The Economic Implications of Climate Change

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All datasets, codes, papers available at : https://github.com/Vedant0925/Climate-Economic-Modelling

Abstract

This analysis presents a comprehensive economic model designed to evaluate the complex impacts of climate change on global financial systems. The model uniquely combines advanced econometric techniques with climate science principles in response to the urgent need for integrating environmental dynamics with economic activities. It aims to bridge the gap between these disciplines, providing a nuanced understanding of the financial implications of climate change. The model quantifies the direct economic costs of climate-related changes and assesses the effectiveness of various mitigation and adaptation strategies, offering a valuable tool for policymakers and researchers.
The findings provide critical insights into the economic trade-offs and policy decisions essential for addressing the challenges of climate change. The model illustrates the dynamic interplay between greenhouse gas emissions, temperature changes, and economic variables and guides optimal strategies for balancing economic growth with environmental sustainability.

Motivation

The motivation for developing an economic model to assess the impacts of climate change stems from the urgent need to understand the complex interplay between environmental dynamics and global economic systems. In an era of heightened climate awareness, quantifying the economic ramifications of climate-induced changes is crucial for effective policy formulation. Traditional economic models often need to more adequately capture the nuanced effects of climate variables, leading to a critical gap in strategic planning and decision-making. This research is driven by the imperative to bridge this gap, offering a comprehensive tool that not only elucidates the economic consequences of climate change but also guides the development of efficient mitigation and adaptation strategies. Our model aims to enhance the capacity of policymakers and stakeholders to make informed decisions in the face of climatic uncertainties, aligning economic growth with environmental sustainability.

Literature Review

- *Rhetoric, Epistemology, and Climate Change Economics*
  This paper explores the role of rhetoric in shaping the economic discourse on climate change. It delves into the epistemological foundations of climate change activism and critiques the economic models used in this activism. The paper scrutinizes the connection between anti-foundational epistemology, language, and rhetoric in climate change economics, offering insights into how mitigation proposals are influenced by activist claims and the broader social and institutional conditions surrounding climate change debates.

- *Econometric Modelling of Climate Systems*
  This article highlights the importance of econometric modeling in quantifying the human impact on climate and the economic impacts of climate change. The paper discusses the equivalence of energy balance models and cointegrated vector autoregressions, emphasizing the need for models to be consistent with the underlying science. It underscores the role of econometric tools in informing policy decisions by quantifying impacts and uncertainties associated with climate change.

- *Climate Econometric Analysis of Temperature and GDP*

This study reviews the evolving field of climate econometrics, mainly focusing on the relationship between temperature changes and gross domestic product (GDP). The paper examines how temperature affects both the growth and level of economic output and introduces approaches to integrate empirical findings with integrated assessment models (IAMs) for improved damage modeling. It reveals that damage estimates through growth effects are generally more substantial than those through level effects, highlighting climate change's diverse impact mechanisms and adaptation effects.

- *Climate Econometrics*

This paper focuses on understanding the impact of climate on societies, which is essential for historical economic development, modern policy design, and future climate change management. It reviews and synthesizes recent advances in methods used to measure the effects of climate on social and economic outcomes. Key topics include the distinction between climate and weather from an econometric perspective, the use of weather variation for identifying climate effects, and the development of new approaches like parameterization of climate variables, nonlinear models, and empirical estimates for future climate change projections. The paper also addresses methodological challenges remaining in the field.

- *New Developments in Econometrics of Energy and Climate*

This paper introduces a special issue of Energy Economics, which is centered on recent developments in the econometrics of energy and climate. The issue compiles articles from a series of workshops that started in 2018, focusing on cutting-edge econometric tools applied to energy and climate change issues. The papers are grouped into four themes: energy markets, price forecasting, energy consumption and macroeconomics, and the unintended consequences of energy consumption on climate change.

Data Used

In this study, we employ a diverse array of datasets to analyze climate change's economic impacts comprehensively.

Each dataset has been selected for its relevance and contribution to our research objectives. They provide a multifaceted view of the complex relationship between climate variables and economic factors.

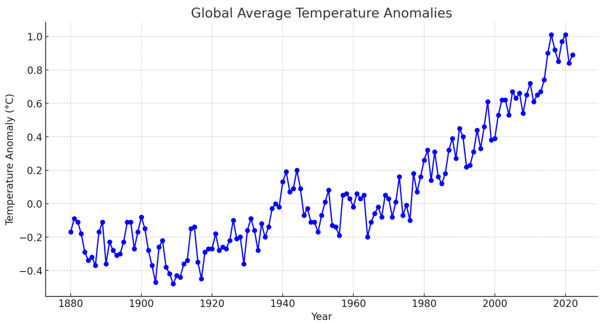
The first dataset focuses on the frequency and characteristics of natural disasters worldwide. It offers valuable insights into the increasing occurrence of climate-related events and their potential economic ramifications. The second dataset comprises detailed records of CO2 emissions, reflecting the environmental footprint of economic activities across different regions and timescales. This data is crucial for understanding the drivers of climate change and evaluating the effectiveness of emission reduction strategies. Additionally, we utilize a dataset on global temperature anomalies to measure the climatic changes occurring over time directly. This data is instrumental in correlating physical climate changes with economic impacts and policy responses. Furthermore, real GDP growth data is incorporated to assess the economic consequences of climate change and the efficacy of adaptation measures. This dataset provides a clear picture of economic growth patterns in the context of a changing climate.

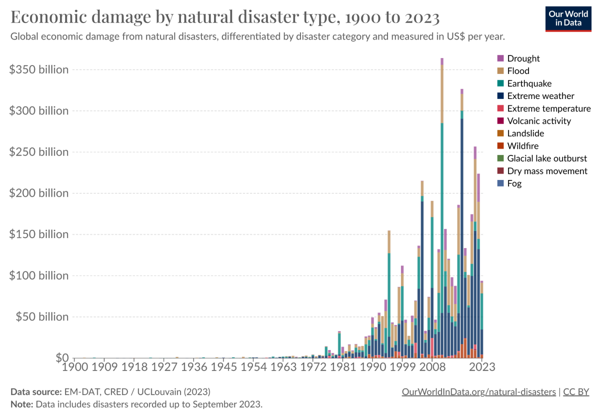
The data has been collected from various sources such as NASA, The World Bank website, The IMF website and an open source data repository called Our World in Data.

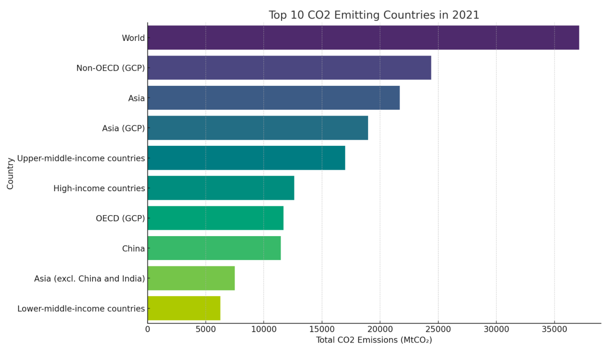
Data Utilization

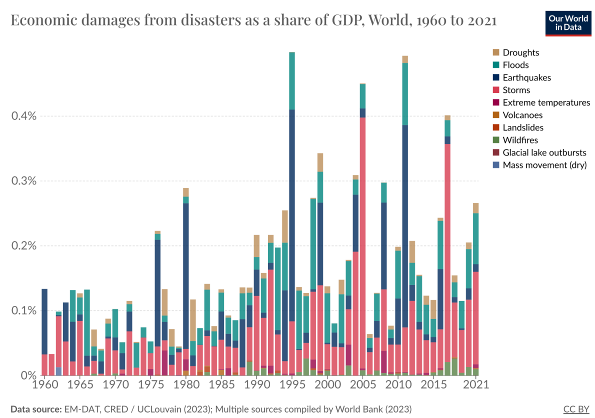
- We will use econometric techniques to analyze the data. This includes regression analysis to understand the relationships between variables, such as the impact of natural disasters and CO2 emissions on economic indicators like GDP growth.
- Time-series analysis will be pivotal in examining trends and patterns in climate data (temperature anomalies) and economic data (GDP growth rates) over time.
- Cointegration tests and Vector Error Correction Models (VECM) will explore long-term equilibrium relationships between climate variables and economic outcomes.
- This model will combine climate science and economic data to assess the impacts of climate change and explore mitigation and adaptation scenarios.
- We will integrate the results from our econometric analyses into this broader framework to forecast future trends and evaluate policy interventions.
- Different scenarios, such as high emission vs. low emission scenarios, will be analyzed to understand the range of possible outcomes and the effectiveness of various climate policies.

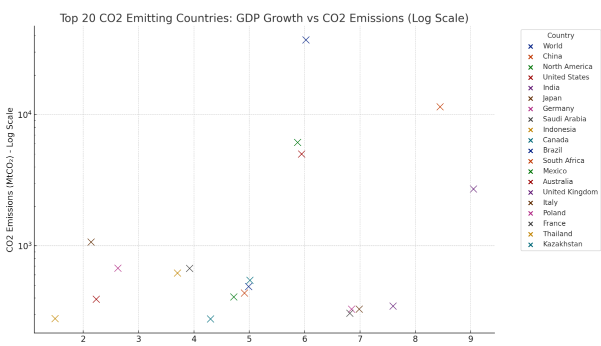
Exploratory Data Analysis

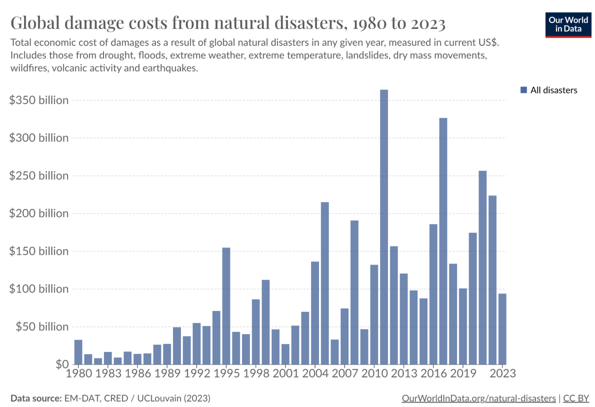


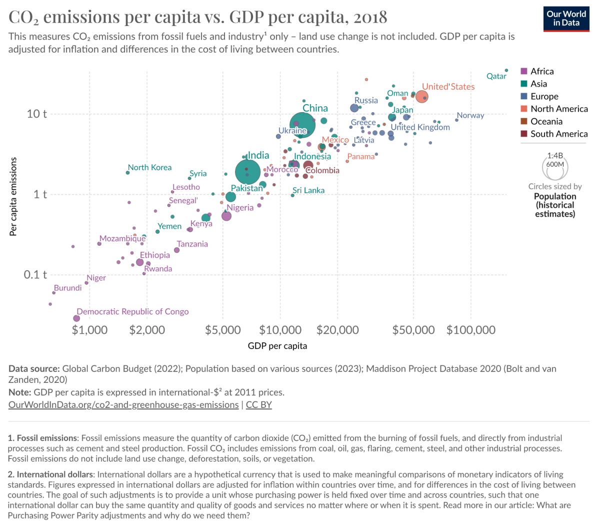












Procedure

The model will integrate key components: climate science dynamics and economic impacts. The goal is to quantify the economic effects of climate change and assess policy interventions.

1. Model Framework Development :
   We begin by establishing a theoretical framework that encapsulates the interactions between economic factors and climate variables. This includes formulating equations to represent greenhouse gas emissions, temperature changes, economic output, and the direct economic damages caused by climate change.
2. Econometric Estimation :
   Econometric techniques are employed to estimate the parameters of the model's equations. This involves using historical data on GDP, population, energy intensity, greenhouse gas emissions, and global temperature changes.
3. Policy Intervention Analysis :
   Scenario analysis is conducted to understand the potential outcomes under various climate and policy scenarios, providing insights into the most effective policy options.
4. Sensitivity Analysis :
   Sensitivity analysis is performed to examine the robustness of the model's outcomes against variations in key parameters and assumptions. This step is crucial to ensure the reliability and validity of the model's predictions.

Modelling

1. Climate Science component:

a. <u>Greenhouse gas emissions equation-</u>

$Et=\beta0+(\beta1.GDPt)+(\beta2.Popt)+(\beta3.EnergyIntensityt)+\epsilon t$

Et: GHG emissions at time t (measured in equivalent units of CO_2)

GDPt: GDP at time t

Popt: Population at time t

EnergyIntensityt: Energy intensity at time t (energy use per unit of GDP, a measure of energy efficiency).

ϵt: Error term representing other unobserved factors affecting emissions.

We will estimate the coefficients ($\beta0$, $\beta1$, $\beta2$,$\beta3$) using regression analysis with time-series data. This will help us quantify the extent to which each factor influences GHG emissions.

Finally after running the regression analysis taking gdp, population and energy_per_gdp as our independent variables, we derive values:

$\beta0$: 561.2188

$\beta1$: -1.3533

$\beta2$: 3.176×10^{-6}

$\beta 3$: 25.1618

ϵt, the error term calculated as the mean of the residuals comes out to nearly 2.33×10^{-7}

b. Temperature Change Model-

$\Delta Temp_t = \alpha 0 + \alpha 1 Et + \alpha 2 Temp_{t-1} + \eta t$

Et are the ghg emissions at time t as taken above.

$Temp_{t-1}$ is the temperature at time t-1

ηt is the error term at time t.

α values are calculated using a regression analysis as follows :

$\alpha 0=-0.002$; $\alpha 1=3.87\times10^{-6}$; $\alpha 2=1.3112$

The error term at time t comes out to be around- 5×10^{-8}.

2. Economic Component :

a. Production Function with Climate Impact-

$$Y_t = A_t K_t^{\gamma} (L_t H(Temp_t))^{1-\gamma}$$

This modified Cobb-Douglas production function incorporates the impact of temperature on labor productivity through the function $H(Temp_t)$.

This economic model integrates the effect of temperature on labor productivity within the traditional Cobb-Douglas production function. In this model, Yt represents the output at time t, At is the total factor productivity, Kt is the capital stock, Lt is labor, $Tempt$ is the temperature at time t, and γ is the output elasticity of capital. The function $H(Tempt)$ modifies labor productivity based on the temperature, reflecting the assumption that temperature can have an impact on the effectiveness of labor. This type of model could be used to study how climate change, through its effect on temperature, could potentially impact economic production.

b. Damage function-

$D_t=\delta_0+\delta_1 Temp_t+\delta_2(Temp_t^2)$

D_t represents the economic damages at time t as a percentage of GDP or output.

$Temp_t$ is the average global temperature deviation from a baseline (pre-industrial levels) at time t.

$\delta 0$, $\delta 1$, $\delta 2$ are parameters that quantify the relationship between temperature changes and economic damages. These parameters are estimated empirically through statistical analysis of historical data on climate impacts and economic outcomes.

$\delta 0$ - 4.186534

$\delta 1$ - (-15.170869)

$\delta 2$ - 13.428534

3. Policy Intervention Modelling :

a. Mitigation Cost Function-

$CMt=\theta(Et-Etarget)$

This function models the cost of mitigation efforts needed to reduce emissions to a target level

In this model, CMt represents the cost of mitigation at time t, θ is a parameter that reflects the cost per unit of emissions reduced, Et is the level of emissions at time t, and E_{target} is the desired target level of emissions. This cost function implies that the cost of mitigation increases linearly with the difference between the current level of emissions and the target level of emissions.

The mitigation cost function is essential for analyzing the economic implications of policy measures aimed at reducing greenhouse gas emissions. It provides a way to estimate the financial implications of moving towards a lower-emissions future and can help policymakers understand the trade-offs between economic costs and environmental benefits.

Determining the target emissions level will require further research and data analysis and same goes for the cost mitigation. The next steps would involve looking for cost mitigation data and reading more on target emission levels and normalising it to fit a global scale. This would be a part of the future work

b. Adaptation Cost Function-

$C_{At} = \phi D_t$

This function represents the cost of adapting to the damages caused by climate change.

C_{At} is the adaptation cost at time t.

Φ is the adaptation cost rate, which translates physical damages into monetary costs.

D_t is the physical damage at time t, which can be derived from a damage function, often related to GDP or another measure of economic output.

The adaptation cost function is used to estimate the financial requirements for strategies that aim to reduce the negative impacts of climate change. This may include investments in infrastructure, technological development, changes in land use, or other preventive measures. The adaptation cost rate, ϕ, is a critical parameter that can vary widely depending on the type of damages and the region's adaptive capacity. The estimation of ϕ will be largely based on historical data and further case studies. The rate could reflect the cost-effectiveness of adaptation measures, the expected rise in costs due to climate change, or the valuation of non-market impacts such as health and ecosystem services.

Takeaways

1. From the Greenhouse gas emissions equation-
   - β_0(561.2188): This constant term represents the baseline level of emissions when all other variables are zero. It serves as a starting point for the emissions model.
   - The negative coefficient for GDP (β1) could be indicative of developed economies where increases in GDP don't necessarily correspond to proportional increases in emissions, possibly due to better technology, energy efficiency, or a shift towards a service-based economy.
   - The positive coefficient for population (β2) underscores the challenge of managing emissions in rapidly growing populations.
   - The large positive coefficient for energy intensity (β3) highlights the significant impact of energy efficiency on emissions, suggesting that improvements in energy efficiency could be a crucial lever for reducing emissions.
2. From the Temperature Change model-
   - The model quantifies the direct impact of GHG emissions on

temperature change, emphasizing the importance of controlling emissions to manage global warming.

- The negative baseline change (α_0) could be due to natural variability or other climatic factors not captured by GHG emissions and past temperatures.
- The significant positive value of α_2 suggests that temperature changes are not only dependent on current emissions but also on the historical temperature, highlighting the importance of historical climate context and inertia in the climate system.

3. Production function with climate impact-
    - This model allows for a nuanced understanding of how climate change, specifically temperature variations, affects economic output. By integrating temperature into a production function, it acknowledges that climate change is not just an environmental issue but also a significant economic concern.
    - The function $H(\text{Temp}_t)$ represents the impact of temperature on labor productivity. This could reflect real-world scenarios where extreme temperatures (both high and low) affect workers' ability to perform, thereby impacting overall productivity.
    - In regions where temperatures rise significantly due to climate change, labor productivity might decline, particularly in outdoor or uncooled environments. Conversely, milder temperatures could potentially improve productivity in areas previously too cold for optimal work.
    - The model can be used to make long-term economic forecasts that consider the potential impact of climate change on labor productivity. This is important for long-term economic planning and investment.
4. Damage Function-
    - δ_0(4.186534): This constant term represents the base level of economic damage when temperature deviation is zero. A positive value indicates inherent damages, possibly reflecting ongoing impacts of climate change or other baseline economic vulnerabilities.
    - δ_1(-15.170869): The negative coefficient suggests that, initially, a slight increase in temperature from the baseline level might reduce economic damages. This could reflect short-term benefits in some

regions or sectors due to milder temperatures before the adverse effects of warming become dominant.

- $\delta 2$(13.428534): The positive quadratic term indicates that as temperature deviations increase further (beyond a certain point), economic damages rise significantly. This captures the accelerating negative impact of higher temperatures, like extreme weather events, sea-level rise, and reduced agricultural yields.
- The negative value for $\delta 1$ seems counterintuitive at first, as we generally expect higher temperatures due to climate change to increase economic damages. However, the negative coefficient can be understood in the context of the overall quadratic function
  - ➔ Initial Decrease, Then Increase in Damages: The quadratic nature of the function $\delta 2(\mathrm{Temp}_t)$^2 suggests that at lower levels of temperature increase, damages might initially decrease (as indicated by the negative $\delta 1$) but then begin to increase as the temperature deviation continues to rise. This is because the quadratic term ($\delta 2(\mathrm{Temp}_t$^2), which is positive) eventually outweighs the linear term.
  - ➔ Potential Benefits at Slight Temperature Increases: The negative $\delta 1$might reflect a scenario where slight increases in temperature from the pre-industrial baseline could initially have some beneficial impacts (such as longer growing seasons in certain regions, reduced heating costs, etc.) before the negative effects (like extreme weather, reduced agricultural productivity in hotter areas, etc.) start to dominate at higher temperature levels.
  - ➔ Model Interpretation and Limitations: It's important to interpret this in the context of the specific model and the range of temperatures being considered. The negative $\delta 1$ value is just one part of a larger function, and its impact should be considered alongside the quadratic term. Also, it's crucial to

be cautious about extrapolating results beyond the range of temperature deviations observed in the historical data used for estimating these parameters.

5. Mitigation Cost Function-
   - Linear Relationship: The model implies a linear relationship between the cost of mitigation and the extent of emission reduction required. The further the current emissions are from the target, the higher the cost of mitigation.
   - Determining E_{target}: Setting an appropriate target emission level is critical and should be informed by scientific research on climate thresholds, international climate agreements, and national commitments.
   - Estimating θ: The cost per unit of emissions reduced can vary significantly based on technology, geographic region, economic conditions, and the nature of the emitting industries. This requires careful evaluation and may need regular updates as new technologies and processes emerge.
   - Incorporating Indirect Costs and Benefits: While the function primarily considers direct costs, it's important to also consider indirect costs and benefits, such as health improvements due to reduced pollution, which can affect the overall economic assessment of mitigation strategies.
6. Adaptation Cost Function-
   - Quantifying Adaptation Costs: This function provides a mechanism to estimate the financial requirements for adapting to the impacts of climate change. It translates the often abstract concept of physical damage into concrete monetary terms.
   - Guiding Investment in Adaptation Measures: The model can inform where and how much to invest in adaptation strategies like infrastructure reinforcement, technological innovations for climate resilience, and changes in land and resource use.
   - Estimating ϕ: The adaptation cost rate can vary significantly based on the region, the nature of the climate impacts, and the specific adaptation measures. Determining this rate requires comprehensive data analysis and may involve complex assessments of various adaptation scenarios.
   - Regional Variability: The costs and effectiveness of adaptation

strategies can differ greatly depending on geographical and socio-economic contexts. This necessitates a localized approach to estimating ϕ and planning adaptation measures.

- Long-Term Planning: Adaptation is often a long-term process, and the function should account for the evolving nature of climate impacts and adaptation needs over time.

Future Work

1. For the mitigation cost function-
    - Dynamic Modeling: Incorporating dynamic elements into the model can help understand how mitigation costs evolve over time, especially as economies transition towards lower-carbon modes of production and consumption.
    - Integration with Economic Models: Linking the mitigation cost function with broader economic models can provide insights into the overall economic impact of climate policies, including effects on GDP, employment, and sectoral shifts.
    - Estimating θ: The cost per unit of emissions reduced can vary significantly based on technology, geographic region, economic conditions, and the nature of the emitting industries. This requires careful evaluation and may need regular updates as new technologies and processes emerge.
    - Determining E_{target}: Setting an appropriate target emission level is critical and should be informed by scientific research on climate thresholds, international climate agreements, and national commitments.
2. For the adaptation cost function-
    - Dynamic Modeling: Incorporating dynamic elements into the adaptation cost function can help understand how adaptation needs and costs evolve as the impacts of climate change unfold over time.

- Integration with Broader Climate and Economic Models: Linking the adaptation cost function with broader climate impact models and economic frameworks can provide a more comprehensive understanding of the overall economic implications of climate change.
- Incorporating Non-Market Impacts: Beyond direct economic costs, adaptation strategies often have significant non-market impacts, such as on health, biodiversity, and ecosystem services. These should be factored into the estimation of ϕ.

References

1. Poitras, Geoffrey. "Rhetoric epistemology and climate change economics." Ecological Economics 184 (2021): 106985. www.elsevier.com/locate/ecolecon
2. Miller, J.I., Bjørnland, H.C., Chang, Y. "Introduction to 'New Developments in Econometrics of Energy and Climate'." Energy Economics 100 (2021): 105323. www.elsevier.com/locate/eneeco
3. Solomon M. Hsiang., "Climate Econometrics", Working Paper 22181 http://www.nber.org/papers/w22181 NATIONAL BUREAU OF ECONOMIC RESEARCH
4. Jun-Jie Chan, Zhifu Mi, Yi-Ming Wei. "Temperature and GDP: A review of climate econometrics analysis ." www.elsevier.com/locate/strueco
5. Felix Pretis, "Econometric modelling of climate systems: The equivalence of energy balance models and cointegrated vector autoregressions ."].Department of Economics, University of Victoria, BC, Canada. www.elsevier.com/locate/jeconom