social pillar.

[1] Although DiRienzo (2019) argued that this finding can be related to the cultural context.

[2] "*All human beings are born free and equal in dignity and rights*".

2.2.3 Governance pillar

As mentioned previously, rich environmental endowments can benefit a country's development if it has a sufficiently strong governance to manage it. On a more general note, a country's governance is of paramount importance from a bondholder perspective. If usually the decision to invest in sovereign bonds is rather based on the assessments of a country's ability to repay its debt and the reward the investor gets from his investment, a poor governance can actually question the willingness of the sovereign to repay its debt (Reinhart and Rogoff, 2009). Good governance and fairness are important, both at the country level, but also on the international scene. An ineffective government can trigger social unrest, jeopardizing a country stability and its economy, but can also lead to distrust from international organizations and other partner countries. Stylized facts show that any stress on a government's ability to efficiently run a country can have a massive impact on sovereign yields (extreme parties high scores, coalition formation, protests, etc.). Government stability and its degree of democracy is therefore crucial for sovereign creditworthiness. To illustrate this issue, Block and Vaaler (2004) showed that elections occurring in developing countries generally imply a downgrade from credit rating agencies, but also bring additional credit costs for the sovereign. Still working on developing countries, Smaoui *et al.* (2017) showed that high electoral competitiveness and political stability reduce sovereign spreads.

A fair distribution of wealth and the institution's independence are also key. On that front, it has been shown that governments from developing countries with a high level of corruption face a higher risk premium on the bond market and lower credit ratings (Ciocchini *et al.*, 2003; Connolly, 2007). Similarly, informational transparency (public finance external audit, detailed budget draft made available to the public) is rewarded by investors, who require a lower sovereign risk premium (Bernoth and Wolff, 2008). Similarly, the ability of a government and its institutions to deliver public and civil services, maintain law and order, manage fiscal revenues and honor their commitments have real implications for a country creditworthiness. Indeed, Jeanneret (2018) found that government effectiveness has a negative impact on sovereign CDS spread, although it especially applies to highly indebted countries with tangible credit risk. More generally, policy credibility is essential to understand the level of sovereign spreads. It does not involve only the economic policy, but also anything related to fiscal, monetary and social policies (Blackburn and Christensen, 1989; Alesina and Tabellini, 1990; Persson and Tabellini, 1990; Obstfeld and Taylor, 2003; De Mendonça and Machado, 2003). In this case, credibility and governance are highly related. The experience of the Greek government-debt crisis between 2010 and 2016 perfectly illustrates how credibility and governance may impact sovereign debt yields.

Citizens' rights, such as freedom of assembly and opinions clearly allow to take the pulse on the degree of democracy and the subsequent risk premium required by investors. For instance, studying corporate bonds from both developed and developing countries, Qi *et al.* (2010) showed that country-level higher political rights and freedom of press imply stronger corporate credit ratings and lower debt cost. Such rights must be safeguarded by a strong legal framework and forceful independent institutions. Sound organization also allows to prevent money laundering and tax avoidance and therefore reinforces government effectiveness. As a matter of fact, Hallerberg and Wolff (2008), using data on the strength of a country's finance minister and its ideal form of fiscal governance found that better institutions reduce sovereign risk premia in EMU.

From a bondholder perspective, creditor rights offered by the sovereign are essential. Avoiding conflicts of interest and ensuring shareholder rights are indeed a prerequisite to secure international investor's appetite. Furthermore, the fact that companies publicly disclose their financial statements and audits being legally regulated translate sound corporate governance at the national level. As Qi *et al.* (2010) demonstrated on corporate bonds, strong creditor rights and accounting disclosure are indeed associated with better credit ratings and lower bond spreads. More generally, firms' ethical behaviors are likely to reflect the sovereign's engagement in term of labor and health standards, its relation with communities and trade unions or fight against corruption.

Since the beginning of the 2000's and the 9/11 attack, the number of terrorist attacks has risen. On top of terrible human losses, terrorism can severely disrupt the economy, shake political stability and stir up trouble on financial markets, which could entail the targeted country creditworthiness. For example, Procasky and Ujah (2016) showed that terrorism increases the cost of debt for affected countries but also for their national firms, the magnitude being more important for developed countries. While no region has been spared and probability of occurrences in a country being – by definition – hard to forecast, governments can still take actions to try preventing terrorism attacks by investing in its police and counter-terrorism capabilities.

2.3 Which pillar is priced in by the market?

As mentioned earlier, to assess the impact of sustainability on a sovereign's borrowing costs, analyzes have often been run on either E, S and G scores or the global ESG score. For instance, Crifo *et al.* (2017) and Capelle-Blancard *et al.* (2019) found that countries with higher ESG ratings face lower bond yield spreads. However, there is no consensus in the literature on the "*winning pillar*". Indeed, on one hand, Capelle-Blancard *et al.* (2019) stated that the environmental pillar is not priced in, while the governance aspect has a more important impact than the social dimension in reducing borrowing costs. On the other hand, Martellini and Vallée (2021) established a negative relationship between environmental rating and bond yield spread. However, many studies mainly concern developed markets. Using a larger set of countries, Dudás and Naffa (2020) found a negative relationship between ESG rating and lending risk premium, while highlighting the time varying importance of different ESG factors in their results, as well as the varying effects across country income group. As a matter of fact, they demonstrated the rising importance of the environmental pillar over the past years, although social and governance pillars remain the biggest drivers of sovereign risk premia, except for low-income countries where some environmental variables stand at the forefront. Regarding the social pillar solely, Semet (2020) found that income inequality tends to raise the sovereign bond yield spreads, although the effect may be peculiar to developed countries. Working on CDS spreads on a sample of developed and emerging countries, Hübel (2021) finds that higher ESG ratings are associated with lower CDS spreads. He also highlighted that governance has a larger impact on a sovereign short-term creditworthiness compared to the environmental and social pillars that are priced into longer-term CDS. To complete this general picture, Martellini and Vallée (2021) found that good social rating implies a reduction of the bond yield spread for emerging countries.

3 Single-factor analysis

3.1 Data

For ESG indicators, we mainly use data from Verisk and complement our dataset with the World Bank and United Nations databases. We manage 269 indicators from which 100 are related to the environmental pillar, 83 to the social pillar and 86 to the governance pillar. The indicators are classified in 26 themes. On the financial data side, we retrieve generic

10 year government bond yields from Bloomberg and Eikon-Datastream. Macroeconomic variables are extracted from the IMF and the World Bank databases.

We restrict our analysis to the 2015–2020 period. Indeed, we know that ESG was a marginal investment theme before 2010 (Bennani *et al.*, 2018). ESG data is certainly not robust or relevant before 2010. Moreover, in order to have an exhaustive dataset, we begin our analysis in 2015, having too many missing values before this date. Despite our aim to work on the largest possible sample of countries, the length and availability of some time series constrain our sample to 67 countries. Still, we manage to have a fairly good coverage of the different world regions and thus of varying levels of economic development[3].

3.2 Methodology

Let $s_{i,t}$ be the bond yield spread of the country i at time t. It is computed as the difference between yield of the 10Y generic government bond and the risk free rate[4]. We consider the following model:

$$s_{i,t} = \alpha + \beta x_{i,t} + \sum_{k=1}^{p} \gamma_k z_{i,t}^{(k)} + \varepsilon_{i,t} \tag{1}$$

where α represents the constant term of the regression, $x_{i,t}$ is the ESG indicator, $z_{i,t}^{(k)}$ is a set of control variables, γ_k represents the slope coefficient of the k^{th} control variable $(k = 1, \ldots, p)$, and $\varepsilon_{i,t}$ is the idiosyncratic error term. The baseline model is obtained by setting $\beta = 0$. In this case, the model measures only the impact of the control variables:

$$s_{i,t} = \alpha + \sum_{k=1}^{p} \gamma_k z_{i,t}^{(k)} + \varepsilon_{i,t} \tag{2}$$

The choice of the control variables is important since the selection of the relevant ESG indicators is dependent on the estimate $\hat{\beta}$ and the improvement of $\Delta\mathfrak{R}_c^2$ between the two nested models (1) and (2). Moreover, we also perform a F-test to test the null hypothesis that the added indicator is significant.

In the economic literature, it is generally accepted that the bond yield spread is dependent on some macroeconomic variables such as inflation, current account balance, debt ratio, economic growth, etc. (Eichengreen and Mody, 2000; Fouejieu and Roger, 2013). Using a statistical selection procedure, we consider six control variables that form the baseline model:

$$\sum_{k=1}^{6} \gamma_k z_{i,t}^{(k)} = \gamma_1 g_{i,t} + \gamma_2 \pi_{i,t} + \gamma_3 d_{i,t} + \gamma_4 ca_{i,t} + \gamma_5 r_{i,t} + \gamma_6 \mathcal{R}_{i,t} \tag{3}$$

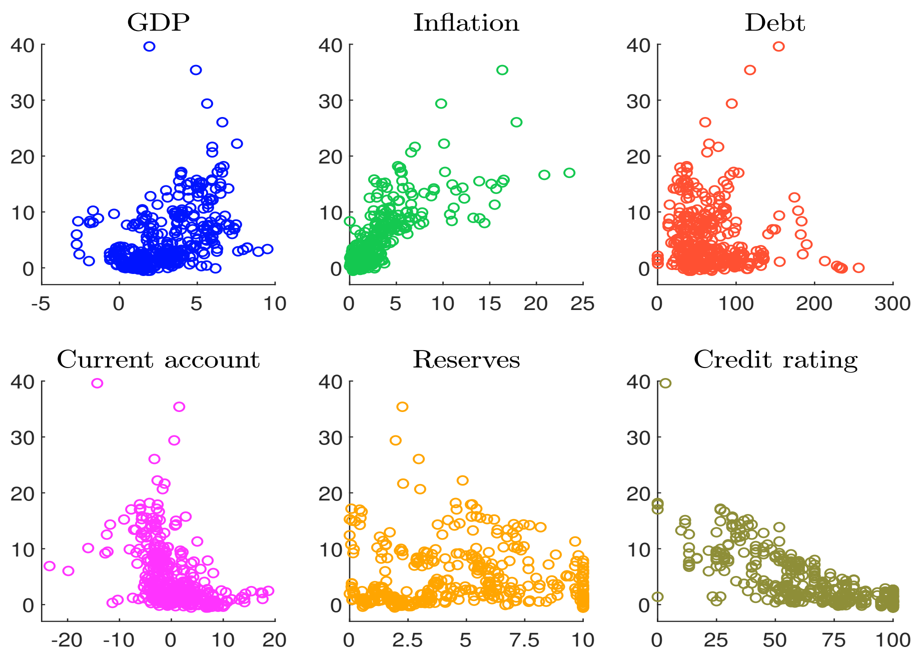
where $g_{i,t}$ corresponds to the growth rate of the gross domestic product (GDP), the inflation variable $\pi_{i,t}$ refers to the percentage change of the consumer price index, the debt variable $d_{i,t}$ measures the ratio between the gross debt and the GDP of the country, $ca_{i,t}$ is the current account balance in percent of GDP, $r_{i,t}$ corresponds to the reserve adequacy and $\mathcal{R}_{i,t}$ is a composite credit score computed as the average credit rating[5] from three credit rating agencies (S&P, Moody's and Fitch). In Figure 1, we have reported the scatter plot between each control variable $x_{i,t}^{(k)}$ and the bond yield spread $s_{i,t}$. We notice that the latter is

[3] The list of countries is available in Appendix A.3 on page 68.

[4] The risk free rate provided by the ECB is a composite rate of a selection of AAA-rated countries of the European Union.

[5] We compute a linear score that ranges from 100 for AAA-rated bonds to 0 for D-rated bonds. The correspondence list is presented in Appendix A.2 on page 68.

Figure 1: Relationship between control variables and the bond yield spread



an increasing function of the inflation and the debt ratio, that is coherent with the economic theory. We also verify that $s_{i,t}$ is highly dependent on the credit rating. The better the credit rating, the lower the bond yield spread. The relationship between $s_{i,t}$, $ca_{i,t}$ and $r_{i,t}$ is less obvious. Concerning the economic growth we obtain a positive relationship, implying that a country that pays a high sovereign risk premium must have high economic growth if it wants to borrow, which contradicts the idea that high GDP growth should instead ease debt servicing and shrink sovereign spreads (Cantor and Packer, 1996). In fact, we observe that the identified relationship may be reversed in some emerging countries. This positive relationship is therefore consistent with the theory of credibility, but could also be explained by the close ties between economic growth and inflation, that drives bond yield spreads upward. Using the pooling method, we finally obtain the following results:

$$\begin{aligned}\ln\left(s_{i,t}+1\%\right) &= \underset{(0.1349)}{1.9477^{***}} + \underset{(0.0125)}{0.0838^{***}} g_{i,t} + \underset{(0.0065)}{0.0524^{***}} \pi_{i,t} - \underset{(0.0007)}{0.0006} d_{i,t} - \\ & \quad \underset{(0.0054)}{0.0332^{***}} ca_{i,t} + \underset{(0.0082)}{0.0275^{***}} r_{i,t} - \underset{(0.0012)}{0.0166^{***}} \mathcal{R}_{i,t} + \varepsilon_{i,t} \qquad (4)\end{aligned}$$

Below each estimate $\hat{\gamma}_k$, we have reported the corresponding standard error $\sigma(\hat{\gamma}_k)$ in parentheses. We also use the conventional scale for the statistical significance of the variables[6]. The model has an overall $\mathfrak{R}_c^2$ of 70%. This is a good explanatory power since the sample is made up of 67 countries and 402 observations. The estimated coefficients confirm the relationships found in Figure 1. They have the right sign for the variables $\pi_{i,t}$, $ca_{i,t}$ and $\mathcal{R}_{i,t}$. The impact of the debt $d_{i,t}$ is not significant, while the sign for the reserves is wrong. Finally, the estimated coefficient for the economic growth is positive, which confirms that an investor requires a strong economic growth for risky emerging countries or those with high inflation levels.

Remark 1. *If we compare Equations (2) and (4), we notice that we use a logarithmic transformation for the endogenous variable $y_{i,t}$. Instead of modeling $y_{i,t} = s_{i,t}$, the regression*

[6] ***, **, * denote statistical significance at 1%, 5% and 10% probability levels respectively.

model estimates $y_{i,t} = \ln(s_{i,t} + 1\%)$. The reason is that we face an heteroscedasticity effect. For instance, we have reported the scatter plot of the observations $y_{i,t}$ and the predicted values $y_{i,t}$ on page 69. In the case $y_{i,t} = s_{i,t}$, we observe that the predicted value $\hat{y}_{i,t}$ is systematically below the observed value $y_{i,t}$ when the spread is greater than 10% (Figure 16). This implies that the residuals are negative in this region. Therefore, the selection of ESG indicators would be focused on high credit spreads. On the contrary, the model is better balanced when $y_{i,t} = \ln(s_{i,t} + 1\%)$ (Figure 17).

3.3 Results

Because the list of indicators is relatively large, we do not report the exhaustive statistics for all the ESG themes.

3.3.1 Environmental themes

In Table 1, we notice that all climate change dimensions (namely exposure, sensitivity and vulnerability) are significant drivers of the sovereign bond yields. Climate change exposure quantifies the degree to which the country is exposed to physical threats of extreme climate events and future changes in climate. In the language of sustainable finance, it corresponds to the physical risk of climate change. The sensitivity dimension assesses the human population's susceptibility to be impacted by these extreme climate-related events. Vulnerability aspect refers to "*the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes*" (Intergovernmental Panel on Climate Change, 2007). Acute measures, that translate the highest risk recorded within a country spatial representation, are particularly relevant. Exposure appears as the biggest determinant. The lower the exposition of a country to extreme or climate-related events, the lower its yield. However, sensitivity and vulnerability are also material. The risk premium is then a decreasing function of these two dimensions. Nevertheless, the exposure dimension tends to be more robust than the sensitivity and vulnerability dimensions. The most relevant indicator of the theme, in terms of explanatory power, is the acute measure of climate change vulnerability.

Table 1: Climate change

Measure	Indicator	$\hat{\beta}$	$\hat{\sigma}(\hat{\beta})$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Average	Climate change exposure	-0.054^{***}	0.012	0.00	2.12%	20.30^{***}
	Climate change sensitivity	-0.060^{**}	0.026	0.02	0.56%	5.46^{**}
	Climate change vulnerability	-0.100^{***}	0.018	0.00	3.11%	31.16^{***}
Acute	Climate change exposure	-0.067^{***}	0.012	0.00	3.39%	32.95^{***}
	Climate change sensitivity	-0.148^{***}	0.024	0.00	3.95%	38.79^{***}
	Climate change vulnerability	-0.128^{***}	0.017	0.00	5.51%	57.19^{***}
Extreme	Climate change exposure	-0.052^{***}	0.007	0.00	4.80%	48.60^{***}
	Climate change sensitivity	0.001	0.011	0.93	0.00%	0.01
	Climate change vulnerability	-0.009	0.018	0.60	0.00%	0.28

Concerning commitment to environmental standards[7], we observe that these indicators impact sovereign bond yields. Regardless of the action taken by countries to favor environmental protection, environmental oriented policies and their regulatory frameworks form a good signal to the market, which in turn adjusts the risk.

[7] The statistics are not reported here.

On the water management front, Table 2 illustrates the dependency, availability and the treatment of water within a country. The average measure stipulates that water import security is associated with higher sovereign yield, the higher the dependency of a country to water import, the lower the cost of borrowing. This counter intuitive result is nuanced by the generic indicator, which suggests that an improvement of the water security leads to a reduction of the sovereign yield. While water stress is perceived as a matter of concern by market participants, some countries do not seem to be financially penalized by their external water dependency. Finally, we observe that the ratio between agricultural water withdrawal and total water withdrawal tends to widen the sovereign yield. The higher the share of water resources devoted to irrigation and livestock production for agriculture, the wider the yield of the sovereign bond. As shown by the F-test and $\Delta\mathfrak{R}_c^2$ statistics, this indicator tends to be an important driver of credit spread.

Table 2: Water management

Measure	Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Average	Water import security	0.049^{***}	0.015	0.00	1.13%	10.90^{***}
	Water stress	-0.023^{*}	0.013	0.08	0.28%	3.08^{*}
Extreme	Water import security	-0.002^{*}	0.001	0.05	0.42%	3.77^{*}
	Water stress	0.002^{**}	0.001	0.02	0.56%	5.47^{**}
Generic	Water security	-0.054^{***}	0.018	0.00	0.98%	8.67^{***}
	Water stress	-0.031^{***}	0.010	0.00	0.99%	8.90^{***}
	Agricultural water withdrawal	0.062^{***}	0.009	0.00	4.02%	47.10^{***}
	Water supply dependency	-0.002^{**}	0.001	0.03	0.56%	4.85^{**}
	Wastewater treatment index	-0.002^{*}	0.001	0.07	0.42%	3.40^{*}
	Water intensity of the economy	0.000^{**}	0.000	0.02	0.69%	5.54^{**}

Concerning non-renewable energy resources[8], we notice that bond market participants do not appear to price CO_2 emissions from energy use, although a slight positive relationship between the share of CO_2 emissions expressed in terms of GDP and the yields can be observed. Results for fossil fuel exports are more straightforward. The higher the proportion of fossil fuel exports, the higher the yield spread. This result demonstrates that the market penalized fossil fuel exporting countries over the past five years. Moreover, the result is robust since the three different measures are statistically significant. The fossil fuel intensity of the economy is also a cardinal indicator of the environmental pillar since it embodies a key aspect of the transition risk. Countries subject to the transition risk are required to pay a premium on their debts. The previous results are exacerbated by the total GHG emissions. As an outcome variable, this score suggests that, countries alleviating their level of GHG are rewarded by the market, supporting similar results previously highlighted by Chaudhry *et al.* (2020). Indeed, they found that carbon emissions significantly explain the sovereign risk for G7 member states. Finally, the last indicator presented in the table, namely total resource rents, measures the contribution of natural resources to economic output. It corresponds to the difference between the price of a specific commodity (oil, natural gas, coal, mineral or forest) and the average cost (extraction or harvesting cost) of producing it. As suggested by the World Bank (2021), "*when countries use such rents to support current consumption rather than to invest in new capital to replace what is being used up, they are, in effect, borrowing against their future*". Nevertheless, we observe that the resource rents tend to reduce the sovereign yield, meaning that countries with high share of natural resources are prone to economic growth and are perceived as less credit risky. From bondholder's

[8]The statistics are not reported here.

perspective, it appears that current endowment's consumption outstrips potential future natural resources shortage. We conclude that there are still some limits in the integration of non-renewable energy use into bond pricing, although countries facing high transitory issues may be penalized.

As far as energy mix is concerned, Table 3 shows that the energy self-sufficiency is the only indicator integrated by the market. This indicator is computed as the difference between the production and the consumption of energy, and broadly speaking, related to fossil fuel consumption. Hence, the indicator is also designed to flag net producer of oil. For instance, an increase of the indicator suggests that the dependency of the country regarding energy supply is reduced. At first sight, the positive sign exhibited by the coefficient is thus surprising. But the nexus between net exporters of energy and the bond yield is not straightforward. Liu *et al.* (2016) found that depending on the period, oil-price volatility has a significant influence on the country risk rating of oil-exporters countries. As a matter of fact, the governance aspect is also a relevant factor of energy security, and might be integrated into the analysis. For instance, Cherp *et al.* (2012) based the definition of energy security on two prominent factors in industrialized countries: import dependency and aging infrastructure. While oil and gas resources have supported economic development in several developed countries and some of emerging markets such as Malaysia, Indonesia or United Arab Emirates, energy exporters can also bear the burden of slower economic growth, poor governance, political instability and conflict, known as the "*natural resource curse*". Bouri *et al.* (2020) suggested that sovereign risk of oil-exporters from the Middle East and North Africa region can be easily predicted by shock in oil prices. However, as suggested by Pavlova *et al.* (2018), aggregate demand and supply fluctuations are not as relevant as oil-specific shocks for explaining the variation of the sovereign credit risk. As the time period considered integrates the 2020's oil price decline, we might consider direct effects on the variation of bond yield of oil-exporting countries. From an ESG viewpoint, the result may also translate the fact that fossil fuel exporting countries may face higher transition risk.

Table 3: Energy mix

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\Re_c^2$	F-test
Energy consumption diversity	-0.003	0.017	0.86	0.00%	0.03
Energy self sufficiency	0.018^{***}	0.004	0.00	1.55%	15.43^{***}
Gas dependency	0.012	0.012	0.33	0.14%	0.96
Renewable electricity output	0.002	0.001	0.10	0.28%	2.66

To deal directly with climate change issues, we study the impact of indicators related to temperature change over the sovereign bond yields[9]. Increasing heating days or decrease in cooling days may transcribe a rising need for building air-conditioning. Reciprocally, an increase in the number of cooling days or a decrease in the heating days may translate a rising need for heating. Therefore, there is a twofold interpretation of these metrics. First, we can assume that a low score implies a strong exposure to adverse climate scenario that triggers health, agricultural and economic issues. Second, either from heating or cooling, a low score can signal an important level of energy requirement. When the number of cooling days increases, it means that countries face a lower exposure to heat and their yields tend to fall. Conversely, an increase in the heating degree days metric is positively related to the yields. Countries more frequently hit by heat waves are thus associated with higher yields. These results are confirmed by the heat stress indicator that measures the expected country' exposure to heat stress. The lower the heat stress sensitivity, the lower the yield. It

[9] The statistics are not reported here.

is interesting to observe that an increase in the air conditioning needs, caused by the global warming and sustained by rising income across the globe, already has a more meaningful impact than heating-induced energy consumption on investor's assessment of sovereign risk.

Table 4 presents the regression results of the indicators related to biodiversity loss. We choose to integrate the air pollution dimension with two indicators of air quality that translate the concentration level of particles smaller than 2.5 micrometers (known as $PM_{2.5}$). While the average measure does not seem to be a matter of concern for the market, extreme concentration of $PM_{2.5}$ becomes material. This result suggests that the market does acknowledge the negative impact caused by air pollution and the various externalities it embodies. Moreover, the materiality of air pollution becomes relevant when it reaches extreme levels. All things being equal, an improvement of the air quality within a country is associated with a reduction of the cost of borrowing. In the same vain, actors of biodiversity conservation are also paying a lower borrowing cost. The biodiversity threatening score measures the country's willingness to protect threatened species by assigning a score between 0 and 1, where 0 implies that all species would have gone extinct in the country. Overall, we see that over the past five years, the biodiversity footprint becomes a concerning topic in the bond pricing. All else being equal, sovereigns with deteriorating biodiversity practices can expect to have a higher cost of borrowing. We also notice that the indicator measuring the proportion of protected areas is integrated by the market. It gathers the proportion of land and marine areas defined as protected. We see that integration and safeguard of the biodiversity might be rewarded by the market. The wider the protected areas, the lower the yield.

Table 4: Biodiversity

Measure	Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Average	Air quality	-0.008	0.015	0.61	0.00%	0.26
Extreme	Air quality	-0.050^{***}	0.012	0.00	1.69%	15.94^{***}
	Net forest change	0.009^{**}	0.004	0.02	0.56%	5.99^{**}
	Biodiversity threatening score	-1.688^{***}	0.284	0.00	3.53%	35.32^{***}
	Protected areas	-0.008^{***}	0.002	0.00	1.24%	9.67^{***}

Concerning natural hazard indicators[10], they can impact the creditworthiness of a country. For instance, the implementation cost of adaptation or mitigation policies can be high in case of recurrent and intense disasters. Overall, estimates of the main parameters of interest, all have the expected signs and are typically different from zero at high levels of significance. Firstly, we observe that severe storm appears to be the most relevant natural hazard priced in by the market. A country less exposed to storms, on average, tends to pay a lesser rate on its debt. Secondly, we notice that the occurrences of tsunamis and volcanic hazards are also relevant indicators in the bond pricing. Intuitively, we recognized that exposure to volcanic and tsunami hazard may have long lasting repercussion and may be a source of economic disruption. Thirdly, we observe that, to a lesser extent, the materiality of seismic disasters is integrated into the sovereign yields. Finally, results suggest that flood hazard, tropical and extra tropical cyclone hazards are hardly relevant in explaining the variation of the sovereign yields.

Concerning natural hazard outcomes and expositions[11], we observe that exposure and losses induced by natural hazards are priced into sovereign bonds. We also notice that indicators related to human life are particularly significant, meaning that human fatalities

[10]The statistics are not reported here.
[11]The statistics are not reported here

and human exposure to natural hazards are cardinal factors in measuring the externalities of natural disasters. The exposure of transport infrastructure to natural hazards is also material. Transport facilities are part of lifeline network, defined as "*the set of structures, infrastructures and services regarded as indispensable for the maintaining or protection of the life of the given systems*" (Leonardi *et al.*, 2016). Lifeline network encompasses energy, telecommunication, water, sanitary issues and transport. The previous study ascertains that transportation is one of the main concerning sector during emergency management since it directly affects the population. Moreover, we easily understand that disruptions of transport channels can hinder the strength of the emergency response. In the case of natural hazard that trigger technological disasters for instance, hazardous material release, fires, explosion and toxic cloud, add indirect fatalities and prevent the emergency response to cope with the disaster and to rescue victims, leading to disruptions escalation. The transport facility exposition is therefore an important point in assessing natural hazards outcome. Finally, we see that earthquake vulnerability metric is statistically significant and positively related to the bond yield of a country. This indicator reflecting the vulnerability of the built environment to earthquakes, is also a useful proxy in assessing the building's vulnerability to all natural hazards. The higher the vulnerability to earthquakes, the higher the spreads.

3.3.2 Social themes

Results presented in Table 5 summarize the materiality of health indicators within the social pillar. First of all, we remark that health expenditure per capita is statistically significant and negatively related to the sovereign yield. Investment made in human health is on average rewarded with a lower cost of borrowing. This theme is essential to the social pillar since a good health system is a pathway toward sustainability and development. The first indicators measuring the prevalence of obesity, overweight, undernourishment and the mean body mass index consider the healthy lifestyle of a country as an outcome. It appears that only the metrics related to undernourishment and mean body mass exert a significant positive impact on spreads. The life expectancy indicator measures the number of years a newborn infant could expect to live if prevailing patterns of age-specific mortality rates at the time of birth were to stay the same throughout the child's life. It is a good proxy to measure the level of development of a country, because this rate tends to increase following the progress in economic, social and health fronts. Indeed, Wilkinson (1992) found that following a fall in the prevalence of relative poverty, life expectancy improved more rapidly, although the nexus is complex. Life expectancy surge can in turn trigger development. For instance, Bloom *et al.* (2003) found that higher life expectancy increases saving rates. Most developed countries may have a lower bond yield spread thanks to their respective level of development, enhancing the capacity of the country to repay its debt.

The life expectancy inequality is used by the United Nations development program (UNPD) to compute the health index of the inequality adjusted human development index (IHDI), that embodies education, income and health achievements. It is derived from the measure of inequality formulated by Atkinson (1970). It represents a relative measure of welfare, translating the level of welfare associated with the variable distribution[12]. Therefore, the indicator can be interpreted as the percentage loss in welfare due to inequality. The higher the welfare induced losses due to life expectancy dispersion between income

[12] The indicator was originally designed to translate income inequalities based on welfare. Conversely to an inequality measure, as the Gini coefficient for instance, which is independent of the total income, a welfare measure transcribes the income distribution regarding inequality but is also sensitives to income growth (Foster *et al.*, 2005).

Table 5: Health

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Health expenditure per capita	-0.019^{***}	0.048	0.00	2.66%	25.65^{***}
Prevalence of obesity	0.004	0.004	0.32	0.14%	0.98
Prevalence of overweight	-0.001	0.002	0.72	0.14%	0.13
Prevalence of undernourishment	0.012^{**}	0.006	0.04	0.40%	4.11^{**}
Mean body mass index	0.034^{*}	0.018	0.06	0.42%	3.45^{*}
Life expectancy	-0.023^{***}	0.006	0.00	1.69%	15.86^{***}
Life expectancy inequality	0.013^{***}	0.005	0.01	0.82%	6.80^{***}
Under 5 mortality rate	0.002	0.002	0.18	0.28%	1.81
Average dietary supply adequacy	0.002	0.002	0.35	0.13%	0.89
Cereal import dependency ratio	0.000	0.000	0.89	0.00%	0.02
Food price inflation rate	0.023^{***}	0.007	0.00	1.25%	9.77^{***}

groups, the wider the yield. Results show that health inequalities seem to be penalized by the market.

Only one indicator related to food security is significant in our analysis. The food price inflation, reflecting the monthly change in international prices of a basket of food commodities, has a positive and statistically significant relationship with the bond yield. The higher the food inflation rate, the higher the sovereign yield. Food inflation is particularly worrisome for a country because it could lead to citizen's undernourishment and may be followed by civil unrest and political instability. Note that the studying period is characterized by a surge in international food prices since they picked up in April 2020 and are expected to increase steadily in the coming years with major repercussions for emerging countries (Ratha *et al.*, 2020).

Table 6 retrieves regression results for the income theme. Intuitively, we see that on average, countries with high monthly wage pay a lower yield on their debts. However, the severance pay indicator, reflecting the average weeks of severance pay that must be paid for redundancies, is positively related to the sovereign yields, meaning that the higher the number of weeks of severance pay, the higher the yield. The nexus between severance pay and the creditworthiness of a country is ambiguous. From an ESG viewpoint, the protection of workers might resonate as a good signal of social progress and social inclusion. However, on the macroeconomic side, severance pay might be viewed as an extra labor cost. Here, the latter argument seems to overcome the former. Moreover, this cost might grow during labor market turmoil which constitutes itself a country risk.

Table 6: Income

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Base pay	-0.000	0.000	0.21	0.14%	1.56
Average monthly wage	-0.119^{***}	0.033	0.00	1.98%	17.14^{***}
Severance pay	0.009^{***}	0.002	0.00	1.41%	13.71^{***}
Frequency of base pay adjustments	0.007	0.008	0.43	0.00%	0.64
Social security employer contribution	-0.005^{*}	0.003	0.06	0.42%	3.49^{*}
Base pay / value added per worker	0.016	0.124	0.90	0.00%	0.02

Concerning civil unrest indicators[13], these social indicators may be interpreted as outcome indicators in that civil unrest may be triggered by economic, political or social disruptions. We observe a positive effect following a reduction of the number and the intensity of

[13]The statistics are not reported here

civil unrest on the bond yields.

Table 7 report the results related to the education theme. Three of these indicators have a significant and negative relationship with sovereign yields. First, the indicator related to public expenditure on education reduces the country cost of borrowing as this amount increases. This indicator hints at the importance given to education by a government. We assume that high spending on education leads to social progress and lowers the level of inequality. Second, we see that the mean years of schooling of adults is negatively related to the sovereign yields, meaning that a higher average is associated with a lower yield. We understand that a larger pool of skilled workers can lead to economic resilience and strengthen growth. Moreover, these two indicators demonstrate the willingness of a country to invest and sustain human capital which in turn benefits to the country's welfare. Still on the outcome variable, the gross graduation ratio from first degrees is also integrated into sovereign bonds pricing. This indicator represents the number of graduate students from first degree programs (Master degree level), expressed as the percentage of the graduation age population that have a diploma. This indicator can serve as a proxy measure for the capital pool of highly skilled workforce within a country, meaning that a sizable proportion of graduates foresees a positive trend for economic prospects. On the opposite, the others indicators that are not statistically significant, although intuitively relevant for assessing the input dimension of the education system, may be subject to selection bias. For instance, the adult literacy average of the sample is around 94% in 2020 and the net primary school enrollment is standing at 96% in 2020. Hence, it could be reasonable to accept that these former metrics, commonly used to assess the education efficiency, are not anymore relevant to capture the progress of the educational system. The inequality dimension of education appears to be integrated into the sovereign bond yields, even if the level significance of the indicator is not the highest. The higher the education dispersion regarding income groups, the wider the sovereign yield. In summary, results on the education theme suggest that the sovereign bond yield of a country integrates both input and outcome variables. The market tends to reward the efficiency of the educational system through its capacity to be universal but also supportive.

Table 7: Education

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Public expenditure on education	-0.037^{***}	0.014	0.01	0.86%	6.73^{***}
Adult literacy rate (+15 years old)	0.000	0.003	0.97	0.00%	0.00
Mean years of schooling of adults	-0.053^{***}	0.015	0.00	1.40%	12.79^{***}
Net primary school enrollment rate	0.000	0.004	0.96	0.00%	0.00
Gross secondary school enrollment rate	-0.002	0.001	0.15	0.28%	2.12
Gross tertiary school enrollment rate	0.001	0.001	0.56	0.00%	0.34
Gross completion rate first degree	-0.006^{***}	0.002	0.00	1.43%	9.98^{***}
Education inequality	0.008^{**}	0.003	0.02	0.67%	5.56^{**}

In Table 8, we observe that several dimensions of gender discrimination are integrated into the sovereign yields. Progress made on women's empowerment reduces the country's cost of borrowing. The women business and the law index, developed by the World Bank, captures the laws and regulations that restrict women's economic opportunities and tries to assert improvements made on the women's economic empowerment. The gender pay gap – one of the key metrics in economic gender gap study – reflecting the remuneration gap via the ratio of estimated female-to-male earned income and wage equality for similar work, is statistically significant and negatively related to the sovereign yields. As suggested by Oostendorp (2009), the gender wage gap tends to decrease with economic development, trade and foreign investment. We also retrieve results on the unemployment gap between male and female. We observe that youth unemployment gender gap is a relevant factor of yield widening but cannot be extended to the total unemployment gap. Here, we assume that the gender employment gap of the youth leads to persistent disadvantage and that the country should be penalized by these discriminations in the long run. As far as LGBT discrimination in employment is concerned, it leads to higher yields and can be a matter of concern since it embodies the largest $\Delta\mathfrak{R}_c^2$ and F-test.

Table 8: Gender

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Sexual harassment sanctions at work	-0.143^{*}	0.078	0.07	0.42%	3.35^{*}
Seats held by women in parliament	-0.003	0.003	0.30	0.14%	1.08
Women business and the law index	-0.011^{***}	0.003	0.00	1.97%	17.14^{***}
Discrimination based on LGBT status	-0.081^{***}	0.011	0.00	5.55%	51.67^{***}
Gender gap in labor force participation	-0.002	0.002	0.23	0.27%	1.45
Gender pay gap	-0.041^{***}	0.014	0.00	1.10%	9.08^{***}
Youth unemployment gender gap	0.634^{***}	0.095	0.00	4.78%	44.40^{***}
Total unemployment gender gap	0.119	0.075	0.12	0.41%	2.49

In Table 9, we study the relationship between water, electricity's access and the sovereign yields. Among the five indicators representing the right to water, only two are statistically significant, but head in the right direction. We observe that the impact of public discontent with water quality affects the bond yield harder than the public satisfaction tightened the yield. The explanatory power of this indicator is also higher as described by the $\Delta\mathfrak{R}_c^2$ and the F-test. Hence, we assume that the market penalizes more for bad behavior than it rewards for social progress. Moreover, the quality dimension seems to overcome the availability of water. We assume that a large share of the countries studied has reach full access to water, suggesting a feeble materiality of water availability. We arrive at the same conclusion concerning electricity access since the proportion of the population with access to electricity is not significant.

Table 9: Water and electricity access

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Basic drinking water availability	-0.002	0.004	0.49	0.00%	0.48
Improved drinking water availability	-0.003	0.003	0.35	0.14%	0.89
Improved sanitation availability	-0.003	0.002	0.16	0.14%	2.02
Public satisfaction with water quality	-0.008^{***}	0.002	0.00	1.13%	10.34^{***}
Public discontent with water quality	0.010^{***}	0.003	0.00	1.55%	15.18^{***}
Access to electricity	0.000	0.002	0.84	0.00%	0.04

Concerning human rights[14], we observe that they are well represented into the pricing of sovereign bonds, in particular freedom and food indicators.

Demographic dynamics are key challenging themes of the social pillar in the sovereign analysis. However, the expected impact on the bond yield might be priced in differently depending on the considered scope. For instance, if we suppose that a surge in the demographic trend benefits the country for fiscal purposes – as described by the age dependency ratio – one

[14] The statistics are not reported here.

can also expect this positive trend to hamper the country's sustainability regarding natural resources management or food dependency. Taking the rural/urban specification, we might expect that an increase in the share of population living in urban area can be advantageous for school attainment objectives for instance, but this could also enhance virus transmission. Thus, the scope on which we rest on has an important role on the results' interpretation. The literature helps to understand this phenomenon. Taking the mainstream debt sustainability viewpoint, we assume that demographic trend might be positive over the long term to restore a sustainable age structure balance and to face concerns about the retirement system since it represents a major country risk over the long term. We base this argument on several empirical analyses. For the Eurozone, Nerlich and Schroth (2018) studied the implications of population ageing through a macroeconomic prism. They list four main repercussions: (1) the decline of labor supply and productivity and their growth-induced externalities, (2) the increase of precautionary savings leading to dampening long-term interest rates, (3) the shift in demand that entails inflationary pressure, and last but not least, (4) the expected public budget imbalance triggered by spending on pensions and health care. Imam (2013) studied the implications of ageing population in Japan. He discussed the drawbacks of the life cycle for the financial stability and underlined several possible channels.

Results related to demographics are presented in Table 10. We observe that the age dependency ratio is statistically significant and negatively related to sovereign yields. At first sight, this result can be counter intuitive, because the metric measures the number of dependent person – people younger than 15 and older than 64 – per 100 working-age population – the independents. The higher the dependency, the lower the yield. However, as explained by the World Bank (2021), "*dependency ratios show only the age composition of a population, not economic dependency. Some children and elderly people are part of the labor force, and many working-age people are not*", meaning that the indicator reveals more about the age structure of the country than its economic dependency. Nonetheless, it remains hard to evaluate the impact of this demographic dimension since the long term expected change in the dependency ratio is not statistically significant and displays a positive coefficient. When taking medium-term expectation measures, we remark that the projected change in national population as well as the demographic pressure indicator tend to increase the borrowing cost. Over a long-term period, the previous result holds. Population pressure penalizes the sovereign cost of borrowing. Since demographic challenges are expected to play an important role in sustainability, the market recognizes it as a country risk. Moreover, these results shed light on the resource dependency argument, meaning that environmental concerns seem to overcome the age structure imbalance.

Table 10: Demographics

Measure	Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Current	Age dependency ratio	-0.007^{***}	0.002	0.01	0.71%	7.04^{***}
	Share of urban population	0.004^{**}	0.002	0.03	0.42%	4.48^{**}
	Share of rural population	-0.004^{**}	0.002	0.03	0.56%	4.72^{**}
Future 5Y	Urban population change	0.012^{**}	0.005	0.01	0.56%	6.17^{**}
	Projected population change	0.224^{***}	0.035	0.00	4.07%	40.47^{***}
Future 10Y	Demographic pressure	0.011^{***}	0.002	0.00	2.40%	22.61^{***}
	Age dependency ratio change	0.035	0.022	0.12	0.28%	2.47
	Urban population change	0.002	0.010	0.87	0.00%	0.03
	Projected population change	0.018^{***}	0.003	0.00	3.11%	29.61^{***}

Concerning labor market standards[15], we observe that they are priced in by the bond market, especially the right to join trade unions.

Finally, in Table 11, we focus on the migration theme. The indicator related to the integration of migrants into the host society is statistically significant and negatively related to the sovereign bond yields. Results show that migrant inclusion is associated with a lower country risk. Intuitively, we understand that the exclusion of migrants leads to marginalization and thus creates a vicious cycle of poverty. The latter tends to be exacerbated during economic crisis, as stated by Ratha *et al.* (2020), "*the adverse effects of the crisis in terms of loss of jobs and earnings, and exposure to and infection with Covid-19, have been disproportionately high for migrants, especially for those in informal sectors and relatively lower-skilled jobs*". As migration flows are expected to grow in the coming years, alongside demographic challenges, there might be a reward for the countries managing efficiently this challenge. In summary, lowering the vulnerability of migrants may be perceived as a positive signal for social integration and thus, reduces the credit spread.

Table 11: Migration

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Migrant workers' rights	-0.037^{***}	0.013	0.00	0.97%	7.53^{***}
Refugees from neighboring state	0.000^{*}	0.000	0.08	0.27%	3.08^{*}
Programs to integrate immigrants	-0.032^{***}	0.009	0.00	1.65%	12.96^{***}
Vulnerability of migrant workers	-0.080^{***}	0.011	0.00	5.83%	53.76^{***}

3.3.3 Governance themes

We start the analysis of governance indicators with the government effectiveness theme. Results are presented in Table 12. As expected, numerous indicators are statistically significant and negatively related to the sovereign bond yields. In the first half of the table, we retrieve the estimates of the indicators provided by the World Bank reflecting the government effectiveness. The measures give the country's score on the aggregate indicator, in units of a standard normal distribution, ranging from approximately -2.5 to $+2.5$. Among them, we observe that all the variables are statistically different from zero at a high confidence level and exert a negative influence on yields. We remark that the government effectiveness indicator tends to have the greatest impact on the yields but the indicator related to voice and accountability has an extra explanatory power as suggested by both statistics, the $\Delta\mathfrak{R}_c^2$ and the F-test. The former captures the perception of the quality of public and civil services, the degree of the government independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. The latter measures the perception of the freedom of political participation, expression and association. It confirms the previous results found on the human rights theme, in that democratic countries may lower their cost of borrowing in contrast with authoritarian regimes, even if this difference does not hinder economic growth (Alesina *et al.*, 1996). However, we find that the separation of powers is not priced into sovereign bonds. Finally, the corruption outcome indicator – where a high score stands for low depth of corruption within a country – is also a significant factor in explaining the sovereign cost of borrowing.

Concerning the political stability theme[16], these indicators reflects the strength of the political system. Alesina *et al.* (1996) studied the links between political stability and

[15]The statistics are not reported here.
[16]The statistics are not reported here.

Table 12: Government effectiveness

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Control of corruption	-0.122^{***}	0.042	0.00	0.95%	8.21^{***}
Government effectiveness index	-0.244^{***}	0.065	0.00	1.64%	13.95^{***}
Voice and accountability	-0.224^{***}	0.044	0.00	3.00%	25.70^{***}
Separation of powers	-0.002	0.011	0.83	0.00%	0.04
Public budget transparency	-0.015	0.016	0.33	0.14%	0.96
Anti-corruption bodies	-0.025^{*}	0.013	0.06	0.42%	3.77^{*}
Corruption outcome	-0.044^{***}	0.012	0.00	1.66%	14.10^{***}
Government accessibility	-0.019^{*}	0.010	0.07	0.42%	3.37^{*}

economic growth. They suggested that the two are interconnected. While political instability may reduce investment and penalize economic development, poor economic performance might in turn alter the political environment, leading to government collapse. They also found that political instability tends to be persistent, meaning that past instability is often a fertile ground for government collapse. Similarly, Cuadra and Sapriza (2008) found that political instability significantly raises the default probability of a country while increasing both the level and the volatility of the spread. Baldacci *et al.* (2011) extended the previous findings on the emerging markets economies and found that the resilience of the sovereign bonds during market turmoil is higher when the political risk is reduced. Finally, Hansen and Zegarra (2016) advocated that this effect can be expanded when the political risk is associated with a weak rule of law or low-quality regulation in the country. However, our results show that a few dimensions of political stability are integrated into the sovereign bond pricing.

Concerning the justice theme[17], we observe that a few indicators explains sovereign bond yields, in particular judicial independence.

Turning to international relationships[18], we observe that restrictions from the European Union seem to be more integrated into the sovereign bond pricing than restrictions coming from the United States. More specifically, financial restrictions and trade restrictions tend to be more relevant than arms restrictions. We easily understand that financial restricted countries are directly penalized on the investment side and may experience wider yield spreads. Bans on international trade can disrupt a country supply-chain and be true opportunity costs for national companies, that do not send a good signal to investors. However, when EU and US trade sanctions are combined (in the lowest part of the table), the indicator is less significant. Smeets (2018) argues that economic sanctions generally entail economic costs to all countries involved in the sanction episodes, and that the sanctioned country is likely to engage with third parties that are not part of the sanction coalition. Trade sanctions can thus be more or less effective and are dependent on specific criteria. The absence of trade restrictions is also positively perceived by bondholders.

Concerning indicators related to national security[19], we observe that most of them have an impact on the cost of borrowing of a country.

Table 13 presents the results for the indicators related to the infrastructure and mobility theme. Infrastructures determine the capacity of a country to enable the movement of goods and people into, out of and within a country. Good quality of infrastructure enables a country to be connected to global trade circuits and improves its overall trade capacity. At the regional level, mobility is also an important point to scrutinize. The availability of seamless transport and access to improved infrastructure have several benefits for education,

[17]The statistics are not reported here.
[18]The statistics are not reported here.
[19]The statistics are not reported here.

employment, natural disaster management, health resilience and so much more. The three prominent indicators of the theme, namely the quality of overall infrastructure, the quality of trade and transport infrastructure and the logistics competences seem to be moderately integrated by the market, their levels of significance being among the lowest from this theme. When looking at more granular indicators, such as roads and rail lines density, we observe a negative relationship with respect to the sovereign yield. This result is exacerbated by the physical connectivity index that reflects the relative remoteness of the population within a country. Therefore, improving the mobility network lowers the credit spread. Reciprocally, as suggested by the proportion of population living six hours away of a major city, physical exclusion of people is associated with a higher yield.

Table 13: Infrastructure and mobility

Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}^2_c$	F-test
Quality of overall infrastructure	-0.073^{*}	0.039	0.06	0.28%	3.46^{*}
Quality of trade and transport	-0.184^{**}	0.073	0.01	0.71%	6.28^{**}
Logistics competence	-0.221^{**}	0.087	0.01	0.71%	6.48^{**}
Air transport departures	0.085^{***}	0.015	0.00	1.00%	9.04^{***}
Customs efficiency	-0.203^{**}	0.082	0.01	0.71%	6.17^{**}
Rail lines km	-2.693^{***}	0.761	0.00	1.23%	12.52^{***}
Roads km	-0.232^{***}	0.024	0.00	6.45%	63.66^{***}
Physical connectivity	-0.098^{***}	0.014	0.00	4.94%	50.76^{***}
Population living away of a major city	0.033^{***}	0.005	0.00	3.81%	38.16^{***}

In Table 14, we focus on the ease of doing business at the country level. We suppose that a good business environment acts as a competitive advantage and attracts entrepreneurship as well as investments. The results are nuanced. In the first part of Table 14, we retrieve absolute measures for enforcing a contract, paying taxes, getting electricity, starting a business and register a property in terms of cost (in $), time (in days) and number of procedures. The indicators have a counter-intuitive signs since an increase of these measures leads to a reduction of the yields. One reason that might explain this result is that a high cost, time and number of procedures can testify a strong administrative background. Moreover, we see that none of these indicators is robust over the three measures, suggesting the poor materiality of these metrics.

In the second half of Table 14, we observe that the score associated to the respect of property rights, reflecting the strength of legal rights and the protections of private property rights – including both physical and intellectual assets – is integrated by the market. Intuitively, its negative impact on yield translates the transparency of the legal framework that allows for efficient policy planning and reduces the business costs. In contrast, lack of consistency of the regulatory system is likely to act as deterrent to investment and provides a fertile ground for corruption. The bank cost to income ratio, representing the operating expenses of a bank as a share of its total net-interest revenue, is also statistically significant but oddly, negatively related to the yields. Intuitively, the higher the cost incurred by banks as compared to income, the higher the likelihood of bank failures. Here, the bank cost seems to actually reflect creditworthiness since Switzerland has the highest value of the panel. The ease of access to loans appraises the ability of a borrower to take out a loan, operate or expand a farm or business. Mechanically, a favorable ground for entrepreneurship should lead to a lower sovereign yield. We also retrieve several outcome variables, measuring the governance pillar within the country's corporate environment. The corporate boards' effectiveness indicator is based on three governance dimensions, namely shareholders' rights

Table 14: Business environment and R&D

Measure	Indicator	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	p-value	$\Delta\mathfrak{R}_c^2$	F-test
Cost	Enforcing a contract	0.000	0.002	0.84	0.00%	0.04
	Paying taxes	-0.003^{*}	0.002	0.07	0.28%	3.24^{*}
	Getting electricity	-0.000^{**}	0.000	0.03	0.56%	5.05^{**}
	Starting a business	0.006^{*}	0.004	0.08	0.28%	3.16^{*}
	Register property	-0.021^{**}	0.008	0.01	0.71%	6.39^{**}
Time	Enforcing a contract	-0.000	0.000	0.48	0.00%	0.51
	Getting electricity	-0.001^{***}	0.000	0.00	0.85%	8.32^{***}
	Starting a business	0.001	0.002	0.75	0.00%	0.10
	Register property	-0.002^{***}	0.001	0.01	0.71%	7.26^{***}
Process	Paying tax	0.001	0.002	0.67	0.00%	0.18
	Getting electricity	-0.045^{***}	0.017	0.00	0.71%	6.73^{***}
	Starting a business	-0.010	0.010	0.30	0.14%	1.07
	Register property	0.018^{*}	0.011	0.10	0.28%	2.77^{*}
	Respect for property rights	-0.087^{***}	0.015	0.00	3.25%	32.59^{***}
	Domestic credit to private	0.000	0.001	0.45	0.00%	0.58
	State of cluster development	-0.082^{*}	0.047	0.08	0.28%	3.00^{*}
	Venture capital availability	-0.090^{**}	0.042	0.03	0.42%	4.59^{**}
	Efficacy of the regulatory system	-0.049^{***}	0.017	0.00	0.85%	8.65^{***}
	Availability of financial services	0.048	0.038	0.20	0.14%	1.62
	Total tax rate as % of profit	0.000	0.020	0.99	0.00%	0.00
	Bank cost to income ratio	-0.004^{***}	0.001	0.01	0.97%	7.29^{***}
	Ease of access to loans	-0.020^{***}	0.002	0.00	6.77%	73.57^{***}
	Corporate boards effectiveness	-0.117^{***}	0.028	0.00	1.84%	17.94^{***}
	Ethical behavior of firms	-0.163^{***}	0.022	0.00	5.37%	55.14^{***}
	Capacity for innovation	-0.007^{***}	0.001	0.00	5.65%	58.58^{***}
	Quality of research institutions	-0.100^{**}	0.042	0.02	0.56%	5.62^{**}
	R&D expenditure (% of GDP)	-0.093^{***}	0.034	0.01	0.84%	7.57^{***}

and role in major corporate decisions, governance safeguards protecting shareholders from undue board control and entrenchment, and corporate transparency on ownership stakes, compensation, audits and financial prospects. We see that higher corporate effectiveness is associated with a lower sovereign yield. The ethical behavior of firms assesses the extent to which business operations and interactions align with the principles of corporate social responsibility (CSR). Results show that respect of CSR principles by companies within a country implies a reduction in the borrowing cost. It illustrates that ESG performance at the corporate level can also triggers benefits at the country level. Here, we assume that the integration of governance effectiveness principles at the country level cannot be separated from corporates' governance. In summary, there is a substantial link between ESG at the corporate level and nationwide standards. Respect of governance principles inside the corporate environment fosters ESG performance at the country level. Finally, from the three last indicators capturing the research and development (R&D) dimension, two of them are statistically significant and negatively related to the sovereign yields. The capacity for innovation reflects the extent to which a country's environment is conducive to innovative activity in both the public and private sectors, notably in the field of climate change transition. Thus, countries investing in R&D are associated with a lower yield.

4 Multi-factor analysis

In this section, we focus on the materiality of ESG at the country level through multivariate analysis. As the logical consequence of the previous part, we must understand the relationships between the sovereign yields and the set of ESG indicators by taking into account the cross-correlations. We extend the single-factor analysis to the multi-factor analysis as follows:

$$\ln \left(s_{i,t} + 1\%\right) = \alpha + \sum_{j=1}^{m} \beta_j x_{i,t}^{(j)} + \sum_{k=1}^{p} \gamma_k z_{i,t}^{(k)} + \varepsilon_{i,t} \tag{5}$$

where $x_{i,t}^{(j)}$ is the set of ESG indicators ($j = 1, \ldots, m$) and $z_{i,t}^{(k)}$ is the set of the six control variables that have been previously selected: the economic growth $g_{i,t}$, the inflation $\pi_{i,t}$, the debt $d_{i,t}$, the current account balance $ca_{i,t}$, the reserve adequacy $r_{i,t}$ and the composite rating score $\mathcal{R}_{i,t}$. One of the issues concerns the large number of ESG indicators. Indeed, considering all the 269 ESG variables is not robust. Therefore, we propose a selection procedure in order to reduce the set of ESG indicators before handling multi-dimensional models. Then, we perform a lasso regression in order to measure the importance of each indicator, theme and pillar. Finally, we perform a sensitivity analysis by distinguishing high-income and middle-income countries. The underlying idea is that the market does not necessarily price the same ESG factors in developed and emerging countries.

4.1 Selection procedure of the variables

Before handling multivariate models, we must restrain the econometric analysis to a smaller sample of indicators, because we cannot fit a linear model to a set of 300 variables. We are looking for a subset of data that exhibits the strongest effects. We also have to deal with cross-correlations between indicators. As seen in the previous part, some of them are closely related to each other within the themes. For instance, environmental indicators assessing the natural hazards or the climate change only differ in their specific measure and are highly correlated. Keeping these variables may be a source of multi-collinearity, leading to spurious relationships.

The selection process follows two steps. The first step consists in filtering the universe of indicators, based on the results from the single-factor analysis. We decide to exclude ESG indicators that are not statistically significant using a 1% threshold. The selection also deals with missing values in order to obtain a sufficient number of observations to perform a multivariate analysis[20]. At the end of the first step, we retrieve 123 indicators. In the second step, we remove highly interdependent variables. Within fifteen themes, we monitor ESG indicators that present pairwise correlations greater than 80%. If there is no pairwise correlation within a theme, we do not proceed to this filtration. From a couple of highly correlated variables, we pick the indicator showing the highest $\Delta\mathfrak{R}_c^2$ in the single-factor analysis and remove the other[21]. This selection process is useful for the ESG indicators sharing the same dimension but differing in their type of measures. At the end of this second step, we keep 74 indicators.

Remark 2. *We perform also a correction step. Indeed, the statistical dependency between two random variables may be measured by a high positive correlation, but also by a high negative correlation. Let us consider an example with three random variables with* $\rho(X_1, X_2) = 90\%$, $\rho(X_1, X_3) = -90\%$ *and* $\rho(X_2, X_3) = -80\%$. *Using the previous selection procedure, the random variable* X_3 *is kept. However, if we consider the random variable*

[20] We reject the ESG indicator when the time-series has more than 20% of missing values.

[21] An example of the selection procedure is provided in Appendix A.1.1 on page 65.

$X_3' = -X_3$, we obtain $\rho(X_1, X_2) = 90\%$, $\rho(X_1, X_3') = 90\%$ and $\rho(X_2, X_3') = 80\%$. In this case, X_3' is highly correlated to X_1 and X_2. The underlying idea of the selection procedure is to reduce the set of explanatory variables and to keep the most relevant dimensions to explain the bond yield spread. This is why we combine a filtering approach based on pairwise cross-correlations with a filtering approach based on the coefficient of determination. In the previous part, we have seen that the estimated coefficient $\hat{\beta}$ is negative in most cases. However, it may be positive for a few number of explanatory variables. Therefore, raw data are transformed into signed data using the following rules:

$$\begin{cases} x_{i,t} \leftarrow x_{i,t} & \text{if } \hat{\beta} < 0 \\ x_{i,t} \leftarrow -x_{i,t} & \text{if } \hat{\beta} > 0 \end{cases}$$

To illustrate the impact of the selection procedure, we report some statistics on the pairwise correlations in Table 15. After the first step, the average correlation of the 123 selected variables is equal to 13.5%. However, we notice that the range is between −99.5% and 100%, and there are 80 pairwise correlations greater than 80%. However, we observe that 16 pairwise correlations are lower than −80%. The histogram of pairwise correlations is given in Figure 2. The correction procedure shifts the distribution to the right, because it eliminates many negative correlations[22]. The second step allows to reduce the number of high correlations, since we have only 11 pairwise correlations that are greater than 80%. If we compare Figures 2 and 3, we verify that the right tail of the distribution has been reduced. Moreover, a principal component analysis of the two correlation matrices (after the first step and after the second step) reveals that we do not have profoundly changed the stochastic dependence structure of explanatory variables, even if their number has been reduced to 74 (see Figure 4).

Table 15: Statistics of pairwise correlations

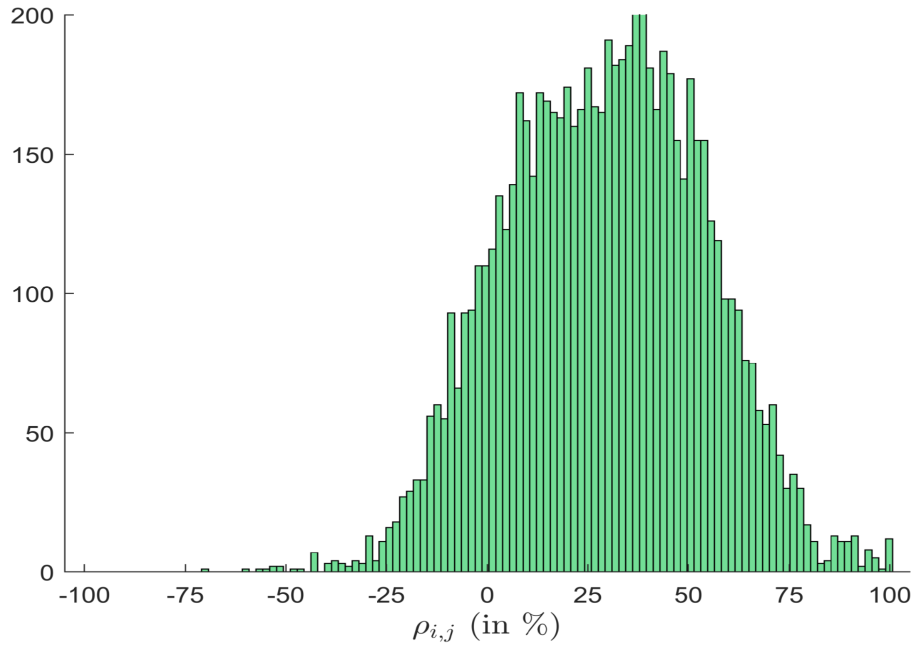
Statistic		Step 1		Step 2	
		Raw data	Signed data	Raw data	Signed data
Mean		13.5	29.1	12.8	26.5
Standard deviation		35.5	24.5	33.8	24.6
Minimum		−99.5	−70.0	−90.8	−70.0
Maximum		100.0	100.0	88.9	90.8
Quantile	1%	−66.9	−24.4	−65.5	−26.1
	5%	−49.9	−10.7	−49.7	−12.8
	10%	−38.7	−3.0	−36.0	−5.4
	25%	−10.2	11.1	−8.7	8.4
	50%	16.5	29.7	14.8	26.0
	75%	40.4	46.8	38.4	45.2
	90%	57.2	60.3	56.7	59.1
	95%	66.0	68.1	65.0	66.4
	99%	80.9	85.9	76.4	76.7
$\#(\rho > 80\%)$		80	96	10	11
$\#(\rho < -80\%)$		16	96	1	0

Remark 3. *We notice that 11 cross-correlations are greater than 80% after the selection procedure. We recall that the second step is performed theme by theme, meaning that the elimination process is done within a theme. This means that there are some high dependence*

[22] The histogram of raw data is given in Figure 18 on page 70.

between variables that belong to different themes. We have decided to not apply the selection procedure between themes, because it will be performed by the lasso regression in the next section.

Figure 2: Histogram of pairwise correlations (signed data, step 1)



4.2 Lasso regression

We now consider a lasso regression procedure in order to find the most relevant features by pillar and then on the whole ESG set. For that, we rewrite Equation (5) as follows:

$$\tilde{y}_{i,t} = \sum_{j=1}^{m} \beta_j \tilde{x}_{i,t}^{(j)} + \sum_{k=1}^{p} \gamma_k \tilde{z}_{i,t}^{(k)} + \tilde{\varepsilon}_{i,t} \tag{6}$$

where $\tilde{y}_{i,t}$, $\tilde{x}_{i,t}^{(j)}$ and $\tilde{z}_{i,t}^{(k)}$ are the centered standardized variables of $y_{i,t} = \ln\left(s_{i,t} + 1\%\right)$, $x_{i,t}^{(j)}$ and $z_{i,t}^{(j)}$. Following Tibshirani (1996), we impose the ℓ_1-norm constraint:

$$\left\|\beta\right\|_1 = \sum_{j=1}^{m} \left|\beta_j\right| \leq \tau \tag{7}$$

Therefore, the lasso estimates are given by the following optimization problem:

$$\begin{aligned} \left(\hat{\beta}, \hat{\gamma}\right) &= \arg\min \frac{1}{2} \operatorname{RSS}\left(\beta, \gamma\right) \\ \text{s.t.} &\quad \left\|\beta\right\|_1 \leq \tau \end{aligned} \tag{8}$$

Figure 3: Histogram of pairwise correlations (signed data, step 2)

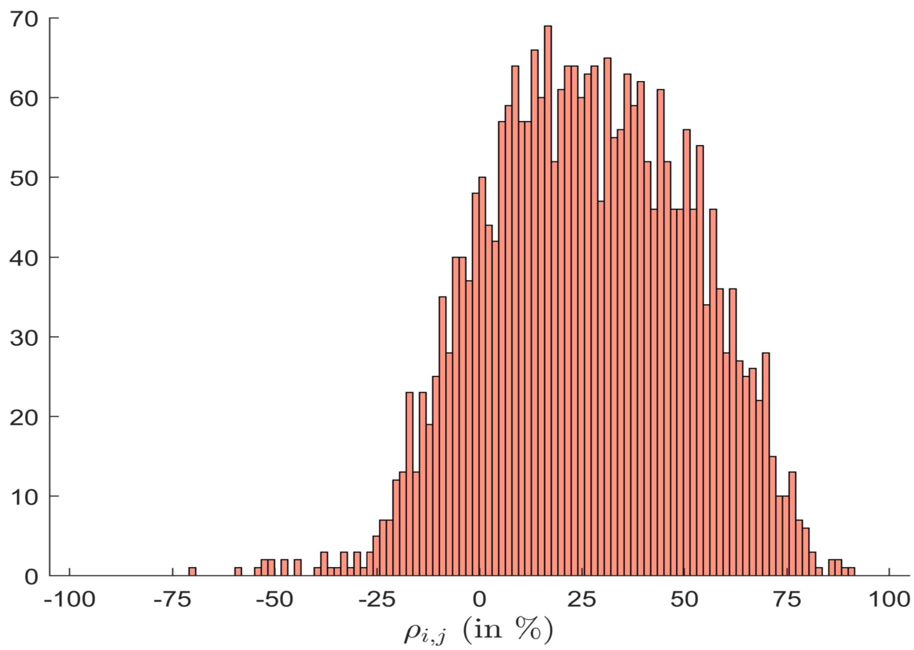
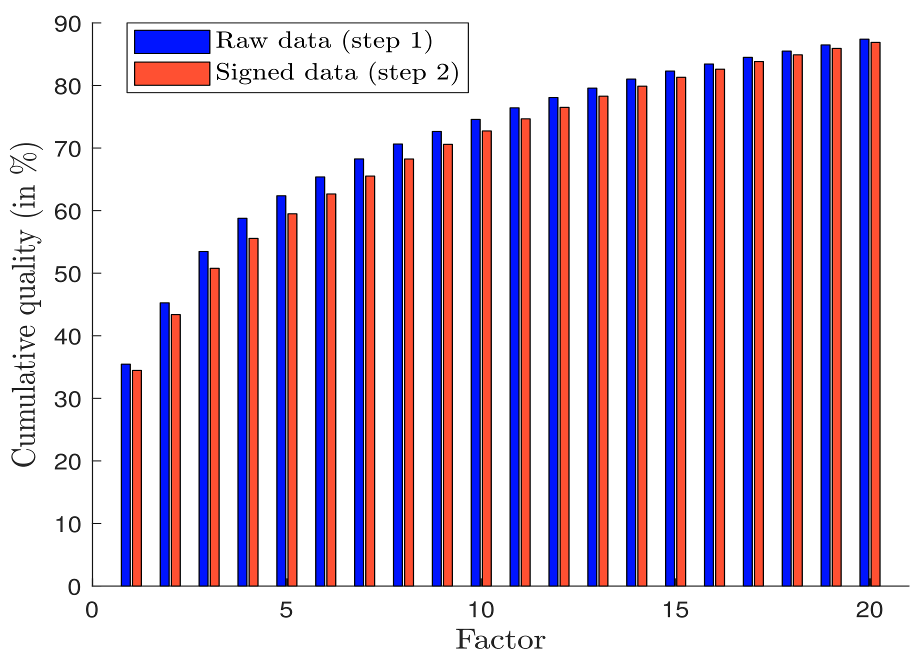


Figure 4: Principal component analysis



where $\text{RSS}(\beta, \gamma) = \sum_{i,t} \hat{\varepsilon}_{i,t}^2$ is the residual sum of squares. Another approach for estimating $\left(\hat{\beta}, \hat{\gamma}\right)$ is to consider a Lagrange problem:

$$\left(\hat{\beta}, \hat{\gamma}\right) = \arg\min \frac{1}{2} \text{RSS}(\beta, \gamma) + \lambda \|\beta\|_1 \tag{9}$$

In this case, we can show that this solution is equivalent to the previous solution by imposing $\tau = \left\|\hat{\beta}\right\|_1$. In Appendix A.1.2 on page 65, we show how to implement the two lasso optimization problems.

Remark 4. *Sometimes, the objective function of the optimization problem is defined with respect to the mean squared error. In this case, we have:*

$$\left(\hat{\beta}, \hat{\gamma}\right) = \arg\min \frac{1}{2} \text{MSE}(\beta, \gamma) + \lambda_{\text{mse}} \|\beta\|_1 \tag{10}$$

We have the following equivalence $\lambda_{\text{mse}} = n^{-1}\lambda$ where n is the number of observations.

In the lasso regression, there is a trade-off between the accuracy of the model and the ℓ_1-norm of the estimated coefficients. By construction, it uses a regularization technique that produces a sparse solution, because the penalization splits the covariates into two groups: useless covariates and useful covariates. The objective is then to determine the importance of each variable in a multivariate framework with respect to the control variables. For instance, we can calculate the degrees of freedom of the model by $\text{df}_\varepsilon = \text{df}_x + \text{df}_z$ where:

$$\text{df}_x = \sum_{j=1}^{m} \mathbf{1}\left\{\left|\beta_j\right| > 0\right\} \tag{11}$$

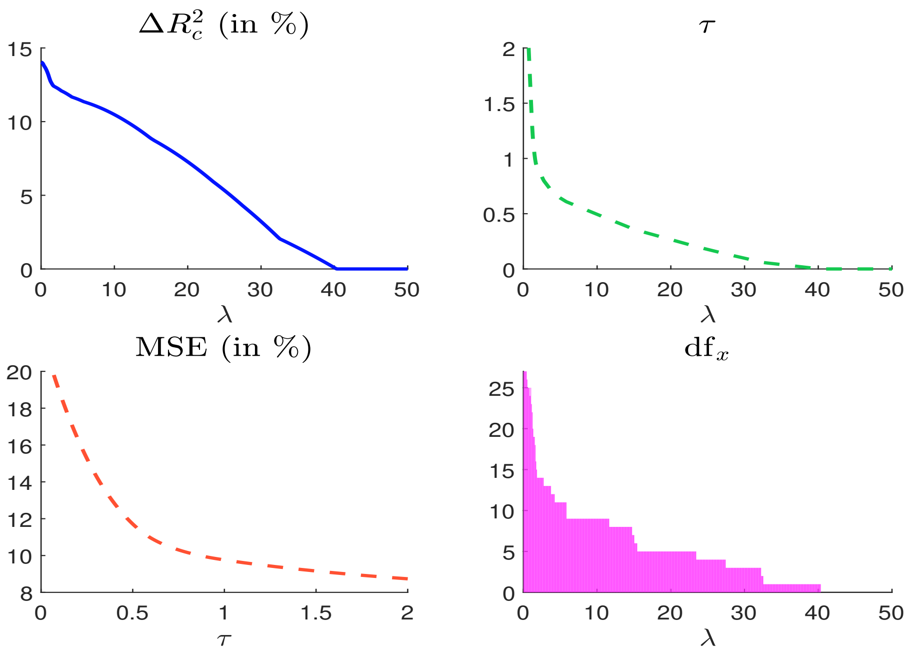
and $\text{df}_z = p$. Since we have $0 \leq \text{df}_x \leq m$, we can select the model with the first, second,... most relevant explanatory variables.

4.2.1 Pillar analysis

We start the lasso analysis by focusing on the selection of indicators within each pillar. Working on the pillar dimension enables to emphasize both the prominent indicators impacting the sovereign yields, and the themes that are material for the market. By this means, we can portray the several aspects of E, S, G, taking separately, that might be concerning for sovereign creditworthiness. We assume that when taken together, several dimensions of ESG investing at the country level might be out of concern while other substantially material. This multivariate framework gives an insight of this dichotomy by first determining the most relevant indicators by pillar and then integrating these indicators altogether into a global analysis. The following results are based on the whole panel, meaning that we focus on the average impact of these indicators, without making any assumption on the countries' particularities.

Environmental pillar Let us consider the selected variables from the environmental pillar. To monitor the consistency of the lasso regression for the variables selection, we provide statistics in Figure 5. The first panel presents the relationship between λ and $\Delta\mathfrak{R}_c^2$. When λ is high, the lasso model reduces to the linear regression model only with the control variables and $\Delta\mathfrak{R}_c^2$ is equal to zero. When λ is equal to zero, the lasso model corresponds to the linear regression model with the explanatory and control variables, and $\Delta\mathfrak{R}_c^2$ is maximum. In this case, we also observe that $\tau = \left\|\hat{\beta}\right\|_1$ and MSE are maximum (second and third panels). In the last panel, we draw the degrees of freedom df_x with respect to λ. We verify that the statistics $\Delta\mathfrak{R}_c^2$, τ, MSE and df_x are a decreasing function of λ. There are several methods to choose the optimal λ. We implement the basic method, which consists in selecting the first $m^\star$ relevant variables and we set $m = 7$.

Figure 5: Statistics of the lasso regression (E pillar)



The list of selected indicators is presented in Table 16. The order selection is given in the fourth column. We observe that the seven most relevant explanatory components are concentrated over five main themes, namely non-renewable energy resources, biodiversity, natural hazard, temperature and commitment to environmental standards. Climate change, natural hazard outcome and water management themes are not part of the final selection. However, we assume that there might be direct links between the selected and the non-selected variables. For instance, the indicators related to climate change are likely to be represented by the temperature change variable as well as the total GHG emission indicator. Natural hazard outcomes are also substantially linked to the metrics directly measuring the intensity and the frequency of natural hazard. Finally, the water aspect of environmental risk might be integrated by the indicator related to drought hazards, but also by the Paris Agreement variable. Despite the fact that the Paris Agreement does not directly integrate water management into its guidelines, one can assume that efficient water management may be a source of resilience against climate challenges.

We plot the estimates of the m relevant indicators in Figure 6, where we draw the value of the lasso estimates with respect to the model statistic $\tau^\star$[23]. We remark that the majority of the indicators have the expected impact on the yields. The two indicators with a positive

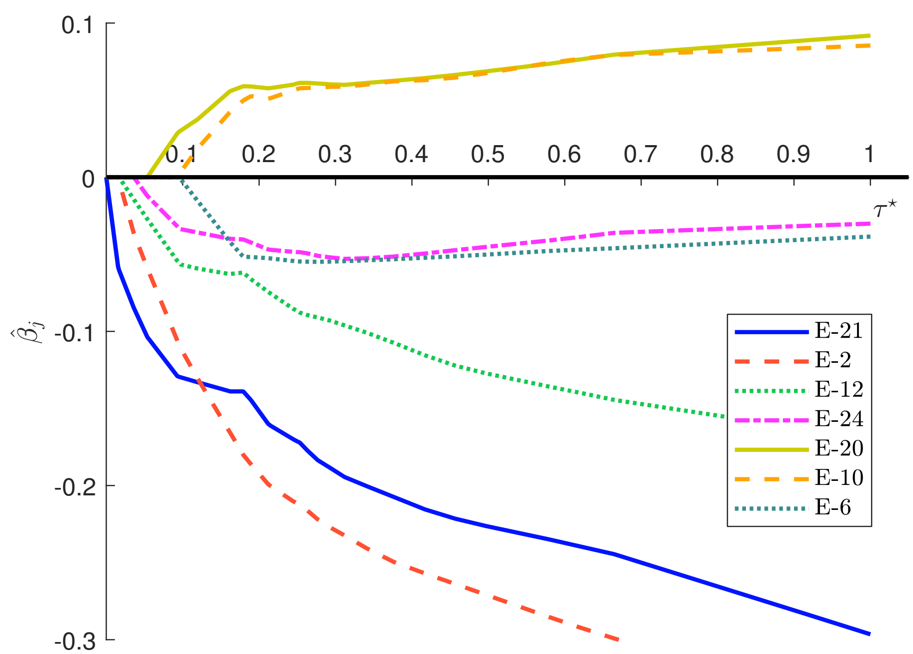
[23] $\tau^\star$ is the ratio between the ℓ_1-norm $\left\|\hat{\beta}\right\|_1$ of the lasso estimates and the ℓ_1-norm $\left\|\hat{\beta}\right\|_1$ of the OLS estimates. By definition, the range of $\tau^\star$ is $[0, 1]$ with the following special cases: $\tau^\star$ is equal to zero when no explanatory variables is selected ($\lambda \to +\infty$) and $\tau^\star$ is equal to one when all explanatory variables are selected ($\lambda = 0$).

Table 16: List of selected variables after the second step (E pillar)

Code	Theme	Variable	Rank
E-1	Biodiversity	Air quality (extreme)	27
E-2	Biodiversity	Biodiversity threatening score	2
E-3	Climate change	Climate change exposure (extreme)	9
E-4	Climate change	Climate change vulnerability (acute)	20
E-5	Commitment to environmental standards	Domestic regulatory framework	14
E-6	Commitment to environmental standards	Paris Agreement	7
E-7	Commitment to environmental standards	Presence of a SEA law	22
E-8	Commitment to environmental standards	Presence of a water law	21
E-9	Energy mix	Energy self sufficiency	13
E-10	Natural hazard	Drought hazard (absolute high extreme)	6
E-11	Natural hazard	Seismic hazard (acute)	10
E-12	Natural hazard	Severe storm hazard (absolute high extreme)	3
E-13	Natural hazard	Tsunami hazard (absolute high extreme)	17
E-14	Natural hazard	Volcanic hazard (absolute hazard area)	23
E-15	Natural hazard outcome	Fatalities from natural disasters	18
E-16	Natural hazard outcome	Earthquakes vulnerability	11
E-17	Natural hazard outcome	Population exposed to natural hazards (absolute)	19
E-18	Natural hazard outcome	Transport infrastructure exposed to natural hazards (absolute)	12
E-19	Non-renewable energy resources	Fossil fuel exports (% of GDP)	15
E-20	Non-renewable energy resources	Fossil fuel intensity of the economy	5
E-21	Non-renewable energy resources	Total GHG emissions	1
E-22	Temperature	Cooling degree days annual average (future)	8
E-23	Temperature	Heat stress (future)	26
E-24	Temperature	Temperature change	4
E-25	Water management	Agricultural water withdrawal	24
E-26	Water management	Water import security (average)	16
E-27	Water management	Water stress (generic)	25

coefficient, namely E-20 (fossil fuel intensity of the economy) and E-10 (drought hazards) are expressed in kiloton per GDP and in km^2 respectively. There is a positive relationship between these indicators and the cost of borrowing. For the other selected indicators, they are expressed in a standardized score, oscillating between 0 (i.e. bad performance) and 10 (i.e. high performance). Only one indicator still has an unexpected sign. Indeed, the E-24 indicator representing the temperature change regarding a fixed threshold, is negatively related to the yields, as found in the single analysis. The first indicator retained by the lasso is E-21. This indicator measuring the country's GHG emissions seems to have a steady negative impact on the yields. This result relies on the decarbonization argument translating that high level of GHG emission increases the transition risk. Countries complying with environmental standards targeting the reduction of carbon emissions mitigate their transition risk. Indeed, countries acting right now to curb their emissions pay a lower yield on their 10-year maturity sovereign bond. The market rewards best-in-class economies regarding their environmental footprint. Moreover, this result can also mirror the principle of *polluter pays*. Countries reluctant to reduce their GHG emissions might expect a higher cost of borrowing. If a country chooses to rest its economy on GHG emitting activities, it will pay the cost on its debt. The second indicator carrying a strong explanatory power in the multivariate analysis is the biodiversity threatening score. The emergency of biodiversity loss is therefore material for the market. Acting for species preservation, depicts commitments to favor natural capital protection. Countries refusing to stem biodiversity loss, pay the induced cost on their debts. The third indicator to be selected by the lasso refers to storm hazards. This result suggests that among physical risks, severe storms are the most material hazards. Severe storms are directly linked to global warming and are expected to increase in intensity and in frequency. Overall, we see that among environmental indicators, transition and physical risks are in the foreground. The commitment to environmental standards, translated by the Paris Agreement, selected seventh, is in the background. It suggests that the market scrutinizes countries in their acts to face the environmental risk, rather than in their faith to act.

Figure 6: Path of the lasso estimates (E pillar)



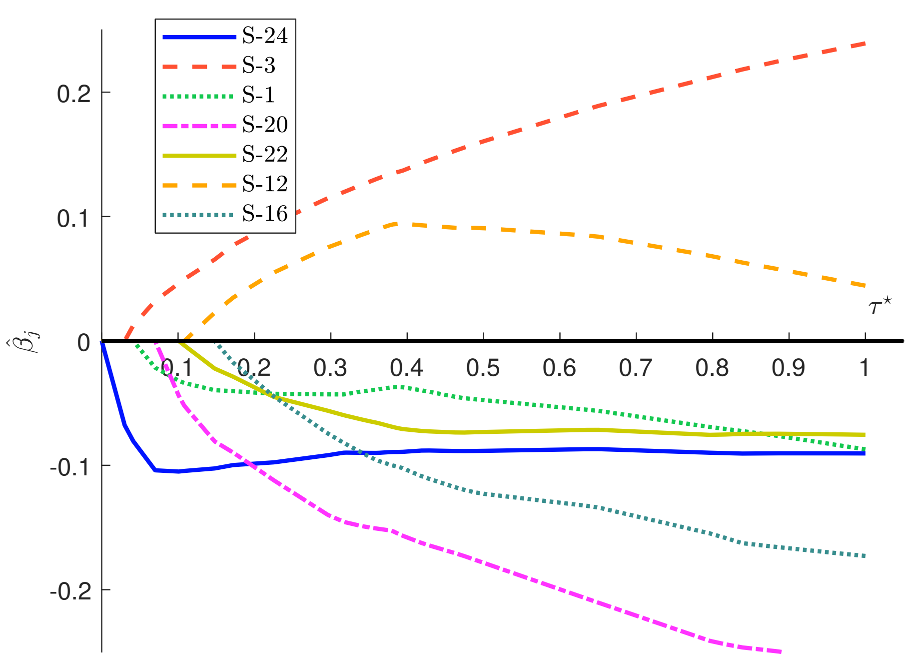
Social pillar We reiterate the previous lasso analysis on the selected variables for the social pillar. The statistics of the lasso regression are provided in Figure 20 on page 71. The list of the selected variables is presented in Table 17. On the first hand, we observe that the selection process leads to a balanced representation of the social pillar's topics since six themes are represented. On the other hand, we are disconcerted by the exclusion of prevalent social themes. We assumed that health, education and gender were determinants to assess sovereign creditworthiness. Unlike the results on the environmental pillar, the nexus between the excluded and included social indicators is not always straightforward to explain. At least, the frequency of civil unrest incidents could originate from a sizable share of the other themes' indicators.

The graphical representation of the lasso estimates is shown in Figure 7. We remark that all of the selected indicators have the expected sign. The two indicators positively related to the yields, namely S-3 (projected population change over five years) and S-12 (the food import security) are expressed in percentage of the population and in ratio between exposure and vulnerability respectively. An increase in these metrics leads to wider bond yield spread. On the negative side, except S-16 (average monthly wage expressed in \$), the

Table 17: List of selected variables after the second step (S pillar)

Code	Theme	Variable	Rank
S-1	Civil unrest	Frequency of civil unrest incidents	3
S-2	Demographics	Age dependency ratio	9
S-3	Demographics	Projected population change (5 years)	2
S-4	Education	Gross completion rate first degree	18
S-5	Education	Mean years of schooling of adults	17
S-6	Education	Public expenditure on education	20
S-7	Gender	Discrimination based on LGBT status	11
S-8	Gender	Women business and the law index	19
S-9	Health	Health expenditure per capita	24
S-10	Health	Life expectancy	14
S-11	Human rights	Basic food stuffs net imports per person	8
S-12	Human rights	Food import security	6
S-13	Human rights	Freedom of assembly	23
S-14	Human rights	Prohibition on torture	13
S-15	Human rights	Significant marginalized group	21
S-16	Income	Average monthly wage	7
S-17	Income	Severance pay	10
S-18	Human rights	Right to a fair trial	22
S-19	Labor market standards	Child labor (extent)	25
S-20	Labor market standards	Index of labor standards	4
S-21	Labor market standards	Right to collective bargaining (protection)	15
S-22	Labor market standards	Right to join trade unions (protection)	5
S-23	Migration	Migrant workers' rights	12
S-24	Migration	Vulnerability of migrant workers	1
S-25	Water and electricity access	Public dissatisfaction with water quality	16

Figure 7: Path of the lasso estimates (S pillar)



indicators are transformed into standardized scores. The first selected indicator from the list is S-14 (vulnerability of migrant workers). Migrant workers are particularly exposed to labor rights or human rights abuses. A fair integration of migrant workers in the society might resonate as a compliance with civil rights' standards. Policies aiming at protecting workers also benefit the labor market and help migrants to accelerate their integration within the host country. The second indicator to be selected is S-3 (projected population change). As seen in the single analysis part, demographic pressures are perceived as negative events that raise the yields. Positive shocks on demographic dynamics may increase the country riskiness, meaning that demographic challenges are crucial for the social pillar. The third indicator entering in the model is S-1 (frequency of civil unrest). As previously discussed, civil unrest is the foreseeable consequence of various turmoil, although it can emanate from diverse dimensions. However, independently of the trigger, protests commonly lead to political instability and economic downturns, which in turn enfeebles the country creditworthiness. Overall, we notice that four indicators out of the seven are sharing a common dimension, the labor aspect. Indeed, the two indicators from the labor standards' theme, the vulnerability of migrant workers and the average monthly wage metric are dealing with working conditions and the protection of labor rights. We easily understand that, at the global level, advanced working conditions are a desired and shared objective for both developed and emerging countries. Broadly speaking, the social pillar is a matter of worker rights.

Governance pillar Concerning the governance pillar[24], the results are presented in Table 18. In the fourth column, we observe that the seven retained indicators are more concentrated than the ones selected for the two other pillars. Only four themes integrate the resulting list. The infrastructure and mobility dimension is by far the most emblematic theme of the G pillar, with a total of three indicators retained. Again, the selection process is excluding several themes that we believed to be prominent in the sovereign analysis. Indeed, none of the indicators related to the government effectiveness, the political stability and the justice themes are included in the final list. However, we believe that these fundamentals actually translate the soundness of a system, that is then able to foster second round effects such as a secured atmosphere, pro-business environment, healthy international relationships and robust infrastructures.

Remark 5. *Although the lasso selection does not select either the government effectiveness index nor the political violence indicator, we must admit that these indicators still play an essential role in explaining sovereign credit spread. Indeed, these indicators are highly correlated to the credit ratings and the sovereign yields. We assume that an effective governance is the anchor point of sustainability and that political violence foresees credit risk, especially when credit rating agencies rest their ratings on these prevalent indicators for the sovereign market. We tried to shed light on this argument in the last section.*

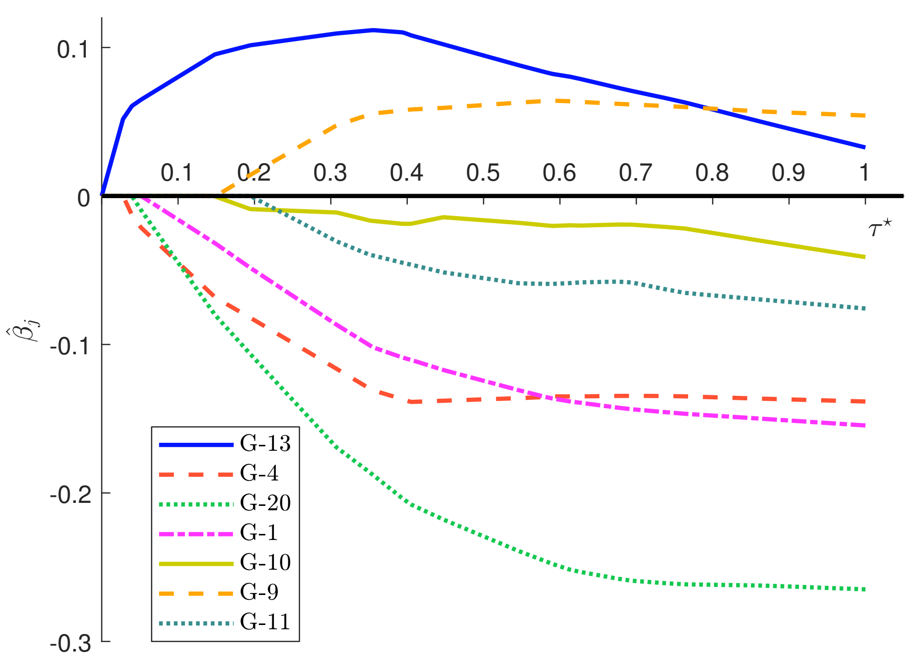
The results of the lasso estimated on the governance indicators are presented in Figure 8. As already hinted at in the single analysis, G-9 (air transport departures), expected to be a strength in the assessment of infrastructure and mobility, is actually positively related to the yields. The other indicators have the expected sign. G-13 (the cost of exporting across borders) measures the cost to export a container, expressed in $. It is the first indicator to be selected by the lasso regression. Countries with effective and globalized market tend to be rewarded with a lower risk premium in the bond market. Meanwhile, we notice that its related blue curve starts to decrease for a value of $\tau^\star$ equal to 0.4, reflecting a lessening of its explanatory power when other indicators are integrated into the model. To a lesser extent, the coefficient of the second indicator to be selected in the lasso, G-4 (ethical behavior of

[24]The statistics related to the lasso regression are available in Figure 21 on page 72.

Table 18: List of selected variables after the second step (G pillar)

Code	Theme	Variable	Rank
G-1	Business environment and R&D	Capacity for innovation	4
G-2	Business environment and R&D	Corporate board effectiveness	15
G-3	Business environment and R&D	Efficacy of the regulatory system	17
G-4	Business environment and R&D	Ethical behavior of firms	2
G-5	Business environment and R&D	R&D expenditure (% of GDP)	16
G-6	Business environment and R&D	Getting electricity (time)	14
G-7	Business environment and R&D	Register property (time)	9
G-8	Government effectiveness	Government effectiveness index	12
G-9	Infrastructure and mobility	Air transport departures	6
G-10	Infrastructure and mobility	Physical connectivity	5
G-11	Infrastructure and mobility	Rail lines km	7
G-12	Infrastructure and mobility	Roads km	19
G-13	International relationships	Exporting across borders (cost)	1
G-14	International relationships	Exporting across borders (time)	11
G-15	International relationships	Trade restrictions (EU)	20
G-16	Justice	Judicial independence	13
G-17	National security	Fatalities from conflict	10
G-18	National security	Military expenditure (% of GDP)	18
G-19	National security	Military expenditure per capita	8
G-20	National security	Severity of kidnappings	3
G-21	Political stability	Political turnover (past 20 years)	21
G-22	Political stability	Political violence	22

Figure 8: Path of the lasso estimates (G pillar)



firms), is plateauing at $\tau^\star = 0.4$. The ethical behavior of firms is material at the country level, as previously highlighted in the single analysis. This result suggests a direct link between ESG at the country scale and ESG at the corporate level. The third indicator to be chosen is G-20 (severity of kidnappings). As formerly discussed, this indicator might depict the level of national security of a country, thus reflecting the well-being of citizens and the country's prosperity. The integration of this indicator tends to be highly relevant, according to the decreasing coefficient associated with the light green dashed curve.

4.2.2 Global analysis

In this section, we retrieve the 21 indicators previously selected in the pillar analysis. The objective is to conduct the lasso analysis over this selection, mixing E, S and G themes, to understand which indicators appear to be the most material at the country level. We perform the analysis over the whole sample, meaning that the ESG analysis can be interpreted at the global level without making any distinction on the country's particularities. This would suggest that some of the ESG dimensions might be integrated globally. The statistics of the lasso regression are available in Figure 22 on page 72. The list containing the ranking selection is presented in Table 19. The first-picked indicator from the whole ESG pool of variables is an indicator of the governance pillar, related to international relationships. Then, we note that the second indicator to be selected by the lasso is coming from natural hazard, a major theme of the environmental pillar. Finally, we remark that the first social indicator to be selected is only ranked tenth. Actually, the seven top-ranked indicators are fairly split between governance and environmental indicators.

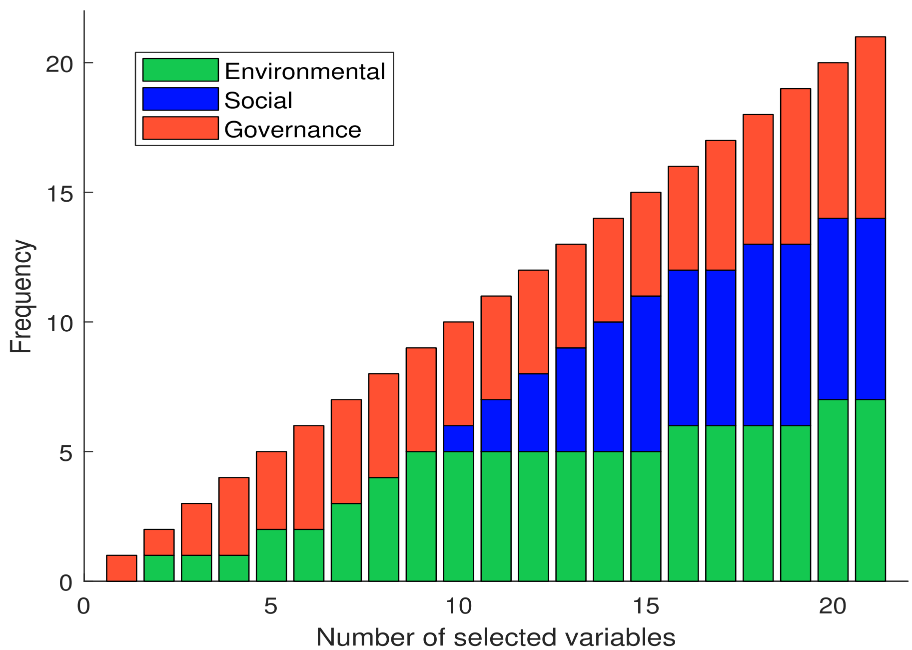
Table 19: List of selected ESG variables

Code	Theme	Variable	Rank
G-13	International relationships	Exporting across borders (cost)	1
E-12	Natural hazard	Severe storm hazard (absolute high extreme)	2
G-1	Business environment and R&D	Capacity for innovation	3
G-4	Business environment and R&D	Ethical behavior of firms	4
E-24	Temperature	Temperature change	5
G-20	National security	Severity of kidnappings	6
E-10	Natural hazard	Drought hazard (absolute high extreme)	7
E-20	Non-renewable energy resources	Fossil fuel intensity of the economy	8
E-2	Biodiversity	Biodiversity threatening score	9
S-20	Labor market standards	Index of labor standards	10
S-3	Demographics	Projected population change (5 years)	11
S-22	Labor market standards	Right to join trade unions (protection)	12
S-12	Human rights	Food import security	13
S-16	Income	Average monthly wage	14
S-1	Civil unrest	Frequency of civil unrest incidents	15
E-21	Non-renewable energy resources	Total GHG emissions	16
G-9	Infrastructure and mobility	Air transport departures	17
S-24	Migration	Vulnerability of migrant workers	18
G-11	Infrastructure and mobility	Rail lines km	19
E-6	Commitment to environmental standards	Paris Agreement	20
G-10	Infrastructure and mobility	Physical connectivity	21

In Figure 9, we illustrate the process selection by emphasizing the importance of the different pillars. This graph represents the order selection from the lasso regression by units of selected variables. Each pillar is represented by a color in order to identify the pillar importance. Undoubtedly, the governance pillar is the winning pillar of the global analysis.

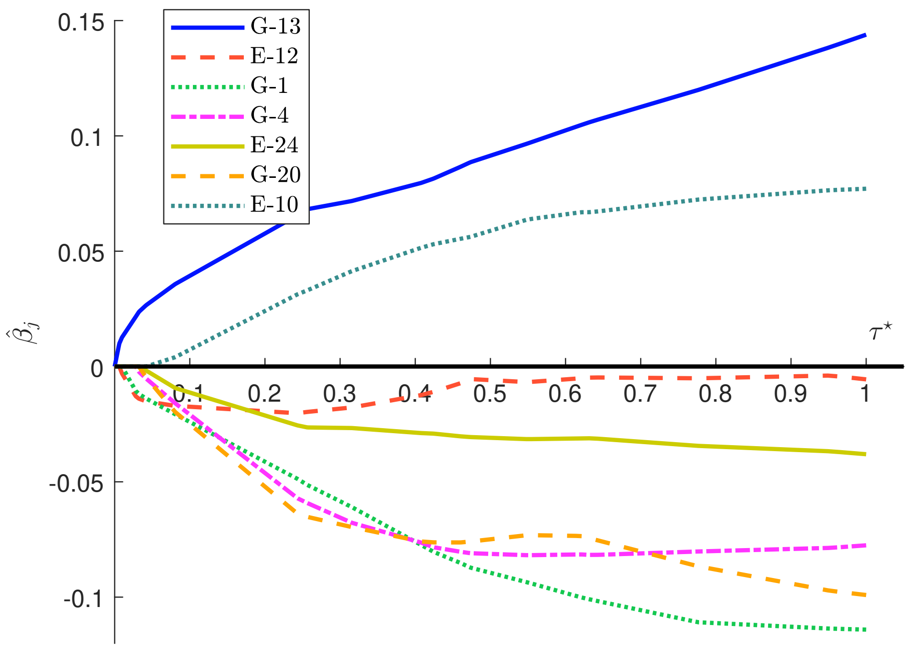
While taking into account the social and environmental impacts on the yields, indicators coming from the G pillar are gradually selected over the first seven steps. As we can see on the graph with the red bars, the integration of the G pillar is predominated by the effect of 4 main indicators until the number of selected variables reaches 16. This means that a substantial share of our ESG model is explained by four indicators related to governance. We notice that the second indicator to be selected is coming from the environmental pillar. This result suggests that globally, country's environmental performance is well integrated by the bond market. Finally, as illustrated by the blue bars, the social pillar is lagging, since nine indicators are selected until the first social metric enters the model. However, we note that starting from ten selected variables, six social indicators are integrated successively. Although they are included later in the model, they represent a larger share of the set of indicators selected consecutively, meaning that their impacts over yields cannot be excluded. However, the social pillar is not integrated by the market globally if we restrict the selection to the first seventh indicators.

Figure 9: ESG pillar importance



Focusing on the indicators per-se, we provide their estimates from the lasso regression in Figure 10. We see that the *contest* between the seven indicators to enter the model is a close-run thing. The first indicator to be selected in this multivariate analysis is G-13 (cost of exporting across borders). We observe that in absolute terms, it has the highest coefficient and a sustained impact on the yields. As seen previously, the indicator might testify the capacity of a country to trade in an effective manner. This indicator is closely followed by E-12 (severe storm hazard). However, we see that this indicator has a more modest impact on the yields as the orange dashed curve is near the x-axis. The third indicator to enter the model is G-1 (capacity for innovation). This indicator, related to R&D aspect of the governance pillar, is a proxy of development and country's willingness to secure international competitiveness, assuming that the country is at a fairly advanced stage of development to invest in innovation capabilities. G-4 (ethical behavior of firms) is fourth. Therefore, the market is sensitive to the microeconomic environment in the sovereign bond pricing. We understand that investors favor countries in which the ESG standards are applied at the corporate level. The ESG performance at the private level notifies the ESG performance at the country level. The fifth indicator to be retained is E-24 (temperature change). The coefficient sign is still inappropriate since we do not expect that a rise in temperature can be rewarded by the market. The penultimate indicator to be retained by the model is G-20 (severity of kidnappings). We observe that the national security aspect of the G pillar comes after the themes related to international relationships and business environment. The last indicator to be selected by the model is E-10 (drought hazard). Threats induced by droughts are material from an investor's viewpoint at the global level. Overall, we observe that indicators coming from the governance pillar have, in absolute terms, a higher impact on the yields than the environmental indicators. This confirms that governance pillar is still the most relevant aspect of the ESG landscape at the global level.

Figure 10: Path of the lasso estimates (ESG pillars)



Remark 6. *Finally, we have estimated the multi-factor model with the seven most relevant ESG indicators. The results are given in Table 29 on page 69. The extra-financial indicators improve the explanatory power of the fundamental model by* 13.51%*.*

4.3 High-income versus middle-income countries

While previous results hold in a global context, the heterogeneity between the development level of the countries composing our panel advocates for a more refined framework of analysis. The rationale behind this split comes from two arguments. First, we assume that the relationship between ESG performance and the sovereign yields is non-linear. There might be differences in the countries' cost of borrowing that originate from their level of development rather than owing to their ESG performance. Intuitively, a country with a high probability of default is not scrutinized over its ESG performance per-se, but rather on its ability to financially face a default[25]. Although we control for this kind of heterogeneity with the set of control variables, the credit rating variable is linear and cannot transcribe perfectly this phenomenon. Second, as indicated by this first statement, there might be relevant ESG metrics to seek, proper to the country's level of development. For instance, one can assume that developed countries might perform well in the environmental front while emerging countries rather target social achievements. If taken altogether, as it is the case in the global analysis, these effects fade. Therefore, we assume that the analysis should be split between the high-income group and the middle-income group. We distinguish high-income and middle-income countries using the classification of the World Bank. The classification is based on the gross national income (GNI) per capita in $. Middle-income economies are those with a GNI per capita between $1,036 and $12,695[26]. High-income economies are those with a GNI per capita superior or equal to $12,696. We have a total of 208 observations with 29 high-income countries and 18 middle-income countries, which we assume to be fairly balanced.

4.3.1 Analysis of high-income countries

We reiterate the lasso analysis on the sample of high-income countries. The list of indicators and their respective ranking is presented in Table 20. The column considering the rank by pillar provides the result of the lasso process for E, S and G topics taken separately (i.e. the seven indicators integrated into the pillar analysis for the high-income group). When considering the global ranking, we observe that the most relevant indicators are coming from the environmental pillar. Among the seven retained indicators, five emanate from the E pillar while two are from the G pillar. The first social indicator to be selected by the lasso is ranked 10$^{\text{th}}$. While the social topics are lagging, the environmental pillar appears to be the winning pillar watched by sovereign bond investors for high-income countries over the past few years.

Figure 11 shows the pillar importance, taking the ESG indicators as a whole for the high-income sample. The plot illustrates the argument previously stated, reflecting that the winning pillar, for the high-income group, is the environmental pillar. For instance, if we had to select only 9 indicators to explain the variation of the yields while controlling for economic effects, we would choose 3 governance indicators against 6 environmental indicators. The entire set of environmental metrics is integrated into the model when the number of selected variables reaches 14 over 21 steps. The G pillar is also relevant for the sample of high-income countries. The first indicator of the G pillar to be selected in the model comes in fourth position. Finally, we see that the social pillar is lagging, with none of the social indicators retained in the list of seven variables, and a feeble integration even after the first indicator get picked up in the model. As a result, none of the social indicators appear relevant for explaining sovereign bond yield spreads in high-income countries. Given the set of indicators used in this analysis, these results suggest that environmental and governance aspects dominate the ESG landscape in bond pricing. Over the past few years, the materiality of social indicators has been in the background for high-income countries.

In Figure 12, we present the lasso estimates of the seven first indicators selected for the high-income group. The first indicator to be picked-up is E-20 (fossil fuel intensity of the economy). The fossil fuel intensity of the economy is therefore the most relevant indicator over the past few years in the ESG landscape for the pricing of bonds in the high-income group. This result gives proof of the integration of the transition risk by the market.

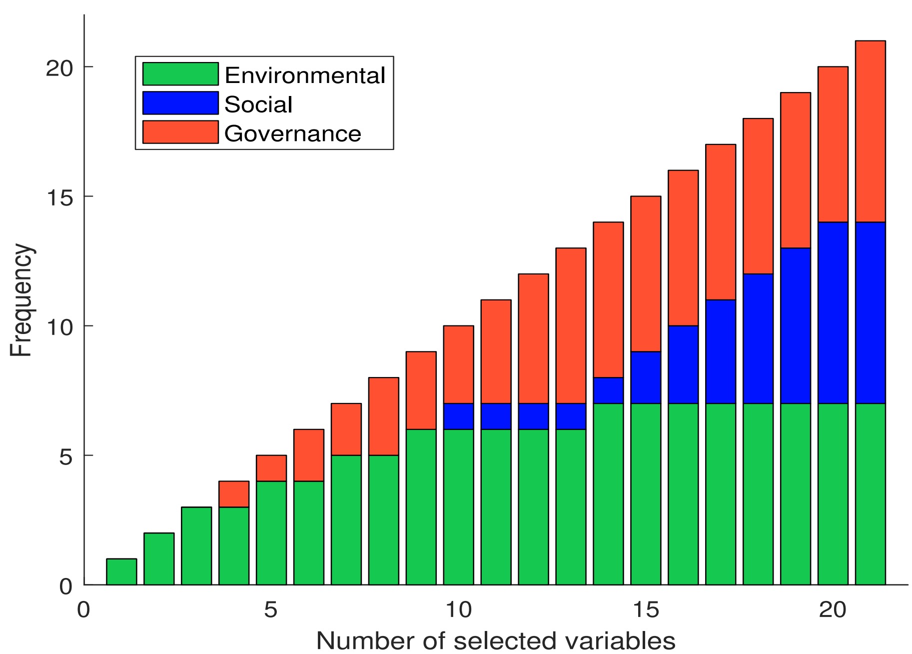
[25] We assume that the two tend to be more and more interconnected, in that ESG performance gives rise to a sustainable economic immunity in the long run.

[26] We do not make the distinction between upper and lower middle-income group.

Table 20: List of selected ESG variables for high-income countries

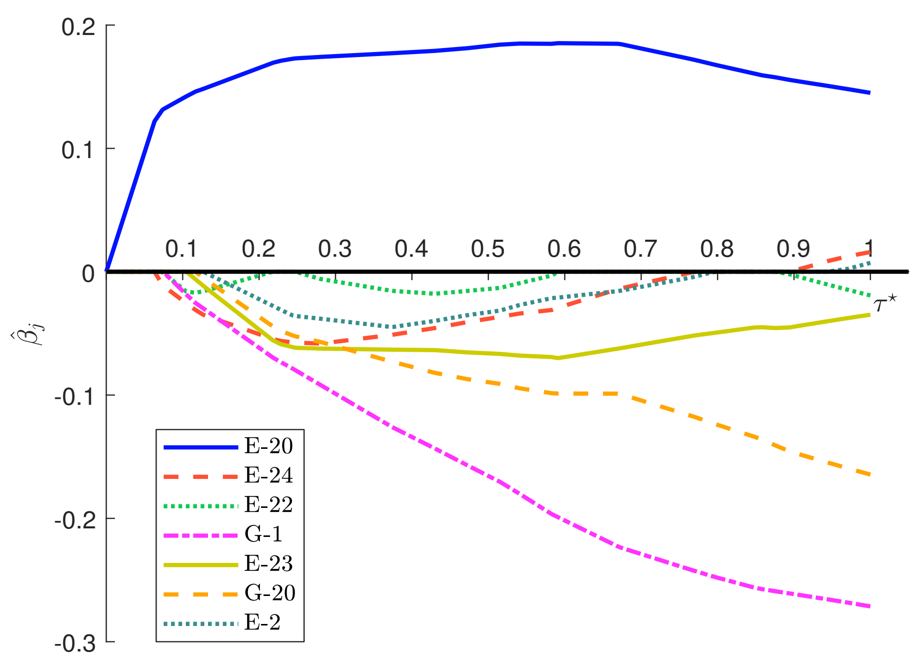
Code	Theme	Description	Global Rank	Pillar Rank
E-20	Non-renewable energy resources	Fossil fuel intensity of the economy	1	1
E-24	Temperature	Temperature change	2	2
E-22	Temperature	Cooling degree days annual average (future)	3	3
G-1	Business environment and R&D	Capacity for innovation	4	1
E-23	Temperature	Heat stress (future)	5	4
G-20	National security	Severity of kidnappings	6	2
E-2	Biodiversity	Biodiversity threatening score	7	5
G-2	Business environment and R&D	Efficacy of corporate boards	8	3
E-21	Non-renewable energy resources	Total GHG emissions	9	7
S-15	Human rights	Significant marginalized group	10	1
G-10	Infrastructure and mobility	Physical connectivity	11	4
G-4	Business environment and R&D	Ethical behavior of firms	12	6
G-11	Infrastructure and mobility	Rail lines km	13	7
E-27	Water management	Water stress (generic)	14	6
S-19	Labor market standards	Child labor (extent)	15	7
S-12	Human rights	Food import security	16	3
S-22	Labor market standards	Right to join trade unions (protection)	17	4
S-3	Demographics	Projected population change (5 years)	18	5
S-14	Human rights	Prohibition on torture	19	6
S-24	Migration	Vulnerability of migrant workers	20	2
G-19	National security	Military expenditure per capita	21	5

Figure 11: ESG pillar importance (high-income countries)



Among the high-income group, countries unaligned with environmental targets such as the Paris Agreement, in order to reduce their dependency on fossil fuel are expected to pay a higher yield on their debt. The following two indicators to be integrated into the model, namely E-24 (temperature change) and E-22 (cooling degree days annual average), have odd curvatures, that make them hard to interpret. They have small and negative coefficients, albeit their effects tend to be shrunk for specific values of $\tau^{\star}$, due to the integration of other variables. The indicator related to the temperature change is reverting, meaning that its effect on the yields is still unclear, as previously discussed. The cooling degree days indicator has only a slight impact. Therefore, the temperature dimension of the environmental risk is doubtful and its impact on the yields tends to be minor for the high-income group. The fourth indicator to enter into the model measures the capacity for innovation. This result suggests that countries investing in R&D are rewarded by the market. This is the most critical governance indicator in the ESG landscape for sovereign bonds issued by the high-income group. The fourth indicator to be integrated by the lasso is E-23 (heat stress), from the temperature theme. Although it has a limited effect on the yields, it remains in negative territory, meaning that reducing exposure to future heat stress tends to lower the sovereign yield. Again, the impact seems to be low and uneven along the x-axis. The fifth indicator to be part of the retained list is G-20 (severity of kidnappings). As discussed previously, this indicator might be understood as a proxy of a safe environment. National security is therefore material for investors and ranked as the second most important theme in the governance pillar among high-income countries. Finally, E-2 (threat to biodiversity) is also integrated into the model. The curve of the indicator conveys a modest but negative impact on the yields. This result gives evidence that biodiversity losses are scrutinized by investors. Countries acting for the biodiversity preservation might be rewarded with tighter bond yield spreads.

Figure 12: Path of the lasso estimates (high-income countries)



4.3.2 Analysis of middle-income countries

The list of selected variables for the middle-income group analysis is presented in Table 21. For the middle-income group, we notice that the most relevant indicator is coming from the E pillar. Unlike the high-income group and the global analysis, there is no lagging pillar, meaning that the ESG landscape is fully accounted for in sovereign bond issued by countries from the middle-income group. Indeed, among the seven indicators selected, two are from the E pillar, two are from the S and three from the G. Once again, we remark that the selection process in the pillar analysis excluded prominent themes. Despite the presence of social and governance indicators, education, health and government effectiveness are not taking part of the resulting list of selected variables.

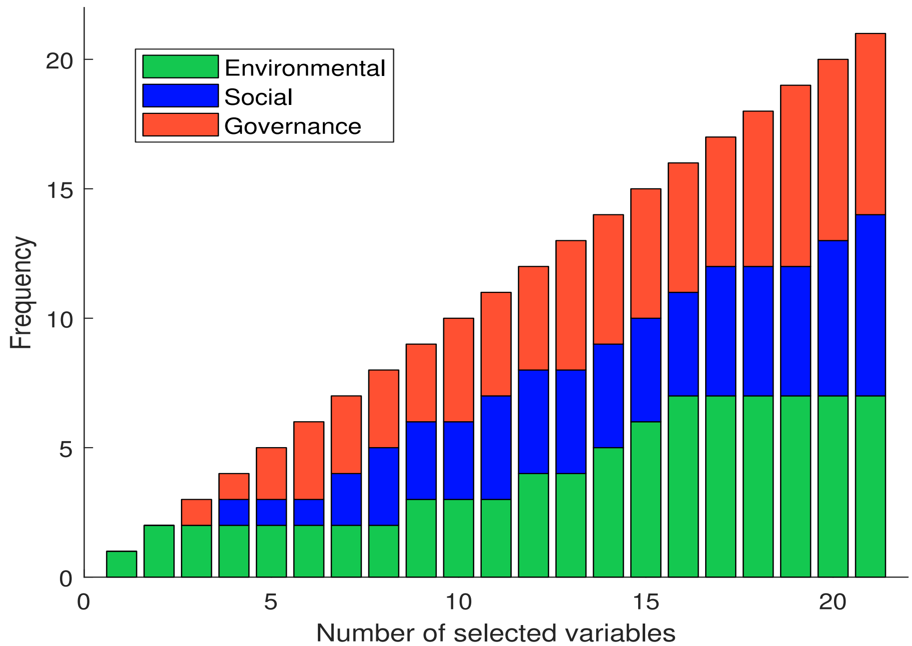
Table 21: List of selected ESG variables for middle-income countries

Code	Theme	Description	Global Rank	Pillar Rank
E-13	Natural hazard	Tsunami hazard (absolute high extreme)	1	1
E-18	Natural hazard outcome	Transport infrastructure exposed to natural hazards (absolute)	2	2
G-20	National security	Severity of kidnappings	3	2
S-7	Gender	Discrimination based on LGBT status	4	3
G-9	Infrastructure and mobility	Air transport departures	5	3
G-13	International relationships	Exporting across borders (cost)	6	1
S-20	Labor market standards	Index of labor standards	7	1
S-24	Migration	Vulnerability of migrant workers	8	2
E-6	Commitment to environmental standards	Paris Agreement	9	3
G-18	National security	Military expenditure (% of GDP)	10	6
S-23	Migration	Migrant workers' rights	11	5
E-11	Natural hazard	Seismic hazard (acute)	12	7
E-7	Commitment to environmental standards	Presence of a SEA law	13	6
E-10	Natural hazard	Drought hazard (absolute high extreme)	14	5
E-27	Water management	Water stress (generic)	15	4
S-3	Demographics	Projected population change (5 years)	16	4
G-21	Political stability	Political turnover (past 20 years)	17	7
G-14	International relationships	Exporting across borders (time)	18	5
S-25	Water and electricity access	Public dissatisfaction with water quality	19	7
S-1	Civil unrest	Frequency of civil unrest incidents	20	6
G-6	Business environment and R&D	Getting electricity (time)	21	4

The pillar importance is presented in Figure 13. We clearly observe the perfect balance between the pillars, since each colored bar increases gradually at a similar path. For instance, if we have to choose only 9 variables, we will take 3 from the E pillar, 3 from the S pillar and 3 from the G pillar. We also notice that the model caps the environmental pillar with two key indicators at the beginning of the selection process, meaning that they are central in explaining the yields in middle-income countries. Finally, we see that the entire set of environmental indicators is selected first, suggesting a better integration of the E pillar for the middle-income group. Nonetheless, for now, we cannot assuredly claim that the environmental pillar is the winning pillar in the middle-income analysis.

Now focusing on the selected indicators, we provide the middle-income group lasso estimates in Figure 14. The first indicator to enter the model is E-13 (tsunami hazard). Despite the inconstancy of the curve, the indicator has a strong impact on the yields. Therefore, tsunami hazards represent the most material physical risk for middle-income country cred-

Figure 13: ESG pillar importance (middle-income countries)

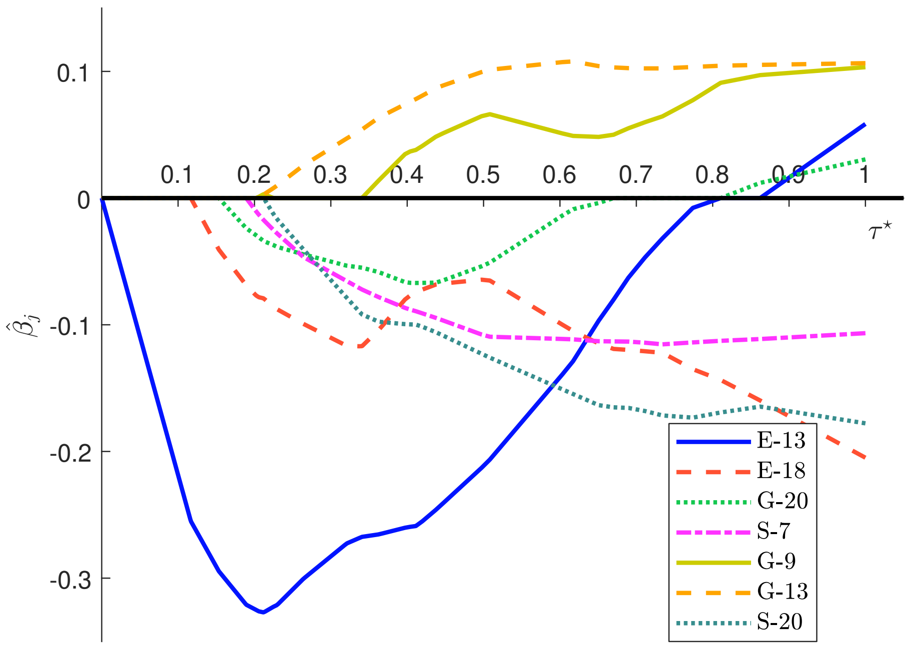


itworthiness[27]. The second indicator to be integrated into the model is E-18 (transport infrastructure exposed to natural hazards). Disruptions of transport caused by natural hazards can immobilize a country for months. Long lasting effects of natural hazards hampers economic activity and delays improvements in human development. Moreover, we easily understand that transport channels disruptions can impede emergency response's efficiency, making the externalities of natural hazards even heavier. Based on these two environmental indicators, we observe a cleavage between the two income groups. While high-income countries' yields rest on the action taken to face climate change, sovereign yields of middle-income countries are rather sensitive to the occurrence of extreme weather events and to the resilience against natural hazards. Even though the environmental pillar is priced in the two samples, the dimension of the E differs substantially between them. The third indicator selected by the lasso is G-20 (severity of kidnapping). This indicator is the only metric in common for both the middle-income group and the high-income group. It confirms the preponderance of national security in the ESG landscape, albeit the impact of the indicator is lower on the yield for the middle-income group compared to the high-income group. The first indicator of the social pillar entering the model is ranked fourth. S-7 measures the extent of discrimination based on LGBT status in a country. Policies sanctioning discrimination and right abuses against LGBT status are rewarded by the bond market participants. Indeed, it transcribes a fair integration of human rights in the country. Social progress is therefore characterized by countries where policymakers are acting for human rights protection. The fourth indicator to be present in the resulting list is G-9 (air transport departures). Again, we notice a counter intuitive path of the indicator in the sense that an increase of flight departures is associated with a higher yield. We doubtfully can argue that air transport would yet be integrated by the market as a transition risk, in that aviation's contribution to global warming cannot be set apart from other sources of pollution. This would suggest

[27] The burden of tsunami hazards is mainly shared by countries coming from the Pacific-rim and the South Asia region, where a significant part of the middle-income countries is located.

that countries relying on air traffic in their means of exchange could face a higher transition risk in the future. The sixth indicator to integrate the list is G-13 (cost of exporting across borders). In middle-income countries, the lower the cost of exporting a container across border, the lower the yield. It translates the trade effectiveness of a country. The last indicator to enter the model is S-20 (index of labor standards). Fair working conditions are therefore scrutinized by investors, reflecting a key ESG element for middle-income countries. We can also argue that violations of labor rights may lead to civil unrest and political violence in middle-income countries that could enfeeble creditworthiness.

Figure 14: Path of the lasso estimates (middle-income countries)



5 Explaining credit ratings with ESG indicators

In this final section, we approximate the part of sovereign credit ratings that can be explained by ESG indicators. We suppose here that credit rating agencies, although focusing on financial criteria to assess the creditworthiness of a country, may inherently appraise ESG performance since it can have a material impact on a country's solvency. Thus, extra-financial indicators could complement financial criterion when assessing a country creditworthiness. It suggests that credit risk analysis cannot be dissociated from ESG considerations, invalidating the dichotomy between fundamental and extra-financial analysis. Therefore, we could argue that social progress, environmental mitigation or governance effectiveness are cardinal factors of the country creditworthiness, for which investors are prone to pay a premium. We are interested in quantifying the overlap between ESG variables that matter for investors and those actually employed by credit rating agencies. Then, we attempt to measure the importance of the different pillars in explaining credit ratings. To do so, we model the probability of a country to be rated upper-grade regarding its performance over several ESG indicators.

5.1 Presentation of the regression model

We want to predict the probability of a country to be included in the high-rated category based on its ESG performance. To model this relationship, we employ logistic regression models. Such model uses a logistic function to link a set of predictors to a binary dependent variable. Conversely to the linear model, it enables to predict probabilities between 0 and 1. The binary dependent variable used to represent the credit rating category is based on our composite credit score computed as the average credit rating from three main credit rating agencies (S&P, Moody's and Fitch). This averaged indicator permits to balance the ratings between these agencies while approximating the creditworthiness of a country numerically. We developed the construction of the score on page 15. From this indicator, we have to find a threshold value that splits efficiently the panel between low and high credit ratings. Moreover, in our panel, the credit ratings are predominantly concentrated over the investment grade universe[28]. Thus, we cannot assume a distinction between investment grade and high yield as an effective split. However, we observe a distinct separation between the two categories when the composite credit score stands at 65. The correspondence list for the rating categories is presented in Appendix A.2 on page 68. The high-rated group includes countries with an upper-grade notch (ratings from AAA to A−). The low-rated group includes countries with a lower-grade notch (ratings from BBB+ to CCC). The two groups are fairly homogeneous in term of sample size, since we have 161 and 145 observations for the high and low-rated group respectively.

In order to analyze which indicator might explain the probability of a country to be rated upper-grade, we estimate a logit model:

$$\Pr\left\{\mathcal{G}_{i,t}=1\right\}=\mathbf{F}\left(\beta_0+\sum\nolimits_{j=1}^{m}\beta_j x_{i,t}^{(j)}\right) \tag{12}$$

where $\mathcal{G}_{i,t}=1$ indicates if the country i is rated upper-grade[29] at time t, $\mathbf{F}(z)=\dfrac{e^z}{1+e^z}$ is the cumulative function of the logistic distribution, and $x_{i,t}^{(j)}$ is the j^{th} selected indicator. Equation (12) can be written as:

$$p_{i,t}=\Pr\left\{\mathcal{G}_{i,t}=1\right\} \tag{13}$$

and:

$$\ln\left(\frac{p_{i,t}}{1-p_{i,t}}\right)=\beta_0+\sum\nolimits_{j=1}^{m}\beta_j x_{i,t}^{(j)} \tag{14}$$

where $p_{i,t}$ is the probability to be rated upper-grade and the expression $\ln\left(\dfrac{p_{i,t}}{1-p_{i,t}}\right)$ corresponds to the log-odds ratio. The coefficients $\left\{\beta_j, j=1,\ldots,m\right\}$ are estimated using the maximum likelihood method. If the predicted probability $\hat{p}_{i,t}$ is greater than 50%, the country is classified as belonging to the upper-grade category. If the coefficients of the model are expressed in the log-odds format, the interpretation of these coefficients is not straightforward. This is why we prefer to express the coefficients in odds ratio which are more intuitive to interpret. Thus, a value greater (resp. lower) than 1 suggests that an increase of the variable by one unit raises (resp. decreases) the probability of integrating the upper-grade group. Then, the model is used to estimate the accuracy of indicators to predict the credit ratings.

[28] When opting for the mainstream rule IG vs. HY, we have 84 (resp. 71) observations where countries are rated speculative against 222 (resp. 235) rated investment grade if we use the S&P (resp. Moody's) classification.

[29] $\mathcal{G}_{i,t}=0$ indicates if the country i is rated lower-grade at time t

5.2 Pillar accuracy to predict credit ratings

5.2.1 The overlap of ESG indicators

To identify the metrics that are meaningful in explaining the probability of a country to integrate the upper-grade rating segment, we have to conduct a complete analysis of the entire set of indicators. We cannot assume that the selected indicators of the previous section would be automatically fitted to this model. Indeed, in previous analysis, we have expressed the relationship between sovereign yields and ESG indicators while controlling for the potential impact of other variables such as the composite credit score. Therefore, we have already indirectly confronted the credit ratings to the indicators, although in a different manner. Indeed, we have demonstrated that some ESG indicators are strong drivers of sovereign yields' variance, not caught by the composite rating score itself. As this section puts the credit rating in the foreground, we may assume that the set of selected indicators may differ substantially from the previous one. In this case, it would demonstrate that investors and credit rating agencies do not ground their fundamental analysis on the same pieces of information.

Here again, we cannot study the impact of the entire set of indicators. To filter the initial universe of 269 indicators we perform several steps. First, we still base our initial selection on the representativeness argument in keeping only the variables with a good historical coverage. We reject the variables with more than 15% of missing data. Second, we perform univariate logistic regressions to retain only the most relevant indicators. We only select the variables that are statistically significant at 1%. Finally, from this list of 100 indicators, we use lasso regressions to select the seven most relevant indicators by pillar. Table 22 presents the resulting list of 21 indicators, and the rank of each indicator within the corresponding pillar.

Table 22: List of selected ESG variables for the logistic regression

Theme	Variable	Rank
Commitment to environmental standards	Domestic regulatory framework	1
Climate change	Climate change vulnerability (average)	2
Water management	Water import security (average)	3
Energy mix	Energy self-sufficiency	4
Water management	Wastewater treatment index	5
Water management	Water intensity of the economy	6
Biodiversity	Biodiversity threatening score	7
Health	Health expenditure per capita	1
Water and electricity access	Public dissatisfaction with water quality	2
Education	Mean years of schooling of adults	3
Income	Base pay / value added per worker	4
Demographics	Urban population change (5 years)	5
Human rights	Basic food stuffs net imports per person	6
Human rights	Food import security	7
Government effectiveness	Government effectiveness index	1
Business environment and R&D	Venture capital availability	2
Business environment and R&D	R&D expenditure (% of GDP)	3
Infrastructure and mobility	Customs efficiency	4
Business environment and R&D	Enforcing a contract (time)	5
Business environment and R&D	Paying tax (process)	6
Business environment and R&D	Getting electricity (time)	7

The selection process leads to a pool of variables substantially different from the one retained as determinant of sovereign yields for the global analysis in the multi-factor part. Only the indicator related to the threat to biodiversity in the environment pillar is also present in this resulting list. We remark that the list integrates previously excluded themes such as health, education, government effectiveness and climate change. We also observe that prominent indicators such as the mean years of schooling of adults, the governance effectiveness index and the climate change vulnerability are part of this list. Overall, there is a low overlap between the ESG indicators that drive sovereign spreads and those captured in credit ratings. This result may reflect a divergence between ESG topics scrutinized by investors and those embodied by credit rating agencies. However, we reiterate that the selection of ESG indicators in the previous section is based on several control variables, including the credit ratings. Therefore, it is normal that an ESG indicator is not selected twice: a first time to explain the credit rating of the country and a second time to explain the sovereign spread of the country, which is already explained by its credit rating.

5.2.2 Environmental pillar

We start the analysis with the environmental pillar. The regression results are presented in Table 23. The parameters are reported in odds format — $\hat{\theta}_j = e^{\hat{\beta}_j}$, while the t-student and p-value statistics correspond to the raw parameters $\hat{\beta}_j$. From the seven selected indicators, only four are statistically significant at 1% but all head in the right direction. We notice that, at the country level, improving the security regarding water import, incorporating environmental laws in the domestic regulatory framework, reducing the vulnerability regarding climate change and acting to persevere the biodiversity increase the probability of a country to stand in the upper-grade rating category. As suggested by the t-student, we emphasize the importance of the climate change vulnerability indicator within the environmental pillar. Hence, countries that are vulnerable to climate change may expect rating downgrades. Conversely, a one unit increase in the resilience of a country regarding climate change leads to an odds ratio of 2.929, implying a higher likelihood to receive a high rating. Overall, we observe that the model accuracy to predict the sovereign's rating is not very efficient since the model is wrong in 16.4% of the cases. Moreover, we estimate the quality of the fitted model with the pseudo R-squared[30]. The latter stands at 49.1%, suggesting a low efficiency of the set of environmental indicators in predicting ratings.

Table 23: Logit model with environmental variables

Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Domestic regulatory framework	1.415	0.156	3.16^{***}	0.00
Climate change vulnerability (average)	2.929	0.572	5.51^{***}	0.00
Water import security (average)	1.385	0.147	3.07^{***}	0.00
Energy self-sufficiency	0.960	0.033	-1.16	0.24
Wastewater treatment index	1.011	0.008	1.36	0.17
Water intensity of the economy	1.000	0.000	-1.02	0.30
Biodiversity threatening score	0.887	0.026	-4.02^{***}	0.00

$\ell\left(\hat{\beta}\right) = -107.60$, AIC $= 231.19$, $\mathfrak{R}^2 = 49.1\%$, ACC $= 83.6\%$

[30] The pseudo R-squared or McFadden's R-squared is equal to $\mathfrak{R}^2 = 1 - \frac{\ell\left(\hat{\beta}\right)}{\ell\left(\hat{\beta}_0\right)}$ where $\ell\left(\hat{\beta}\right)$ is the log-likelihood value of the fitted model and $\ell\left(\hat{\beta}_0\right)$ is the log-likelihood value of the intercept model — $\Pr\left\{\mathcal{G}_{i,t} = 1\right\} = \mathbf{F}\left(\beta_0\right)$.

5.2.3 Social pillar

The results for the social indicators are presented in Table 24. All of the metrics are significant at 1%, suggesting that this set of social indicators is well suited to predict the sovereign rating group. The signs of the coefficients are also intuitive. In addition, we notice that the rating prediction of this model is based on a well-balanced set of themes such as education, demographic dynamics or health. Besides, the impact of the indicator measuring the change in urban population is high. Overall, the model is better than the previous one as suggested by the AIC criterion and the pseudo $\mathfrak{R}^2$. Social indicators enable to make good predictions of sovereign credit ratings since this model is right in 87.9% of the cases. Thus, we assume that credit rating agencies heavily relate the creditworthiness of a country to its extra-financial variables that belong to the social pillar.

Table 24: Logit model with social variables

Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Health expenditure per capita	1.001	0.000	3.47^{***}	0.00
Public dissatisfaction with water quality	0.889	0.024	-4.27^{***}	0.00
Mean years of schooling of adults	2.710	0.583	4.64^{***}	0.00
Base pay / value added per worker	0.000	0.000	-5.13^{***}	0.00
Urban population change (5 years)	1.653	0.131	6.36^{***}	0.00
Basic food stuffs net imports per person	0.996	0.001	-3.58^{***}	0.00
Food import security	0.973	0.006	-4.33^{***}	0.00

$\ell\left(\hat{\beta}\right) = -72.41$, AIC $= 160.83$, $\mathfrak{R}^2 = 65.6\%$, ACC $= 87.9\%$

5.2.4 Governance pillar

Results are given in Table 25. As suggested by the statistics, the governance pillar is the best one, since it gives the most effective and accurate predictions. We notice that the significant indicators are concentrated over the theme assessing the business environment of a country (time to get electricity, time to enforce a contract and procedures for paying taxes). It suggests that credit rating agencies are looking scrupulously over this dimension among others to rate a country. Intuitively, improving the quality and the effectiveness of the business environment strengthens the creditworthiness of a country. Moreover, the venture capital availability seems to be a determinant factor of the G pillar. A one unit increase in this score leads to an increase of the odds ratio by 1.020. The accuracy of the model in predicting the probability of a country to be rated upper-grade is equal to 90.1%, which is a high figure.

Table 25: Logit model with governance variables

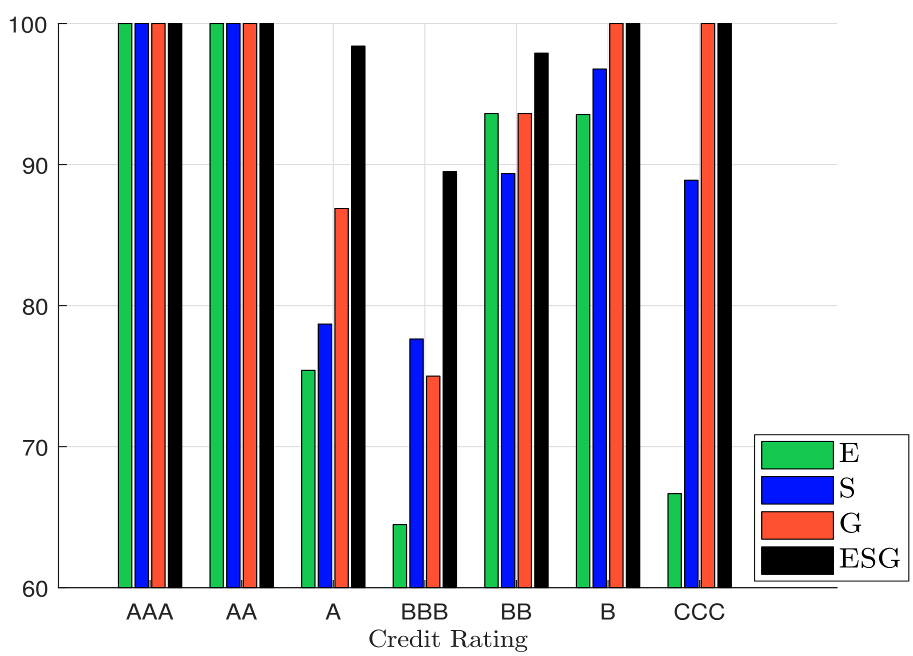
Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Government effectiveness index	1.096	0.035	2.81^{***}	0.00
Venture capital availability	1.020	0.005	4.16^{***}	0.00
R&D expenditure (% of GDP)	2.259	1.006	1.83^{*}	0.06
Customs efficiency	2.193	1.657	1.04	0.29
Enforcing a contract (time)	0.997	0.001	-3.69^{***}	0.00
Paying tax (process)	0.914	0.031	-2.63^{***}	0.00
Getting electricity (time)	0.989	0.004	-2.73^{***}	0.00

$\ell\left(\hat{\beta}\right) = -67.78$, AIC $= 151.57$, $\mathfrak{R}^2 = 67.9\%$, ACC $= 90.1\%$

5.2.5 Pillars' prediction accuracy

Finally, in Figure 15, we illustrate the model accuracy in predicting the credit ratings separately for each rating groups. First, we observe that the governance pillar is leading the others. For the majority of the rating groups, the governance pillar's accuracy to predict rating is higher than the one obtained with environmental or social data. The governance indicators are less effective to determine a country rating than the social ones only in the BBB segment of rating. This segment is particularly difficult to predict because it encompasses the defined separation threshold. In the other cases, indicators from the G pillar are, solely, predicting at least 90% of the sovereign credit ratings. Second, we notice the perfect accuracy of the models in predicting the sovereign ratings for the highest rating groups (AAA and AA ratings). The results are sparse for the lower-grade ratings. While the B rating group is generally well predicted by the indicators from the three pillars, the CCC segment is predicted perfectly only when using the governance indicators. The G pillar is therefore the most reliable pillar to approximate the whole universe of sovereign ratings. Third, unlike the results found in the previous section, we notice that the environmental pillar is lagging, displaying a lower level of prediction accuracy. This is particularly true for the CCC segment, where the prediction accuracy falls below 70%. This result suggests that credit ratings are less sensitive to the E pillar. Overall, we understand that sovereign credit ratings encompass extra-financial metrics and are correlated to E, S and G indicators.

Figure 15: Prediction accuracy in % of logit models



5.3 Combining ESG variables to predict credit ratings

Let us now perform the logistic regression over the set of ESG indicators from the three combined pillars. Using the statistically significant variables from the previous analysis, we obtain the results given in Table 26. When mixing the three pillars altogether, we observe that some variables do not remain significant. Indeed, only five (resp. seven) variables are statistically significant at 1% (resp. 5%). The environmental indicators vanish, corroborating the weak power of the E pillar to predict sovereign credit ratings. These results confirm that governance and social dimensions certainly lead the analysis. We witness that the indicator assessing (1) the mean years of schooling of adults is particularly relevant for the analysis since it displays the highest t-student. For every one-year increase in the schooling time, the odds ratio for a country to be assigned a strong credit rating increases by a factor of 68. The other important dimensions are (2) getting electricity, (3) the urban population change, (4) venture capital availability and (5) food import security. As attested by the statistics, taking ESG indicators as a whole improves the prediction accuracy. In 96.7% of the cases, the model is right in predicting the sovereign credit rating based on the selected ESG metrics[31].

Table 26: Logit model with the ESG selected variables

Pillar	Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
E	Domestic regulatory framework	2.881	2.108	1.44	0.14
	Climate change vulnerability (average)	0.275	0.302	-1.17	0.24
	Water import security (average)	0.717	0.467	-0.50	0.61
	Biodiversity threatening score	1.029	0.199	0.14	0.88
S	Health expenditure per capita	0.998	0.002	-1.10	0.26
	Public dissatisfaction with water quality	1.332	0.269	1.41	0.15
	Mean years of schooling of adults	68.298	85.559	3.37^{***}	0.00
	Base pay / value added per worker	0.000	0.000	-1.07	0.28
	Urban population change (5 years)	3.976	1.857	2.95^{***}	0.00
	Basic food stuffs net imports per person	0.990	0.004	-2.07^{**}	0.03
	Food import security	0.803	0.067	-2.59^{***}	0.00
G	Government effectiveness index	1.751	0.412	2.37^{**}	0.01
	Venture capital availability	1.099	0.035	2.93^{***}	0.00
	Enforcing a contract (time)	0.999	0.004	-0.31	0.75
	Paying tax (process)	0.846	0.096	-1.47	0.14
	Getting electricity (time)	0.882	0.037	-2.95^{***}	0.00

$\ell\left(\hat{\beta}\right) = -18.91$, AIC $= 71.83$, $\mathfrak{R}^2 = 91.1\%$, ACC $= 96.7\%$

If we perform an analysis by credit rating segment, we obtain the following prediction accuracy ratios: 100% for ratings AAA, AA, B and CCC, 98.4% for rating A, 97.9% for rating BB and 89.5% for rating BBB. Therefore, combining the three pillars improves the prediction accuracy for all rating segments. In the worst case (corresponding to the BBB rating), the model is right in almost 90% of the cases. For the other segments, the prediction accuracy is close to 100%. Given the set of selected ESG indicators, the model is highly efficient since it manages to perfectly predict the rating affiliations of countries regardless of financial metrics and development levels. Therefore, this result shows that the gap between fundamental and extra-financial assessments can actually be quite tight. Over the past years, extra-financial indicators form relevant metrics to approximate sovereign credit ratings. The materiality of ESG indicators is then critical from the credit rating viewpoint. It does not mean that extra-financial indicators explain financial indicators, but they are correlated. This explains the high interconnectedness between sovereign credit ratings and some ESG variables.

[31] This is also emphasized by the pseudo $\mathfrak{R}^2$ which reaches 91.1%.

6 Conclusion

In this paper, building on 26 ESG themes, we first assess how relevant 269 variables are when it comes to explaining the sovereign credit spreads of 67 countries between 2015 and 2020. As a matter of fact, all the chosen themes embody metrics that determine a country creditworthiness, which corroborates extra-financial criteria being integrated into bond pricing by investors. The subset made up of the most significant variables ensures a fairly well-balanced representation of the environmental, social and governance pillars. For each pillar, we then use lasso regression to pick those with the strongest explanatory power on bond yield spread. Finally, 21 ESG metrics are selected. On the global sample, results demonstrate the prevalence of non-renewable energy resources, threats to biodiversity, natural hazards and commitment to environmental standards. We highlight that both transition and physical risks are therefore accounted for. On the social front, migration, demographic pressures, civil unrest, labor market standards, human rights and income inequality seem to be priced into the sovereign bond market. We note that most of these themes echo working conditions, which therefore must be carefully watched by investors. As far as governance is concerned, international relationships, business environment and R&D, national security, infrastructure and mobility dominate the other themes. For a country, these factors act as safeguards for smooth and efficient international trade, competitiveness, but also for diplomatic relationships.

However, dropping the pillar analysis, and working on the different E, S and G metrics altogether portrays a different picture. The three pillars are not equally important when looking at the global sovereign bond pricing picture. Indeed, governance and environmental aspects dominate social themes. Refining this analysis on separate samples of high-income vs. middle-income countries, we conclude that environmental issues are actually at the forefront of investors concerns when assessing sovereign risk. However, we observe a divergence between the two income groups regarding the environmental dimension. While sovereign yields in high-income countries are related to actions taken to combat climate change, sovereign yields in middle-income countries are rather sensitive to their ability to handle natural hazards and mitigate their impacts. Those results reflect the perception of the investors that transition risk primarily impacts developed countries whereas emerging countries are more concerned by physical risk. Governance follows closely, independently of the level of development. The clear cut-off between high- and middle-income countries also lies in the importance of the social pillar. For highest income countries, it is picked well after E and G metrics. For middle-income countries, it is nearly as important as governance. We believe that these phenomena could be explained by the homogeneity among high-income countries on many social achievements. There would be more leeway for improvements in middle-income countries, that would therefore be more closely scrutinized by investors. All in all, improvements in the identified E, S and G metrics induce a lower borrowing cost for the sovereign issuer, but the importance of each distinct pillar is a function of the country's level of development.

Finally, attempting to predict credit ratings solely based on extra-financial criteria, we demonstrate that governance and social pillars are actually the most critical factors. The E pillar is lagging, suggesting that credit rating agencies tend to underweight environmental issues. Taking all ESG indicators together, we attest that for each rating segment, the set of selected indicators makes a correct prediction in 95% of the cases on average. However, we obtain higher figures for high (AAA and AA) and low (B and CCC) rating segments and lower figures for middle rating segments (A, BBB and BB). Interestingly enough, we remark that the set of selected metrics to predict the ratings substantially differs from the one used to explain the sovereign bond yields. At first sight, we could conclude that there is divergence in the ESG indicators used by credit rating agencies and those scrutinized by investors to appraise the country risk. Nevertheless, we could also argue that the market selects ESG metrics that are not already embedded in credit ratings to avoid double counting.

Our analysis not only sheds light on the key ESG metrics and themes priced in directly and indirectly by the bond market, but also allows us to rank the influence of the different E, S and G pillars depending on the country's level of development, highlighting that all factors are not equal. This is insightful since some of the identified ESG indicators could complement a traditional credit risk analysis when deciding to hold a sovereign bond or evaluating the country risk premium. In this context, opposing extra-financial and fundamental analysis does not make a lot of sense. On the contrary, our results advocate for a greater integration of ESG analysis and credit analysis when assessing sovereign risk.

Table 27: Summary of the results

What is directly priced in by the market?	What is indirectly priced in by credit rating agencies?
E ≻ **G** ≻ **S** Significant market-based ESG indicators ≠	**G** ≻ **S** ≻ **E** Relevant CRA-based ESG indicators
• High-income countries Transition risk ≻ Physical risk • Middle-income countries Physical risk ≻ Transition risk	**E** metrics are second-order variables: • Environmental standards • Water management • Biodiversity • Climate change
S matters for middle-income countries, especially for Gender inequality, Working conditions and Migration	Education, Demographics and Human rights are prominent indicators for the **S** pillar
National security, Infrastructure and mobility and International relationships are the relevant **G** metrics	Government effectiveness, Business environment and R&D dominate the **G** pillar
Fundamental analysis: $\mathfrak{R}_c^2 \approx 70\%$ Extra-financial analysis: $\Delta\mathfrak{R}_c^2 \approx 13.5\%$	Accuracy $> 95\%$ AAA, AA, B, CCC ≻ A ≻ BB ≻ BBB

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A Appendix

A.1 Technical appendix

A.1.1 Selection procedure of the variables

To illustrate the selection procedure, we consider the following example:

Variable	$\Delta\mathfrak{R}_c^2$	Correlation $\rho_{i,j}$					
		X_1	X_2	X_3	X_4	X_5	X_6
X_1	2.12%	1.00	0.74	0.80	0.48	**0.92**	0.77
X_2	3.89%	0.74	1.00	0.65	0.51	0.73	**0.89**
X_3	4.80%	**0.80**	0.65	1.00	0.54	0.79	0.71
X_4	3.95%	0.48	0.51	0.54	1.00	0.76	**0.81**
X_5	3.11%	**0.92**	0.73	0.79	0.76	1.00	0.89
X_6	5.51%	0.77	0.89	0.71	**0.81**	0.89	1.00

For each variable, we conduct the selection process on the highest pairwise correlation. We obtain the following pairs: (X_1, X_5), (X_2, X_6), (X_3, X_1), (X_4, X_6), (X_5, X_1) and (X_6, X_5). Among these couples, we retain the variables showing the highest $\Delta\mathfrak{R}_c^2$, namely X_3, X_5 and X_6. We see that X_3 has no correlation coefficient higher than 80% with the two other variables X_5 and X_6. Thus, we select this variable. However, we see that X_5 and X_6 are showing high correlation. Thus, we reiterate the same process on these variables. We prefer X_6 to X_5 due to its higher power of explanation. As a result, we keep X_3 and X_6 in this example.

A.1.2 Solving the lasso problem

We consider the following linear regression problem:

$$Y = X\beta + Z\gamma + U \tag{15}$$

where Y is a $n \times 1$ vector, X is a $n \times m$ matrix, β is a $m \times 1$ vector, Z is a $n \times p$ matrix, γ is a $p \times 1$ vector and U is a $n \times 1$ vector. In this equation, Y is the endogenous variable, X is the set of exogenous variables, Z is the set of control variables and U is the residual. Let $\theta = (\beta, \gamma)$ be the vector of parameters. We can write Equation (15) as follows:

$$Y = M_{x,z}\theta + U \tag{16}$$

where $M_{x,z} = \begin{pmatrix} X & Z \end{pmatrix}$ is the $n \times (m + p)$ matrix of explanatory variables. We deduce that the OLS estimate is:

$$\hat{\theta}_{\text{ols}} = \begin{pmatrix} \hat{\beta}_{\text{ols}} \\ \hat{\gamma}_{\text{ols}} \end{pmatrix} = \left(M_{x,z}^\top M_{x,z}\right)^{-1} M_{x,z}^\top Y \tag{17}$$

In the case of the lasso regression, we impose that:

$$\|\beta\|_1 = \sum_{j=1}^{m} \left|\beta_j\right| \leq \tau \tag{18}$$

In order to solve the lasso problem, we use the quadratic programming (QP) algorithm with the technique of augmented variables. For that, we write β as follows:

$$\beta = \beta^+ - \beta^- \tag{19}$$

where $\beta^{+} \geq \mathbf{0}_m$, $\beta^{-} \geq \mathbf{0}_m$ and $\min\left(\beta^{+}, \beta^{-}\right) = 0$. We deduce that:

$$\begin{aligned}
\theta &= \begin{pmatrix} \beta \\ \gamma \end{pmatrix} \\
&= \begin{pmatrix} I_m & -I_m & \mathbf{0}_{m,m} \\ \mathbf{0}_{p,m} & \mathbf{0}_{p,m} & I_p \end{pmatrix} \begin{pmatrix} \beta^{+} \\ \beta^{-} \\ \gamma \end{pmatrix} \\
&= M_\theta \tilde{\theta} \qquad (20)
\end{aligned}$$

The residual sum of squares associated with the linear regression (16) is equal to:

$$\begin{aligned}
\operatorname{RSS}(\theta) &= \left(Y - M_{x,z}\theta\right)^\top \left(Y - M_{x,z}\theta\right) \\
&= Y^\top Y - \theta^\top M_{x,z}^\top M_{x,z}\theta - 2\theta^\top M_{x,z}^\top Y \\
&= Y^\top Y - \tilde{\theta}^\top \tilde{M}_{x,z}^\top \tilde{M}_{x,z}\tilde{\theta} - 2\tilde{\theta}^\top \tilde{M}_{x,z}^\top Y \qquad (21)
\end{aligned}$$

where:

$$\begin{aligned}
\tilde{M}_{x,z} &= M_{x,z} M_\theta \\
&= \begin{pmatrix} X & Z \end{pmatrix} \begin{pmatrix} I_m & -I_m & \mathbf{0}_{m,m} \\ \mathbf{0}_{p,m} & \mathbf{0}_{p,m} & I_p \end{pmatrix} \\
&= \begin{pmatrix} X & -X & Z \end{pmatrix} \qquad (22)
\end{aligned}$$

Moreover, we have:

$$\begin{aligned}
\|\beta\|_1 &= \sum_{j=1}^{m} \beta_j^{+} + \sum_{j=1}^{m} \beta_j^{-} \\
&= \mathbf{1}_m^\top \beta^{+} + \mathbf{1}_m^\top \beta^{-} \\
&= \begin{pmatrix} \mathbf{1}_m^\top & \mathbf{1}_m^\top & \mathbf{0}_p^\top \end{pmatrix} \tilde{\theta} \qquad (23)
\end{aligned}$$

We conclude that the augmented QP problem is defined by:

$$\begin{aligned}
\tilde{\theta}^\star(\tau) &= \arg\min_\theta \frac{1}{2}\tilde{\theta}^\top Q \tilde{\theta} - \tilde{\theta}^\top R \qquad (24) \\
&\text{s.t.} \quad \left\{ \begin{array}{l} \begin{pmatrix} \mathbf{1}_m^\top & \mathbf{1}_m^\top & \mathbf{0}_p^\top \end{pmatrix} \tilde{\theta} \leq \tau \\ \tilde{\theta}^{-} \leq \tilde{\theta} \end{array} \right.
\end{aligned}$$

where $\tilde{\theta}^{-} = \left(\mathbf{0}_{2m}, -\infty \cdot \mathbf{1}_p\right)$ is a $(2m+p) \times 1$ vector,

$$\begin{aligned}
Q &= \tilde{M}_{x,z}^\top \tilde{M}_{x,z} \\
&= \begin{pmatrix} X^\top \\ -X^\top \\ Z^\top \end{pmatrix} \begin{pmatrix} X & -X & Z \end{pmatrix} \\
&= \begin{pmatrix} X^\top X & -X^\top X & X^\top Z \\ -X^\top X & X^\top X & -X^\top Z \\ Z^\top X & -Z^\top X & Z^\top Z \end{pmatrix} \qquad (25)
\end{aligned}$$

and:

$$\begin{aligned} R &= \tilde{M}_{x,z}^{\top} Y \\ &= \begin{pmatrix} X^{\top} Y \\ -X^{\top} Y \\ Z^{\top} Y \end{pmatrix} \end{aligned} \tag{26}$$

Therefore, the lasso estimator is equal to:

$$\begin{pmatrix} \hat{\beta}_{\text{lasso}}(\tau) \\ \hat{\gamma}_{\text{lasso}}(\tau) \end{pmatrix} = M_{\theta} \tilde{\theta}^{\star}(\tau) \tag{27}$$

Remark 7. *Another way to estimate $\hat{\theta}_{\text{lasso}}$ is to consider the Lagrange optimization problem:*

$$\hat{\theta}_{\text{lasso}}(\lambda) = \arg\min \frac{1}{2} \text{RSS}(\theta) + \lambda \left\| \beta \right\|_1 \tag{28}$$

The associated augmented QP problem is:

$$\begin{aligned} \tilde{\theta}^{\star}(\lambda) &= \arg\min_{\theta} \frac{1}{2} \tilde{\theta}^{\top} Q \tilde{\theta} - \tilde{\theta}^{\top} R(\lambda) \\ \text{s.t.} &\quad \tilde{\theta}^{-} \leq \tilde{\theta} \end{aligned} \tag{29}$$

where:

$$\begin{aligned} R &= \tilde{M}_{x,z}^{\top} Y + \lambda \begin{pmatrix} \mathbf{1}_m^{\top} & \mathbf{1}_m^{\top} & \mathbf{0}_p^{\top} \end{pmatrix} \\ &= \begin{pmatrix} X^{\top} Y \\ -X^{\top} Y \\ Z^{\top} Y \end{pmatrix} - \lambda \begin{pmatrix} \mathbf{1}_m \\ \mathbf{1}_m \\ \mathbf{0}_p \end{pmatrix} \end{aligned} \tag{30}$$

Therefore, the lasso estimator is equal to:

$$\begin{pmatrix} \hat{\beta}_{\text{lasso}}(\lambda) \\ \hat{\gamma}_{\text{lasso}}(\lambda) \end{pmatrix} = M_{\theta} \tilde{\theta}^{\star}(\lambda) \tag{31}$$

We have the following correspondance:

$$\hat{\theta}_{\text{lasso}}(\lambda) = \hat{\theta}_{\text{lasso}}(\tau) \tag{32}$$

where:

$$\tau = \left\| \hat{\beta}_{\text{lasso}}(\lambda) \right\|_1 \tag{33}$$

A.2 Credit rating composite

Table 28: Correspondence table of the sovereign credit ratings

Group	S&P	Moody's	Fitch	Score	Category
AAA	AAA	Aaa	AAA	100	Upper-grade
AA	AA+	Aa1	AA+	95	
	AA	Aa2	AA	90	
	AA−	Aa3	AA−	85	
A	A+	A1	A+	80	
	A	A2	A	75	
	A−	A3	A−	70	
BBB	BBB+	Baa1	BBB+	65	Lower-grade
	BBB	Baa2	BBB	60	
	BBB−	Baa3	BBB−	55	
BB	BB+	Ba1	BB+	50	
	BB	Ba2	BB	45	
	BB−	Ba3	BB−	40	
B	B+	B1	B+	35	
	B	B2	B	30	
	B−	B3	B−	25	
CCC	CCC+	Caa1	CCC	15	
	CCC	Caa2	CC	10	
	CCC−	Caa3		5	

A.3 List of countries

Here is the list of the 67 countries that are used in the statistical analysis:

- High-income countries (38) Canada, Chile, United States, Cyprus, Hong Kong, Israel, Japan, Singapore, South Korea, Taiwan, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, Australia, New Zealand

- Middle-income countries (29) Uganda, Egypt, Kenya, Morocco, Namibia, Nigeria, South Africa, Tanzania, Zambia, Brazil, Colombia, Mexico, Peru, Bangladesh, China, Georgia, India, Indonesia, Lebanon, Malaysia, Pakistan, Philippines, Sri Lanka, Thailand, Turkey, Vietnam, Bulgaria, Russia, Ukraine

A.4 ESG indicators

We use a database of 269 ESG indicators. 183 indicators come from the Verisk Maplecroft database. These indicators have been completed by 86 indicators from EDGAR, EM-DAT, EPI, FAO, IEA, ILO, IUCN, ISSA, SIPRI, UN, UNESCO, UNPD, UNSA, USGS, WDI, WEF, WGI, WHO and World Bank.

A.5 Complementary results

Table 29: Final multi-factor model (global analysis)

Variable	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	t-student	p-value
Intercept α	2.834	0.180	15.72***	0.00
GDP growth $g_{i,t}$	0.017	0.012	1.37	0.17
Inflation $\pi_{i,t}$	0.048	0.007	6.64***	0.00
Debt ratio $d_{i,t}$	−0.001	0.001	−1.71*	0.08
Current account balance $ca_{i,t}$	−0.012	0.005	−2.45**	0.01
Reserve adequacy $r_{i,t}$	0.005	0.007	0.74	0.45
Rating score $\mathcal{R}_{i,t}$	−0.013	0.001	−9.08***	0.00
Exporting across borders (cost)	0.000	0.000	4.11***	0.00
Severe storm hazard (absolute high extreme)	−0.015	0.009	−1.66*	0.09
Capacity for innovation	−0.004	0.001	−4.99***	0.00
Ethical behavior of firms	−0.061	0.021	−2.79***	0.00
Temperature change	−0.149	0.042	−3.50***	0.00
Severity of kidnappings	−0.032	0.007	−4.25***	0.00
Drought hazard (absolute high extreme)	0.000	0.000	2.60***	0.00

$\Delta\mathfrak{R}_c^2 = 13.51\%$, F-test $= 29.28$***

Figure 16: Scatter plot of $y_{i,t}$ and $\hat{y}_{i,t}$ when the endogenous variable is the spread $s_{i,t}$

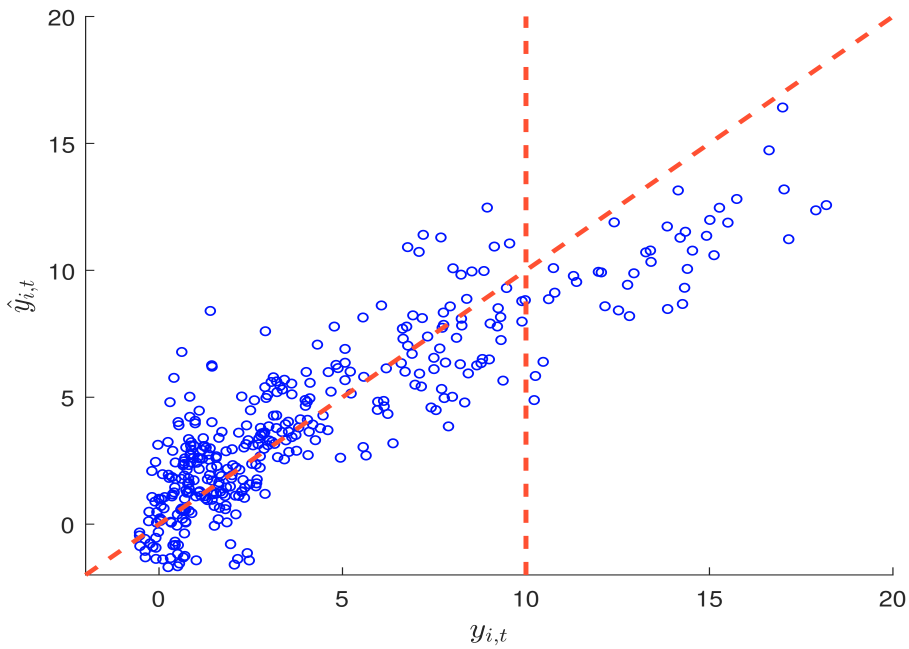


Figure 17: Scatter plot of $y_{i,t}$ and $\hat{y}_{i,t}$ when the endogenous variable is equal to $\ln\left(s_{i,t} + 1\%\right)$

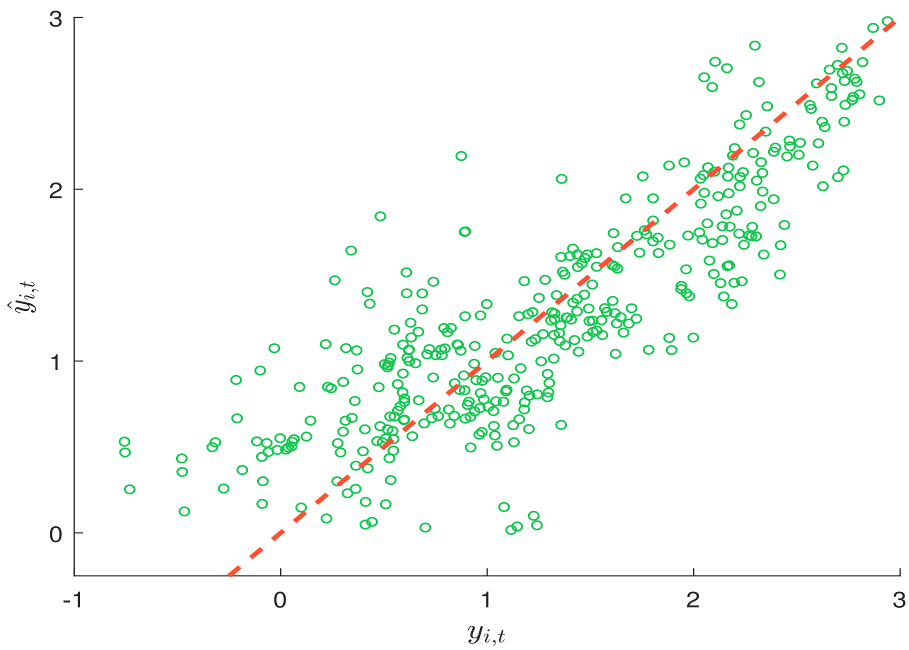


Figure 18: Histogram of pairwise correlations (raw data)

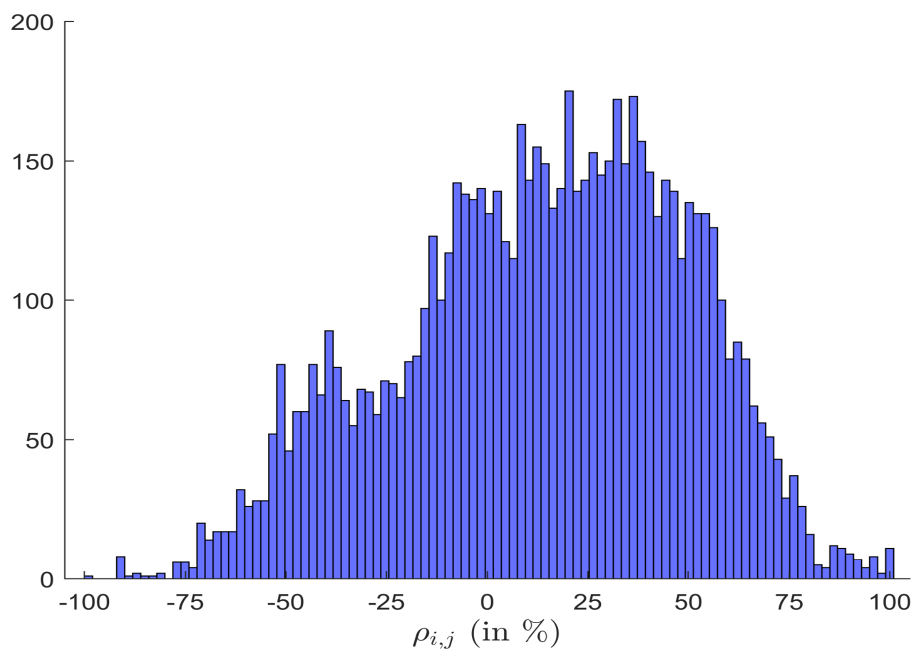


Figure 19: Histogram of pairwise correlations (selected raw data)

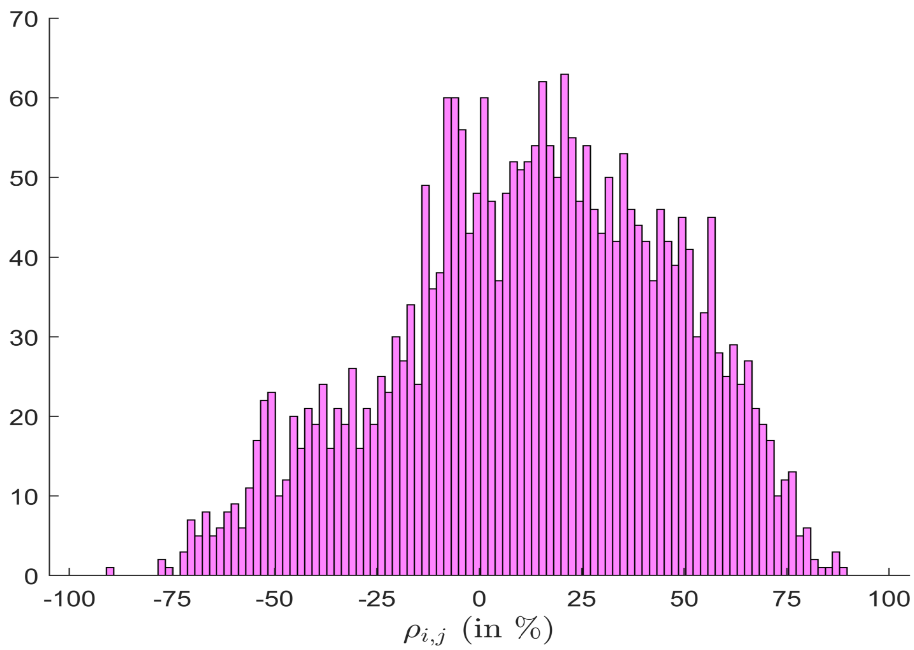


Figure 20: Statistics of the lasso regression (S pillar)

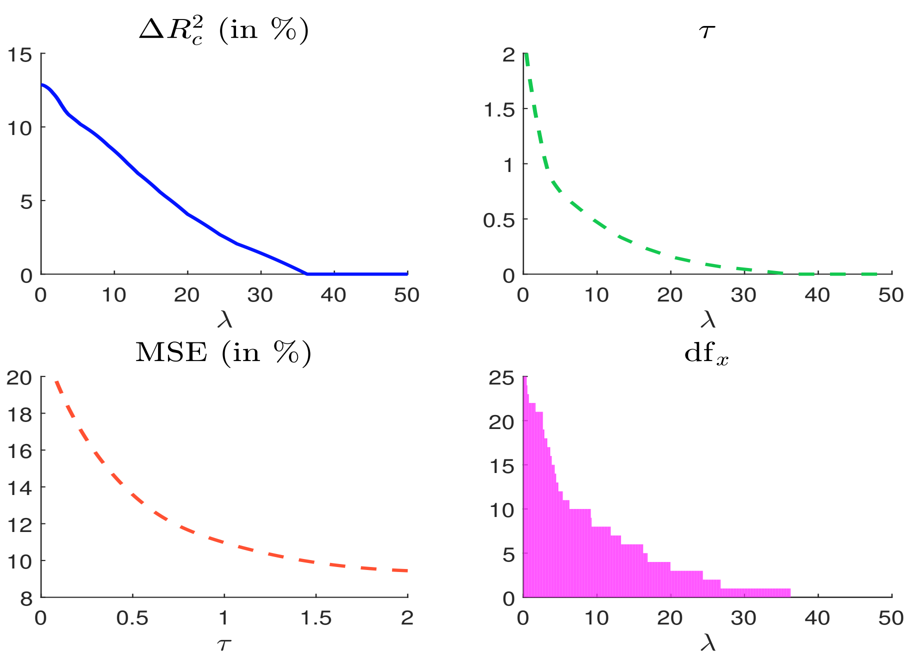


Figure 21: Statistics of the lasso regression (G pillar)

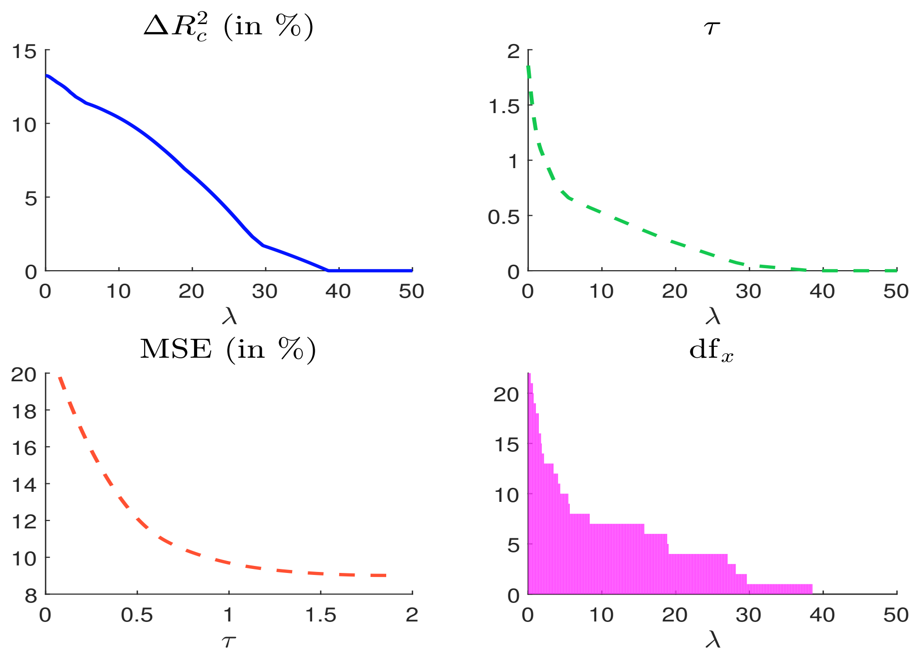
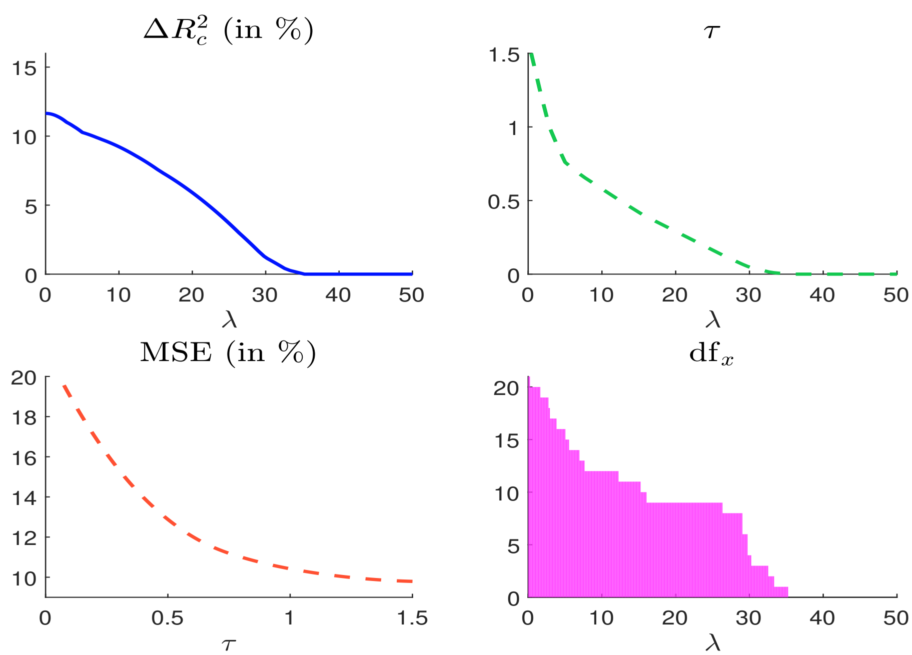


Figure 22: Statistics of the lasso regression (ESG)



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ASSET MANAGEMENT

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