Climate-Linked Bonds*

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Abstract

Climate-linked bonds are sovereign debt instruments designed to address the incentive gap that discourages governments from undertaking credible long-term climate policies. These bonds tie payments to observable climate outcomes, such as temperature anomalies or national greenhouse gas emissions, lowering debt service costs when mitigation targets are met. We develop a stylized model to study the pricing and risk-sharing properties of these instruments and show how they can align fiscal incentives with climate action. We then analyze climate-linked bonds in a political economy framework and demonstrate that they operate through a fiscal channel that can mitigate underinvestment in climate policy. The strength of this channel depends on political stability—through the degree to which incumbents value future fiscal outcomes—and on the share of climate-contingent debt in sovereign issuance, which governs the sensitivity of public finances to climate realizations. A central result is a design trade-off between risk-sharing and policy discipline, which constrains the optimal structure of climate-contingent sovereign debt.

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1 Introduction

Avoiding the irreversible consequences of climate change requires urgent and coordinated policy action from governments (Lenton et al., 2020; IPCC, 2023; Ripple et al., 2024). Climate policy is however inherently asymmetric. Governments face substantial obstacles in building consensus around mitigation policies such as carbon pricing, regulatory standards, or public investment, and once implemented, these policies are politically costly and easily reversed when economic conditions deteriorate or political priorities shift. Climate change mitigation therefore suffers from a fundamental incentive problem: while the benefits of reduced greenhouse gas emissions accrue over long horizons and often beyond national borders, the political costs are immediate and borne domestically. As a result, sustaining credible and ambitious climate policy across successive governments remains challenging.

The international community has primarily addressed this incentive problem through multilateral coordination. The Paris Agreement, together with annual Conference of the Parties (COP) meetings, provides a framework for voluntary national commitments and peer monitoring. While this framework has generated progress, outcomes remain uneven across countries. Emissions reductions, renewable energy deployment, and climate investment vary widely across jurisdictions. This heterogeneity reflects both an ambition gap—current pledges fall short of stated climate targets—and an implementation gap—announced policies are only partially implemented.

An open question is whether financial instruments can address the underlying incentive problem in climate policy. We argue that climate-linked bonds can do so. These sovereign debt contracts feature payments that adjust with observable climate outcomes, such as temperature anomalies or national greenhouse gas emissions. By tying debt service to objective climate metrics, they align governments' fiscal incentives with long-term climate outcomes and support poli-

cies for sustained mitigation across administrations. Governments that credibly reduce climate risk benefit from lower debt service costs. Climate-linked bonds build on established instruments, including inflation-indexed bonds (Campbell et al., 2009; Bekaert and Wang, 2010) and weather derivatives (Alaton et al., 2002; Yang et al., 2009), which link payoffs to observable macroeconomic or environmental variables, respectively. This connection highlights the feasibility of conditioning sovereign debt on externally verifiable climate outcomes.

In this paper, we study climate-linked bonds in a stylized formal framework. We develop a model in which governments issue climate-linked debt and investors trade climate risk, and we characterize the resulting pricing and risk-sharing properties. Embedding this pricing mechanism in a political economy setting with debt rollover and electoral turnover, we show that linking debt service to climate outcomes induces a forward-looking fiscal cost of emissions that disciplines current policy. The strength of this disciplining channel depends on political survival and implies a trade-off between risk sharing for investors and fiscal discipline for issuers. We further show that equilibrium prices equal expected payoffs plus a climate risk premium. Our analysis characterizes how climate-linked bonds address dynamic policy commitment problems and differ from existing sovereign debt instruments, and it yields implications for their optimal design.

The key economic mechanism is that indexing debt service to climate outcomes aligns governments' fiscal incentives with long-term mitigation. Governments that reduce climate risk face lower future financing costs, mitigating intertemporal free-riding across administrations. By embedding climate risk in sovereign bond prices, these instruments also make climate risk and associated premia observable, strengthening expectations of future policy. The resulting reduction in perceived climate risk lowers borrowing costs and improves fiscal positions. The magnitude of these effects depends on the extent to which national policies influence the underlying climate variable, with stronger incentives arising when policy has greater impact on emissions or transition dynamics.

At the international level, coordinated issuance of climate-linked bonds can support collective action by underpinning a *climate club*. Joint issuance combined with mitigation commitments

strengthens incentives while mitigating global free-riding (Nordhaus, 2015; Pedersen, 2023). Further, optimal design requires aligning financial structure with climate fundamentals: climate science can identify metrics closely linked to damages, while economic design determines how contractual features discipline policy and limit free-riding.

Beyond reducing the incentive gap, climate-linked bonds can also narrow information and insurance gaps. By embedding climate outcomes into sovereign debt prices, they make climate risk and associated risk premia more transparent.[1] In addition, these instruments can partially mitigate the insurance gap by allowing investors to hedge long-term climate risk. By making implicit government backstops more explicit, they can crowd in private risk-bearing capacity in the presence of increasing climate-related tail risks (Swiss Re, 2023; EEA, 2023; ECB & EIOPA, 2023, 2024).

Climate-linked bonds differ from other ESG- and climate-related instruments. Unlike *green bonds*, which require proceeds to be earmarked for specific eco-friendly projects such as renewable energy or clean transportation (Baker et al., 2022; Vladimirova and Fang-Klingler, 2024; Monasterolo et al., 2024), climate-linked bonds do not restrict the use of funds but instead link debt servicing to climate outcomes. In contrast to *sustainability-linked bonds* (SLBs), whose coupons adjust based on the issuer's achievement of self-selected ESG targets, climate-linked bonds are indexed to objectively observable climate variables, such as temperature anomalies or greenhouse gas emissions. Because governments influence these variables only indirectly, payoffs are typically specified as continuous functions of climate outcomes rather than discrete step-up or step-down adjustments tied to target thresholds (Kölbel and Lambillon, 2022; Chen et al., 2023). This structure provides marginal incentives for mitigation at the margin, rather than incentives tied to the attainment of discrete targets. In contrast to *catastrophe bonds* (cat bonds), which transfer the financial risk of acute disasters—such as hurricanes or earthquakes—to investors through binary payout structures (Morana and Sbrana, 2019), climate-linked bonds provide state-contingent

[1] See also van Binsbergen and Brøgger (2022), who propose carbon futures on firm-level emissions to address information frictions.

payoffs tied to chronic or systemic climate risks rather than one-off events. In addition, because sovereigns are the primary issuers of climate-linked bonds, they internalize the effect of climate outcomes on future financing costs. This creates direct incentives to implement policies that reduce underlying climate risk, a channel largely absent in cat bond issuance by (re)insurers. Taken together, these features make climate-linked bonds a distinct financial instrument that embeds climate risk into public finances while aligning long-term policy incentives.

The remainder of this paper is structured as follows. Section 2 presents a stylized model of climate risk sharing and the pricing of climate-linked bonds. Section 3 embeds this framework in a political economy model with government turnover to analyze the resulting disciplining effects. Section 4 discusses implementation issues, including contract design, transparency, and governance, and highlights associated operational risks. Section 5 concludes.

2 Risk sharing and the pricing of climate-linked bonds

In this section, we will delve into the pricing climate-linked bonds. We will present a stylized model of climate risk pricing to illustrate the key mechanism and factors influencing the valuation of climate-linked bonds in equilibrium and the investment behavior of agents exposed to climate risk. Our pricing model clarifies how climate-linked bonds contribute to reducing the aforementioned incentive gap. By explicitly capturing the embedded climate risk premium, the model reveals the market-consistent expectations of future climate risks. It further illustrates that issuing agents, in particular governments, are incentivized to issue these bonds because they expect to earn a positive premium, while agents exposed to climate risk are willing to purchase them as a hedge against chronic (non-acute) physical risks. One can think of a climate-linked bond as issuing a nominal bond together with a climate-linked swap in which the issuer pays a floating rate based on the realization of the climate variable and the investor pays a fixed rate.[2]

To explore the key mechanism behind the pricing of climate risk bonds in equilibrium, we

[2]This relates to the arbitrage strategy which replicates the payoff of an inflation-linked bond through an inflation-linked swap. See Fleckenstein et al. (2014).

now build a stylized one-period model of an economy populated with agents who need to decide on their asset allocation under climate risk. We use a CARA-normal setup with simple climate dynamics to keep the problem analytically tractable.[3]

2.1 Baseline Model of Climate Risk Sharing

The economic effects of climate change are heterogeneous across time and space. To capture this in a stylized setting that highlights the risk-sharing role of climate-linked bonds, we consider an economy with two types of agents: a fraction δ of the population is exposed to potential climate damages, and a remaining share $1-\delta$ that is not. This heterogeneity can reflect, for example, municipalities or individuals vulnerable to sea-level rise or extreme heat, versus those whose geographic location shields them from such risks. We denote $i \in \{e, u\}$ as an index for the exposed and unexposed agents, respectively. Assume that all agents in the economy have a CARA utility over wealth y of the form:

$$u(y) = -\frac{1}{\alpha} e^{-\alpha y}, \tag{1}$$

where α is a coefficient of risk-aversion.

We model the climate variable abstractly, using temperature as the underlying driver of bond payoffs. This choice reflects the strong link between temperature and physical climate damages, making it a natural proxy for chronic climate risk. However, temperature-based instruments may be subject to delayed feedback and heightened free-riding incentives, as governments have limited direct control over global temperature outcomes. An alternative approach ties payoffs to national emissions, which are more directly influenced by policy and linked to transition risk. While emissions are less proximate to physical damages and may exhibit longer lags, they represent a more actionable and accountable metric. Using a country's own emissions as the climate variable can mitigate free-riding and better align incentives between issuer and investor.

[3]For studies relating the intricacies of climate dynamics with those of the dynamics of a production economy, especially within an asset pricing setting, we refer to Barnett et al. (2020) and Chikhani and Renne (2022).

Future work could examine hybrid structures or more granular frameworks that capture both physical and transition risks. We return to this discussion in Section 4.1.

So, assume that the temperature difference relative to a reference temperature $\overline{T}$ is normally distributed, such that:

$$\Delta T \equiv T_{t+1} - \overline{T} \sim N(\mu, \sigma^2). \tag{2}$$

Herein, μ is the expected incremental temperature change over the investment horizon relative to the reference temperature and σ represents the volatility or uncertainty in the incremental temperature changes.[4] In this model, temperature fluctuations are treated as exogenous. This can be conceptualized as representing a small country whose economic activity does not significantly influence global climate change.

For simplicity, we assume that climate-related damages are a linear function of temperature changes:

$$D_{t+1} = d_0 + d_1 \Delta T + \epsilon_{t+1}. \tag{3}$$

In this function, D_{t+1} represents the dollar amount of climate damages at time $t+1$, so that total damages in the economy are δD_{t+1}, with d_0 denoting the baseline amount of damages irrespective of temperature change and d_1 is a sensitivity parameter that represents the amount of additional damages per unit of temperature change, with $d_1 > 0$ and $\epsilon_{t+1} \sim N(0, \sigma_{d,\epsilon})$ captures the idiosyncratic risk of damages not related to temperature increases.[5] The damages materialize at the terminal date and are deducted directly from the final wealth of exposed agents. The damage function reflects the anticipated effectiveness of existing resilience infrastructure.

All agents in the economy choose an investment plan at time t for the subsequent period.

[4] In practice, $\overline{T}$ may be set to the expected future temperature, making μ zero. However, we maintain a more general setup to accommodate deviations in bond structures. Regardless, the choice of $\overline{T}$ will be reflected in the equilibrium bond price. Also, we abstract in our model from potential general equilibrium effects and the positive impact that the issuance of climate-linked bonds will have on the temperature dynamics. One can think of Equation 2 already reflecting this.

[5] We use a linear damage function to keep the model tractable and to illustrate the mechanism. In reality, the impact of extreme events is non-linear, increasing disproportionately with temperature change (Burke et al., 2015) and potentially subject to tipping points (Lenton et al., 2020). With non-linear damages, the case for climate-linked bonds quantitatively will be even stronger.

At t, agents are endowed with wealth y_t, which can be allocated between a risk-free asset and climate-linked bonds. For expositional clarity, both securities are modeled as zero-coupon bonds. The risk-free asset is priced at 1 and delivers a gross payoff $R_f = 1 + r$ at maturity, where r denotes the one-period risk-free rate. The climate-linked bond is priced at B_t and pays off at maturity according to realized changes in temperature. Specifically, the bond's payoff at $t+1$ is given by:

$$P_{t+1} = b_0 + b_1 \Delta T. \tag{4}$$

Where b_0 is the face value or baseline dollar payment established at bond issuance, i.e., the payment of the bond if the actual temperature does not change relative to the reference temperature, $b_1 > 0$ is the coefficient that determines the sensitivity of the bond's payments to deviations in temperature, and $\Delta T = T_{t+1} - \overline{T}$ represents the change in temperature from the reference temperature.[6]

Now, let θ_t^i denote the number of climate-linked bonds that agents of type i buy at time t. The rest of their wealth is invest in risk-free bonds. The wealth of each type of agent at the horizon date can then be expressed as:

$$y_{t+1}^i = \theta_t^i P_{t+1} + (y_t - \theta_t^i B_t) R_f - D_{t+1} \mathbb{1}_i, \tag{5}$$

where $\mathbb{1}_i$, an indicator function equal to one if $i = e$ and zero otherwise. This function ensures that only the exposed agents are affected by the damages, which are subtracted from their end-of-period wealth.

Note that without climate-linked bonds, exposed agents have no means to hedge against potential climate damages. The introduction of these bonds allows both types of agents to trade

[6]It is important to distinguish the mechanics of climate-linked bonds from those of catastrophe bonds. Catastrophe bonds are structured to protect the issuer, offering higher yields to investors who bear tail risks associated with discrete events. In contrast, climate-linked bonds provide protection to investors and, as we show below, can lead to more favorable financing terms for the issuer. Moreover, whereas catastrophe bonds typically involve binary, event-triggered payouts, climate-linked bonds feature continuous payoff adjustments based on a climate variable. This continuous structure enables a more granular and potentially more effective alignment of financial incentives with climate outcomes.

and manage climate risk effectively.[7]

So far we have laid down the pay-off structure of climate-linked bonds and the framework for investment decisions by all agents in our model. We now aim to determine the equilibrium price of climate-linked bonds based on two key conditions: (1) Each type of agent optimizes their asset holdings, and (2) The market clears in equilibrium, meaning that the total number of bonds bought by one party equals the total number sold by another party.

Agents optimize: Formally, agents' optimal level of climate-linked bond holdings (if positive) or issuance (if negative) is:

$$\theta_t^i = \arg\max \mathbb{E}u(y_{t+1}^i) \equiv \arg\max \left\{ \mathbb{E}(y_{t+1}^i) - \frac{\alpha}{2}\mathbb{V}\text{ar}(y_{t+1}^i) \right\} \tag{6}$$

subject to the budget constraint in (5). Here we make use of the standard properties of CARA-normal optimization with the mean-variance formulation above representing the certainty equivalent (CE) of the agent. The first-order condition then ensures that, in optimality, bond holdings for each type of agent are:

$$\begin{aligned} \theta_t^i &= \frac{b_0 + b_1\mu - B_t R_f}{\alpha\sigma^2 b_1^2} + \frac{d_1}{b_1}\mathbb{1}_i \\ &= \underbrace{\frac{1}{\alpha\sqrt{\mathbb{V}\text{ar}(P_{t+1})}} SR(P_{t+1})}_{\textbf{Investment Motive } \theta_{ID}^i} + \mathbb{1}_i \cdot \underbrace{\frac{\mathbb{C}\text{ov}(D_{t+1}, T_{t+1})}{\mathbb{C}\text{ov}(P_{t+1}, T_{t+1})}}_{\textbf{Hedging Motive } \theta_{HD}^e}, \end{aligned} \tag{7}$$

where $SR(P_{t+1}) = \frac{\mathbb{E}(P_{t+1}) - B_t R_f}{\sqrt{\mathbb{V}\text{ar}(P_{t+1})}}$ is the Sharpe ratio of the climate-linked bond, with $\mathbb{V}\text{ar}(P_{t+1})$ the variance of its payoff; and the ratio of co-variances measuring the relative sensitivity of damages and, respectively, bond payoffs to temperature changes.

Thus, we show that the agents' demand for climate-linked bonds can be separated into two terms: θ_{ID}^i, the investment motive, driven positively by the Sharpe ratio that these risky instru-

[7] We model the introduction and pricing of climate-linked bonds in a market setting where exposed and non-exposed agents freely trade. In practice, the government will play a role in issuing the bonds and will act as an intermediary between the agents exposed and the agents unexposed to climate damages.

ments offer, and negatively by the risk aversion of the agents; and second, the hedging component θ^e_{HD}, relevant only for the agents exposed to climate change impacts, which is positively related to the bond sensitivity to damages.

The investment motive is negatively related to temperature variation, as this can be seen as the main risk driver for climate-linked bonds. Risk-averse investors reduce their demand for temperature-sensitive investments in case the risk is higher, leading to this inverse relationship. Note that the idiosyncratic risk of damages, represented by $\sigma_{d,\epsilon}$, does not affect the asset allocation decision. Since this specific risk of climate damages is unrelated to temperature change, it cannot be hedged using climate-linked bonds, whose returns are systematic and driven by temperature changes. Therefore, this idiosyncratic risk does not influence the investment motive for these bonds.

In our model, by construction, climate damages are perfectly correlated with the bond payoff, as both are affine transformations of the temperature variation. This implies that the impact of temperature changes can be perfectly hedged, and as a result, the hedging motive is independent of the temperature variance. It depends only on the relative sensitivity terms, d_1/b_1, as illustrated in (7).

Market clearing: The next step is to determine the market price of the climate-linked bond. To do this, we need to ensure that, at the bond issuance date, the amount of bonds issued is exactly matched by the amount purchased.[8] The market-clearing price of the bond will ensure that supply equals demand, such that the net amount outstanding is zero at the start of the period. We will show that, in equilibrium, the number of bonds purchased by the exposed agents equals the number of bonds supplied by the unexposed agents, weighted by their relative sizes in the economy. For now, assume that the market clears, such that:

$$\delta\theta^e_t + (1-\delta)\theta^u_t = 0. \tag{8}$$

[8]See Van Binsbergen et al. (2014) for a similar market clearing approach that allows pension funds with different age distributions to trade with each other.

Substituting in the optimal bond holdings from (7) we get the equilibrium price of the climate-linked bond:

$$\begin{aligned} B_t = & \underbrace{\frac{1}{R_f}\mathbb{E}(P_{t+1})}_{\text{Expected Climate Payoff}} + \underbrace{\frac{1}{R_f}\delta\alpha\mathbb{C}\mathbb{o}\mathbb{v}(P_{t+1}, D_{t+1})}_{\text{Climate Premium} > 0} \\ = & \frac{1}{R_f}\left(b_0 + b_1\mu + \delta\alpha\sigma^2 b_1 d_1\right). \end{aligned} \tag{9}$$

The bond price thus consists of two components: the present discounted value of the expected payoff and the present discounted value of a risk component related to the covariance between the bond's payoff and climate damages.

Substituting the equilibrium bond price (9) back in the optimal holdings equation (8), we get:

$$\theta_t^e = \frac{(1-\delta)d_1}{b_1} > 0, \quad \theta_t^u = -\delta\frac{d_1}{b_1} < 0. \tag{10}$$

This implies that exposed agents will have a net positive demand for the bonds, while agents who are not exposed to damage are willing to issue climate-linked bonds because in expectation they earn a positive risk premium equal to $E(P_{t+1})/R_f - B_t$. Before we move on to the next subsection, it is important to note that, due to this positive risk premium, exposed agents also have an incentive to issue climate-linked bonds. However, their net demand for these bonds will remain positive because of their hedging needs. We will now continue to further explore the hedging dynamics.

3 The Disciplining Effect of Climate-Linked Bonds

This section analyzes whether, and under what conditions, climate-linked bonds discipline sovereign policy choices. Building on the pricing channel derived in Section 2, we embed these instruments in a simple political economy framework featuring political turnover and fiscal rollover frictions. The core mechanism is that a higher share of climate-contingent debt links current emissions to

future debt service through their impact on realized climate outcomes. When incumbents assign sufficiently high probability to remaining in office, they internalize part of this expected fiscal cost and choose lower emissions.

3.1 Model environment

Time is discrete, $t = 0, 1, 2, \ldots$. In each period, an incumbent government chooses consumption C_t, emissions $E_t \geq 0$, and new debt issuance N_t (in euros). Output is endowment-like but includes a reduced-form "emissions technology" and convex costs:

$$Y_t = \bar{Y}_t + AE_t - \frac{c}{2}E_t^2, \tag{11}$$

where $A > 0$ captures the contemporaneous benefit of emissions-intensive activity and $c > 0$ the convex cost of emissions.

Temperature responds to emissions with a one-period lag:

$$T_{t+1} = \overline{T} + \rho E_t + \varepsilon_{t+1}, \qquad \varepsilon_{t+1} \sim \mathcal{N}(0, \sigma_T^2), \tag{12}$$

where $\rho > 0$ is a reduced-form climate response parameter. This specification implies that current emissions affect the conditional mean of future temperature, thereby linking emissions to expected bond payoffs, while leaving idiosyncratic climate risk ε_{t+1} to investors.

Assets and pricing. As in Section 2, investors trade two one-period assets: (i) a risk-free claim priced at 1 with gross payoff R_f, and (ii) a climate-linked zero-coupon claim priced at B_t with payoff:

$$P_{t+1} \;=\; b_0 + b_1\,(T_{t+1} - \overline{T}), \qquad b_1 > 0. \tag{13}$$

In the CARA–Normal equilibrium of Section 2, the bond price decomposes into the discounted

expected payoff plus a (positive) climate risk premium:

$$B_t \;=\; \frac{1}{R_f}\Big(\mathbb{E}_t[P_{t+1}] + \phi\Big), \qquad \phi \equiv \delta\,\alpha\,\sigma_T^2\,b_1 d_1 \;>\; 0, \tag{14}$$

where again δ is the share of investors exposed to climate damages, α is risk aversion, and d_1 is the sensitivity of exposed agents' damages to temperature. Using (12)–(13) we can write:

$$\mathbb{E}_t[P_{t+1}] = b_0 + b_1(\mathbb{E}_t[T_{t+1}] - \overline{T}) = b_0 + b_1\rho E_t. \tag{15}$$

This shows that the equilibrium climate-linked bond price is increasing in current emissions through the expected temperature channel.

Debt mix and rollover. Let N_t denote the euro amount of new debt issued at time t. A fixed share (constant over all time periods) $\lambda \in [0,1]$ of issuance is raised via climate-linked bonds and the remaining share $1-\lambda$ via risk-free debt.

Since one unit of the climate-linked bond is priced at B_t and pays P_{t+1} next period, raising λN_t euros requires issuing $\lambda N_t/B_t$ units of the climate-linked bond. Accordingly, the realized repayment associated with today's issuance is $(\lambda N_t/B_t)P_{t+1}$. The remaining share $(1-\lambda)N_t$ is financed through risk-free debt, which entails a repayment of $R_f(1-\lambda)N_t$ at $t+1$.

Based on our simplifying assumption that the composition of sovereign debt is time invariant, debt issued at $t-1$ has the same fixed composition: a fraction λ is climate-linked and a fraction $1-\lambda$ is risk-free. Total debt service due at time t is therefore:

$$S_t \;=\; R_f(1-\lambda)N_{t-1} \;+\; \frac{\lambda N_{t-1}}{B_{t-1}}\,P_t. \tag{16}$$

The government's within-period budget constraint is:

$$C_t + S_t \;=\; Y_t + N_t. \tag{17}$$

The key friction is intertemporal: emissions increase contemporaneous output via (11), while they also affect future fiscal costs through the climate-contingent component of outstanding debt in (16). We work throughout with this period-by-period formulation. The standard no-Ponzi condition can be imposed and delivers the usual intertemporal budget constraint, but is not binding for the results of interest.[9]

Expected climate-linked debt service costs. A useful object is the expected per-euro gross service cost of the climate-linked component of issuance at time t, defined as:

$$R_t^{\text{CLB},e} \equiv \frac{\mathbb{E}_t[P_{t+1}]}{B_t} = R_f \cdot \frac{\mathbb{E}_t[P_{t+1}]}{\mathbb{E}_t[P_{t+1}] + \phi}. \tag{18}$$

Since $\phi > 0$, it follows that $R_t^{\text{CLB},e} < R_f$: investors accept a lower expected yield because the climate-linked bond provides insurance by delivering higher payoffs in adverse climate states (see Section 2). At the same time, $R_t^{\text{CLB},e}$ is increasing in the expected payoff and therefore in current emissions. Differentiating (18) and using (15), we obtain:

$$\frac{\partial R_t^{\text{CLB,e}}}{\partial E_t} = \underbrace{\frac{1}{B_t}\frac{\partial \mathbb{E}_t P_{t+1}}{\partial E_t}}_{\text{Expected Payoff Effect} > 0} + \underbrace{\frac{\partial}{\partial E_t}\left(\frac{1}{B_t}\right)}_{\text{Price Effect} < 0} = R_f \cdot \frac{\phi}{(\mathbb{E}_t[P_{t+1}] + \phi)^2}\, b_1 \rho > 0. \tag{19}$$

In expectation, next period's debt service on today's issuance can be written as:

$$\mathbb{E}_t[S_{t+1}] = R_f(1-\lambda)N_t + \lambda N_t\, R_t^{\text{CLB},e}. \tag{20}$$

Hence, a higher share λ increases the sensitivity of expected fiscal outlays to climate outcomes, strengthening the transmission from emissions to sovereign financing costs.

[9] Iterating the flow budget constraint forward and imposing the no-Ponzi condition yields the standard intertemporal budget constraint: the market value of debt equals the present value of primary surpluses under the pricing kernel that prices government liabilities. Since issuance is assumed to be fairly priced each period, this representation does not affect the marginal incentives that are the focus of the analysis.

3.2 Political turnover

Political survival is stochastic: the incumbent remains in office at $t+1$ with probability $q \in (0,1)$.[10] The incumbent government maximizes expected discounted utility from consumption, discounted both by time preference and the probability of remaining in office. Let $\tilde{\beta} \equiv \beta q$ denote the effective discount factor, where $q \in (0,1)$ captures political survival risk. The government's objective is:

$$\max_{\{C_t, E_t, N_t\}_{t\geq 0}} \mathbb{E}_0 \sum_{t\geq 0} (\tilde{\beta})^t u(C_t), \tag{21}$$

subject to (11), (12), and (17), taking λ as given. Political turnover ($q < 1$) effectively shortens the planning horizon and weakens incentives to internalize the fiscal consequences of current emissions.

The problem can be written recursively. Let $L_t = N_{t-1}$ denote legacy debt. The value function is:

$$V(L_t, T_t) = \max_{E_t, N_t} \Big\{ u(C_t) + \tilde{\beta}\, \mathbb{E}_t[V(L_{t+1}, T_{t+1})] \Big\}, \tag{22}$$

subject to:

$$L_{t+1} = N_t,$$

$$C_t = Y_t + N_t - S_t,$$

$$S_t = (1-\lambda) R_f L_t + \frac{\lambda L_t}{B_{t-1}} P_t,$$

and the state equations (11), (12), and (13). The first constraint simply ensures that yesterday's choice variable N_{t-1} becomes tomorrow's legacy state variable L_t.

[10] Note that here we exclude the corner cases for q: when $q = 1$, the problem becomes that standard infinite-horizon planner problem; when $q = 0$ the incumbent government knows with certainty that it does not face re-election and therefore places zero weight on all future payoffs, behaving in a fully myopic, purely static manner.

The first-order condition with respect to N_t is:

$$u'(C_t) + \tilde{\beta}\, \mathbb{E}_t[V_L(L_{t+1}, T_{t+1})] = 0, \tag{23}$$

capturing the intertemporal trade-off between current resources and the marginal value of inherited debt.

For emissions, using $\partial T_{t+1}/\partial E_t = \rho$, the first-order condition is:

$$u'(C_t)(A - cE_t) + \tilde{\beta}\, \rho\, \mathbb{E}_t[V_T(L_{t+1}, T_{t+1})] = 0. \tag{24}$$

Since temperature has no intrinsic persistence beyond its contemporaneous dependence on emissions, T_{t+1} affects continuation utility only through its impact on next-period fiscal outcomes. From (17) and (16), the marginal effect of T_{t+1} on C_{t+1} arises from the climate-linked bond service term:

$$C_{t+1} = Y_{t+1} + N_{t+1} - S_{t+1} \quad \Rightarrow \quad \frac{\partial C_{t+1}}{\partial T_{t+1}} = -\frac{\lambda N_t}{B_t}\, b_1.$$

Therefore,

$$V_T(L_{t+1}, T_{t+1}) = u'(C_{t+1}) \cdot \frac{\partial C_{t+1}}{\partial T_{t+1}} = -u'(C_{t+1}) \frac{\lambda N_t}{B_t} b_1,$$

and substituting into (24) yields the Euler condition:

$$u'(C_t)(A - cE_t) = \tilde{\beta}\, \rho\, \frac{\lambda N_t}{B_t} b_1\, \mathbb{E}_t\big[u'(C_{t+1})\big]\,. \tag{25}$$

Equation (25) makes the disciplining mechanism transparent: higher emissions increase current output at the margin $(A - cE_t)$, but also raise expected future fiscal costs through their effect on climate-linked bond payoffs. The strength of this channel is governed by the effective discount factor $\tilde{\beta} = \beta q$ and by the exposure to climate-linked debt, measured by $\lambda N_t/B_t$.

3.3 When do climate-linked bonds discipline: Risk-sharing versus discipline

Two comparative statics follow directly from (25). First, the effectiveness of climate-linked bonds in providing incentives depends on political stability. As political turnover becomes extreme ($q \to 0$, implying $\tilde{\beta} \to 0$), the government fully discounts future fiscal consequences and chooses emissions to maximize contemporaneous output:

$$\tilde{\beta} \to 0 \quad \Rightarrow \quad u'(C_t)(A - cE_t) = 0 \quad \Rightarrow \quad E_t = \frac{A}{c}.$$

In this limit, climate-linked bonds exert no disciplining effect through the fiscal channel, as incumbents place no weight on future debt service costs.

Conversely, the disciplining effect strengthens as political stability increases (higher q). The greater the likelihood that current policymakers internalize future fiscal consequences, the stronger the incentive to reduce emissions in response to climate-linked debt exposure.

Second, the disciplining effect strengthens as the share of climate-contingent debt increases. Holding all else constant, a higher λ increases the sensitivity of future debt service to climate outcomes, thereby raising the marginal fiscal cost of emissions. In the Euler condition (25), an increase in λ shifts the right-hand side upward, requiring a lower optimal level of emissions E_t (i.e., a smaller $A - cE_t$) to restore equilibrium. Intuitively, a larger share of climate-linked bonds makes the government's intertemporal budget more state-contingent on climate realizations, thereby strengthening incentives to mitigate emissions.

The model also highlights a fundamental design trade-off in climate-linked bonds. Risk-sharing considerations favor a payoff structure that increases in adverse climate states ($b_1 > 0$ in (13)), as this provides hedging benefits to investors and generates a positive climate risk premium ϕ, thereby supporting demand and lowering ex-ante funding costs (Section 2). At the same time, equilibrium pricing introduces an offsetting effect. Because the bond price B_t increases with expected future temperature (14)–(15), higher expected emissions reduce the number of bonds required to raise a given amount of resources, partially attenuating the increase in expected

repayment obligations. This is reflected in the per-euro expected cost $R_t^{\mathrm{CLB},e}$ in (18), which depends on the ratio of expected payoff to expected payoff plus the climate risk premium. Thus, while higher emissions increase expected future service costs through higher payoffs, this effect is partially dampened by endogenous price adjustments in equilibrium.

In this baseline formulation, the disciplining effect operates through expected future service costs and is strongest when political turnover is limited (higher q), when climate outcomes are more sensitive to domestic emissions (higher ρ), and when the share of climate-linked bonds in refinancing is larger (higher λ). When q is low, the direct fiscal channel weakens, and the role of climate-linked bonds shifts toward information and reputational mechanisms. In this case, market prices reveal the expected climate trajectory embedded in sovereign financing conditions, potentially increasing political or international accountability costs even for myopic incumbents. These channels are complementary to, rather than substitutes for, the fiscal mechanism emphasized in the baseline analysis.

Discussion and next steps. The framework above is deliberately stylized to isolate the fiscal disciplining mechanism. Several extensions are natural. A first step is to solve explicitly (analytically or numerically) for equilibrium emissions E_t^* as a function of $(\lambda, q, \rho, b_1, \phi)$ under a parsimonious specification for $u(\cdot)$ and $\bar{Y}_t$, and to characterize how discipline varies with political survival:

$$\frac{\partial E^*}{\partial \lambda} < 0, \qquad \frac{\partial^2 E^*}{\partial \lambda \, \partial q} < 0,$$

i.e. climate-linked bonds discipline more when (i) the climate-contingent share is larger and (ii) incumbents are more likely to internalize future service costs. Second, one can endogenize λ by allowing the sovereign to trade off discipline against exposure to climate-contingent fiscal volatility. Third, introducing persistence in temperature (or a stock externality) would increase the relevance of long maturities and allow a richer mapping between climate-linked bonds maturity structure and the horizon over which governments internalize climate consequences. Finally, a game between successive administrations could link the mechanism more directly to classic

models of strategic debt and political turnover.

4 Practical considerations when issuing climate-linked bonds

In this section, we discuss the implementation of climate-linked bonds in financial markets. We describe their contractual specifications, highlight key challenges in designing climate-linked securities, and outline associated operational and implementation risks.

4.1 Climate-linked bond specifications

The payoff of a climate-linked bond is adjusted based on a physical variable that reflects climate change dynamics. In this section, we will discuss in more detail the climate variables that can define the payoff of these bonds.

4.1.1 Temperature

When constructing climate-linked bonds, a potentially useful climate variable is the temperature anomaly, which refers to the deviation of a specific temperature measurement from the long-term average for a given location and time period. It is typically expressed as the difference between the observed temperature and the average temperature over a reference period, often calculated as a baseline average temperature for the same location over some years.[11] Positive temperature anomalies indicate temperatures warmer than the long-term average, while negative anomalies indicate temperatures cooler than average. At bond issuance a reference temperature $\overline{T}$ at time t is taken as the benchmark. Deviations from the reference temperature over time lead to changes in the pay-off. One potential amendment to the pay-off specification in equation (4) is to constrain the bond pay-off to be non-negative all the time:

$$B^{'}_{t+1} = b_0 + \max(b_1 \Delta T, 0). \tag{26}$$

[11] Appendix B presents the annual temperature anomalies for large economies since 2000.

The maximum operator thus ensures that the payment cannot become negative and represents an implicit put option embedded in the bond's payoff.[12] The formula indicates that if the observed temperature exceeds the reference temperature, the payment for that period will increase. However, if the observed temperature falls below the reference, the payment will not decrease below the agreed-upon base amount. The magnitude of the change in payments depends on the coefficient b_1. Parameters b_0 and b_1 can be based on market conditions, and such that the price volatility of the bond and its sensitivity to temperature changes are within an acceptable range.

Temperature movements can be specified in different ways, each influencing the issuing government's incentives. Global Land Surface Temperature (LST) offers a broad perspective on climate change trends and could serve as a standardized reference for globally issued climate-linked bonds, enhancing liquidity. In contrast, local or regional LST may better reflect local damages, such as heatwaves, droughts, and biodiversity loss, and could be politically more acceptable. Tying national public debt to local LST also mitigates free-riding concerns, as local or national policies are more likely to influence local LST than global LST.

4.1.2 Greenhouse gas emissions and concentration levels

A similar framework can be applied to climate variables more directly influenced by human activity, such as greenhouse gas (GHG) emissions. For example, at the time of bond issuance, a forward-looking reference level for GHG emissions aligned with the targets of the Paris Agreement can be established as a benchmark. Positive deviations from this benchmark then determine the bond's payoff. This linkage directly incentivizes governments to implement policies aimed at reducing GHG emissions and upholding climate initiatives, ultimately leading to lower debt funding costs.[13] From this perspective, climate-linked bonds are closely related to the class of sustainability-linked bonds Furthermore, given that GHG emissions in the short run correlate

[12] In practice, inflation-linked bonds adjust the principal using an index ratio, calculated as the ratio of the CPI at the reference (issue) date to the current CPI. However, to prevent negative coupons, there is a floor on the principal, Barnes et al. (2010).

[13] See Appendix C for CO_2-trajectories for major economies, highlighting deviations from the 1991-2020 average CO_2 emissions from fossil fuels and industry, excluding land-use changes.

strongly with economic activity, such climate-linked bonds align with the standard fiscal objective of maintaining sustainable debt levels with low default risk. They do so without constraining a country's deficit during economic downturns, thereby acting as automatic stabilizers akin to GDP-linked bonds (Shiller, 1998).

Alternatively, the bonds could be tied to atmospheric GHG concentrations already in the atmosphere, such as CO_2-levels in the atmosphere, regardless of when they were emitted. Given that GHG concentrations are directly linked to global temperature rise, this could offer a broader and more standardized approach for designing climate-linked bonds. The bond's payoff could be linked to whether GHG concentrations remain below a certain level, that decreases over time, in line with the Paris Agreement, providing governments with an incentive to maintain or reduce emissions over time. While emissions are more localized and tied directly to specific entities or policies, concentrations are a global measure.

4.2 Challenges in constructing climate-linked securities

Ideally, governments and supranational institutions would play a central role in issuing climate-linked bonds to foster a deep and liquid global market. However, aligning their multiple objectives—providing financial incentives, offering effective hedging instruments, and generating reliable information—poses significant design challenges. The success of climate-linked bonds depends on the degree of standardization across markets and on their cost-effectiveness at scale.

Typically, investors attach an additional cost to complex financial products due to the need to understand their underlying intricacies (Sato, 2014; Thakor and Merton, 2023). To address this, it is crucial to align the design of climate-linked bonds with investors' hedging preferences, thereby reducing the risk associated with a mismatch between the chosen variable and the climate risks investors face. For a robust market, consistent and large-scale issuance of these bonds is essential, and this can be supported by governments and supranational organizations. Their involvement is critical in fostering a global market that achieves significant scale and uniformity, making these bonds more cost-effective and mitigating the additional costs associated with complex financial

products.

Another significant challenge is ensuring sufficient liquidity and offering a broad range of maturities. A liquid market facilitates easier buying and selling of bonds, attracting more investors and enhancing price discovery. Adequate diversity in maturities is crucial for constructing a comprehensive term structure of climate risks. This diversity helps investors and issuers better understand and manage climate risks over their relevant time horizons. For instance, property and casualty (P&C) insurers typically have short-term liabilities related to claims payments for damages and repairs, while pension funds generally have long-term exposures and liabilities. For both types of insurers, climate-linked bonds can be a part of their hedging strategy, but this segmentation underscores the importance of offering bonds with various maturities to meet the needs of different investor types and to improve overall market efficiency.

Furthermore, for climate-linked bonds to effectively achieve environmental goals, governments need to exert some influence over the climate variables associated with these bonds. This influence is vital for ensuring that the bonds' performance aligns with targeted environmental outcomes. However, achieving this alignment is complicated by the inherently unpredictable and complex nature of climate-related factors. Effective implementation of these bonds often requires international or even global coordination to address climate risks comprehensively and uniformly. Such coordination helps ensure that climate-linked bonds are integrated into broader environmental strategies and that efforts to mitigate and adapt to climate change are consistent across borders.

One challenge in constructing an adjustment mechanism that effectively hedges against climate risk is the potential for tipping points in climate change, where damages may increase exponentially after reaching a certain threshold (Lenton et al., 2020). To address this, the coupon structure of climate-linked bonds can be designed to be non-linear with respect to temperature. The key challenge is to align *ex ante* the sensitivity of the coupon structure to temperature with the sensitivity of climate damages to temperature.

4.3 Basis risk for investors

Investors will experience *basis risk* when investing in climate-linked bonds. This basis risk arises when the climate-related variables used to adjust the bonds' payoffs do not perfectly correlate with the investors' actual climate risk exposures or damages. We identify three key factors that complicate effective hedging against climate-related exposures:

1. **Emission Levels:** The amount of greenhouse gas emissions in the coming decades is uncertain, largely depending on current and future policy decisions, technological advancements, and societal changes.

2. **Climate Sensitivity:** There is scientific uncertainty regarding the extent to which global temperatures will rise in response to a given concentration of emissions. This uncertainty arises from potential tipping points in the climate system and complex feedback processes, such as changes in cloud cover, ice-albedo effects, and carbon cycle responses, which complicate the precise quantification of climate sensitivity. Based on current scientific estimates, if carbon concentrations double from pre-industrial levels, global average temperatures are expected to increase by 2°C to 4.5°C (Sherwood et al., 2020). However, there is potential for higher sensitivity due to tipping points IPCC (2021).

3. **Economic Damages:** Another source of uncertainty is the extent of economic damages, in monetary terms, that will result from a given level of temperature increase. These damages can vary widely depending on geographic location, economic resilience, and adaptive capacity.

Climate-linked bonds, especially those tied to temperature or emissions, are designed to mitigate the first and, to some extent, the second sources of uncertainty related to climate damage. However, the third source of uncertainty—the actual monetary damages that an investor experiences following increases in the climate variable—remains a significant residual risk. To manage this type of basis risk, investors can diversify their portfolios of climate-linked bonds

across different climate variables, thereby spreading the risk and reducing the likelihood that a single uncorrelated event will significantly impact their overall hedging strategy.

For a more exact hedge against specific climate risks, investors can also consider catastrophe bonds or private insurance contracts. These options are likely to become more widely available as private (re-)insurers can hedge their aggregate, diversified exposure across individual insurance contracts by investing in these bonds.

4.4 Political aspects of climate-linked bond issuance

A potential concern with climate policies is the long transmission lag or significant delay between the implementation of policies designed to reduce climate emissions and the observable effects on climate-related variables, such as average land temperature or water levels.[14] This delay poses a challenge in providing immediate feedback on the effectiveness of climate policies.

Additionally, government debt can be strategically used to impose constraints on future politicians, particularly those from a different party than the incumbent (Alesina and Tabellini, 1990). This raises questions about the efficacy of climate-linked bonds as financial incentives for governments to combat climate change, especially given the long transmission lags associated with climate policies.

However, several arguments counter this concern. Firstly, issuing these bonds with various maturities means that the political party in power today could indirectly bind itself if climate policies are unsuccessful, as the financial repercussions would span multiple terms. Conversely, successful climate policies would alleviate future financial obligations related to these bonds, benefiting the issuing party. Secondly, climate-linked bonds provide immediate feedback and incentives at the time of issuance, as their parameters are determined based on market perceptions at that moment.

It is important to note that individual governments have only partial control over the vari-

[14] Transmission lags are longest for temperatures, but for intermediate variables such as greenhouse gas emissions, the transmission lag will be shorter.

ables underlying climate-linked bonds. Even if a government implements effective policies and adaptation measures, the reference variable tied to a climate-linked bond may still fluctuate due to the actions or inaction of other governments. As a result, *free-riding* effects are a significant concern in the policy debate surrounding climate change and the energy transition. For instance, when the underlying variable is global temperature, some countries, particularly those with limited capacity to influence the variable, may have an incentive to rely on the efforts of larger countries.

However, we argue that these free-riding concerns are no greater than those associated with other climate-related policies. In fact, since climate-linked bonds provide immediate feedback effects—both negative and positive—they may serve as a mechanism to incentivize governments to engage in collective action. As noted earlier, the institutional setting of a climate club, in the style of Nordhaus (2015), can provide additional external motivation for governments to adhere to their climate obligations.[15] The international policies imposed by a climate club are likely to be more stringent, given that the issuance of climate-linked bonds provides national climate policies with a direct financial dimension.

Also, geographical factors, that cannot be influenced by governments can influence climate variables. Additionally, there is the issue of climate justice: some governments have contributed more to climate change in the past than others. As a result, the effectiveness of the incentives in climate-linked bonds increases as more governments collaborate and issue this instrument or if the bonds are issued at a supranational level.

4.5 Implementation and operational risks

Climate-linked bonds offer many benefits, but they also carry operational and implementation risks. These risks can be mitigated through precise calibration of adjustment mechanisms, transparent data reporting, robust governance frameworks, and advanced data collection and analysis

[15] More recently, Bolton et al. (2024) also suggest coalitions of advanced economies to prevent free riding in the context of large-scale climate finance.

technologies.

The calibration of adjustment mechanisms must be transparent and precise to maintain investor confidence. Any lack of clarity or perceived manipulation in how climate variables are measured and adjusted could harm the credibility of these instruments. To ensure accurate calibration, adjustments in coupon or face value must accurately reflect the underlying climate processes. Inaccurate calibration can lead to mispricing of the bonds, eroding investor confidence and reducing their attractiveness.

Overall, transparency in how climate variables are measured and reported is essential. This requires the use of reliable data sources and clear, consistent and stable methodologies for data collection and analysis. Any ambiguity or perceived manipulation in the data can undermine the credibility of the bonds, making them less appealing to investors. Transparent reporting standards are necessary to provide investors with regular and accurate updates on performance. This includes detailed disclosures on how climate variables are measured, how adjustments are calculated, and any changes in the methodologies used. Regular reporting helps to build trust and confidence among investors, making climate-linked bonds a more attractive investment option.

To further ensure the integrity and reliability of climate-linked bonds, robust governance frameworks are essential. This includes clear guidelines for data collection, calibration of adjustment mechanisms, and reporting standards. Independent oversight bodies can play a crucial role in monitoring compliance with these guidelines and ensuring that the bonds are managed transparently and effectively. To mitigate operational risks, issuers of climate-linked bonds should invest in robust data collection and analysis infrastructure. This includes leveraging advanced technologies such as satellite imaging, remote sensing, and climate modelling to gather accurate and real-time data on climate variables. Issuers should also establish clear protocols for data validation and verification to ensure the integrity of the information used for bond adjustments.

5 Conclusion

The introduction of climate-linked bonds represents an important step towards enhancing the comprehensiveness of financial markets, while concurrently providing a more tangible framework for measuring and mitigating climate risks. By incorporating climate-linked bonds into the financial landscape, the exposure to climate risks becomes intricately woven into the fabric of the government's balance sheet and the issuance of climate-linked bonds serves to explicitly delineate and formalize the government's role in addressing climate-related challenges, especially when confronted with significant external shocks. For investors, climate-linked bonds offer an investment opportunity in a new and innovative asset class that is less correlated with the business cycle and can be used to hedge against long-term climate risks.

In this paper, we highlight how a liquid market for climate-linked bonds *ex-ante* offers favorable pricing for issuers, such as national governments or supranational organizations, while providing long-term climate risk hedging opportunities for investors, including insurance companies and pension funds that are exposed to chronic losses resulting from climate change. Both advantages reflect the supply and demand for the innovative instruments. The hedging capabilities of climate-linked bonds are shown by how closely the bond payouts track the damages linked to the climate variable, such as temperature changes, emissions, or river water levels.

Furthermore, we explain how the pricing of climate-linked bonds provides information on the expected level of the climate variable (e.g. the expected temperature rise) as well as the perceived variance around this expectation, which we interpret as climate risk premium. We argue that this price discovery mechanism in the climate-linked bond market assists in the adequate pricing of climate risk. As we illustrate, this is crucial for enhancing market-based risk-sharing between agents. Moreover, we contend that a liquid climate-linked bond market improves the availability and pricing of other climate-contingent claims, thereby fostering climate risk insurance.

The concepts we present can be extended to nature-linked bonds. This can be achieved by applying similar principles while focusing on variables related to environmental conservation and

biodiversity. For instance, the face value or coupon payments of nature-linked bonds could be tied to metrics such as deforestation rates, wildlife populations, or water quality indicators. Like climate-linked bonds, nature-linked bonds incentivize governments to protect and restore natural ecosystems. Additionally, these bonds can serve as a tool for investors to hedge against environmental risks while promoting sustainable practices. By expanding the scope of climate-linked bonds to include nature-related variables, governments and investors can collectively contribute to preserving ecosystems and biodiversity, ultimately leading to a more sustainable and resilient future. In the case of nature-linked bonds, governments can likely influence the relevant metrics more directly because biodiversity effects are often more regional.

Overall, climate-linked bonds (or nature-linked bonds) provide an opportunity to hedge against key risks, making explicit the government support that often implicitly exists in the event of large natural disasters. As we have illustrated, these instruments further complete financial markets in the context of the looming transitions toward addressing climate change and achieving a net-zero economy. By integrating these bonds into investment strategies, stakeholders can better align their portfolios with climate action goals and contribute to more effective climate risk mitigation.

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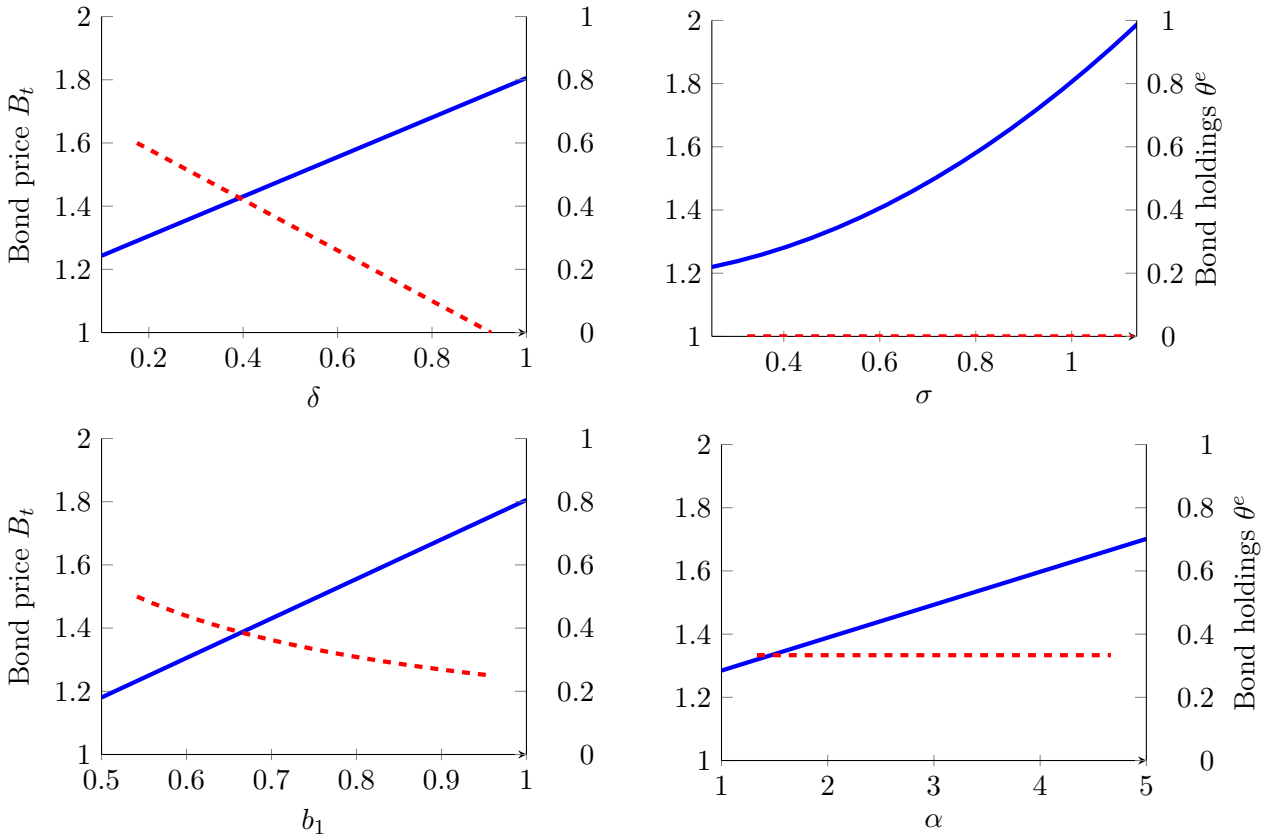
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A Model calibration

Figure 1 explores numerically how the bond price and the bond holdings of the exposed agents depend on (1) the fraction δ of agents exposed, (2) the uncertainty σ around the expected temperature, (3) the sensitivity b_1 of the climate-linked bond's pay off to the climate variable, (4) the risk aversion α. Our estimates provide a rough estimate based on the stylized model that we have explored. For the baseline calibration, we consider a 30-year investment horizon and take the risk-free return to be $R_f = 1.8$, which is roughly the accumulated wealth invested at a 2% interest rate over that period. Assuming that the reference temperature $\overline{T}$ equals the current temperature, we assume an expected temperature change of 1.5 degrees Celsius, with a standard deviation of 1 degree. In terms of damages, we assume that for every degree increase in temperature, the exposed individuals face a financial damage of 50 cents per euro currently invested.

We can observe from the figures the relationships that were already suggested analytically: a higher proportion of exposed agents increases the *aggregate* hedging demand, which in turn leads to a higher bond price, which in turn, in equilibrium lowers the *individual* holdings of exposed agents, θ^e, for the bond. Similarly, higher risk aversion, temperature variance, and bond payoff sensitivity to temperature increase the price of the bond. Note that the optimal holdings of climate-linked bonds in the second figure does not depend on climate change uncertainty (σ). This is easy to see because in equilibrium the optimal bond holdings for individuals only depends on the share of exposed agents (δ) in the economy and the sensitivities of the bonds (b_1) and damages (d_1) to climate change.

Figure 1: Equilibrium pricing: Bond price (solid blue, lhs) and demand (dashed red, rhs) of the exposed agents for climate-linked bonds



Note. This figure shows the relationship between bond price and demand under various parameters. The charts illustrate the effects of varying (1) the fraction of exposed agents (δ), (2) the impact of temperature standard deviation in degrees Celsius (σ), (3) the sensitivity of the climate-linked bond (b_1) to temperature, and (4) the risk aversion of agents. For the baseline calibration we use a risk-free return of $R_f = 1.8$, risk aversion $\alpha = 3$, expected temperature change $\mu = 1.5$ degrees, standard deviation of $\sigma = 1$ degree, strike $T^s = 1.75$, damage sensitivity to climate change $d_1 = 0.5$, fraction of exposed $\delta = 0.5$, and bond sensitivity to climate change $b_1 = 0.75$, with $b_0 = 1$.

B Temperature anomalies

Figure 2 shows annual temperature anomalies for large economies since 2000, indicating deviations from the 1991-2020 average surface temperature in degrees Celsius. These figures highlight the variations in average temperatures each year. This data provides an indication of how the coupons on climate-linked bonds, which are linked to these anomalies, could vary over time. The

mean temperature anomaly for the US is 0.234 degrees Celsius with a standard deviation of 0.469 degrees Celsius on an annual basis. Germany experienced the largest temperature anomaly on average, at 0.308 degrees Celsius over last 24 years. Canada shows the highest standard deviation, which is 0.782 degrees Celsius.

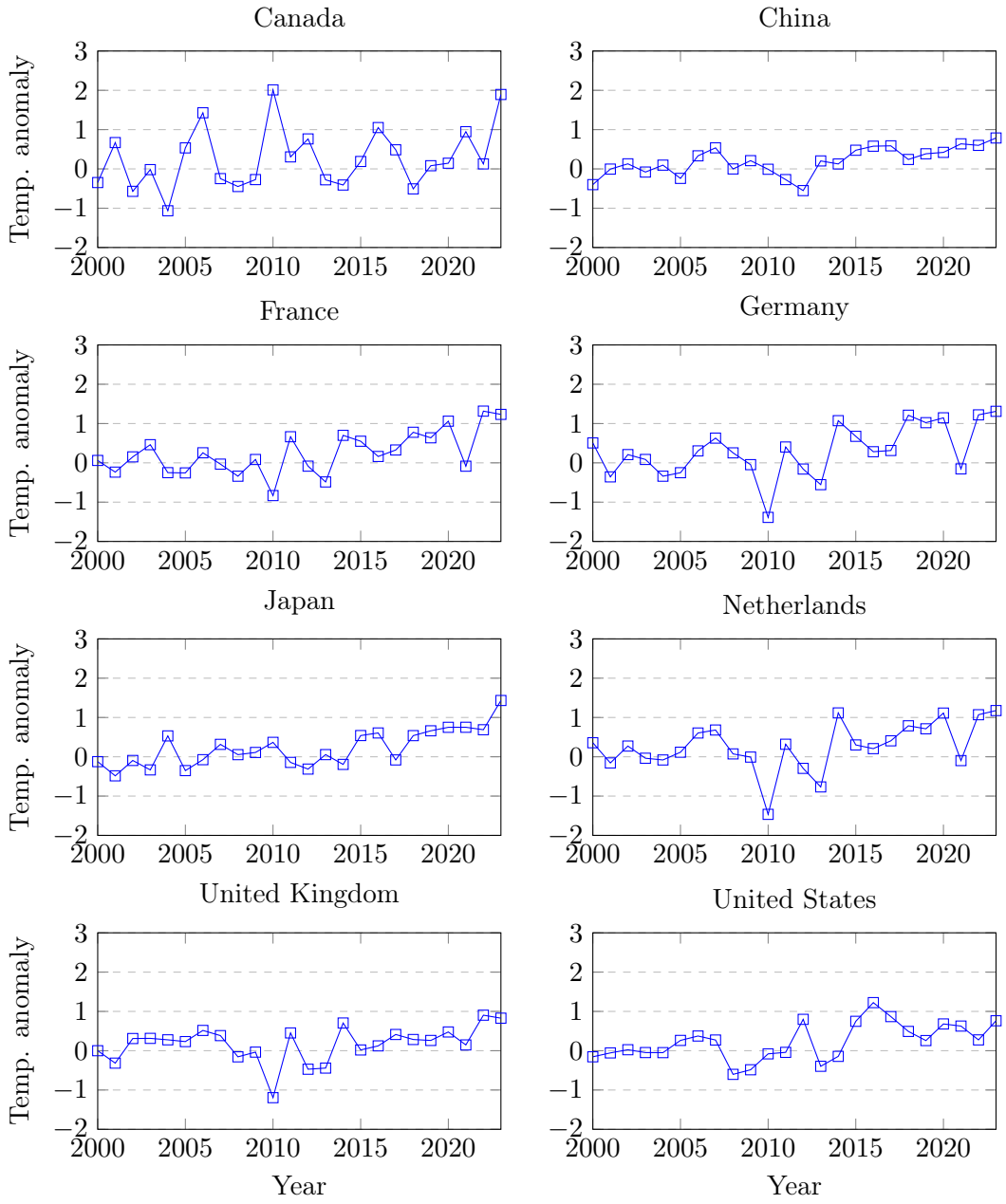
There are a couple of implications for setting the pay-off structure. First, if the temperature unit changes, the anomaly calculation will be different, and thus the pay-off structure needs to be adjusted to maintain the intended economic impact. For instance, a temperature anomaly in Fahrenheit will not be directly equivalent to the same numerical value in Celsius, so the conversion must be factored in. Second, climate-linked bonds will include provisions to ensure that coupons or redemption values cannot be negative. This is a crucial feature to protect investors and maintain the bond's value. If the temperature-based pay-off calculation could potentially lead to negative values, the bond's structure must incorporate mechanisms to ensure that such values are not realized.

C CO_2-trajectories

Figure 3 illustrates the annual CO_2-trajectories for major economies, highlighting deviations from the 1991-2020 average CO_2 emissions from fossil fuels and industry, excluding land-use changes. Each subfigure represents a different country, including Canada, China, France, Germany, Japan, the Netherlands, the United Kingdom, and the United States, covering the period from 2000 to 2023.

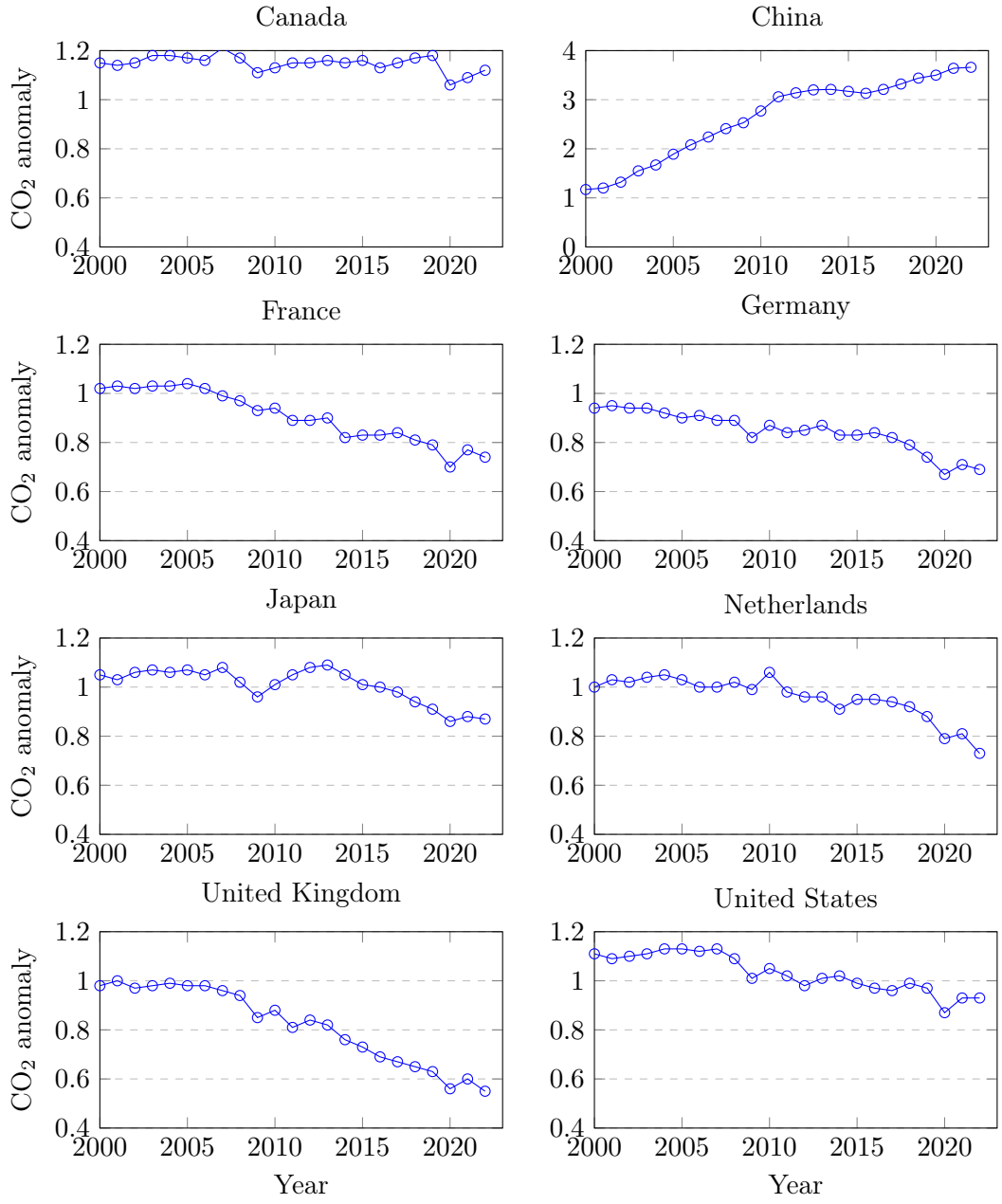
China's CO_2-trajectory shows a significant upward trend, with emissions rising sharply over the period, reflecting the country's rapid industrial growth. In contrast, the trajectories for Canada, France, Germany, Japan, the Netherlands, the United Kingdom, and the United States show relatively stable to downward trends, with some annual fluctuations that could be reflected in the payoff structure of climate-linked bonds.

Figure 2: Temperature anomalies for major economies



Note. This figure shows the annual temperature anomalies for large economies since 2000, indicating deviations from the 1991-2020 average surface temperature in degrees Celsius. The source includes modified information from the Copernicus Climate Change Service. Source: https://ourworldindata.org/grapher/annual-temperature-anomalies.

Figure 3: CO_2-trajectories for major economies



Note. This figure shows the annual CO_2-trajectories for large economies since 2000, indicating deviations from the 1991-2020 average CO_2 emissions from fossil fuels and industry. Land-use change is not included. Source: https://ourworldindata.org/co2-dataset-sources.