Climate Change Risk in Brazil

Ricardo Buscariolli

Abstract

In this paper I estimate the risk of long run temperature shifts over assets and I quantify the price of this risk using GMM. I use an econometric specification based on a theoretical model that integrates the interaction between global warming and economic growth, accounting for the (endogenous) risks of climate-induced damages. I find that climate change risk is already factored into asset prices, endowing capital markets with crucial information regarding the cost of climate change.

1 Introduction

In this paper I estimate the risk of long run temperature shifts over assets and I quantify the price of this risk. The impact of climate change on the macroeconomy is a critical consideration in the ongoing policy debate surrounding global warming (Stern, 2007; Nordhaus, 2008). However, accurately quantifying the economic costs associated with rising temperatures poses substantial empirical challenges, given that the most severe consequences of global warming have yet to materialize, making them difficult to discern from past output or income data. This paper contends that forward-looking equity prices, reflecting expectations regarding future growth and risk, offer valuable insights into the economic toll of global warming. My analysis leverages the influence of climate change on the short-term risk-return tradeoff, driven by investors' apprehensions about the long-term ramifications of temperature escalation for the overall economy. Utilizing capital market data, I show evidence that low-frequency temperature fluctuations exert a significant negative impact on asset valuations and carry a positive risk premium.

To elucidate the economic repercussions of long-term temperature shifts on present asset prices and anticipated returns, I use the climate change model of Bansal, Kiku and Ochoa (2019) that integrates the interaction between global warming and economic growth, accounting for the (endogenous) risks of climate-induced damages (Xavier, Scanlon, King, and Alves, 2022). In this model, a sustained temperature increase, driven by anthropogenic factors, induces a low-frequency component in future output drift and left-tail distribution—a manifestation of temperature's role as a source of long-term economic risk, reflected in current asset valuations and risk premiums. Analytical solutions are derived for lifetime utility, asset prices, risk premiums, and the social cost of carbon, explicitly illustrating the implications of temperature risks.

The cross-sectional variation in long-term growth risks in cash flows plays a pivotal role in identifying the economic impact of temperature risks, forming the basis of our baseline empirical analysis of Brazilian capital markets across ten book-to-market sorted portfolios known to display significant differences in long-term growth risks (Bansal, Dittmar and Lundblad, 2005; Parker and Julliard, 2005; Hansen, Heaton and Li, 2008; Bansal, Dittmar and Kiku, 2009).

The temperature beta of equity returns, representing exposure to temperature risks, is predominantly negative, particularly for portfolios characterized by high long-term consumption risks. The

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[*] Departament of Economics, Universidade Federal do ABC. E-mail: ricardo.buscariolli@ufabc.edu.br

cross-sectional variation in temperature betas facilitates the quantification of the price of long-term temperature risks inherent in current equity prices.

The evidence from our empirical analysis underscores that climate change risk is already factored into asset prices, endowing capital markets with crucial information regarding the cost of climate change.

Several studies have examined the impact of temperature variations on economic growth (Dell, Jones, and Olken, 2012; Bansal and Ochoa, 2012; Colacito, Hoffmann, and Phan, 2019). In contrast, my focus is on forward-looking equity valuations and asset returns, integrating the effects of global warming on risk premiums—insights unattainable from past growth rate data.

This is a working paper in early stage. The remainder of the paper unfolds as follows: Section 2 introduces a model of climate change and the macroeconomy to establish the nexus between temperature and asset prices. Section 3 identifies the economic impact of temperature risks using capital market data. Section 5 concludes.

1.1 Climate Change Economy

THe rationale I follow in this paper follows Bansal, Kiku and Ochoa (2019). Their model provides insights into how climate change affects economic dynamics and asset pricing, emphasizing the role of temperature in shaping risk and return profiles. They model the adverse effects of climate change on the economy starting with a functional form for the aggregate consumption growth (Δc_{t+1}) given by:

$$\Delta c_{t+1} = \mu + \sigma_\eta \eta_{t+1} + D_{t+1}$$

Here, μ is a constant term representing baseline consumption growth, σ_η is the standard deviation of consumption growth innovations, η_{t+1} is the i.i.d. consumption growth innovation, and D_{t+1} represent the climate-change driven damages. This last term D_{t+1} is determined by:

$$D_{t+1} = N_{t+1} d$$

Where $d < 0$ represents the decline in consumption growth due to temperature, N_{t+1} is Poisson process with intensity increasing with temperature anomaly (T_t) such that $\pi_t = \ell_0 + \ell_1 T_t$, $\ell_0, \ell_1 > 0$. Global temperature anomaly (T_t) evolves as

$$\begin{aligned} T_{t+1} &= \chi \mathcal{E}_{t+1} \\ \mathcal{E}_{t+1} &= \nu \mathcal{E}_t + \Theta \left(\mu + \sigma_\eta \eta_{t+1}\right) + \sigma_\zeta \zeta_{t+1} \end{aligned}$$

Climate sensitivity to emissions ($\chi > 0$) drives carbon emissions ($\mathcal{E}_{t+1}$), which is influenced by both endogenous and exogenous factors. The persistence of emissions and temperature ($\nu \in (0,1)$) and carbon intensity of consumption (Θ) shape these dynamics. Temperature, a consequence of anthropogenic carbon emissions, is driven by two types of shocks: endogenous industrial emissions, which is a function of aggregate output ($\mu + \sigma\eta\eta_{t+1}$) and exogenous innovation ($\zeta_t \sim$ i.i.d. $N(0,1)$). Assuming $\Theta > 0$, economic growth raises emissions, increasing temperature and the likelihood of climate-related damages. This feedback loop, from growth to temperature and back to growth, affects asset prices. Temperature fluctuations increase economic risk, raising the likelihood of damages and decreasing economic growth. This aligns with the conclusion of the Intergovernmental Panel on Climate Change (IPCC) on the link between greenhouse gas concentrations and global temperature rise.

The model uses recursive preferences, as in Epstein and Zin (1989), to capture the interplay between current and future consumption:

$$U_t = \left\{ (1-\delta) C_t^{1-\frac{1}{\psi}} + \delta \left(E_t \left[U_{t+1}^{1-\gamma} \right] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right\}^{\frac{1}{1-\frac{1}{\psi}}}$$

Where δ is the rate of time preference, γ is the coefficient of relative risk aversion, ψ is the intertemporal elasticity of substitution. The log of the intertemporal marginal rate of substitution determines asset prices in the following way:

$$m_{t+1} = \theta \log \delta - \frac{\theta}{\psi} \Delta c_{t+1} + (\theta - 1) r_{c,t+1}$$

Where $\theta = \frac{1-\gamma}{1-\frac{1}{\psi}}$, and $r_{c,t+1}$ is the endogenous return on wealth. The conditional risk premium of the consumption claim is expressed as:

$$\ln E_t \left[R_{c,t+1} \right] - r_{f,t} = \underbrace{(1 + \chi \Theta A_1)(\gamma + (1-\theta)\chi\Theta A_1)\sigma_\eta^2}_{\text{Growth Premium}} + \underbrace{(1-\theta)(A_1 \chi \sigma_\zeta)^2}_{\text{Temp-Premium}} + \underbrace{\gamma d^2 (\ell_0 + \ell_1 T_t)}_{\text{Damage-Premium}} \quad (1)$$

The first term, the Growth Premium, incorporates the impact of endogenous temperature risks in addition to the C-CAPM-implied premium of $\gamma\sigma_\eta^2$. The second and third terms denote premia for exogenous temperature variations and temperature-induced damage risks, respectively. These risk premia increase with temperature, reflecting the heightened likelihood of damages.

The impact of temperature on discount rates differs under the two preference specifications. Under a preference for early resolution of uncertainty, future discount rates increase due to higher risk premia, leading to decreased asset valuations with temperature rise. Conversely, under power utility with $\gamma > 1$, rising temperature lowers future discount rates, resulting in a positive temperature elasticity of asset prices.

Controlling for economic growth is crucial in measuring the impact of temperature risks and their premia. Omitting growth controls may bias the estimate of the temperature risk premium. In the feedback model of climate change, rising consumption leads to higher temperature and increased likelihood of climate-induced damages. Hence, a climate abatement policy mitigating emissions will have a larger benefit in high consumption states. Abatement actions lowering the probability of damages will decrease the climate-change risk premium. If abatement policies succeed in mitigating climate risks, the climate-change risk premium could decline over time. The focus lies in understanding how rising temperature affects asset prices, considering both future expectations and potential abatement efforts.

They examine cross-sectional variation in temperature exposure, relating to assets' sensitivity to consumption risks:

$$\begin{aligned} \Delta d_{i,t+1} &= \varphi_i \Delta c_{t+1} + \sigma_i u_{i,t+1} \\ &= \varphi_i (\mu + \sigma_\eta \eta_{t+1} + D_{t+1}) + \sigma_i u_{i,t+1} \end{aligned}$$

Where φ_i is the dividend beta, and σ_i is the asset-specific dividend shock. Assets' returns are affected by exposure to consumption growth risks and temperature risks, from the Euler equation, it follows that the risk premium of asset i is given by::

$$\ln E_t \left[r_{i,t+1} \right] - r_{f,t} = \beta_{i,\eta} \lambda_\eta \sigma_\eta^2 + \beta_{i,\zeta} \lambda_\zeta \sigma_\zeta^2 + \beta_{i,D} \lambda_D (\ell_0 + \ell_1 T_t) \quad (2)$$

In which $\beta_{i,\eta}$, $\beta_{i,\zeta}$, $\beta_{i,D}$ are the betas for different risks, and ℓ_0, ℓ_1 are the parameters influencing temperature anomaly we see in the poisson process N_{t+1}. The parameters $r_{i,t+1}$ and $r_{f,t}$ are, as we commonly see in other asset pricing models, the return of asset i and the return on the risk-free asset, respectively, in period t.

The main insight of this model is that temperature risks impact the economy through their influence on future growth. Consequently, the variability in temperature risks across assets is determined by the variability in consumption risks. Specifically, assets with higher dividend betas tend to exhibit higher (more negative) temperature betas. The model's testable prediction is that these two distinct risk measures—dividend beta and temperature beta—should demonstrate a negative correlation if temperature indeed poses a source of future macroeconomic risk.

2 Empirical Evidence

Bansal, Kiku and Ochoa's (2019) model shows that that forward-looking equity prices reflect expectations regarding the impact of rising temperature on the macroeconomy. Risk-averse investors preferring early resolution of uncertainty see a wealth decline with rising temperature and demand a positive premium for assets negatively correlated with temperature. Even before the full effects of rising temperature are realized, current asset prices and returns already incorporate expectations of future economic impact.

In order to access these insights, I use capital market data to quantify the cost of temperature and its variations. I focus on forward-looking capital market information which potentially offers insights beyond income-based measures as empirical studies linking global warming to historical income changes are, usually, backward-looking (Nordhaus, 2006).

I build 10 and 25 portfolios based on size, boot-to-market. Size portfolios are around for a long time (Fama and French, 1992) as small firms can suffer a long earnings depression that bypasses big firms suggests that size is associated with a common risk factor that might explain the negative relation between size and average return. I use book-to-market (BM) portfolios as high BM stocks have much higher sensitivity to long-run growth risks relative to low BM stocks (Hansen, Heaton, and Li, 2008). I try to explore the insights on how climate change affects the economy through the long-run growth-risk channel by accounting for the measurable differences in long-run growth risks across BM portfolios.

I use averages of annual data as the insights of Bansal, Kiku and Ochoa's (2019) model are focused on the economic implications of long-run variations in temperature associated with global warming rather than short-run variations that represent fluctuations in weather.

I try to access long-run shocks in temperature taking the difference in temperature at different frequencies. The time horizons range from one to five years. The notation is somehow intuitive. Let T_t denote annual temperature, hence $\Delta_K T \equiv T_t - T_{t-K}$. I, once again, follow Bansal, Kiku and Ochoa (2019) and assume that $K = 1$ corresponds to short-run fluctuations in weather and that $K \gg 1$ represents long-run temperature risks that corresponds to global warming. I also use moving-averages of temperatures ranging from 1 to 5 years as the dependent variable in my regressions.

The dataset commences in 1995, coinciding with the conclusion of the Brazilian hyperinflation era following the successful implementation of the stabilization plan known as Plano Real. This period witnessed significant changes in financial markets. To maintain consistency in microstructure, data preceding the Plano Real era is omitted. Due to the relatively limited post-1995 sample size, horizons exceeding five years are not considered.

I opt not to apply a liquidity filter. However, I exclude the top and bottom 10% of returns from the distribution. This trimming procedure mitigates the impact of outliers, which may arise from illiquid or penny stocks. Consequently, I solely employ a filter for return outliers, rather than incorporating a liquidity filter as well.

2.1 Data

I collect data on returns, prices, market, and book values from Economatica, a Brazilian firm specialized in compiling financial data. As a proxy for the risk-free rate, I utilize the average rate of interbank transactions conducted through interbank certificates of deposits (CDI). Although this rate may not be entirely risk-free, it remains a prevalent choice in Brazilian academic literature (Machado and Medeiros, 2011; Flister Bressan and Amaral, 2011; Machado, 2013; Blank et al., 2014). This preference likely stems from the perceived risk associated with government bonds in Brazil, leading researchers to opt for CDI as a pragmatic alternative to minimize ambiguity in selecting other proxies.

Data on average temperatures in Brazil are not readily accessible. Brazilian agencies offer data from each meteorological collection station across the country. [1] However, since 2016, Brazil has benefited from a daily gridded meteorological dataset with a spatial resolution of 0.25°× 0.25°, covering the period from January 1, 1980, to December 31, 2013. Xavier, Scanlon, King, and Alves (2022) have enhanced this dataset by refining the resolution of minimum and maximum temperature interpolations from 0.25°× 0.25°to 0.1°× 0.1°. This improvement incorporates data on topographic relief and extends the time frame from January 1, 1961, to July 31, 2020. Their methodology involves the application of ranked cross-validation statistics to determine the optimal interpolation method, selecting from inverse distance weighting and angular distance weighting techniques. The average Brazilian temperature is calculated using Xavier, Scanlon, King, and Alves' (2022) methodology using data until 2019 [2]

I draw data on consumption (Produto interno bruto (PIB) - consumo final) from the Instituto Brasileiro de Geografia e Estatística, Sistema de Contas Nacionais (IBGE/SCN Anual). This data is compiled by the Institute for Applied Economic Research (Ipea). [3]

2.2 Temperature Risk

I measure temperature risk in equity returns, the temperature betas, by their exposure to temperature variations. For each portfolio I run the following regression,

$$R^e_{i,K,t} = a_i + \beta_{i,T}\Delta_K T_t + \beta_{i,m} R^e_{m,K,t} + \beta_{i,c}\Delta_K c_t + u_{i,K,t} \tag{22}$$

where $R^e_{i,K,t}$ is the K-period cumulative excess return of portfolio $i, \Delta_K T_t$ is the K-year change in temperature, $R^e_{m,K,t}$ is the cumulative excess return of the aggregate market portfolio, and $\Delta_K c_t$ is the cumulative log growth of aggregate consumption. My controls for sources of risk other than temperature are motivated by Bansal, Kiku and Ochoa's (2019) model and by the consumption-based CAPM of Sharpe (1964), Lucas (1978), and Breeden (1979).

The five-year temperature betas are reported in Table 1. Note that on average, temperature beta is negative. In some specifications, high BM portfolios (the top two portfolios) have significantly negative exposure to temperature risks, that is, they tend to perform poorly when temperature rises. Low BM portfolios feature positive temperature betas. Temperature betas feature an almost monotonic decline across BM portfolios except when I use the fourth delta.

2.3 Temperature Risk Premia

The inverse relationship between temperature betas and average returns suggests that the market price of temperature risk is negative as predicted by our model. I exploit the Euler condition to

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[1] https://bdmep.inmet.gov.br/

[2] I thank professor Alexandre C. Xavier at the Universidade Federal do Espírito Santo for generously providing access to this data

[3] http://www.ipeadata.gov.br/

Table 1: Temperature betas

Port	β_{temp}	β_{Δ_1}	β_{Δ_2}	β_{Δ_3}	β_{Δ_4}
1	-3.98	-8.34***	1.84***	10.97***	6.59***
	(2.37)	(8.91)	(7.79)	(9.35)	(10.62)
2	-6.61***	7.72***	-1.4***	10.3***	8.95***
	(2.27)	(10.63)	(9.48)	(10.76)	(11.33)
3	-7.17***	-5.69***	-5.96***	-6.64***	-13.5***
	(1.49)	(7.27)	(5.85)	(6.84)	(6.92)
4	-4.53***	-0.41***	-3.04***	-0.55***	4.37***
	(1.5)	(6.61)	(5.68)	(6.32)	(6.71)
5	-7.94***	3.97***	-8.64***	-5.55***	-12.97***
	(2.07)	(9.57)	(8.29)	(9.14)	(9.11)
6	-3.58	-6.5***	-7.25***	-10.89***	-9.41**
	(2.44)	(9.29)	(7.69)	(8.52)	(10)
7	-2.87**	-7.64***	-6.12***	-5.12***	-1.46***
	(1.07)	(4.86)	(3.99)	(4.38)	(4.97)
8	-6.92***	-10.76***	-9.64***	-6.41***	-10.75***
	(1.68)	(7.49)	(5.8)	(7.22)	(8.32)
9	-8.27***	-0.61***	-9.58***	-19.29***	-25.09**
	(2.58)	(11.54)	(9.1)	(10.7)	(11.92)
10	-8.06**	-12.98**	-16.47**	-12.55**	-24.10*
	(3.34)	(13.21)	(11.08)	(14.14)	(15.54)

obtain an estimate of the market price of temperature risks:

$$\begin{aligned} &E\left[R^e_{i,K,t}\left(1+M_{K,t}\right)\right]=0,\ \text{for } i=1,\dots,N \\ &M_{K,t}=-\lambda_{\Delta T}\left[\Delta_K T_t-\mu_T\right]-\lambda_m\left[R^e_{m,K,t}-\mu_m\right]-\lambda_c\left[\Delta_K c_t-\mu_c\right], \end{aligned} \tag{28}$$

Table 2 reports the GMM estimates of the price of temperature, market and consumption risks - $\lambda_{\Delta T}, \lambda_m, \lambda_c$. Consistent with the prediction of the model, the price of temperature risks is negative. However it is only 5%-significant when I use the temperature in level, in the other specifications is non significant at any conventional level.

Table 2: Cross-sectional premia

VARIABLES	Level	Δ_1	Δ_2	Δ_3	Δ_4
β_{return}	26.15***	28.30***	24.03***	25.42***	29.84***
	(3.24)	(4.76)	(5.95)	(5.37)	(4.52)
β_{temp}	15.92**	0.16	0.00	0.07	0.15
	(6.29)	(0.14)	(0.23)	(0.12)	(0.09)
β_{cons}	9.06**	0.07*	0.09	0.11	0.36**
	(3.67)	(0.03)	(0.07)	(0.08)	(0.13)

3 Conclusion

This paper tries to grasp the effects of temperature over the long run risk of assets in Brazil. It is a working paper so there is still a lot to do. I need to run robustnes tests, more frequencies, different specifications and econometric tests. temperature seems to be playing a role in explaining equity risk and this should be studied more seriously.

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