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Debt Issuance Strategies and Climate Risk

By Veronica Mammetti

ABSTRACT

This work assesses the effects of climate transition risk on the debt issuance strategy of a country. We apply it to a general Euro area country with low debt levels, assuming a high exposure to carbon-intensive sectors. Our results suggest that transition risk implies a shift from shorter to longer maturity bonds for a given level of refinancing risk. A larger issuance of longer-term instruments entails an increase in the maturity of debt issued and makes the sovereign entity's financing strategy more expensive. We also show that increasing the level of transition risk worsens debt dynamics. Moreover, we find that under climate transition risk the state authority gains from locking in borrowing rates for a longer time when refinancing risk tolerance is low, as we observe that it effectively optimizes the issuance strategy despite the more costly debt.

1. INTRODUCTION

Over the last decade, the temperatures projected to rise by 4 degrees Celsius have prompted to the intervention of state leaders (Intergovernmental Panel on Climate Change, 2014). Nevertheless, the likelihood of successfully curbing global warming and climate catastrophes is strictly related to the countries' ability to coordinate.[1] The signing of the Paris Agreement in 2015 and the release of the European Climate Law in 2020 marked the first joint efforts toward a coordinated policy intervention,[2] and resulted in a growing awareness of the necessity of green policies (An et al., 2021; Barrymore and Sampson (2021)), for instance in the reallocation of capital towards green investments (Flammer, 2020; Benedetti et al., 2021; De Angelis et al., 2022).

However, the transition from a carbon-intensive to a low-carbon economy introduces a new type of financial risk that deeply affects sovereign debt management. The debt issuance strategy builds on the compliance with sustainability conditions

1. See also Hansen (2022) for a discussion on the link between climate change and systemic risk.
2. The priority is to implement a set of policies – e.g., carbon tax – to achieve climate neutrality by 2050, with the goal of reducing greenhouse gas emissions by 55% by 2030. See Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021, available at: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX:32021R1119.

that prevent the entity from defaulting. If the transition is not timely anticipated and properly addressed, the sovereign financing strategy might become unsustainable.[3] The implications are non-negligible in those states that are highly dependent on carbon-intensive sectors: a climate intervention affects the value of these assets, thereby exposing state authorities to the risk of creditworthiness deterioration due to the repricing of their wealth and consequently jeopardizing the financing of its operations. Analyzing climate transition risk in the context of sovereign debt is also relevant at a systemic level. Around $12 trillion in assets are estimated to become stranded by 2050 (Banque de France, 2019; Van der Ploeg and Rezai, 2020), and if the transition occurs in a way that prevents stakeholders from anticipating the change (disorderly transition), then financial institutions and investors with sovereign instruments in their portfolio will suffer large losses (Roncoroni et al., 2021). This calls for a set of interventions able to detect the effects of climate transition risk on public debt and suggest the appropriate risk management procedures aimed at neutralizing potential damages. A useful tool to guide debt management-focused policies is debt sustainability analysis (DSA), an effective framework to assess the sustainability and the resiliency of a country's debt structure through sensitivity tests applied to a baseline scenario.[4]

Our work investigates the implications of climate transition risk in debt sustainability analysis applied to sovereign debt, providing an answer to the following questions: How does the risk of climate policy intervention affect financing decisions in a country highly exposed to carbon-intensive sectors? How does the trade-off between debt cost and risk change in this new setting? Should the sovereign entity issue shorter- or longer-term debt?

We address these questions considering a representative Euro area country with low debt levels. We include climate transition risk in the main trade-offs embedded in sovereign DSA, analyzing the relationship between debt cost and refinancing risk. Then, we derive the appropriate issuance strategy for a given level of risk while ensuring sustainability. Additionally, we study how increasing the level of transition risk affects the cost-risk trade-off.

We propose a new empirical solution to account for climate transition risk that assigns probabilities to a policy-induced transition exploiting a scenario tree structure in discrete time and state space. Climate transition risk is integrated into the debt sustainability analysis, which we implement following the framework of Zenios et al. (2021). Employing stochastic programming, we generate a scenario tree calibrated on a low-debt country. Leveraging the theoretical results of Battiston and Monasterolo (2020) on the impact of climate transition risk on sovereign refinancing rates, we artificially create a risk dimension by exogenously imposing a change in bonds val-

3. Janetos (2020) discusses on the necessity of timely policies for climate adaptation whereas Jakubik and Uguz (2021) study the effect of green policies on the equity prices of European insurance companies.
4. A more detailed definition is available at the IMF official website https://www.imf.org/external/pubs/ft/dsa/.

ue only on a restricted number of paths. Such change, which depends strictly on the exposure that the entity has towards the sectors targeted by the climate policy, is computed using the financial projections of Integrated Assessment Models (IAMs).[5] The criterion through which we choose the appropriate patterns to endow with the impacts of climate policy implementation is based on the paths probabilities. Calculating the probability of occurrence of tree patterns and setting an arbitrary value $\alpha \in [0,1]$, we impose the change in the price of the instruments only on the lowest α-quantile of paths distribution, that is, on the α % least likely paths. This is consistent with the view that climate risk identifies as a tail risk (Ilhan et al., 2021). We derive an efficient frontier capturing the cost-risk trade-off informed by the risk of an intervention-driven change in the value of debt instruments. Then, we quantify the impact of the risk based on the difference in expected net interest payments and in the quantity issued of each instrument across the two settings, i.e., with and without climate transition risk, for different levels of risk.

New findings arise once we account for climate transition risk. We show that including transition risk in a country highly exposed to carbon-intensive sectors leads to a more costly debt issuance, and that the gap between expected net interest payments (NIP) with and without climate transition risk grows larger for higher levels of refinancing risk tolerance. Increasing the transition risk implies an even greater gap, and we document a shift up to more than 2% in the weights of the quantity issued from the short- to the medium-term debt instrument that builds up as refinancing risk tolerance becomes tighter. An increase in the weighted average maturity of debt issued ensues.

Another result that emerges is that locking in interest costs for a longer period is an advantage when considering transition risk. Despite the shift towards more costly and longer-term instruments, the smaller gap between the transition risk-free expected NIP and the expected NIP under transition risk when refinancing risk tolerance is more restrictive suggests that the state authority can more successfully optimize higher debt costs under climate risk when subjected to tight refinancing risk constraints.

Our results enrich the current literature on climate finance and debt sustainability analysis from an empirical perspective. To the best of our knowledge, this is the first work that exploits a scenario tree structure to assign probabilities to a policy-driven climate transition. This paper builds on the discussion concerning the impact of climate risk on financial instruments and how to potentially price it. We add to an extensive branch of the literature on climate finance which relies on IAMs and their projections for advanced assessments (Dietz et al., 2016; Monasterolo et al., 2018; Battiston et al., 2019; Battiston and Monasterolo, 2020; Roncoroni et al., 2021; and Zenios, 2021.). Other studies focus on theoretical approaches. Capasso et al.

5. Over the last few years, IAMs have emerged as forward-looking systems able to supply projections on macroeconomic, microeconomic, fiscal, and financial, driving several academic studies to question how portfolios would be affected was a climate policy to be implemented or was a climate-related shock to occur.

(2020) show that shocks due to climate-related events, such as the signing of the Paris Agreements, decrease the distance to default of high-emitting companies. Karydas and Xepapadeas (2022) set up a general equilibrium asset pricing model capturing physical and policy risk, with the latter being linked to the risk of extreme weather events.[6] The model suggests that risk-averse investors do price a climate risk premium, whose existence has been extensively discussed, for instance in Oestreich and Tsiakas (2015), Bansal et al. (2016) and Bolton and Kacperczyk (2021). The idea that climate shocks cause a deterioration in sovereigns' borrowing rates is addressed by Klusak et al. (2021) and in a study by Cevik and Jalles (2020), showing that differences across countries in climate vulnerability and resilience can determine up to a 3% differential in yields. Agliardi and Agliardi (2021) introduce a structural model to price corporate bonds under transition risk while including green bonds portfolio allocation.

We also contribute to the research on the sustainability of sovereign financing. Several studies focus on the appropriate debt issuance strategy ensuring debt sustainability. For instance, Cole and Kehoe (2000) show that issuing longer-term debt can avoid sovereigns self-fulfilling refinancing crises, while Arellano and Ramanarayanan (2012) find that countries in recession gamble for redemption by shortening their debt maturity. Both the papers address the role of maturity structures either short- or long-term debt in a binary setting. We depart from this set-up and include a medium-term bond in the instruments base. Other works address debt sustainability studies in continuous time (Bornstein, 2020), either considering sustainability conditions with a stochastic debt-to-GDP ratio (Mehrotra and Sergeyev, 2021) or using stochastic models to evaluate the sustainability of budget deficits (Bohn, 1995). We enrich the literature on debt sustainability analysis in discrete time accounting for different levels of climate transition risk.

2. THE MODEL

2.1. Notation

Stochastic programming finds a useful application in the context of debt sustainability analysis, which entails planning under uncertainty. One way to employ stochastic programming techniques to address decision-making problems – such as implementing a cost-effective issuance strategy – consists in generating multi-period scenario trees, as in structures that identify potential patterns of realizations while preserving certain statistical properties of the data considered. In this section, we present the model set-up and the theoretical background on climate risk to be included in the debt sustainability analysis, focusing on the impacts of climate transition risk on the sovereign's issuance strategy.[7]

6. Lee and Zhao (2021) show that climate-related extreme events are more important than gradual changes – e.g., in the temperature – in driving decisions on adaptation strategies and more likely to lead to their implementation.
7. See Balibek and Koksalan (2010), and Date et al. (2011) for further works employing stochastic programming for debt management purposes.

First, we introduce some notation. Fixing a time horizon, which goes from time (or stage) 0 to T, we consider $n \in N_t$ possible states in which the economy can be at time t. We identify a path $P(n)$ which is unique and includes a set of consequent states leading to a terminal state $n \in N_T$, starting from a singular root state at time $t = 0$. Any such terminal state at the end of a unique path corresponds to a scenario. We distinguish between states of the world and nodes: states in which the economy can be at any time include realizations of scenarios, whereas nodes are only those states of nature where optimizing decisions are made and from which a predefined number of branches expands. Along the path $P(n)$, each state n has a unique prior state, generally denoted $a(n)$: if n occurs at time $t = \tau(n)$, then its ancestor $a(n)$ will be realized at time $t\text{-}1 = \tau(a(n))$. All information from past states is known in t. Starting from $t = 1$, the states $n \in N$ along the tree, where N is the total number of states excluding the root, are assigned conditional and unconditional probabilities, p^n, to each state.

2.2. *The Impact of Climate Transition Risk*

Drawing from Battiston and Monasterolo (2020), we set up the framework to capture the climate transition risk stemming from policy-induced shift from a carbon-intensive to a low-carbon economy. We quantify the shock through a change in the probability of default of the issuer itself that is proportional to its exposure to Climate Policy Relevant Sectors (CPRS). Such adjustment leads to a change in the value of the bonds issued, thereby allowing us to account for assets revaluation in the financing decision process.

In order to assess the impact of climate policy shocks on the value of the bond, we adopt the valuation model under risk-neutral setting. In this way, we discount the expected payoff of the instrument j at the sovereign risk-free rate, r_f^n. For each unit of debt, the price of bond j is:

$$B_n(j) = e^{-r_f^n T}\, E[B(j)], \tag{2.1}$$

$$E[B(j)] = 1 - q_t LGD_j, \tag{2.2}$$

where q_t is the time-varying probability of default. The expected value of the payoff is a function of the state-dependent loss given default, LGD_j, which is in turn determined by the recovery rate of the instrument, R_j, i.e., $LGD_j = (1\text{-}R_j)$. If we assume that the adjustment in the sovereign issuer's probability of default is a function of climate transition risk only and is directly proportional to the shock in the entity's exposure to CPRS through time, the change in q across time is:

$$\Delta q_t = -\textstyle\sum_{k=1}^{K} \chi^k u_t^k c^k, \tag{2.3}$$

where χ^k is the issuer's profitability deriving from sector k; u^k is the shock in the gross value added (GVA) of the related sector in time, i.e. $(\Delta GVA^{(k,n)})/GVA^{(k,a(n))}$; c^k is the exposure of the sovereign issuer to that sector with respect to total GVA of CPRS, assumed constant over time. As a result, the change in the expected value of the bond is:

$$\Delta E[B(j)] = -\Delta q_t LGD_j \ . \tag{2.4}$$

Therefore, climate transition risk enters the sovereign bond valuation through the adjustment in the probability of default, which is assumed to be equal to 0 before policy implementation.

2.3. Introducing Climate Transition Risk in the Model

We impose that, along the tree, the following debt financing equation is satisfied:

$$\sum_{j=1}^{J} X_t^n(j) = GFN_t^n \ , \tag{2.5}$$

where the gross financing needs (GFN) at time t, in state n, must be met by an equal amount of issued debt at that time, across all available instruments. Each financing decision in the vector X_t^n linked to a specific instrument contributes to funding the gross financing needs according to proportional nonnegative weights $w_t^n(j)$:

$$w_t^n(j) = \frac{X_t^n(j)}{GFN_t^n} \ , \tag{2.6}$$

$$\sum_{j=1}^{J} w_t^n(j) = 1. \tag{2.7}$$

Depending on the type of financing strategy considered, such weights can be either time- and state-invariant (fixed-mix strategy), time-dependent but state-invariant (adaptive fixed-mix strategy), or time- and state-dependent (dynamic strategy). However, although the dynamic strategy would intuitively achieve the best results in terms of cost minimization, the excessive flexibility proves to be impractical in the real world for the state authority.[8] For this reason, our analysis focuses exclusively on implementing fixed-mix and adaptive fixed-mix issuance strategies.

We include the risk of climate policy implementation in the model by imposing a change in the value of the instruments only for a restricted number of paths on the tree. Our criterion for selecting the appropriate number of paths relies on the probability of occurrence of scenarios. The state authority can thereby assign a subjec-

8. See Zenios et al. (2021).

tive level of importance to climate transition risk, denoted with α. If the sovereign entity believes that an imminent disorderly transition is unlikely, then the progressive bond depreciation (appreciation) is imposed exogenously only on the 5% least likely paths; if, instead, it deems an immediate climate intervention more likely than in the previous instance, then the model will consider a higher quantile of paths distribution, e.g., $\alpha = 25\%$, and take issuance strategy decisions accordingly. Hence, we take the lowest α-quantile of scenarios probability distribution and choose the patterns on which we impose the change in bonds' value for an arbitrary value of α. In particular, $\alpha = 0$ stands for no climate transition risk and $\alpha = 1$ implies certainty of disorderly transition due to policy implementation. The change in bonds value as expressed in (2.4) enters the model directly through the quantity of debt issued, in the following way:

$$(1 + \Delta E[B(j)]^{\alpha}) \cdot X_t^n(j) = w_t^{(n,\alpha)}(j) GFN_t^n \,, \tag{2.8}$$

or

$$X_t^{(n,\alpha)}(j) = \frac{w_t^n(j) GFN_t^n}{1 - \Delta q_t^{\alpha} LGD_j}\,, \tag{2.9}$$

for each instrument j and level of climate transition risk α.

2.4. Optimization Problem and Constraints

The variable of interest that the treasury aims at minimizing is the expected net interest payments (NIP), which enters the objective function subject to the debt flow and the debt stock constraints. The optimization problem is structured as follows:

$$\begin{aligned} &\min_{w} \sum_{n \in N} p^n NIP_t^{(n,\alpha)} \\ s.t. \qquad &\Psi\left(\left|\frac{GFN^{\alpha}}{PB}\right|\right) \le \epsilon, \\ &\Psi(\Delta_t^{\alpha}) \le \delta, \end{aligned} \tag{2.10}$$

where α is the level of transition risk.

We rely on risk-specific restrictions on both debt flow and debt stock. In particular, we use a tail risk measure $\Psi(\cdot)$ to better capture the extreme nature of an event as that of unsustainability. Since we are dealing with a portfolio of many instruments available, we adopt a coherent risk measure that satisfies the properties set out by Artzner et al. (1999). This justifies and validates the use of the expected shortfall (or CVaR). We apply the CVaR to the absolute value of the ratio of aggregate gross financing needs to the primary balance (PB) and on changes of debt over time (Δ_t^{α}).

3. EMPIRICAL ANALYSIS

3.1. Calibration

The time horizon on the tree, which is calibrated on a yearly basis, goes from 2022 to 2042, where 2021 is stage 0. The tree is calibrated for 32 scenarios in five years, in a 2^5 structure, that is, two branches per node for five stages. Moreover, we design a balanced symmetrical structure, meaning that the number of branches is the same for all nodes in the same period.

We calibrate the stochastic programming part of the model on a general, realistic, low-debt economy in the Euro area. Legacy debt for the realistic economy is set around 60% of GDP, to mirror legacy debt of a non-crisis economy in Europe, and the amortization schedule is set such that most of it matures gradually in the first four years of the analysis.

Shocks in the CPRS sectors are computed from the trajectories provided by IAMs. We assume a fossil-oriented economy and assign an 80% weight c^k to fossil sectors and 20% to renewable sectors, both weightings equally split among the two CPRS categories. Additionally, since the trajectories for the chosen sectors are only provided in time steps of 10 years, we consider sectors shocks from 2020 to 2030 and from 2030 to 2040 and compute a progressive change in bonds value by evenly distributing the shocks over the two decades. We complete the computation of the change in default probabilities imposing a sector-invariant profitability parameter χ^k equal to 0.2 (Battiston and Monasterolo, 2020). The recovery rate R is fixed at 40% for all instruments in all stages, at all nodes.

3.2. Results

We extend the DSA framework to include the risk of a disorderly unanticipated intervention leading to a change in bonds value for different quantile levels α. As we increase α, the number of tree paths where a sudden transition occurs increases as well, implying a stronger impact of transition risk on instruments price over the tree. We impose the policy implementation starting from the first stage.[9]

Our main results are shown in Figure 1, which reproduces the empirical findings from the previous section in a transition risk-free setting and compares them with the case of low risk of climate transition, for $\alpha = 0.05$. We first choose a low α as a sudden implementation of a stringent climate policy is unlikely at present times.[10] Hence, we consider climate transition risk as a tail risk. Because of the higher exposure to carbon-intensive CPRS rather than low-carbon ones, the sovereign entity expe-

9. The analysis could be adjusted to account for an intervention that is not necessarily imminent, but could occur later in the time span of the model.
10. See Battiston et al. (2019).

riences a devaluation in the issuance instruments that makes debt more costly in case of disorderly transition, given the same level of risk tolerance. Interestingly, the differential between expected costs for $\alpha = 0.05$ and interest payments in the case of $\alpha = 0$ grows larger for higher risk tolerance levels. For small values of ϵ, debt under climate risk is 3bp more expensive compared to debt without climate risk, whereas this difference increases to almost 5bp for $\epsilon > 45$.

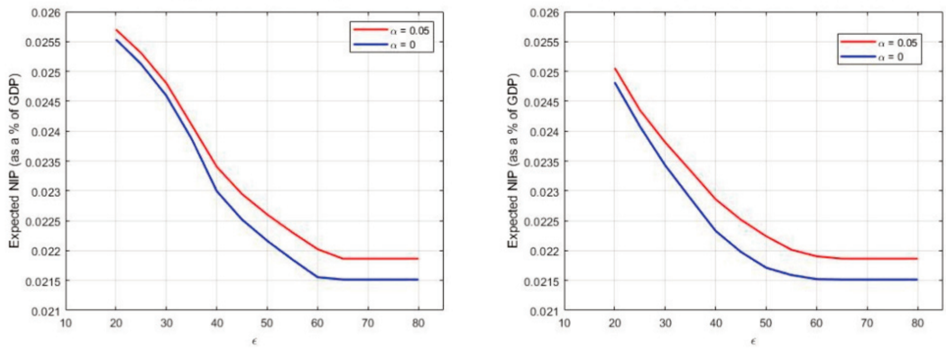

Figure 1: (Left) Refinancing risk trade-off for fixed-mix strategy with low vs zero climate transition risk. (Right) Refinancing risk trade-off for adaptive fixed-mix strategy with low vs zero climate transition risk.

The economic intuition behind this behavior in the curve may be attributed to the restriction on refinancing risk itself. When the constraint is relaxed and risk tolerance is high, the state authority can shift towards a riskier but cheaper short-term financing. Nevertheless, in the case of climate transition risk, such a shift entails incurring still larger costs than in a transition risk-free setting because of bonds devaluation. That explains the divergence in the two settings for higher risk tolerance levels and their convergence for lower values.

An interesting finding also emerges and contributes to explaining the dynamics of the gap between the expected NIPs with and without transition risk. When the constraint on short-term financing is binding, the sovereign entity cuts on short-term debt, shifting part of its issuance strategy to longer-term instruments – mostly medium-term, as the 5-year bond is less costly than the 10-year bond. Once we introduce the risk of climate-induced devaluation, the model optimizes expected costs for a more expensive debt and finds that issuing medium-term bonds is actually cheaper than issuing a greater quantity of short-term debt. That is the case at any risk tolerance level, though at a decreasing rate: the difference in the weights of quantity issued for all residual maturities in the two strategies increases as risk tolerance decreases and the refinancing constraint becomes very binding.

Weights (%)				
	$\epsilon = 20$		No constraint	
Instrument j	$\alpha = 0$	$\alpha = 0.05$	$\alpha = 0$	$\alpha = 0.05$
$j = 3$	19.54	17.17	99.99	99.99
$j = 5$	80.46	82.83	2.660E-05	2.719E-05
$j = 10$	2.237E-07	2.276E-05	6.756E-06	6.768E-06

Table 1: Shift in quantity issued of the instruments by weight for the most binding restriction value and for absent constraint, respectively, given minimum climate risk level $\alpha = 0.05$ (fixed-mix).

The shift in the weights of the quantity of issued debt from 3-year to 5-year bonds amounts to 2.37% for the lowest feasible level of risk tolerance.[11] We would expect the two expected NIPs to grow apart since the medium-term instrument is more expensive than the short-term bond. Instead, the gap between the expected NIPs in the two settings tends to close up. Furthermore, evidence shows a minimal difference in quantity issued even when the constraint on risk tolerance is completely relaxed. That corroborates our stance that, for low climate transition risk, there is an actual advantage in locking interest costs for a longer time period and that a lower risk tolerance amplifies this effect. The argument applies to both the cases of fixed-mix and adaptive fixed-mix strategies.

Moreover, we find that the flattening of the efficient frontier when $\alpha = 0.05$ denotes a deterioration of debt dynamics.

In Figure 2, we relate the expected NIP to different α values and show how expected net interest payments change as climate transition risk increases. For a given medium level of risk tolerance, $\epsilon = 40$, we select eight quantile values for α, increasing from 0.05 to 0.75 by 0.1.[12] Greater risk levels lead to higher debt costs to be financed optimally, and the optimal financing strategy suggests issuing a larger quantity of longer-term bonds. For $\epsilon = 40$, expected net expenses increase up to 16bp for varying levels of transition risk.

11. The lowest attainable level is actually around $\epsilon = 17$ in this setting, but the frontier is derived considering an interval $\epsilon \in [20, 80]$ every 5 values, for practical algorithm tractability. Consequently, the optimizing point of the expected NIP corresponding to $\epsilon = 15$ results infeasible, whereas the one related to $\epsilon = 20$ is the lowest feasible.
12. We purposely leave out the cases for $\alpha > 0.75$, as it would imply accounting for almost certainty of disorderly transition.

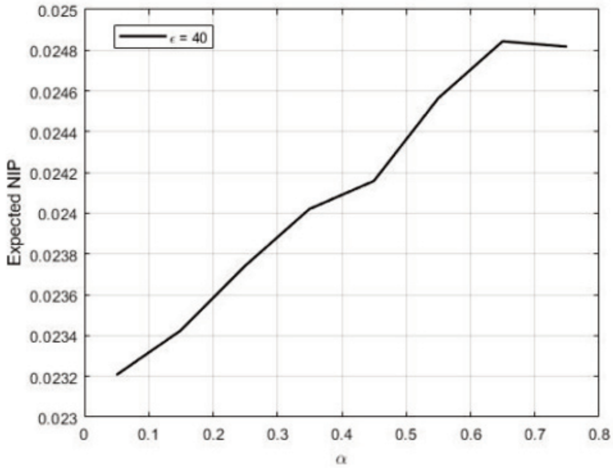

Figure 2: Expected NIP as a percentage of GDP vs climate transition risk, for $\epsilon = 40$ (fixed-mix).

Therefore, increasing level of transition risk entail a worsening of debt conditions.

4. CONCLUSIONS

We investigate and quantify the effects of climate transition risk on the issuance strategy of sovereign debt. Exploiting a scenario tree structure and borrowing the results obtained by Battiston and Monasterolo (2020), we manage to artificially create a new risk dimension that accounts for transition risk, and study how it affects the debt cost-flow trade-off documented in DSA and what is the impact on the financing strategy. We apply the model to a realistic Euro area country with low debt levels and observe that, for a more costly debt and a given refinancing risk tolerance, the sovereign entity is better off issuing more medium-term debt for a higher risk of bond devaluation. This entails an increase in the weighted average maturity of issued debt. It follows that, in the event of such depreciation due to disorderly climate intervention in a highly carbon-intensive economy, the state authority locks in interest costs for a longer period. We also provide empirical evidence on transition risk worsening debt dynamics as the risk increases, due to a higher cost of debt. Climate transition risk is thereby captured and quantified into our debt sustainability framework, and the intensity is adjusted in the analysis according to the state authority's subjective view on the exposure to transition risk.

In this work we provide an empirical solution to a major concern for the regulator by integrating climate transition risk in an adjustable and informative way into a practical set-up for the optimization of debt issuance strategy. Rather than carrying out what-if analyses, our criterion to introduce transition risk allows for a more flexible valuation of the risks related to climate-induced deterioration in sovereign creditworthiness.

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