The Coalition of Finance Ministers for Climate Action

The critical role of Ministries of Finance for investment in adaptation and the analytical principles and tools available

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Adaptation is macrocritical and Ministries of Finance can play a key role

Adaptation—the process needed to minimize losses and maximize benefits from climate change —is essential for both advanced and developing economies because climate will continue changing for decades, even with strong global mitigation (Intergovernmental Panel on Climate Change 2021). The global temperature will keep increasing for several decades, sea levels will continue rising for centuries, and extreme weather will become more frequent.

Adaptation can greatly reduce potentially devastating economic losses of climate change, but it requires additional public spending and a conducive environment for private adaptation investment. Returns on adaptation investments can be very large across sectors and countries (Hallegatte et al., 2019; Global Center on Adaptation, 2018). For example, adaptation can reduce the cost of sea-level rise by 80% in most countries (e.g., Diaz, 2016). Different crops, increased access to irrigation, updated building codes, efficient risk pricing, and early warning systems can minimize climate change impacts and save lives (Massetti and Mendelsohn, 2018). Building a stronger infrastructure avoids repair costs and key network failures during extreme weather at modest cost (Hallegatte et al. 2016). Some adaptations will require direct public intervention, including public finance, because markets will not invest optimally in them. Firms and individuals will instead have an incentive to invest in adaptations that bring them tangible benefits, but this requires a conducive market and regulatory environment.

Ministries of Finance can play an important role because at its core, climate change adaptation is a problem of economic development for which they already have a rich toolbox. Adaptation requires a constant and dynamic readjustment of consumption, production, and public policies under budget constraints. Individuals, firms, and societies have adapted to a wide range of climates, but it is now time to reconsider and update how adapted they are to present and future conditions (Massetti and Mendelsohn, 2018). In most places, climate adaptation will likely consist in adopting the technologies, behaviors, and public policies already used in other places with a similar climate. Technological innovation might be needed in places that already have extreme climates and where new challenges will emerge. Adaptation requires technological diffusion, innovation, and behavioral change (Mendelsohn, 2000, 2012; Massetti and Mendelsohn, 2018; Kahn, 2016; Tol et al., 1998). Adaptation can thus be seen as an optimization process against a set of changing external conditions under the usual budget constraints. The uncertainties around future climate changes and in the vulnerability of future societies are large, but—barring existential threats with robust mitigation efforts—investors and policymakers face similar large uncertainties when they invest in other sectors, e.g., artificial intelligence, health, and energy. The key message is that economists in Ministries of Finance have a rich toolbox of theory and methods that can be applied to adaptation as well as to other development problems.

This contribution proposes the definitions and key principles economists in MoFs can use with their toolbox to derive policy priorities and estimate investment needs for adaptation. A key message is that—apart from obvious large empirical challenges—without a clear definition of adaptation to climate change, transparent and consistent principles to define optimal adaptation, and a boundary for Government action, it is not possible to estimate and compare adaptation costs. The discussion intentionally omits complex and technical issues to focus on key concepts. For more details the interested reader can consult recent work by the Fiscal Affairs Department of the IMF (Bellon and Massetti, 2022a,b; Aligishiev et al., 2022).

Defining adaptation to climate change

First, it is useful to define investment needs in climate change adaptation as the difference between optimal investment levels with and without climate change (the strict additionality definition). Without a clear and universal working definition it is impossible to define the scope of the problem and to compare policy prescriptions and estimates of investment needs. Consensus on such a definition would be beneficial for international discussions on climate finance, but it is at least necessary within the same government.

The above definition intentionally excludes investments in development that would be optimal even without climate change. While a more educated population can better adapt to future climate challenges, climate change itself will not inherently increase the optimal number of school years or the optimal teacher/student ratio. But if tropical cyclones intensify in Tonga due to climate change, for example, and building stronger schools costs more, the education budget may be affected. The bulk of education spending should not be counted as an adaptation to climate change, but any increase in spending needs attributable to climate change should be counted as an adaptation investment. If a looser definition is used, and all investment that helps reduce vulnerability to climate change is counted as adaptation to climate change, virtually all investment in development becomes an investment in adaptation. This distinction is particularly relevant for tracking adaptation spending in national budgets and for international climate finance.

Defining climate change adaptation needs via strict additionality also excludes the cost of closing the gap to achieve an optimal level of adaptation to current climate conditions. In countries not optimally adapted to the current climate, investment needs for resilience can exceed the additional costs of addressing climate change effects. For instance, flood-prone areas may benefit from protective infrastructure investments under current conditions, and only relatively small additional costs may make them also resilient to projected changes in flood risks. Closing adaptation gaps to the historical climate is considered a development problem.

The lack of a shared definition explains a large fraction of the wide range observed in estimates of adaptation investment needs. Significant differences stem from different assumptions about economic development and future vulnerability, climate change itself, and adaptation technology. But the inclusion or exclusion of broad development investments that would be needed even without climate change can dramatically change estimates of investment needs in adaptation (Hallegatte et al., 2018). The criteria used to define optimal adaptation are also important sources of differences in estimates of investment needs, as discussed in the next section.

Choosing optimal spending on adaptation

After defining adaptation, it is necessary to adopt a principle to choose how much to spend on adaptation. Without an optimality criterion, it is not possible to say how much investment is *needed*. This is a complex problem because there is not a right or wrong answer. Governments have wide latitude in choosing their own principle—for example, preserving present levels of risks, economic efficiency, or protecting certain populations—but it is important to make a transparent choice and then to consistently apply the same criterion to determine all other development goals.

Welfare economics and cost-benefit analysis (CBA) provide a concrete useful starting point to calculate investment needs based on the criterion of economic efficiency. The question of what to do, when, how, and at what cost ultimately relies on ethical choices that should reflect the preferences of each society. However, CBA, complemented by analysis and the correction of distributional impacts, can help decision-makers maximize overall social welfare by avoiding wasting scarce resources. According to this logic, the social value of avoided climate impacts should be at least greater than the social cost of adaptation (Net Present Value (NPV) > 0: cost-effective adaptation). The optimal level of protection is found by maximizing the net benefit of adaptation across all possible adaptation strategies (efficient adaptation). To maximize the impact of public spending, it is essential that CBA is applied to adaptation as well as to all other development programs in a consistent manner to ensure there are no missed opportunities across sectors and the development potential of the country is maximized. CBA aims at maximizing measures that aggregate the net benefits to society, but distributional impacts can be critical and should be estimated by the analysts and assessed by the Government (for more details, see Bellon and Massetti, 2022a).

There are limitations and challenges to implementing CBA, but it can still play a significant role in helping decision-makers to collect, aggregate, and compare information on adaptation projects. Many of the challenges of adaptation projects—uncertainty, lack of data, long time horizons—are shared by other complex investments in other sectors, such as early-age education, railroads, and hydroelectric

power plants. The same guidance developed for these sectors can be used for adaptation projects (see, for example, Asian Development Bank 2013; Boardman et al., 2018).

Alternative methods can be applied to reflect important goals besides economic efficiency, but CBA can still provide useful inputs to decision-makers. For example, the goal may be reducing the number of people living in poverty or the preservation of cultural heritage. There may also be interest in minimizing impacts in the worst-case scenario or in investing in projects with the lowest risk of failure. If these goals cannot be implemented using standard CBA—for example, by estimating the willingness to pay (WTP) of society to attain them—Governments would benefit from assessing trade-offs transparently and consistently.

Establishing a boundary for public investment

After defining adaptation and choosing a criterion to determine optimal investment in adaptation, to estimate *public* investment needs it is necessary to define a boundary for government intervention. Many adaptations have immediate and almost exclusively private benefits. For example, air conditioning is a private good for those that have invested in this technology and can afford to use it. Farmers that adopt heat-tolerant crops reap the full benefit of their choices. This means that individuals and firms have incentives to invest in adaptations that are beneficial for them (Mendelsohn, 2000). Also in this case, different assumptions on the boundary for government action can lead to vastly different estimates of *public* financing needs.

A lower bound on public spending in adaptation can be determined by considering only investment in public goods, e.g., infrastructure, coastal areas, water management projects, weather forecasts, and early warning systems. It is unlikely that individuals and firms will invest optimally in these adaptations because they are public goods. By adding indirect impacts of climate change—for example, lower revenues induced by lower economic activity, and higher welfare spending induced by higher poverty or natural disasters—it is possible to estimate the overall impact of climate change on public finance.

An upper bound on public spending needs in adaptation can be calculated by including compensation to individuals and firms to offset the cost of adaptation or of residual damages. With this larger scope, financing needs for climate change and adaptation would be equal to the full national cost of climate change.

MoFs have considerable flexibility in determining the best allocation of funds within this broad spectrum but must remain vigilant about potential inefficiencies and inconsistencies in other areas of public spending. Providing compensation to lower the costs of private adaptation might inadvertently encourage individual risk-taking behavior, which increases the cost of climate change for society. For instance, providing subsidies for private adaptation in flood-prone regions or offering subsidized risk insurance premiums in areas increasingly threatened by wildfires can reduce adaptation costs for private homeowners. However, this may unintentionally encourage people to reside in high-risk areas. A more effective approach is to assess the social value of adaptation compared with a retreat from these areas. If the NPV of retreat exceeds that of adaptation, compensation could be used to mitigate private losses. However, these distributional concerns should align with broader equity principles and objectives. If poverty reduction is the goal, more efficient tools, such as unconditional income transfers, might be preferable.

Methods to estimate spending needs in adaptation

After establishing a framework with clear definitions and goals, spending needs on adaptation can be estimated using empirical methods that have their own challenges. There are no easy formulas, and very few studies quantify country-by-country needs, and those that do provide limited coverage of climate risks and sectors. For example, the UNEP's Adaptation Gap Report estimate of investment needs in adaptation relies on a handful of relatively old studies (United Nations Environment Programme, 2023). In simple terms, analysts need a reference scenario without climate change and a scenario with climate change to obtain an estimate of climate damages. They must then collect information on potential adaptation strategies, their effectiveness in reducing climate change, and

their spending needs. Separating these steps and including all possible adaptations with their costs and benefits is challenging. Economists have explored different ways to tackle this problem, each with important limitations (for a review, see Massetti and Mendelsohn, 2018). Empirical results should always be critically reviewed, and important choices should be grounded on multiple lines of evidence.

Process-based or economic simulation models have been used widely to estimate investment needs in adaptation. These allow modelers to develop all the individual steps necessary to calculate optimal adaptation spending. For example, agronomic and forestry models are used to simulate the effects climate change has on crop yields and forest growth under alternative management and input choices (Nelson et al., 2014; Rosenzweig et al., 2014; Blanc and Reilly, 2017; Favero et al., 2021). Power-sector models simulate the effect of climate change on hydropower generation and costs and benefits of modifying power supply and/or demand to respond to climate impacts (e.g., van Vliet et al., 2016). Coastal models are used to study adaptation to sea-level rise. The case of coastal protection to sea-level rise illustrated in detail in Box 1 provides a clear example that can be replicated for other sectors. Simulation models provide a rich characterization of adaptation costs and benefits but must rely on good data on climate change impacts and include the full set of adaptation possibilities, their effectiveness, and costs.

Box 1. Estimating the cost of sea-level rise and adaptation

Adaptation to sea-level rise (SLR) is a useful case study to understand how the definitions, principles, and suggested methods can be used for practical assessments of public adaptation investment needs. As seawalls and similar coastal adaptations generally have no other benefit than protecting the coastline from rising sea levels, they easily satisfy the optimality criterion. A baseline scenario with sea-level rise, projected coastal development, and no adaptation is developed as a reference case using a model. The costs and benefits of alternative adaptation options can be calculated using this reference case. If the government uses CBA as a choice rule, the optimal adaptation strategy is the one with the largest NPV. Other normative criteria can be used to determine the optimal level of protection. All these calculations can be simulated using models that have been used widely during the past three decades (Nicholls et al., 2019; Hinkel et al., 2018; Diaz, 2016; Hallegatte et al., 2013; Nicholls and Tol, 2006).

IMF staff use the state-of-the-art Coastal Impact and Adaptation Model (CIAM) to estimate the cost of sea-level rise under alternative adaptation strategies. CIAM is a global model for estimating the economic costs and benefits of adaptation to sea-level rise (Diaz, 2016). The global coastline is divided into more than 12,000 segments of different lengths, grouped by country. Each segment is further divided into areas with different elevations, for which the model has data on capital, population, and wetland coverage. By using projections of local sea-level rise from Kopp et al. (2014), it is possible to estimate the areas that will be inundated and the amount of capital and population at risk. Storms cause periodic inundations on top of sea-level rise. The model does not consider increased risks from river floods.

The model calculates the cost of SLR—protection costs plus residual losses—under alternative adaptation options.

1. The *no-adaptation* scenario assumes that the population does not relocate to areas with higher elevation until the sea has inundated the area where it lives. Society keeps building and maintaining capital until inundation causes irreversible losses and capital is abandoned. The cost of sea-level rise is calculated as the sum of the residual value of the abandoned capital, the demolition costs, and the value of the inundated land. The model uses the rental value of agricultural land in proximity to the coastline, following Yohe et al. (1990), because as SLR progresses, coastal proximity rents will shift from land that is inundated to adjacent land. Population density and development opportunity costs are assumed to be capitalized in agricultural land values. The disutility cost of reactive migration is monetized.
2. Conversely, a *protection* scenario assumes that society invests in cost-effective seawalls and other barriers along the entire coastline to avoid inundation from sea-level rise, but

storms can still periodically inundate protected areas if such barriers are not sufficiently high. Capital and land are not lost and the population does not move, but storms periodically cause capital and human losses. The cost of SLR is equal to the cost of protection plus the expected value of the cost of storms.

3. Another adaptation option relies on *planned retreat* from areas that will be subject to inundation. The goal of planned retreat is to keep using coastal areas without building new capital and letting the existing capital depreciate. For example, a coastal road is used until it needs major retrofitting investment. Then, a new coastal road is built inland on higher ground. This strategy accepts that land and some residual value of capital will be lost, but it avoids coastal protection costs. The population gradually moves to higher ground before areas are inundated. Usually, this does not require migration to distant places, but rather relocation within the same coastal area. The cost of SLR is equal to the sum of the residual cost of capital, the value of inundated land, and the disutility cost of relocation.
4. The model considers variants of protection and retreat scenarios to deal with risks from storm surge floods. For example, the model calculates the height of the coastal protections necessary to contain SLR and increasingly large storm surges (1-in-10-, 1-in-100-, 1-in-1,000-, and 1-in-10,000- year events). In the base scenario (Retreat 1), the retreat perimeter is calculated to only deal with the permanent inundation of land, but the retreat perimeter can be extended to also avoid storm surges (from 1-in-10- to 1-in-10,000-year events).
5. For each coastal segment, the model calculates the NPV of SLR costs for each adaptation strategy. Loss of life is monetized using the Value of Statistical Life, and the loss of wetland due to either SLR or protection of barriers that impede the normal circulation of tidal waters is monetized using estimates of willingness to pay for biodiversity preservation.
6. The cost of building and maintaining seawalls, and other key parameters, are taken from the literature. Storm surge costs are incremental with respect to the baseline scenario in which storms occur without SLR.
7. By comparing SLR costs across all scenarios it is possible to find the *least-cost adaptation strategy* for each coastal segment, and to calculate the lowest possible cost of SLR for the country. Coastal protection is usually the least cost strategy in areas with large existing capital and high population density. Planned retreat is usually the least-cost strategy in areas with low capital and low population density. The optimal height of coastal protection infrastructure and the optimal retreat perimeter are determined by many factors, including the projected incremental costs of protection, the opportunity cost of not using land that would normally not be flooded, the capital and population at risk, and the different sea-level rise scenarios.

Despite many uncertainties and some necessary simplifying assumptions, CIAM provides a useful framework to systematically study the costs and benefits of alternative SLR adaptation strategies. More granular coastal modeling and more accurate mapping of assets can provide a more precise assessment of the costs and benefits, but the key insights developed with a baseline scenario provide a useful starting point for dealing with a complex, multidecadal challenge.

The CIAM has been used to complement Article IV country reviews and in Technical Assistance missions related to the Resilience and Sustainability, with the goal of highlighting risks and suggesting a path toward informed and consistent policy choices. Countries in which the CIAM has been used include Palau, Vanuatu, Morocco, Jamaica, Dominican Republic, Papua New Guinea, Togo, Curaçao, and Antigua and Barbuda. The model results are clearly preliminary and incomplete but are very useful to suggest a practical way to think about a very complex problem, based on an objective assessment of the benefits and costs of adaptation. Governments are presented with alternative adaptation strategies, each having its own costs, benefits, and policy hurdles. The no-adaptation case is used to provide a benchmark high-cost scenario that can materialize without any preemptive action. Costs are estimated for different categories of impacts, from loss of life due to storm flooding to loss of assets and ecosystem services. The case of full coastline protection is used to illustrate that it is often possible to avoid the permanent inundation of coastal areas and minimize storm flood

impacts, but this usually comes with large investment needs for protection. The case of planned retreat illustrates a strategy that does not have direct public finance costs and is usually the least costly for society as a whole, but it comes with its own planning and distributional challenges. This modeling exercise necessarily relies on strong simplifications, and any practical final decision requires granular data and much larger resources, but the CIAM provides a first opportunity to start a structured conversation within Government around a very complex problem. It is also a useful way to illustrate the logic of applying CBA to climate change adaptation, highlighting the trade-offs between alternative adaptation options that will likely be found in other sectors. The CIAM also provides a blueprint to create similar assessment tools in other sectors.

IMF staff provide access to model simulations using a simple Excel spreadsheet and can share all the data with authorities, but the model is open access and can be used and modified by economists in MoFs. The model is written in general algebraic modeling system (GAMS) language and is available via the CIAM GitHub repository.[1] GAMS is an optimization software that requires a paid subscription. It is not strictly needed to find a solution to the problem of coastal protection in CIAM, but rewriting the model in another software language is challenging. A Python version of CIAM, called pyCIAM, is available via the pyCIAM GitHub repository.[2] This version also introduces some changes to CIAM's parameters. pyCIAM relies on open-access software, but users need to be well-versed in Python.

Cross-sectional econometric methods can estimate the likelihood of certain adaptations being chosen, but do not immediately reveal spending needs. These methods use the observed behavior of (ideally) identical individuals in different climates to predict responses to climate adaptations. For instance, they have been applied to forecast farmers' crop choices in Africa, Latin America, and Asia in response to climate change (Kurukulasuriya et al., 2006; Seo and Mendelsohn, 2008), as well as to predict changes in energy demand for heating and cooling based on empirically estimated heating and cooling demand functions (e.g., Aroonruengsawat and Auffhammer, 2011; Rapson, 2014). These methods enable the estimation of spending needs related to these adaptations. The models, which rely on observed behavior, emphasize long-run responses to a shift in climate, which provides greater realism than simulation studies. However, they cannot decompose all the steps as simulation models. CBA is implicit. The methods reveal the choices of (presumably) efficient agents. The main challenge for these methods is separating the effect of climate on individuals' choices from many other potentially important factors, many of which are not easily measurable. Ignoring these factors leads to biased results (Blanc and Schlenker, 2017).

Panel econometric methods can estimate the cost of climate change including short-term adaptations, but intentionally omit many long-term more effective adaptations. By exploiting the time dimension of a panel, it is possible to remove unobserved characteristics that bias results. For example, after applying fixed effects, first differences, or a combination of both, variation in the variable of interest (for example, electricity demand) is explained using the variation in climate variables. This is not a trivial transformation. The model estimates the response of a relatively small weather shock, not a long-term response to a change in climate. Some short-term adaptations employed by the agents in the panel are included and may not be replicated in the future, but more complex adaptations that are not used as a response to a random weather shock are not included. Simplifying, it is possible to use these methods to identify the impact of climate change without adaptation, which can then be used as the upper bound of adaptation spending needs. Box 2 illustrates new work by Akyapi et al. (2025) that relies on big data and machine learning methods to estimate the effect of weather shocks on macrofiscal variables. The results can be used to update macrofiscal frameworks and to perform climate stress tests in the short term. For example, using the distribution of the selected weather variables over the past 30 years, it is possible to build best- and worst-case impact scenarios to inform policymakers and to make contingency plans. This method

1 https://github.com/delavane/CIAM
2 https://github.com/ClimateImpactLab/pyCIAM

has been used during Technical Assistance missions in Jamaica, Morocco, and Azerbaijan, and for Article IV reviews for Cyprus, Togo, and Ecuador.

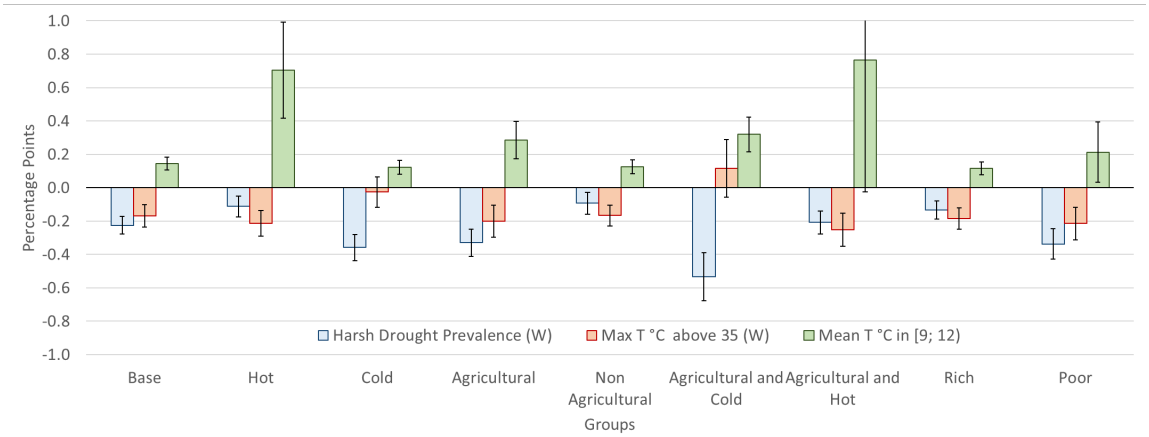
Box 2. Estimating the macrofiscal impacts of weather shocks using billions of weather observations

Estimating the impact of weather shocks on macrofiscal variables is a useful starting point to tackle long-term climate change. While weather shocks are very different from climate change—weather is the year-to-year, day-to-day random realization of climate—estimating their effect on gross domestic product per capita and other macrofiscal variables provides insights into the key vulnerabilities of the economy that could be exacerbated by long-term climate trends.

A study by Akyapi et al. (2025) moves the literature beyond average annual weather by leveraging hundreds of billions of daily weather measurements using machine learning methods. From high-resolution daily observations of temperature and precipitations the authors build hundreds of weather variables that can potentially explain economic outcomes. To select the most important variables to explain economic impacts they use the Least Absolute Shrinkage and Selection Operator (LASSO). They expand the analysis beyond the weather's effect on GDP to examine fiscal aggregates such as expenditure and revenue.

An increase in the incidence of high temperatures and severe droughts, and a reduction in the incidence of mild temperatures reduce GDP. These variables substantially improve the share of GDP variations explained compared to applications that use average annual temperature. A change of one standard deviation in the selected variables leads to a ~0.2 percentage point impact on GDP. The results for the full panel specification and for selected subgroups of countries are shown in Figure 1. The response of fiscal variables to weather shocks tends to mitigate the effects of a weather shock by implying a larger fiscal deficit when the shock has negative consequences for GDP.

Figure 1. The impact of weather shocks on GDP per capita

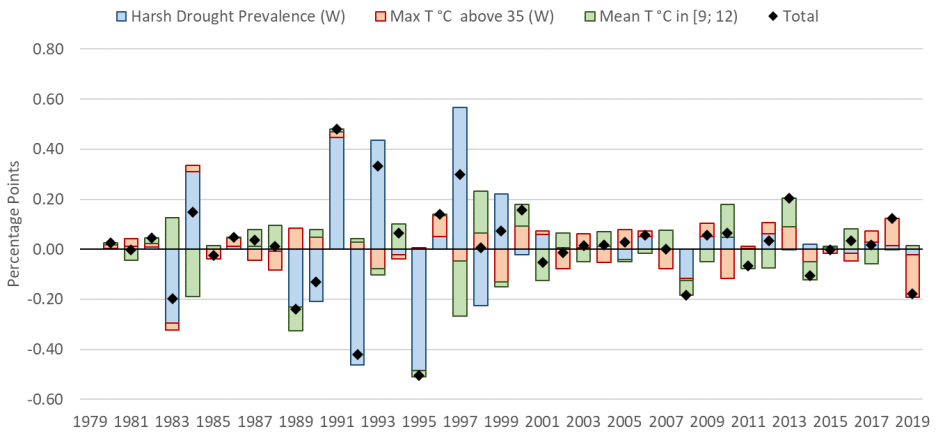


Notes: The figure illustrates the estimated impact of each weather variable using the baseline specification of Akyapi et al. (2025) and for different subgroups. The vertical lines show the 95% confidence intervals using standard errors clustered by country. Climate variables are standardized. Harsh drought prevalence: the share of grid-months during which the Palmer Drought Severity Index (PDSI) is < −4. Max T°C above 35: the share of grid-days with a maximum daily temperature greater than 35°C. Mean T°C in [9; 12]: the share of grid-days with mean temperature in the interval [a, b]. (W) indicates population-weighted variables. The figure only shows the results for groups that include the country.

Hot (N=3,315): 1979–2019 average temperature > 22.8°C. Cold (N=3,338): 1979–2019 average temperature ≤ 22.8°C. Agricultural (N=3,130): share of "Agriculture, forestry, and fishing, value added (% of GDP)" in 2002 is above median across countries. Non-Agricultural (N=3,062): countries that are not Agricultural. Agricultural Cold (N=1,334): agricultural and cold. Agricultural Hot (N=1,785): agricultural and hot. Rich (N=3,823): "High Income" and "Upper Middle Income" in WDI. Poor: "Low Income" and "Lower Middle Income" in WDI (N=2,727).
Source: Author, based on data from Akyapi et al. (2025).

The empirical setup is not ideal to quantify the effect of climate change on long-run growth rates but provides insights on the effect of past weather shocks. For example, Figure 2 shows the aggregate effect of observed values of the three selected weather variables on historical GDP per capita. Weather shocks are defined as the first differences of the weather variables and tend to offset each other, leaving average economic growth largely unchanged, but they explain interannual fluctuations that can be sizable. The analysis can also reveal changes in the vulnerability to weather shocks over time.

Figure 2. The impact of selected climate variables on GDP per capita (in percentage points)



Notes: the impact of variables selected in Akyapi et al. (2025) on GDP per capita in a randomly selected country. Harsh Drought Prevalence: the share of grid-months during which the Palmer Drought Severity Index (PDSI) is < −4. Max T°C above 35: the share of grid-days with a maximum daily temperature greater than 35°C. Mean T°C in [9; 12]: the share of grid-days with mean temperature in the interval [a, b]. (W) indicates population-weighted variables Black diamonds indicate the net impact of all variables.

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