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An Exogenous Risk in Fiscal-Financial Sustainability: Dynamic Stochastic General Equilibrium Analysis of Climate Physical Risk and Adaptation Cost

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Abstract: This research aims to explore the fiscal and public finance viability on climate physical risk externalities cost for building social-economic-environmental sustainability. It analyzes climate physical risk impact on the real business cycle to change the macroeconomic output functions, its regressive cyclic impact alters tax revenue income and public expenditure function; This research also analyzes that the climate physical risk escalates social-economic inequality and change fiscal-financial policy functions, illustrates how the climate damage cost and adaptation cost distorts fiscal-finance cyclical and structural equilibrium function. This research uses binary and multinomial logistic regression analysis, dynamic stochastic general equilibrium method (DSGE) and Bayesian estimation model. Based on the climate disaster compensation scenarios, damage cost and adaptation cost, analyzing the increased public expenditure and reduced revenue income, demonstrates how climate physical risk externalities generate binary regression to financial fiscal equilibrium, trigger structural and cyclical public budgetary deficit and fiscal cliff. This research explores counterfactual balancing measures to compensate the fiscal deficit from climate physical risk: effectively allocating resources and conducting the financial fiscal intervention, building greening fiscal financial system for creating climate fiscal space.

Keywords: fiscal sustainability; budget; deficit; fiscal cliff; climate physical risk; tax revenue; GDP; contingent liabilities; public expenditures; insolvency; equilibrium; liquidity; DSGE

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1. Introduction

Public finance and fiscal sustainability mostly focus on demographic development and their impact on public expenditure in health care, education and social security etc. Some scholars extend their analysis to the long-term challenges for public finance such as international immigration and labor immigrant, but the effects of climate physical risk and adaptation cost are rarely taken into account to the fiscal and public financial sustainability. In particular emerging market and developing countries have faced the fiscal-financial challenges for creating fiscal space to the low-carbon and climate resilient social economic transition. Sometimes arise a large budgetary deficit and fiscal cliff in developing and emerging market during climate disaster period. Therefore, building green sustainable fiscal viability is essential for reaching Paris global climate change net-zero transition target and UN SDG 2030.

Extreme weather events and chronic change in temperature and precipitation have triggered different losses of microeconomic output, disrupting supply chain, and exacerbating working environment and declining labor productivity, subsequently reducing GDP growth. However, very few governments credibly estimate the cost and uncertainty from climate change physical risk and corresponding impact on the public finance and budgetary viability. In 2021 ten most destructive weather events cost a combined $170 billion in damages (Damian 2021). Moreover, the extreme weather events trigger economic-financial risk and spillover into realm of political-economic risk includes climate-induced international immigration and conflict etc. Climate disaster impact on labor income and businesses profit, revenue losses, welfare, labor mobility and mortality, forced migrations (Barnett 2003; Arnell 2004; Parry et al. 2004; Van Lieshout et al. 2004; Stott et al. 2004). Climate immigration triggers the potential losses of cultural heritage sites, biodiversity losses and new conflict etc. However, as Agarwala and Burke (2021) highlighted that fiscal-public financial systems are far behind and poorly equipped to estimate and manage these climate-induced risks. The fiscal-financial challenges and government budget deficit due to climate disasters happen across advanced economy, emerging and developing countries.

Climate mitigation and adaptation are cheaper than the alternative inaction in implementing climate policy. Recent studies and observation show that the increase in the global average temperature to below 2 degrees Celsius above pre-industrial levels will reduce global income by 1.07 percent by 2100. However, inaction in climate change will reduce world real GDP per capital by 7.22 percent by 2100 (Kahn et al. 2019). Moreover, there are growing scientific and economic evidences show that the social-economic and financial-fiscal effects of climate physical risk are deteriorated, disrupts the financial-fiscal general equilibrium, exacerbates the fiscal-financial stability and leads to fiscal cliff and government deficit. However, a well-designed climate financial-fiscal policy intervention can actually serve to reduce financial-fiscal risk and improve trade-off between the financial fiscal equilibrium and the climate adaptation and damage cost. Thus, it is paramount for policy makers and central bank to estimating the fiscal and public financial sensitivity to climate change, analyzing climate physical risk damage cost impact on the macroeconomic output and fiscal-monetary policy adjustment, public expenditure and revenue income. This aims to improving financial-fiscal resilient viability and fiscal space to offset the climate-induced fiscal-financial shock, building climate fiscal capacity and sustainability for managing fiscal climate risk.

Research objectives This research aims to examine the public finance exposure to climate physical risk and climate adaptation cost, explore the prototype of climate induced public financial and fiscal distortion; analyze the fiscal-finance sensitivity and distortion rate to climate change physical risk, providing rigorous assessment for creating the fiscal space addressing to the fiscal-financial vulnerability to global climate physical risk.

Literature review There is a lack of concerning on integrating climate physical risk into the public finance and fiscal sustainability, this topic has not yet been explored and there is a big gap of a lack of testing the climate physical risk impact on public finance and fiscal equilibrium in contemporary literature. Some scholars attempt to quantify the effects of climate change on economic performance: agricultural, labor employment and productivity, commodity prices, health, conflict and economic growth (Stern 2007; Neumann et al. 2020; Howard and Sylvan 2021). A few scholars have started research on climate change impact on the fiscal sustainability, Agarwala and Burke (2021) analyze the climate change transition risk and physical risk impact on sovereign creditworthiness and debt risk. Some scholars (Lamperti and Bosetti 2019) analyze the cost of climate-induced financial instability, the rescuing insolvent banks will cause an additional fiscal burden of approximately 5–15% of GDP per year and increase the ratio of public debt to GDP, but their research highlights the climate change impact on the labor productivity and stock capital damage. Lint Barrage (2020) analyzes the fiscal costs of Climate change and highlighted the climate mitigation and adaptation policy like carbon pricing and distortionary tax impact on fiscal revenue. Parry et al. (2018) and Schneider et al. (2007) discussed the risk and vulnerability of global climate change. This research fulfills a gap in the current literature, modeling the impacts of climate physical risk externalities on the multiple dimensional financial-fiscal equilibrium distortion: macroeconomic output and economic-social inequality, fiscal and monetary policy, regressive impact on revenue income and increased public expenditure, trigger fiscal deficit and financial shock.

It is challenging to specify a dynamic stochastic general equilibrium model (DSGE) with reasonable macroeconomic implications and fiscal disaster risk. Gabaix (2012) and

Gourio (2012) applied DSGE to test the macroeconomic impact and exogenous risk. This research develops Bayesian DSGE estimation, it is used throughout this research to constitute the economic distortion rate equations, testing economic shock probability parameters, and demonstrating climate physical risk externalities impact on fiscal finance equilibrium through the cyclical-structural economic function change.

Research questions This research sheds light on the questions of how climate physical risk externalities might affect the public financial stability and fiscal sustainability, how climate physical risk impact on the revenue income and public expenditures, change the financial-fiscal general equilibrium? How to assess the fiscal and public finance sensitivity and distortion ratio to climate physical risk and building green fiscal viability?

Research assumptions This research hypothesizes that financial-fiscal exposure to climate physical risk externalities, distort financial-fiscal structural and cyclical equilibrium and triggers potential government deficit and fiscal cliff. This research assumes that the climate physical risk externalities exacerbate the macroeconomic growth, escalate social-economic inequality, increase public expenditure and tax revenue losses, generate expansionary fiscal-financial policy, triggers structural and cyclical financial-fiscal deficit and increases public debt ratio to GDP. Thus, fiscal budget is highly sensitive to climate disaster and the financial-fiscal equilibrium is distorted by climate physical risk. This research assumption is based on that the climate adaptation cost and damage cost will distort economic function and slow down the GDP growth, increasing public expenditures and revenue losses by comparing to the counterfactual hypothetical approach.

Research methodologies and research variables This research applies dynamic simulation-based stochastic general equilibrium analysis (DSGE) and Bayesian theorem, as well as binary and multinomial logistic regression analysis to test the fiscal-financial sensitivity to climate physical risk externalities, analyzing how exogenous climate shock variables impact on the endogenous economic parameters shock, distorts fiscal-financial function, how the climate adaptation and damage cost deflect financial-fiscal equilibrium. Observing and analyzing various climate externalities variables and the unmeasurable heterogeneous economic impact aim to modeling the channels which trigger general financial fiscal distortion. On the basis of the marginal likelihood and the Bayes factors, climate disaster magnitude and resilience are used to capture the stochastics and dynamics of climate physical risk as the external variables distorting fiscal-financial equilibrium, as long as a sufficient number of structural and cyclical economic function shock is considered in this research.

In this research DSGE is an application of the real business cycle methodology with dynamic climate physical magnitude and climate resilience. Climate physical magnitude is indexed to climate scale, scope and persistent time. Climate resilience depends on adaptation infrastructure. DSGE model and Bayesian method transmit the climate change exogenous shocks into endogenous business cycle fluctuations and distorts economic cyclical-structural functions. The model incorporates climate externalities with multinomial economic variables like productivity, labor supply, consumption, investment, value chain, supply chain, labor income, subsidies, tax revenue, insolvency and normal interest rate etc.

This research develops a SDGE model and Bayesian theorem to test the 9 climate exogenous variables interaction with observable but unmeasurable 39 economic variables, constructed 10 economic function cyclical-structural shocks: GDP, financial market, capital market, fiscal and monetary policy shocks, insolvency and public expenditure, liquidity and equilibrium, fiscal deficit and cliff. The Bayesian estimation specifies the Climate disaster impact GDP growth shock and sensitivity rate parameters, finance policy shock parameters, public expenditure sensitivity and distortion rate to climate escalated social-economic inequality.

This research also develops SDGE to test how climate disaster distorts tax revenues functions including multinomial fiscal variables: personal income tax, corporate income tax, VAT, tax relief, subsidies for commodity, declined tax revenue, fiscal financial liquidity, fiscal financial equilibrium etc. Bayesian theorem will be used to explore the tax revenue equilibrium shock probability and distortion rate parameters.

The last chapter of this research uses a SDGE to test how climate disaster distorts multinomial variables of public expenditure: bailout for businesses, bailout for social protection, subsidies for consumer goods, public infrastructure adaptation cost, for insolvent financial institutions, human health and ecosystem service etc. This triggers government budget deficit and fiscal cliff, debt ration to GDP orthogonal structural shocks. Bayesian theorem will be used to explore the public expenditure shock probability and distortion rate parameters. Finally, this research will test the binary and multinomial logistic regression impact of climate externalities on finance-fiscal equilibrium function, explore the fiscal finance shock probability and distortion rate, as well as the increased debt ration to GDP.

In this research A represents Prior climate disaster condition, B represents posterior climate disaster condition. The external climate shock is assumed to be proportional to aggregate above assumption: positively and negatively. "−" represents negative proportional relationship, "+" represents positive proportional relationship. It is estimated with Bayesian techniques by using climate exogenous variables and the above key economic variables.

2. Climate Physical Risk Distorts GDP Growth and Cyclical Fiscal Function

Climate physical risk generates negative impact on real businesses cycle and GDP growth, labor productivity and employment, consumption and investment, distort economic functions and finance-fiscal equilibrium, changes tax base and reduce tax revenue and fiscal income, triggers financial shock and fiscal cliff.

2.1. Real Macroeconomic Impact of Climate Disasters: Analysis Based on Real Business Cycle

Climate hazards distort economic function and fiscal equilibrium. The climate damage function shows that the climate externalities distort economic performance as the followings: disrupting supply chain, undermining consumption and investment, reducing labor productivity and employment, damaging physical property including houses, machinery and equipment etc., triggering physical capital losses and market capital depreciation, increasing subsequent insurance expenditures and triggering security and equity price volatility in stock market. Thus, the real business cycle performance exposure to climate hazards will directly reduce the real GDP growth and drive to cyclical fiscal function distortion, declining tax base and tax revenue income.

The climate externalities are assumed as exogenous stochastic component causing the real business cycle shock and market price fluctuation. Climate disaster scenario comprises of disaster scale = Cds, scope = Cdp, magnitude = Cdm, severity = Cds, and persistence timing = Cdt. value chain resilience = Vcr, market resilience = Mr, labor productivity decline = LPd, Employment Rate deline = Erd, Production output decline = Oud, Investment decline = Ind, consumption deline = Cod.

The disruption of supply chain ends up increasing input cost or/and suspending businesses operation, declined investment and consumption, labor productivity and employment declined. Direct human capital losses = Labor security insurance + labor cost = Hs, direct physical capital losses = machinery + equipment + housing property = Ps, this real business cycle losses from climate disaster depend on the climate disaster externalities magnitude and resilience scenarios, trigger the economic cyclic decline, resulting in production output and GDP growth declined = GDPd.

Simultaneously, Climate hazards also generate negative impact on the contiguous region's economic output, because the supply chain disruption triggers spillover impact along its value chain. This is the extra economic damage = Exnp. The distributional impacts from climate disaster reflects the accumulative climate disaster economic losses:

$$\text{GDPd} = (\text{Hs}, \text{Ps}, \text{LPd}, \text{Erd}, \text{Oud}, \text{Ind}, \text{COd}) + \text{Exnp}.$$

Bayesian DSGE estimation is used to model the GDP shock probability induced:

$$P\ (\text{GDP BIA}) = \sum (\text{PLPd, P Erd, P Qud, P Ind, P Cod, P Exnp})\ (\text{BIA})$$

$$\text{Cdem} = (\text{Cdc, Cds, Cdt, Mr}),\ \text{Resilience: Res} = (\text{Mr Vcr})$$

The GDP sensitivity rate is calculated as the followings:

$$\begin{aligned} R(\text{GDP BIA}) &= \sum(\text{PLPd, PErd, PQud, PInd, PCod, P Exnp})(\text{BIA})(1-\text{MrVcrBIA})/1-(\text{Cdc, Cds, Cdt, Mr}) \\ &= \frac{\sum\ P\ (\text{GDP BIA})\ (1-\text{MrBIAVcrBIA})}{1-\text{Cdm}(\text{BIA})} \end{aligned}$$

Under the various climate disaster magnitudes the real business cycle shock is heterogeneously deflected from counterfactual general equilibrium, climate disaster drives inflation and declines GDP growth function, distorts finance-fiscal equilibrium. The entire function of climate disasters impact on output and real GDP as the following diagram Table 1, this generates a multinomial regression process for fiscal equilibrium.

Table 1. Climate disaster distorts GDP growth functions and change fiscal-finance equilibrium.

Climate Disaster as Exogenous Shock	Labor Productivity A I B (LPd)	Employment Rate A I B (Erd)	Production Output A I B (Oud)	Overall Liquidity Condition in Market A I B	Investment A I B (Ind)	Consumption A I B (Cod)	GDP Growth A I B	Financial Fiscal Equilibrium A I B
Scope A I B	–	–	–	–	–	–	–	–
Scale	–	–	–	–	–	–	–	–
Severity A I B	–	–	–	–	–	–	–	–
Persistence time A I B	–	–	–	–	–	–	–	–
Market resilience A I B	+	+	+	+	+	+	+	+
Value chain resilience A I B	+	+	+	+	+	+	+	+
Magnitude A I B	–	–	–	–	–	–	–	–
Economic A I B diversification	+	+	+	+	+	+	+	+
Climate disaster exposure A I B	–	–	–	–	–	–	–	–

This Table 1 reflects the climate disaster impact on the real business cycle and the macroeconomic output, generating the multinomial regression to GDP growth and determining that fiscal revenue income is multinomial and no-leaner, this shows the negative-proportional relationship and positive proportional relationship between climate externalities and economic variables.

2.2. Chronic Climate Damage Cost and Its Impact on GDP Growth Function

The chronic increase in temperature, humidity, sea level rise and precipitation triggers social-environmental-economic damage and biodiversity losses, distort economic growth functions and fiscal-financial equilibrium and liquidity.

According to the IPCC 2013, the global average temperature has increased by 0.85 Celsius since the industrial revolution, estimates of future warming by the end of current century range from 0.9 to 5.4 Celsius degrees (Fernando et al. 2021) given no any mitigation and adaptation is taken. The climate damage function is estimated from the future temperature and precipitation change scenarios interaction with environmental and social economic system: decrease in sea ice and increase in heat waves and heavy precipitation, risk of inland flood and sea level rise, inducing significant risk of biodiversity loss in many tropical areas, redistribution of demographic populations due to sea level rise, change human healthy wellbeing, labor productivity, human mortality and immigration etc. Chronic global warming reduces labor productivity, increasing the human mortality and mobility. Productivity declines roughly by 1.7% for each 1 °C increase in daily average temperature above 1.5 °C (Deryugina 2014). There is a productivity loss in various cognitive and physical tasks about 2 percent per 1 °C for temperature over 25 °C.

The NCAV (2021) found that if global temperatures rise 2.4 °C, it could result in a loss of 0.5 to 2.5 percent in GDP by 2090. In 2007 the world bank and China's State Environmental Protection Agency jointly produced an assessment on the cost of various types of environmental damage at 5.8 percent of China's GDP (World Bank 2007), Harris and Roach (2021). The Network for Greening the Financial System projected that federal revenue could be 7.1 percent lower annually by 2100 (about $2 trillion in today's terms) under a scenario in which climate change reduced U.S. GDP by 10.0 percent compared to a no-further-warming counterfactual (NGFS 2021).

There is a very few positive impact from global warming on businesses and industries. In the Arctic region the chronic global warming will facilitate agriculture growth, reduce energy consumption for heating, stimulating biodiversity growing, opening navigational opportunities in the Arctic Ocean, but the global warming also promotes snow melt, sea level increasing and flood to the low altitude places. Thus, the overall impact from the chronic global warming and increase in precipitation will be negative. The chronic damage cost reflects the global climate change future impact on world agriculture, cost of protecting against rising sea levels, health effect and ecological impact (de Mooij et al. 2012). The calibration and estimation of economic damage functions transform climate weather patterns into social-economic benefits and damages functions.

Social cost of carbon is used to evaluate the climate social-economic damage but the ecosystem service is omitted. Current social cost is very low to reflect the climate damage cost and external environmental cost of GHG emission. Theoretically, the social cost of carbon should increase over time because the natural environment and economic systems will become more stressed as the impacts of climate change accumulate. In the U.S the interim social cost of carbon has yet to be finalized or incorporated into regulations.

A number of multidisciplinary research projects develop multisectoral climate impact models and parameterize the socioeconomic and climate scenarios. Mendelsohn et al. (1999) estimated a damage function econometrically: cross-sectional Ricardian framework is the most widely used approach in climate impact to date. Burke and Emerick (2016) created an approach with plausibly causal estimates of climate damage function combining with the panel data estimation approach using short-run weather fluctuation. Neumann et al. (2020) built the set of 15 sectoral models estimating U.S. 22 sectoral damage functions including damage for human, economic, bio-ecosystem, and infrastructure sensitivity to climate chronic change. The AVOID (Avoiding Dangerous Climate Change) project in the UK (Arnell et al. 2013) developed global multi-sectoral regional assessment for impact of climate change; PESETA (Projection of economic impacts of climate change in sectors of the European Union based on bottom-up Analysis) project (Ciscar et al. 2014); BRACE (Building Resilience Against Climate Effects) project (Marinucci et al. 2014) develops a framework for managing risk and climate impact in public health sector.

The Stern Review of the Economics of Climate Change (Stern 2007) concluded that if no climate mitigation and adaptation is taken, the overall costs and risks of global climate change will be equivalent to losing at least 5% of global gross domestic product (GDP) each year, now and forever. Andandarajah et al. (2020) projected that the climate damage cost causes 10% reduction in GDP for scenario 2 °C by 2050, and a high impact of 25% on the Business As Usual scenario by 2100. The effect of climate change impacts on annual global GDP is projected to increase over time, leading to a global GDP loss of 0.7% to 2.5% by 2060 (Dellink et al. 2014). If we take no adaptation and no mitigation, climate change could cost the world $1.7 trillion a year by 2025, increasing to about $30 trillion a year by 2075 (Howard and Sylvan 2021). These different economic losses depend on the different global climate change scenarios and projections, as well as economic structure and development level.

3. Climate Physical Risk Escalates Economic Inequality Domestically and Internationally

3.1. Developing Countries Are More Vulnerable Than Developed Countries to Global Climate Change

Global climate change impact is highly heterogeneous across different social-eco nomic-system. Nicholls (2004) and Nicholls and Tol (2006) found that development level and population growth are very important factors affecting climate vulnerabilities. The country development level heavily impacts on the general climate adaptation capacity and its exposure sensitivity to climate hazards. The high climate-exposed economy includes agriculture, forestry, fishing and hunting, mining, construction, manufacturing and transportation, tourism and utilities (Graff Zivin and Neidell 2014; Cardona et al. 2012). These high climate-exposed sectors share largely GDP in developing countries, and the livelihood of many people depends crucially on the functioning of a natural system. The most damaged countries and the top 10 countries in term of disaster mortality are basically in the developing countries. Kreft et al. (2007) discussed who suffers most from extreme weather events in (Kreft et al. 2007). Therefore, developing countries are more sensitive to global climate change physical risk.

Big gap of adaptation capacity among low-income and high-income countries The vulnerability is not a measurable, it is instead a dynamic state which is the result of multiple interacting variables (Fritzsche et al. 2014). The low technical feasibility of certain adaptation and the low availability of financial resources in developing countries can't compensate the damage cost of climate physical risk, the low economic resilience induces severe economic financial shock. That said, the high level of poverty is equivalent to the low adaptation capacity and low resilience. Developing countries have high climate vulnerability and exposure but low climate resilience and adaptation capacity. This indicates that developing countries are much more vulnerable to climate physical risk than developed economies.

High exposure sensitivity to climate physical risk Most people's living and working conditions are more easily and frequently affected by climate change in developing countries. Thus, climate hazards and damage functions severely deteriorate the macroeconomic growth and microeconomic businesses cycle in developing countries. The sea level rise and coastal flooding have worsen living areas and working condition, increase their social vulnerability, in particular for low-income householders and vulnerable groups in developing countries. Low income householders are highly exposed to climate change: micro small businesses, agriculture and fisheries are highly sensitive to global warming and climate hazards, suffering labor hour losses and labor productivity reduction. Thus, global climate change physical risk marginalizes and impoverish rural agriculture and fishing group in developing countries.

3.2. Social Vulnerable Group at the High Exposure to Climate Physical Risk

Social vulnerable groups[1] have high sensitivity and high exposure to global climate change, moreover, they have less mitigation and adaptation capability, low income and less resilience capacity to global climate change. Their limited adaptation capacity to access climate resilient infrastructure and health care shows that they have very limited climate institutional resources (Marinucci et al. 2014).

In the U.S minorities are 41% more likely than non-minorities to currently live in areas with the highest projected increases in traffic delays from high tide flooding associated with 50 CM of global sea level rise (USEPA 2021). Most indigenous and low-income households are heavily reliant on the natural system, their livelihoods are dependent upon small scale agriculture particularly vulnerable (Morton 2007; Harvey et al. 2014). While economic structure and infrastructure climate resiliency may determine some countries and communities' climate adaptation capability. The Fourth National Climate Assessment (NCAV 2021) in the U.S found climate change increasingly threatens Indigenous communities' livelihoods, economies, health, and cultural identities. This escalates the social-economic gaps between indigenous and low-income people with the high-income householders. Thus, climate change increases social-economic inequality both internationally and domestically.

Government needs huge financial resources for implementing social protection programs for low-income householders and vulnerable groups, in particular during the climate disaster period a large amount of public expenditure is distributed to life networks and social programs. The U.S.A. budget ensures that 40% of the benefits from tackling the climate crisis are directed toward addressing the disproportionately high cumulative impacts on disadvantaged communities (FBE 2022).

3.3. High Health Adverse Effects from Climate Change and Air Pollution

Global climate change triggers biodiversity losses and ecological-social-economic systemic vulnerability. The low-income householders and vulnerable groups have poor food supply systems and poor medical care, lack of clean water resources and water sanitizing systems, they are more vulnerable to biodiversity losses, oceanic and air pollution.

Low income communities suffer disproportionately high rates of climate death and injury from extremely high temperature and climate disaster. Climate-driven mortality and premature death is disproportionate among low-income and high-income householders. Minorities and Individuals with low income have suffered highly air pollution exposure and health effects related to climate change exposure and air pollution exposure (Kioumourtzoglou et al. 2016) Some scholars discussed the healthy impact on vulnerable group of global climate change in the U.S.A. (Gamble et al. 2016).

The U.S federal climate-related health care spending in a few areas could increase by between \$824 million and \$22 billion by the end of the century (OMB 2022). Apparently, the required financial expenditure to climate induced medical care has gradually increased due to the severity of global warming and the magnitude of the climate disaster is exacerbated, this is a large fiscal burden in developing countries.

This research denotes: Labor income = Li, Business profits = Bp, Living conditions = Lc, Adaptation capacity = Ac, climate driven mortality = Cdm, Climate induced medical expenses = Cimc, Cash transfer for life network social program = Ctln, Subsidies = Sub, Financial and fiscal equilibrium = FFe. The finance and fiscal equilibrium shock probability driven by climate disaster is calculated as the followings:

$$\text{P (FFe BIA)} = \sum \text{(PLi P Bp P Lc P Ac P Cdm P Cimc PCtln PSub) (BIA)}$$

The finance and fiscal equilibrium distortion shock rate parameter driven by climate disaster is calculated as the followings:

$$\begin{aligned} \text{R(FFe BIA)} &= \sum\text{(PLiPBpP Lc P Ac P Cdm P Cimc PCtln PSub) (BIA) } (1 - \text{MrBIAVcrBIA}) \parallel 1 - (\text{Cdc, Cds, Cdt, Mr})\text{BIA} \\ &= \frac{\sum \text{P(FFe BIA)}(1 - \text{MrBIAVcrBIA})}{1 - \text{Cdm B I A}} \end{aligned}$$

The negative-proportional relationship and positive proportional relationship between climate physical risk magnitude and social-economic development level as analyzed in the Table 2, this reflects the climate physical risk impact on the low-income and marginalized group, escalate social-economic inequality function, generating the multinomial regression to financial and fiscal equilibrium.

Table 2. Climate physical risk escalates social economic inequality and distort financial and fiscal equilibrium function.

Climate Disaster as Exogenous Shock A I B	Labor Income A I B	Business Profit A I B	Living Conditions A I B	Adaptation Capacity A I B	Climate Driven Mortality A I B	Climate Induced Medical Care A I B	Cash Transfer Life Network A I B	Subsidies A I B	Financial Fiscal Equilibrium A I B
Scope A I B	+	+	+	+	+	+	-	-	-
Scale A I B	+	+	+	+	+	+	-	-	-
Severity A I B	+	+	+	+	+	+	−	-	-

Table 2. *Cont.*

Climate Disaster as Exogenous Shock A I B	Labor Income A I B	Business Profit A I B	Living Conditions A I B	Adaptation Capacity A I B	Climate Driven Mortality A I B	Climate Induced Medical Care A I B	Cash Transfer Life Network A I B	Subsidies A I B	Financial Fiscal Equilibrium A I B
Persistence time A I B	+	+	+	+	+	+	+	+	+
Magnitude A I B	+	+	+	+	+	+	+	+	+
Economic structure A I B	–	–	–	–	–	–	–	–	–
Climate disaster exposure A I B	+	+	+	+	+	+	+	+	+

4. Climate Hazards Impact on Financial Market and Monetary Policy Change

Climate change is a significant variable impacting central bank monetary policy for stabilizing market price and financial volatility. The main reason for the central bank to consider global climate change due to the large inflation caused by climate hazards. The exogenous climate disaster triggers the large commodity price shocks and the end-consumer goods' price volatility. There is growing economic evidence that climate hazard triggers disruption of supply chain, commodity price and end-consumer market price inflation. In 2022 the extremely hot wave in Europe and Central Asia generated low yields of agriculture, and the food price was very high globally; The supply chain disruption also triggers large commodity like energy, water and food prices' abrupt increase, subsequently, this is transferred to the value added end-consumer goods' price, triggering end-consuming market price inflation. In addition, the expenses for climate disasters' damaged human capital and physical capital are often transferred to the end-consumer goods price, this consuming goods' price inflation usually is delayed. Inflation rates are heterogeneous across different geographic jurisdictions, different economic structure and climate hazard persistence time. Sometimes, the large price shock can reach to an average 25–30% of inflation volatility (Batten et al. 2022). The inflation pressure will heavily impact the employment rate and GDP growth, investment and consumption, enabling the central bank to face the high price pressure and financial stability challenge.

Climate disaster also affects the assets price, housing price and equity price, stock price will get lower and capital liquidity slow down. Economic shock impacts financial market volatility, slows down investment and consumption, exacerbates the capital liquidity and public financial equilibrium, triggering government budget deficit and fiscal cliff due to rescue of humanitarian crisis, reconstruction and recovery from climate disaster.

Climate hazards could also increase uncertainty for investors, causing stock assets prices volatility and non-performing loans, increasing equity capital risk, triggering huge uncertainty for businesses profits and debt solvency. Subsequently, the reduced solvency capability will drive credit risk for banks and financial lending, trigger underperforming loans, increasing the frequency and magnitude of banking crises, low financial liquidity and high insurance expenditures.

Central banks pursue a target to maintain stable market price and finance stability for macroeconomic growth and employment rate. To manage market price inflation, strengthen capital liquidity, the Central bank takes tightening monetary policy by either hiking interest rate or quantitative easing policy: government purchasing more bonds or debt, raising interest rate and exchange rate to control inflation and increase monetary supply and liquidity.

Central banks have responded differently to climate disasters. The climate hazards magnitude impact and inflation level enable the Central Bank to change monetary policy. Sometimes the Central bank takes no action to some short-run and limited inflation, sometimes inflation scale is within the market expectation and can be adjusted by market force and diversified economic structure. People' Bank of China has not adjusted the interest rate for the annual typhoon in the Eastern coast of China. The People's Bank of China generally hasn't established a disaster response mechanism; the diversified economic structure and high liquidity of economic factors can help to absorb climate disasters' negative effects. However, the U.S federal reserve increased the interest rate in the aftermath of 2005 hurricane Katrina (Henderson 2005), the U.S federal reserve has also increased its interest rate in the aftermath of COVID-19 pandemic high domestic inflation.

Climate hazards heavily impact on banking assets performance, triggers a significant non-performing loans, threatening solvency and internal capital adequacy of financial institutions and businesses, triggers potential bank crisis and increases insolvency of financial institutions, subsequently will increase the Central Bank resecure expenditure for maintaining financial equilibrium and liquidity, drove to the cyclical financial deficit. Financial capital losses are driven by the underperforming loans and the disaster magnitude and persistence time, as well as the capital market responses to the real business cycle losses.

The interest rate is denoted as Mr, Inflation rate is denoted as Ir, Asset price is denoted as Ap, solvency of financial institution is denoted as Sf, underperforming loan is denoted as Lu, financial liquidity is denotes as Fl, financial equilibrium is denoted as Fe, Fiscal budget equilibrium is denoted Fse, Government Debt is denoted as Gd.

The sensitivity of fiscal and public finance to climate disaster is denoted as $P\ (F_E)$.

The fiscal finance shock probability driven by climate disaster is estimated as the followings:

$$P\ (F_E) = \sum (P\ I_r\ P\ M_r\ P\ F_m\ P\ A_p\ P\ L_f\ P\ S_f)(BIA)$$

The fiscal finance distortion rate parameter driven by climate disaster in estimated:

$$R(FFeB\ I\ A) = \sum \left(PI_r\ PM_r\ PF_m\ PA_p\ PL_f\ P\ S_f\right)(B\ IA)\ (1-MrVcr\ BIA)\left|1-(Cdc,\ Cds,\ Cdt,\ Mr)BIA\right. = \frac{\sum\ P(FFe\ BIA)(1-MrBIAVcrBIA)}{1-Cdm\ B\ I\ A}$$

The negative-proportional relationship and positive proportional relationship between climate physical risk magnitude and fiscal financial equilibrium functions as analyzed in the following Table 3. This reflects the climate disaster distorts the finance market and finance policy functions, generating the multinominal regression to financial and fiscal equilibrium.

Table 3. Climate disaster distorts financial and fiscal equilibrium functions.

Climate Disaster as Exogenous Shock A I B	Inflation Rate A I B	Interest Rate A I B	Asset Price A I B	Financial Market Volatility A I B	Solvency Financial Institute A I B	Under Performing Loan A I B	Financial Liquidity A I B	Government Debt A I B	Financial Fiscal Equilib-rium A I B
Scope A I B	+	+	+	+	+	+	–	_	_
Scale A I B	+	+	+	+	+	+	_	_	_
Severity A I B	+	+	+	+	+	+	_	_	_
Persistence time A I B	+	+	+	+	+	+	+	+	+
Market resilience A I B	_	_	_	_	_	_	_	_	_
Value chain resilience A I B	–	–	–	–	–	–	–	–	–
Magnitude A I B	+	+	+	+	+	+	+	+	+
Economic diversification A I B	–	–	–	–	–	–	–	–	–
Climate disaster exposure A I B	+	+	+	+	+	+	+	+	+

5. Binary Regression of Fiscal Equilibrium: Declined Revenues and Increased Expenditure

5.1. Declined Fiscal Revenues

The climate physical risk distorts economic functions and triggers GDP growth decline. This drives the tax base reduced and lower revenue income. Government will implement a bailout program and tax relief, reducing labor income tax and asset income tax, corporation income tax, subsidizing food and drinking water, value added tax will decline due to declined consumption and investment during the climate disaster period. Climate disasters impact on the tax revenue and the damages subsequently intensified every year since the 1990s (Guha-Sapir et al. 2016). Obviously, Climate disaster generates cyclical tax revenue decline. It is very difficult to monetize biodiversity loss and increased ocean acidification, there is a huge uncertainty associated with assessing revenue losses and significant variation across different countries.

Because of the robust negative effect of the high tax burden on economic growth, increasing tax is not a solution for stimulating economic recovery and increasing revenue income during a climate disaster period. Thus, this research assumes that the average tax rate remains unchanged as the appropriate tax rate: Trc, the initial tax rate without climate disaster = Tr, assuming Trc = Tr, the declined labor income: Tl; the declined asset income: Ta; the declined corporation income: Tc; the declined added value: Tv; the government tax relief: Trg; the subsidies for food, energy during climate disaster = Sg. $\sum$ represents the counterfactual tax revenue without climate disaster, C represents initial personal income tax (labor + asset) and corporate income tax. Compared to the counterfactual revenue the aggregate decreased tax revenue:

$$\sum_{i=0}^{n} a = \text{Trc} \times (\text{C} - \text{Tc} - \text{Tl} - \text{Ta} - \text{Tv}) - (\text{Trg} + \text{Sg}).$$

When government reduce tax rate to respond climate disaster damage, Trc < Tr, $\sum_{i=0}^{n} b$ represents aggregate decline tax revenue,

$$\sum_{i=0}^{n} b = \text{Trc} \times (\text{C} - \text{Tc} - \text{Tl} - \text{Ta} - \text{Tv}) - (\text{Tr g} + \text{Sg}),$$

This scenario is the most worse revenue income situation, the declined revenue is much higher than tax rate remains no changed. The decreased tax revenue curve is heterogenous over climate disasters time and across different jurisdiction, depending on the climate disaster magnitude and climate resilience, economic structure and local government responses to contingent liability etc.

The fiscal finance cyclical-structural shock probability driven by climate disaster is calculated:

$$\text{P (F FE)} = \sum \text{(PPir PCir PVat PTr PSbc) (BIA)}$$

The fiscal finance structural sensitivity rate driven by climate disaster is calculated:

$$\begin{aligned} \text{R(FFeB I A)} &= \sum(\text{PPir PCir PVat PTr PSbc})(\text{BIA})(1 - \text{MrVcr BIA})\|1 - (\text{Cdc, Cds, Cdt, Mr}) \\ &= \frac{\sum \text{P(FFe BIA)}(1 - \text{Mr Vcr BIA})}{1 - \text{Cdm B I A}} \end{aligned}$$

The negative-proportional relationship and positive proportional relationship between climate disaster magnitude and tax revenue functions as analyzed in the Table 4. This reflect that the climate disaster distorts the cyclical-structural tax revenue functions, generating the cyclical multinomial regression to financial and fiscal equilibrium.

Table 4. The diagramed climate disasters distorts the tax revenue functions.

Climate Disaster A I B	Personal Income Tax A I B	Corporate Income Tax A I B	VAT AI B	Tax Relief A I B	Subsidies for Commodity A I B	Declined Tax Revenue A I B	Fiscal Financial Liquidity A I B	Fiscal Financial Equilibrium A I B
Scope A I B	+	+	+	+	+	+	+	+
Scale A I B	+	+	+	+	+	+	+	+
Severity A I B	+	+	+	+	+	+	+	+
Persistence Time A I B	+	+	+	+	+	+	+	+
Magnitude A I B	+	+	+	+	+	+	+	+
Market resilience A I B	–	–	–	–	–	–	–	–
Value chain resilience A I B	–	–	–	–	–	–	–	–
Market A I B Expectations	-	–	–	–	–	–	–	–

5.2. Increased Public Expenditures for Climate Adaptation and Contingent Liabilities

The increased public budget for climate adaptation Public expenditures for climate disaster prevention, recovery and reconstruction are largely underestimated and heterogeneous across different jurisdictions (OECD 2019). The adaptation cost mainly focuses on the government expenditure for climate disaster relief and reconstruction, improving climate resilience including structural adaptation measures and management adaptation measure: transportation, energy, telecommunication, investment in irrigation and water sanitation, etc. OECD estimates $6.3 trillion per year required under Business-as-Usual just to meet the infrastructure needs for continued economic development (OECD 2018), Government and public finance need to drive the initial investment to climate adaptation, and climate investment could provide up to $23 trillion new opportunities in emerging market by 2030 (World Bank 2018).

The government is the main funder of the public response to climate disasters with around 75% of funding coming from domestic sources. Public finance can be used to mobilize private finance for climate resilient infrastructure at national, local, sector and project level. Financing climate-resilient infrastructure will require a mixture of public and private finance resources, with the share of public finance estimated at 60–65% in developing countries compared to 40% in developed countries (Bhattacharya et al. 2016; Ahmad 2016). Obviously, increasing private finance in climate adaptation is the most important way to reduce public finance burden in climate adaptation investment. Therefore, a climate finance policy to mobilize private finance to climate resilient investment can reduce public expenditure.

Climate infrastructure investment needs to consider new regulation and national technical standards for climate resilience, this will automatically change price and cost. However, the benefits of investment in climate resilience infrastructure outweigh the damage costs of climate physical risk. The average integrating climate resilience would add 1–2% of the total cost of infrastructure projects. However, climate change risk can add 25% to the average costs of an environmental and impact assessment (Iqbal and Suding 2011).

Low-carbon climate resilient investments are cheaper than their fossil fuel-based counterparts, climate smart investment also cheaper than the inaction climate damage cost. The reduction of pollution and climate change impact through rapidly increased use of renewable energy by 2030 could save up to $4.2 trillion per year worldwide-15 times higher than the associated costs of doubling the share of renewables (The IRE 2021).

The Increased public expenditure for climate social program Government has contingent liabilities to moving people out of harm's way and improving health care services during climate disasters. Social expenditure consists of cash benefits, prioritizing redistribution of resources and tax relief for low-income households, elderly, disabled and sick, unemployed or young peoples. Deploying different social safety nets for poor and vulnerable people, implementing relevant social labor benefit programs: cash transfer, contributory pension for social protection, labor benefit and services coherent packages. The social safety net program provides timely compensation for poor people: cash-based social safety nets as well as other forms of compensation may be used, likewise, energy and food subsidies for poor, lifeline rates for electricity, district heating and natural gas. The social protection program expenditures account for the reduction of the government budget and revenue income, including taxation relief and tax redistribution. The world bank database shows that the social public expenditure shares a very low percentage of GDP in developing countries compared to the developed economies. This caused by the limited fiscal budget availability in developing countries and suffered from social protection inefficiencies, poorly targeting economic distortions for new economic growth cycles (World Bank 2015–2021). Therefore, formulating new social funds and building a diversified fiscal-financial system can be supplementary to the government budget deficit.

Bailout program for businesses and industries Government has the contingent liability over bailout for insolvent banks and firms during climate disaster: tax relief and subsidizing commodities. The government bailouts have been frequently increased during COVID-19 pandemic period, this simultaneously increases the ratio of public debt to GDP and reduces credit inflow and firm investment. This exposes the government budget to climate disaster, triggering government budget deficit and fiscal cliff.

Assuming the public expenditure for climate resilience infrastructure = E^x, E^{bs} represents public expenditure for social protection, E^{bc} represents public expenditure for bailout businesses. E^{bi} represents public expenditure for financial institutions insolvency. The total public expenditures for climate disaster prevention, recovery and reconstruction lead to huge structural fiscal shock: potential fiscal deficit and budget deficit. The increased public expenditure for compensating climate disaster damage is denoted as E^D. $E^D = E^x + E^{bs} + E^{bc} + E^{bi}$, time different is denoted as A and B. Here are two random variables A and B.

The probability of public expenditure increase is calculated as the following:

$$\mathrm{P(Ed\ A\ I\ B)} = \sum(\mathrm{P\ E^x\ PE^{bs}\ P\ E^{bi}})\ (\mathrm{BIA})$$

The public expenditure distortion rate is calculated as the following:

$$\begin{aligned}\mathrm{R\ PEd(A\ I\ B)} &= \sum \left(\mathrm{P\ E^xP\ E^{bs}PE^{bi}}\right)(\mathrm{AIB}))\Big|1 - (\mathrm{Cdc,\ Cds,\ Cdt,\ Mr})\mathrm{BIA} \\ &= \frac{\sum\ \mathrm{P(Ed\ BIA)(1-MrVcrBIA)}}{\mathrm{1-Cdm\ B\ I\ A}}\end{aligned}$$

This specific public expenditure of government contingent liability is assigned for compensating economic losses from climate disaster and chronic climate change to stimulate economic recovery, this is dynamic across different timelines and jurisdictions. The increased public expenditure is a multinomial regression process for fiscal balance over climate disaster period as the following Table 5 shows, this triggers government fiscal structural shock: budget deficit and fiscal cliff, raises public debt and debt ratio to GDP.

The negative-proportional relationship and positive proportional relationship between climate physical risk magnitude and public expenditures functions as analyzed in the above Table 5. This reflect the climate disaster distorts the public expenditure functions, generating the structural multinomial regression to fiscal equilibrium, government budget and debt.

Table 5. The diagramed climate disasters impact on the public expenditure.

Climate Disaster A I B	Bailout for Businesses A I B	Bailout for Social Program A I B	Subsidies for Consumers Goods A I B	Public Infrastructure Adaptation Cost A I B	For Insolvent Financial Institution A I B	Human Healthy and Ecosystem Service A I B	Government Budget Deficit Fiscal Cliff A I B	Debt Ratio to GDP A I B
Scope A I B	+	+	+	+	+	+	+	+
Scale A I B	+	+	+	+	+	+	+	+
Severity A I B	+	+	+	+	+	+	+	+
Persistence Time A I B	+	+	+	+	+	+	+	+
Market resilience A I B	−	−	−	−	−	−	−	-
Value chain resilience A I B	−	−	−	−	−	−	−	−
Market Expectation A I B	−	−	−	−	−	−	−	−

5.3. Fiscal Affordability and Sustainability, Deficit and Fiscal Cliff

The public expenditures for climate resilience and compensating climate damage have been increased, bailout costs are increased as a share of GDP in the scenarios of labor and capital damages (Lamperti and Bosetti 2019). The growing empirical evidences show that the increased public expenditures and revenue losses will trigger large risk of government deficit and fiscal cliff, declining an inherited public budget designated to long term economic growth, crowding out fiscal budget and public expenditure on the counterfactual innovation investment and hypothetical trade and production development, this leads to a cyclical fiscal deficit. The multiple logistic regression distorts fiscal equilibrium and increases the public debt ratio to GDP.

Though the public expenditure for climate disasters rescue and bailout programs can be applied for innovation investment to increase labor productivity, promoting sustainable economic growth etc. Under the counterfactual circumstances the public expenditure and fiscal revenues remain as false equilibrium status, because climate externalities cost will overweight the government expenditures in adaptation and compensation to damage cost in the long term. The counterfactual climate inaction or less public expenses for climate disaster will drive the more severe damage in GDP growth and fiscal revenue income losses. Eventually this inaction will be ended up with reducing more revenue income and risk GDP growth, increase public debt and cyclical fiscal deficit. The increased public debt to GDP ratio and the fiscal deficit severity will be dependent on the climate disaster magnitude, economic structure and economic resilience etc.

The maxim functions of fiscal revenue income determine the fiscal affordability and the fiscal cliff level, as well as the government budget deficit level. Climate physical risk externalities trigger potential fiscal cliff and deficit, increasing public debt rate to GDP. Thus, the government needs to mitigate the fiscal deficits, strengthening fiscal consolidation and making financial-fiscal intervention policy. However, climate physical risk and climate adaptation cost will only increase public expenditure for improving climate resilience and compensating climate damage. The tax burden is defined as the ratio of tax revenues to personal income or corporate income, during climate disaster period labor income tax and corporate income tax can't be increased, the revenue income will be declined. The robust negative effect of climate disaster damage to economic growth, this will decrease the tax base. These binary regression of revenue will trigger structural fiscal cliff and deficit.

The climate hazards drive local employment rate declines and economic recession. It leads to expansionary fiscal policy, and the government lowers taxes to stimulate economic recovery and maintain purchasing power. Given high inflation but cannot take contractionary tightening fiscal policy because tightening fiscal policy will lead to taxes raises and cuts spending, the contractionary fiscal policy does not fit disaster reconstruction and climate risk-preventing and trigger economic recession.

Thus, governments need special fiscal financial resources to increase climate resilience and compensate for climate damage, to stimulate economic growth and price stability, increase employment rate and fulfill contingent liabilities over climate disaster. This requires optimal allocation of fiscal-financial resources. Therefore, it is needed to build a specific green climate fiscal pool, implementing fiscal-financial climate policy, mobilizing public and private finance to climate resilience investment.

Conclusion and fiscal consolidation Climate physical risk triggers tax revenue income decline and increases public expenditure, this binary fiscal regression leads to potential fiscal cliff and government deficit, increasing public debt ratio to GDP. It is needed to strengthen fiscal consolidation and establish financial-fiscal stimulus intervention instruments, mobilizing fiscal financial resources and minimize government deficit to offset climate physical risk and increase climate resilience investment against climate disaster and fiscal cliff.

Given the urgent response to the increasing public expenditure and huge tax revenue decline, the government needs to build an extra fiscal pool for managing climate hazards damage cost, increasing fiscal-financial viability for climate resilience building and disaster prevention and reconstruction. The growing evidences and economic research demonstrate that the increasing tax is not feasible approach to improve fiscal viability during climate disaster period, but the effective monetary policy intervention like adjusting interest rate and exchange rate, quantitative easing monetary policy and open market operation to increase financial market liquidity and monetary supply, increasing lending and investment to climate project will reduce the fiscal pressure, increasing financial liquidity and equilibrium. Building special climate fiscal pool for fiscal-financial stimulus intervention and managing market inflation adjustment, climate social funds and diversifying the financial fiscal system, greening the fiscal and financial system to mobilize private financial resources to climate smart investment are more optimistic approaches than no action or increasing tax during a climate disaster period.

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Abbreviation

DSGE	Dynamic General Equilibrium Model
GDP	Gross Domestic Product
GHG	Green House Gas
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel of Climate Change
OECD	Organization for Economic Co-operation and Development

Notes

[1] Vulnerable populations-defined based on economic income, social-political status, educational level, indigenous race and minority ethnicity, aging age, they may be more exposed to the high impacts of climate hazard and climate vulnerability. in particular elderly and the poor or indigenous communities more severely impacted by global climate change.

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