EQUITABLE GROWTH, FINANCE & INSTITUTIONS NOTES

World Bank Group Macroeconomic Models for Climate Policy Analysis

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Contents

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Policymakers in developing countries face multiple challenges related to climate change, among them: assessing the impact of climate change on economic growth and living standards; identifying a mix of policies and investments that can make countries more climate-resilient; and developing credible options for mitigation compatible with planetary limits and their own development objectives. Over the past decades, the World Bank Group has developed a range of macroeconomic models for projections, diagnostics, and policy impact simulations. Since 2019, the WBG has accelerated its efforts to make its modeling portfolio climate-aware. This note, prepared by staff from DEC, EFI and SD, provides an overview of the climate aspects of these macroeconomic models, as well as complementary tools to investigate the links with poverty, inequality, or financial stability. It illustrates how these tools interact with each other, and how they are applied in operations.

>>> GREENING THE WBG'S PORTFOLIO OF MACROECONOMIC MODELS

To provide policymakers with reliable recommendations on a variety of climate related policies, the WBG has a diverse and complementary set of models. The analytics range from evaluating the aggregate, sectoral, and welfare effects of mitigation measures to assessing country-specific adaptation needs, considering the impacts of extreme weather events as well as gradual global warming. Key indicators include macroeconomic outcomes (GDP, consumption, inflation, exchange rates, fiscal impacts, debt), sectoral indicators (energy prices, industrial, agricultural and service sector output), co-benefits (health and productivity improvements from reduced air pollution, and tax efficiency gains when carbon tax revenues allow a distorting tax to be removed), and poverty and distributional issues (e.g., by income group, geographical region and skill types). Table 1 summarizes the range of climate and development issues addressed by each model in the WBG suite, revealing both strengths and limitations of individual models, as well as the complementarity among models.

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TABLE 1 - Scope of WBG Climate Informed Modeling Approaches

MODELS	MFMOD	ENVISAGE	MANAGE	CPAT	FSAP	SHOCK WAVES/ UNBREAKABLE	GIDD
Impacts of mitigation/adaptation policy on							
Macroeconomic indicators	✓	✓	✓	✓			
Sectoral indicators	✓	✓ ✓	✓ ✓	✓		✓	
Co-benefits	✓		✓	✓			
Poverty/distributional impacts		✓~	✓~	✓		✓	✓
Impact of extreme weather events on							
Macroeconomic indicators	✓				✓		
Sectoral indicators	✓~					✓	
Financial indicators	✓~				✓		
Poverty/distributional impacts						✓	✓
Impact of gradual global warming on							
Macroeconomic indicators	✓	✓	✓				
Sectoral indicators	✓~	✓	✓ ✓			✓	
Financial indicators	✓				✓		
Poverty/distributional issues		✓~	✓~			✓	✓

Source: World Bank staff; Note: the combined symbol ✓~ implies the issue is partially addressed in the framework.

These models can be used alone, as well as in conjunction with other tools and models. For instance, macroeconomic model can include reduced-form simplified versions of highly complex sectoral models (e.g., crop models or catastrophe models) or be calibrated based on results from sectoral analysis. Similarly, outputs from macroeconomic models can be used directly to inform decision-makers or be used as inputs for further analysis (e.g., on distributional impacts or financial stability). For instance, climate-enhanced FSAPs (Financial Sector Assessment Program) assess risks, including from climate, and opportunities to improve regulatory and supervision practices, using a framework combining sectoral models, macroeconomic models, and financial-sector models.

The main features of these models are the following:

- **Macro-Fiscal Model (MFMod)** is a customizable macro-structural country-level modelling framework, including expenditure and sectoral national income accounts, financial and current accounts of the balance of payments, labor markets, inflation, exchange rates and monetary policy. The framework has a mix of empirically determined short-run behaviors and a theory-informed long-run effects. Parameters of the model are country-specific and are estimated econometrically using historical data. MFMod is suitable for forecasting and can be used to simulate a range of climate and policy scenarios. Models cover greenhouse gas (GHG) emissions from five sources and economic damages from climate change derived from the literature that include physical damage from extreme weather events and the impacts of higher temperatures and increased rain variability on economic activity (e.g., effects on competitiveness, say of tourism, reduced labor and agricultural productivity, and declines in health and labor supply). The framework also incorporates co-benefits from mitigation (e.g., reduced pollution, resulting in improved health outcomes, lower health spending, and increased labor productivity and supply) and interactions with other country-level externalities, such as those coming from excess informality or the elimination of tax distortions. The standard model includes a basic adaptation module that can be supplemented with country-specific data and estimates. MFMod is particularly handy for exploring the dynamics after economic shocks (e.g., natural disasters or material price changes). It is easy to use, build and maintain and can be paired with a microsimulation module such as the GIDD system described below to explore distributional issues, as well as with sectoral models (e.g., EPM, MESSAGEix and GTAP-BIO-W).

- **ENVISAGE and MANAGE** are state-of-the-art dynamic-recursive Computable General Equilibrium (CGE) models. ENVISAGE is a global model, covering 127 countries and aggregating the remaining into 20 regions. ENVISAGE's strengths lie in tracing the impacts of policies imposed in one country on the economies of other, and global or regional scenarios. MANAGE is a highly customizable country-level modelling framework and includes a more extensive modelling of both climate damages and adaptation. Both models are calibrated on data at a single point in time, using elasticities drawn from the literature and, where available, supplemented with country-specific estimates. Their strengths lie in their micro-foundations and sectoral detail, which in some cases includes 50 or more. The models cover most of the same physical damages and mitigation and adaptation policies described for the MFMod system. The greater sectoral detail means they can provide a more disaggregated accounting of losers and winners from economic damages and climate policies than the MFmod system. The standard single household can be disaggregated into different (urban rural/ high-low skilled; deciles) groups or a model can be paired with a microsimulation mode to analyze distribution issues. Dynamics in both models are relatively simple and focus on equilibrium impacts after economies have time to adjust; therefore, they do not capture well the out-of-equilibrium behavior of economies following a shock and are less well suited than MFMod for analyzing the impacts of extreme weather events. Both systems can be paired with more detailed sectoral models to strengthen the micro basis for simulations. Both systems are technically demanding and typically require a specialist to operate.

- **Carbon Pricing Assessment Tool (CPAT)**, a joint World Bank - IMF product, is a reduced form model designed to assess the first-order climate-macro implications of environment tax reform. Policy designs can be selected at a granular level due to a high flexibility in making choices regarding carbon pricing instruments, sectoral coverage, subsidy reform, and revenue recycling. The tool covers a wide range of climate-macro measures: emissions, energy consumption, public revenues, GDP, equity, air pollution, health costs, and transport externalities. Its tractability allows its use without specialized training. CPAT can be linked to a Multi-Regional Input-Output (MRIO) model, which is a framework for simulating the effects of climate-fiscal policy shocks on domestic and international sectoral outputs and employment. CPAT features a large set of market imperfections and is estimated using Bayesian statistical techniques.

- **ARIO**—Adaptive Regional Input-Output model—is a short-term framework that can be run at daily and weekly frequencies to model how firm-level dependencies and transportation networks can propagate localized economic disruptions such as floods or wind damage to other parts of the economy via the supply chain and transportation networks, generating knock on effects potentially much larger than the first round impacts typically accounted for. The model has been used to represent the impacts of hurricanes (e.g. in the US and India), earthquakes (e.g., in the US, Japan, and China), and COVID-19 (globally, with an application to the impact on GHG emissions).

To extend the exploration of the poverty and inequality, these macroeconomic models can be complemented with bottom-up household-level approaches or their outputs can be connected to microsimulation models to disaggregate results at the household levels. Available tools include:

- **Global Income Distribution Dynamics (GIDD)** is a microsimulation tool used to assess the distributional impact of structural changes brought on by large shocks. The model has been used at the country, regional and global levels to assess a wide range of issues, including the impact of climate change, demographic changes, trade reforms, and the expansion of biofuels, among others. The microsimulation component takes output, employment, wage and price results of the MANAGE/ CGE or MFMod models to generate income distributions over time consistent with the macro forecasts. GIDD allows for projections of poverty and inequality and distributional impacts across household types, regions, and vulnerable categories.

- **SHOCK WAVES** estimates the impacts of macroeconomic transformations and climate shocks on household incomes, including poverty and inequality by modelling the poverty impacts of gradual global warming and natural disasters and shocks, in a bottom-up way. It creates baselines for the future evolution of poverty and other distributional metrics to represent the impact on policy choices regarding growth, and redistribution, and estimate climate change impacts at the household level using results from sectoral models for five channels: food prices, farmer incomes, health impacts such as diarrhea, malaria and stunting, labor productivity effects, and natural disasters such as storms, floods, droughts. The model is short run with a time horizon at 2030 and aims to inform adaptation priorities. It helps to understand future socioeconomic and climate evolutions with due consideration of uncertainty. Its objective is not to forecast, but to identify the main vulnerabilities and the most effective policies to dampen climate change impacts.

- **UNBREAKABLE** estimates the impacts of acute covariate shocks including natural disasters and layoffs on household consumption and welfare and provides estimates of “socioeconomic resilience” for countries or regions. This is a proxy for the ability of the population to cope with and recover from shocks, based on individual characteristics like access to finance, but also government capacity like ability to finance, contingent planning, and adapt social protection. It identifies ex ante risk factors, tracks differential impacts, and assesses the long-term benefits of risk reduction and resilience strategies. Where data are available, the model can be run at the national or regional or provincial scale, accounting for spatial heterogeneity in natural, social and economic conditions.

This overview is not an exhaustive stocktaking of WBG modeling approaches because it is restricted to macroeconomic and distributional models deployed across multiple country and regional practices. Other standalone, country-specific models have been developed over time for specific research questions related to climate change. Other adaptable analytic frameworks cover a wide range of regulatory policies. For instance, the Climate Change Institutional Assessment (CCIA) identifies the strengths and weaknesses of the institutional framework for addressing climate change. The Social Protection System Stress Test assesses the adaptiveness of social protection systems focusing on their ability to respond to climate and other covariate shocks. National Environmental and Social Impact Assessment (ESIA) systems categorize the environmental and social impacts of projects and policies. The Emissions Intensity and Trade Exposure (EITE) Country Comparison tool provides a historical snapshot of the relative emissions intensity and trade exposure of key products to identify the sectors facing high transition risks. Finally, the Electricity Planning Model (EPM) identifies least-cost electricity mixes based on climate ambitions.

>>> UNRESOLVED PROBLEMS WHEN USING A MACRO MODEL TO ANALYZE CLIMATE CHANGE

To provide the best possible guidance to client countries, the WBG is working to improve compatibility across and communication between models, building on their individual strengths. For instance, MFMod and MANAGE results can be used as inputs to CPAT or the Equity Policy Lab’s microsimulation tool, and vice versa. Strengthening inter-model compatibility between sectoral models such as energy, water, agricultural and financial model also ongoing and central to improving economic insights and granularity. In parallel, many open questions remain in the field of macro climate modelling.

>>> THE AGGREGATION OF LOCAL EVENTS AND ACTIVITIES TENDS TO MUTE SOME EFFECTS

- Disasters or policy actions (e.g., coal mine closures) often have impacts that are concentrated on small regions (e.g., New Orleans in the US). Their local effects are difficult to discern in the data when aggregated to the country level.
- In models with representative households, savings and borrowing constraints of the households immediately affected by a disaster may be underestimated and hence the speed of post-shock adjustment overestimated by lumping unaffected households with affected households.
- Similarly, the impact of sudden shocks that affect a specific component of the supply chain may be under-estimated in cases where the shocked sector albeit small economically, has few substitutes and is an important input to other larger sectors.
- Finally while adjustment speeds in models reflect empirical realities, narrow shocks that require that generate shifts in labor demand in terms of tasks, skills, and spatial distribution may imply bigger disruptions than the historical averages incorporated into the models.

Theoretically, a fully articulated macroeconomic model could be constructed to include the rich detail of households, firms, geography and technological change. In practice such a model would be too large and impossible to solve, and expensive to maintain. Instead work on these issues focuses on the coupling of macroeconomic models with more granular models at the sectoral or regional level, and the combination of top-down and bottom-up models that represent individual households or firms. Initial work has focused on soft-links such that results are coherent between the systems. Future work at the WBG will deepen the interactions between systems.

>>> THE UNCERTAINTY OF GLOBAL CLIMATE CHANGE AND ITS COUNTRY IMPACTS

The future path of global carbon emissions, the global and local climates, economic policy and technology are all inherently uncertain and yet each will have potentially enormous impacts on the macroeconomics of climate change.

- Climate modelers deal with the first of these uncertainties through scenario analysis, providing a series of climate and societal pathways based on different assumptions about these outturns. The macro models follow suit by adopting one or more of these well-defined scenarios when simulating future climate outcomes. But there are no guarantees that any of the pathways will be achieved.
- Technological change, notably change that affects either the use of energy (e.g., the spread of electric vehicles or energy-efficient lightbulbs) or the cost of producing renewable energy (e.g., PV cell cost reductions or hydrogen storage technologies), can completely change the relative prices upon which energy decisions on both the consumer and producer side are made, with major ramifications for economic projections. Again, in the absence of new scientific analyses about how technology will evolve, this uncertainty must be dealt with via scenario analysis.
- A third source of uncertainty concerns the reaction of economies to extreme events. While models deal with the normal day-to-day interactions of multiple shocks, there is limited empirical information for dealing with extreme events and tail risks. As a result, scenarios including probabilistic simulation strategies will under-estimate the full range of possible outcomes unless they are explicitly laid out.
- Finally, while models can help us judge the likely efficacy of some policies (notably price-based policies for which they have been designed), they are inevitably limited in their ability to represent peculiarities in how a policy is actually implemented. Notably, they struggle to represent regulatory policies that do not rely on economic incentives (e.g., technology mandates) or that are intended to promote technological innovation or scale economies.

Given the intractable nature of these uncertainties, including the extent to which policy may affect productivity, a scenario approach is typically followed. And while scenarios can cover a wider range of potential outcomes, they do not normally include the kind of extreme negative outcomes that might result in climate or economic tipping points. As a result, even probabilistic scenarios likely do not include the worst-case scenarios and therefore may, when viewed as an ensemble, be biased to the upside. Work is underway to improve our understanding of these uncertainties and the mechanisms behind tipping points and endogenous technical change, but it is likely to be some time before results are achieved and these can be fully incorporated into macro models.

>>> ISSUES FOR POLICY MAKERS TO CONSIDER WHEN USING MODELS

Model simulations are one of many inputs into the policymaking process. Some issues to bear in mind:

- Each of these models is an abstraction of reality, and none covers the full range of issues inherent to the interaction of climate and macroeconomics. Critically important factors like the full scope of potential climate outcomes including tipping points, or the pace of technological change under different policy regimes are fundamentally unknowable and can only be addressed through scenario analysis, or the interactions of unspecified economic distortions and climate change are not dealt with and likely bias results.
- Model results expressed as percent of GDP or consumption or income reflect part of the story. Social welfare includes issues many other criteria including economic stability, distributional equity, and of course the pathway to an end result matters. Two pathways may end up at the same level of GDP and carbon emissions, but if one is smooth and associated with limited disruption it may well be preferred to one that is bumpy and associated with extended periods of unemployment and macroeconomic instability. While models can incorporate some sort of social welfare function, ultimately the choice of pathway is an inherently political one.
- The choice of model and approach should be driven by the questions that policymakers want to answer.

So, for example, the MFMod framework has limited sectoral disaggregation as compared with MANAGE but does a much better job of simulating the path of an economy out of equilibrium following a shock and the possibilities and implications of economic instability. The CGE platforms are best for looking at long-term policy issues, or physical transitions that may require substantial structural changes, or when the focus is on finer dis-aggregations of economic activity. The CPAT framework is relatively easy to use and perhaps best suited to looking at mitigation issues over the near term; like most models, it does not do well as forecasting horizons lengthen.

- Finally, no single model can address all the policy-relevant questions that arise. In many cases, employing more than one model, or using a combination of macro and sectoral models is the best approach.

>>> ANNEX: LINKS TO MODEL DOCUMENTATION

As work extends the climate features incorporated into these models, the references below, while reflecting the most recent publicly available documentation for the various models necessarily may not reflect fully their current state.

MFMOD (climate enhanced) : https://openknowledge.worldbank.org/handle/10986/36307
ENVISAGE: https://mygeohub.org/groups/gtap/File:/uploads/ENVISAGE10.01_Documentation.pdf
MANAGE: https://mygeohub.org/groups/gtap/File:/uploads/MANAGERef.pdf
GIDD: https://web.worldbank.org/archive/website01589/WEB/IMAGES/PARAL-31.PDF

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