FISCAL AFFAIRS

Climate Change Fiscal Risks

User Guide for the Quantitative Climate Risk Assessment Fiscal Tool (Q-CRAFT)

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CONTENTS

ACRONYMS

DSA	Debt Sustainability Analysis
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IMF	International Monetary Fund
Q-CRAFT	Quantitative Climate Risk Assessment Fiscal Tool
UN	United Nations
WB	World Bank
WDI	World Development Indicators
WEO	World Economic Outlook

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I. Introduction[1]

Climate change poses long-term risks to economic growth and public finances. The slow but persistent increase in temperature, shifts in precipitation patterns, and more volatile weather events can have long-term macroeconomic effects by slowing productivity growth, depleting capital stock, and adversely affecting human capital. These macroeconomic effects of climate change will add to fiscal pressures, which could accumulate over time if a government does not adapt to climate change. However, the slow-building, but significant, nature of the economic effects of climate change means the associated fiscal risks might not be discernible over the budget cycle or even the medium-term fiscal framework horizon.

The extent of macroeconomic fiscal risks associated with climate change varies across climate change scenarios. There is considerable uncertainty surrounding the global efforts to reduce carbon emissions, and there are also uncertainties about how carbon emissions can affect the economy. Nevertheless, the rise of average temperature is expected to negatively impact economic output particularly in severe climate change scenarios. Kahn et al (2021)[2] estimate that global GDP per capita reductions from rising temperatures could be as low as one percent by the end of the century if all commitments made in the 2015 Paris Agreement are implemented. In contrast, potential loss of global GDP per capita might be as high as 7 to 13 percent by the end of the century in pessimistic climate change scenarios relative to a baseline in which temperatures increase according to their historical trends. Beneath this range of global effects, there is considerable cross-country variation in potential macroeconomic, and thus fiscal, effects of climate change.

In assessing macroeconomic fiscal risks from climate change, country authorities should consider a range of scenarios, from benign to pessimistic. Exploring a pessimistic scenario is useful for fiscal risk analysis as it helps to define a boundary of worst case but plausible outcomes. Quantification of long-term fiscal risks emanating from climate change under different global warming scenarios informs policymaking and illuminates tradeoffs involving long-term commitments and fiscal pressures (for example from demographic change, or development needs). Further, a high-level quantification exercise helps identify areas for deeper analysis, including specific expenditure or revenue categories, financing and debt dynamics, and specific climate change fiscal risks with

[1] The Q-CRAFT User Guide was prepared by Tjeerd Tim and Jyoti Rahman for primary use in Capacity Development. This guide has greatly benefited from the guidance of Carolina Renteria, Jason Harris, and Maximilien Queyranne. Additionally, Q-CRAFT and the User Guide has received substantial quantitative inputs from Emanuele Massetti, Filippos Tagklis, Mehdi Raissi, and Samuele Centorrino. The guide also incorporates analytical suggestions from Bryn Battersby, John Grinyer, Andy King, Matthew Quillinan, and Yannick Vel.

[2] Kahn, M. E., Mohaddes, K., Ng, R. N. C., Pesaran, M. H., Raissi, M., & Yang, J. C., (2021), Long-term macroeconomic effects of climate change: A cross-country analysis. Energy Economics, 2021, 104, pp. 105624/1–13.

transitory impacts fiscal impacts due to a, for example, natural disaster triggering higher expenditure on relief, recovery and reconstruction or the materialization of a contingent liability.

The Quantitative Climate Change Risk Assessment Fiscal Tool (Q-CRAFT) supports governments in quantifying macroeconomic fiscal risks of climate change. To assess the potential fiscal impacts of various climate change scenarios, the analytical tool Q-CRAFT has been developed to project stylized macroeconomic and fiscal prospects for 171 economies under different climate change scenarios through 2099.[3] Q-CRAFT projects a baseline macro-fiscal scenario for GDP and key fiscal indicators that is grounded in a simple production function and standard debt dynamic equation, using available budgetary, economic, and demographic data, and some assumptions that can all be easily modified by users. Subsequently, cross-country empirical estimates[4] using the Kahn (2021) methodology, of temperature impacts on GDP per capita under different climate scenarios are applied to the baseline to project to 2099 key fiscal indicators, such as the debt-to-GDP ratio, under different climate scenarios. As such, it is essentially a partial-equilibrium set-up.

Q-CRAFT serves as a starting point for climate change fiscal risk analysis. The results are stylized, although based on country specific empirical data. The tool is useful for Ministries of Finance and Economic Development and, as well as Central Banks. Q-CRAFT is designed to generate stylized analysis by all governments at different levels of capacity, and it can be used as foundational framework for further in-depth fiscal sustainability analysis using more sophisticated general equilibrium models and granular data by governments with relatively stronger capacity institutions.

Q-CRAFT's stylized results do not account for the potential impacts of climate change induced natural disasters, sea-level rise risks and other environmental risks, rendering the outcomes conservative. Inference about income losses up to 2099 based on past data involves model uncertainty and climate change scenario analysis is subject to deep uncertainty. The scenarios and their economic impacts reflect historical relationships between changing temperatures and economic outcomes. Therefore, the empirical data used for Q-CRAFT does not account for tipping points, non-market damages (e.g., morbidity and mortality, conflicts, and food insecurity or spillovers). Finally, climate change is likely to aggravate specific fiscal risks following discrete events such as the triggering of implicit or explicit contingent liabilities, but these are not analyzed in the tool. Instead, Q-CRAFT provides an option to manually add potential fiscal impacts of such discrete events like

[3] Several studies are used here to generate the estimates of the impact of changing climate on GDP provide estimate to 2099.

[4] FADCP Climate Dataset (Massetti and Tagklis, 2023), using CRU data (Harris et al., 2020), CMIP6 data (Copernicus Climate Change Service, Climate Data Store, (2021): CMIP6 climate projections), and Centorrino, S., E. Massetti, and F. Tagklis. 2024. "Climate Effects on GDP Growth: Updated Estimates of Kahn et al. (2021)" Reference Guide. The precise estimates of in Q-CRAFT may sometimes differ with empirical data in the original Kahn (2021) paper because Q-CRAFT uses the more recent vintage of estimates as provided in the FADCP Climate Dataset.

increased expenditure on relief, recovery, and reconstruction. The tool also does not generate information on the fiscal impact of climate change adaptation spending.

Q-CRAFT's operating structure is transparent, and it can be deployed without any additional data, even in low-capacity settings. Q-CRAFT can build scenarios using publicly available economic, fiscal, and demographic data from the IMF's World Economic Outlook (WEO), the United Nations (UN) and the World Bank (WB). The different data sources are further explained in subsequent sections of this User Guide. Country expertise, however, is needed to generate a baseline scenario that would align with a country's macroeconomic and fiscal framework.

Q-CRAFT supplements country macroeconomic models. Q-CRAFT is not a forecasting model nor a general equilibrium model of the economy. The information needed for creating the long-term projections, such as long-term productivity growth rate, inflation, and interest rates, are assumed and can be manually changed by the user. Further, structural transformation of the economy, fiscal implications of demographic changes, and fiscal effects of climate change adaptation are not explored in detail. Finally, the external and monetary sectors are exogenous to the analysis. Country authorities must have other models and analytical frameworks for budget preparation, policy analysis, or medium-term debt sustainability analysis. Similarly, environmental agencies will likely have detailed models and analysis of climate change. Q-CRAFT analysis should be used in conjunction with these other techniques, but the tool itself is not designed for macroeconomic forecasting and modelling.

As with any tool, the robustness of Q-CRAFT and the baseline it creates largely depends on the inputs and assumptions. Q-CRAFT comes pre-loaded with international data: the UN population projections to 2100; the IMF WEO projections (currently to 2028) for macro-fiscal variables; WB World Development Indicators (WDI) historical data for labor productivity; and thus the estimates of the effect of climate change on growth in GDP per capita to 2099. Authorities can use their own data, including medium-term fiscal framework or projections from the debt sustainability analysis and demographic projections, to customize the outputs in the national context.

This User Guide will be periodically updated. The climate scenarios in Q-CRAFT reflect currently employed scenarios by the research community (see Chapter IV.B), while empirical estimates of the linkages between climate and the economy are taken from the recent, peer reviewed, literature on the topic. The empirical estimates will be updated, amended, and refined over time as better data and techniques become available. The IMF team working on this tool welcomes feedback and comments on the tool, this guide, and how both could be improved.[5]

This User Guide explains how to set up and use the tool and interpret the results. The rest of the User Guide is structured as follows:

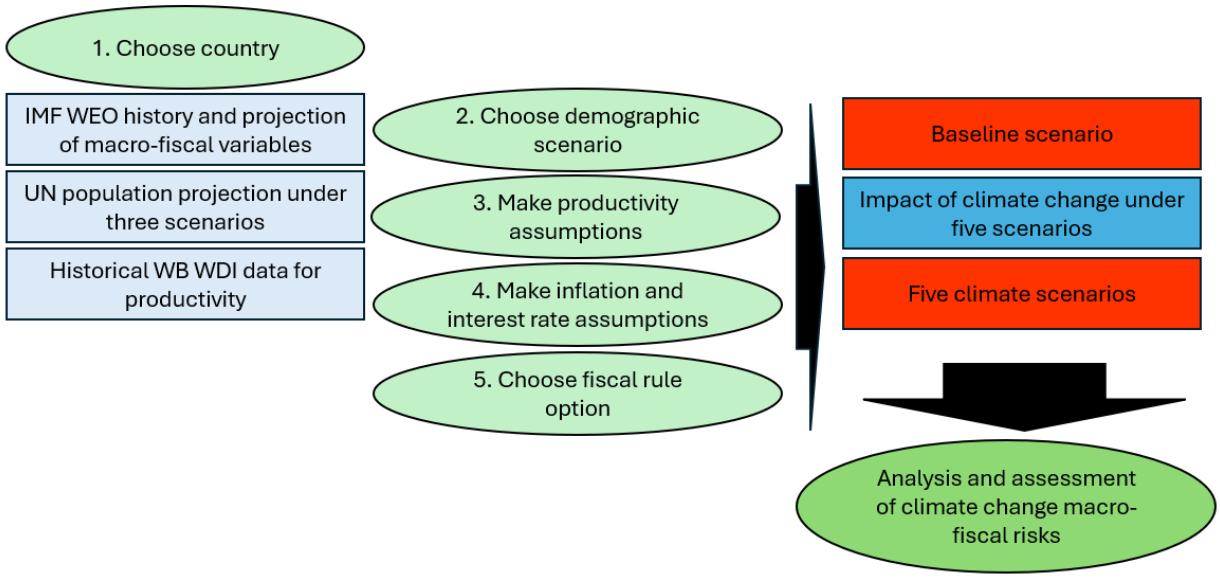
[5] Please contact FiscalRisk@imf.org and FADM1AST@imf.org for questions or provide feedback.

- Section II: Functional Overview. This section describes various features of the spreadsheet including its set up and color conventions, the data sources, and the steps needed to operationalize Q-CRAFT.
- Section III: Illustrative Example. A fictional country is used to demonstrate how to set up the tool.
- Section IV: Detailed Explanation of the Methodology. This section lays out the conceptual framework and empirical relationships that underpin Q-CRAFT.

II. Functional Overview

Q-CRAFT is a tool designed to generate long-term fiscal projections under different climate change scenarios, utilizing publicly available data in a structured approach. This section provides a functional overview of the tool, covering various features of the spreadsheet including its set up and color conventions, data sources, and steps needed to set it up. First, Q-CRAFT requires the user to select the country and key assumptions for demography, productivity, inflation, and interest rates. After that, long-term projections for key fiscal aggregates under the baseline and alternative climate change scenarios are automatically generated. All these steps are explained in more detail after Figure 1, which illustrates Q-CRAFT's operative structure.

Figure 1. Visual Representation of Q-CRAFT's Operations



A. Q-CRAFT SPREADSHEET MANAGEMENT RULES

To make it easy to understand and use, Q-CRAFT has been developed in accordance with strict formatting rules.

Q-CRAFT has the following worksheets:

- The blank "Read me" worksheet provides information for the user to operate Q-CRAFT.
- The green "Dashboard" worksheet has the dashboard in which users can select the parameters needed for Q-CRAFT to generate the baseline and climate change scenarios.
- The blue worksheets contain the data needed to generate the scenarios. Q-CRAFT comes pre-loaded with data from the IMF, the United Nations, and the WB. The input data can be replaced with a country's own estimates.
- The red worksheets are used by Q-CRAFT to calculate the baseline and the different climate scenarios. These worksheets should not be changed by the user.
- The yellow "Output" worksheets provide the user with output tables and charts. These worksheets should not be changed by the user.

The following formatting and coloring conventions are used:

- Cells with blue digits are hard-coded data from an external data source;
- Cells with green digits link data between different worksheets; and
- Cells with black digits contain the calculations.

B. SETTING UP THE BASELINE SCENARIO

The Dashboard worksheet allows the user to choose the parameters needed to set up the baseline scenario (Figure 2). The first step in using Q-CRAFT is to choose the country in the dashboard. The next step is to choose the demographic scenario. The third step is to choose the assumptions for productivity growth. This is followed by the assumptions on inflation and interest rates. The baseline scenario is generated automatically once these steps are completed. Each step is explained in more detail in the paragraphs below Figure 2.

Figure 2. The Dashboard

Select Country	Australia	
		Relevant Pages in the User Guide
Assumptions required for the BASELINE SCENARIO		
Demography	Medium	Page 11 - 12
Productivity		Page 12 - 14
Start	1.2	
End	1.2	
Inflation		Page 14
Start	2.0	
End	2.0	
Interest rate		Page 14 - 15
Constant	Nominal interest rate	
(a)real interest rate, if chosen	1.0	
Assumptions required for the FISCAL RULE		
Rule	Yes	Page 16 - 18
Debt-to-GDP	60.0	
Assumptions required for the CLIMATE SCENARIOS		
Expenditure Rigidity	1.0	Page 18 - 20

Choosing the Country in the Dashboard, loading the data in the Macro-fiscal worksheet

Once the country is selected in the Dashboard, all the required economic and fiscal data and the medium-term projections from IMF's WEO database are automatically loaded in the Macro-fiscal worksheet (Figure 3). The following variables are loaded for the period 2001-28: real GDP; nominal GDP; the GDP deflator; revenue; expenditure; overall balance; primary balance; and gross debt.

- All the figures are in billions of local currency units, unless stated otherwise (for example, the GDP deflator is an index). All fiscal variables are for the general government sector.
- A set of summary charts are also produced in the Macro-fiscal worksheet to help with macroeconomic diagnostics, which is important for setting productivity, inflation, and interest rates assumption and interpreting the long-term fiscal projections.

Figure 3. The Macro-fiscal Worksheet

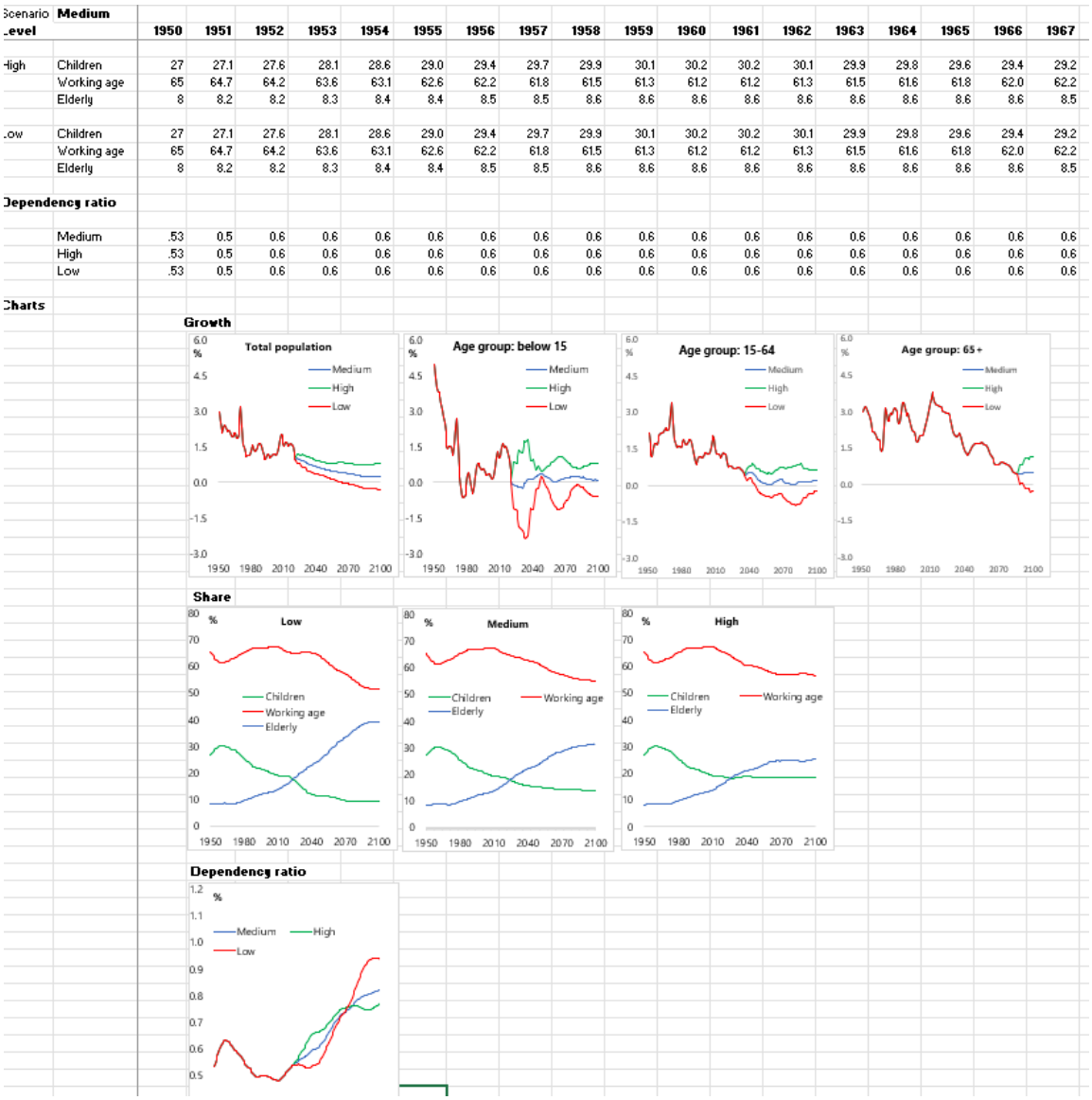
Users can replace the IMF WEO data with their own estimates and projections by hard pasting the figures into the blue-shaded cells in the Macro-fiscal worksheet. However, this will delete the original data in the Q-CRAFT, which cannot be undone. It is also possible to replace with other projections, like the WEO projections with IMF-WB Debt Sustainability Analysis that extend beyond 2029 (to the 2040s in some cases) by hard-pasting the figures in the Macro-fiscal worksheet and making other minor adjustments in the Productivity, Interest rate, Inflation, and Baseline worksheets. This allows the Q-CRAFT baseline scenario to be consistent with the IMF-World Bank Debt Sustainability Analysis (DSA) projections. However, Q-CRAFT results only complement, and not replace, DSA projections.

Demographic assumptions and the Demography worksheet

There are three demographic scenarios in Q-CRAFT: medium, high, and low. These reflect different fertility assumptions underpinning the UN's population projections.[6] Q-CRAFT has the UN data for all economies preloaded. Users can choose a scenario in the Dashboard worksheet, and estimates and projections for population by age groups (total, 15-64-year-old or the 'working age', over 65 or the 'elderly', and below 15 or the 'children') are presented for the period 1950-2100 in a table and along with a set of automatically generated charts in the Demography worksheet (Figure 4). In Q-CRAFT, demographic changes affect GDP growth through the production function used in the model, as detailed in the next paragraph.

[6] For further details on the demographic data used, including its underlying assumptions, see the World Population Prospects, 2022. Available at: https://population.un.org/wpp/.

Figure 4. The Demography Worksheet



Users can replace the UN population projections with their own projections by hard pasting the figures into the shaded cells in the Demography worksheet. However, this will delete the original data in the Q-CRAFT, which cannot be undone.

Productivity assumptions and the Productivity worksheet

Productivity is defined as GDP per employed person in Q-CRAFT. This is the broadest definition of labor productivity. It is used in Q-CRAFT as climate change affects labor productivity through real GDP per capita in the empirical dataset based on Kahn et al (2021). The historical data in the tool is used in the WB's WDI dataset.

Productivity assumptions are critical because they directly shape the long-term economic growth projections in Q-CRAFT. Since productivity growth increases the GDP per employed person, these assumptions affect overall economic output and fiscal capacity. Credible productivity projections ensure realistic assessments of future growth, which are essential for effective policy analysis and planning.

Users need to enter realistic expectations for productivity growth over the long term. Q-CRAFT uses the WB WDI data for productivity growth until 2021 and derives productivity growth for the period between 2022 and 2028 from the WEO projection of real GDP growth and the UN projection of the working-age population growth. The productivity growth thus calculated in 2028 is the 'start' productivity growth rate—that is, it is the productivity growth rate in 2029, the start of the Q-CRAFT projection period. Users need to form a view about the structural productivity growth rate for the economy in the long run (the end period, 2090 to 2100). Once the user has entered this information, Q-CRAFT calculates a productivity trajectory to 2100. These steps are further explained below with more detailed information.

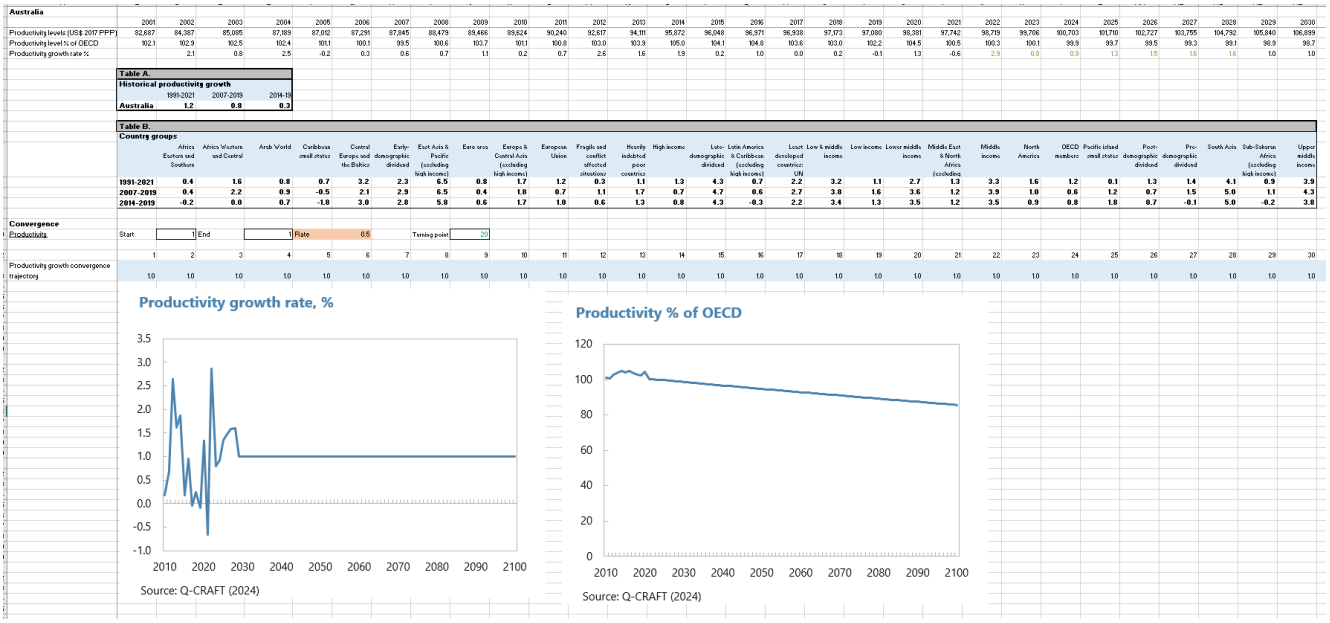
- To help users contextualize the projected productivity growth over the WEO period and therefore the 'start' productivity growth, average growth rate over three periods is presented in Table A, using WB WDI data: 1991-2022; 2007-19 (covering the period between the cyclical peaks before the Global Financial Crisis to the Covid-19 pandemic); and 2014-19 (five years to the pre-pandemic cyclical peak)—see Figure 5.

- Users can choose to use these growth rates as the start and end productivity growth rate. To further assist with a plausible choice for the end period assumption, historical (1991-2021, 2007-19, and 2014-19) productivity growth rates for a number of country groupings are provided in Table B—see Figure 5.

Using the productivity growth rates as selected by the user, Q-CRAFT produces a productivity trajectory for the period 2029-2100 (Figure 5). Two sets of figures and charts are generated.[7] First, Q-CRAFT derives annual productivity growth based on the 'start' period assumption in the 2020s, gradually changing to the 'end' period assumption by the 2090s using a linear trajectory. Second, the country's productivity level relative to OECD is calculated for the period to 2100, with the assumption that OECD productivity continues to grow at 1.1 percent per year that has been achieved between 1991-2022.

[7] The productivity convergence trajectory is based on a logistics function, which uses the parameters 'Rate' and 'Turning Point'. The 'Rate' parameter determines the slope of the function. It is set at 0.5 (rose-pink highlighted in the spreadsheet) and should not be changed. The 'Turning Point' parameter determines the inflection point in time —that is, how many years into the future that the economy transitions from the 'start' productivity growth to 'end' productivity growth. This parameter can be adjusted.

Figure 5. The Productivity Worksheet



Productivity level relative to the OECD is a key realism check. For example, for an emerging economy, productivity growth assumptions that imply the country becoming significantly more productive than the OECD average by the end of the century might not be a realistic projection. While for developing economies it may be relevant to assume some catch up growth, users should consider a productivity growth rate assumptions that is realistic. Furthermore, the conservative productivity growth assumption might be more realistic for countries that are expected to undergo severe demographic transition leading to shrinking population.

Users can override the productivity trajectory with their own projections by hard pasting the figures into the shaded cells in the Row 23 of the Productivity tab. However, this will delete the original data in the Q-CRAFT, which cannot be undone. There are some economies in the IMF WEO database for which the WB WDI productivity data is not available.[8] Productivity levels of similar economies might be a useful substitute for these cases.

Inflation assumption

The inflation rate assumptions should be entered by the user and should reflect the Central Bank's inflation target. Usually, Central Banks target inflation of 2-3 percent in advanced

[8] At the time of current publication, productivity data are not available for the following economies: Andorra; Antigua and Barbuda; Aruba; Dominica; Eritrea; Grenada; Kiribati; Kosovo; Marshall Islands; Micronesia; Nauru; Palau; San Marino; Seychelles; South Sudan; St Kitts and Nevis; Syria; Taiwan Province of China; Tuvalu; Yemen. Further, historical productivity data in the WB dataset may have structural breaks or gaps in some countries. The user needs to make a judgment drawing on country expertise and national data sources in such cases.

economies and 3-6 percent in emerging and developing economies. If the WEO projections of inflation are in that range in 2028, then they should be entered as both 'start' and 'end' inflation rates. Otherwise, the WEO projection for 2028 should be chosen as the 'start' inflation rate and the 'end' rate should be set to the Central Bank's target. In either case, inflation will be constant in the long run. The long-run constant inflation assumption implies the Central Bank will maintain macroeconomic stability over the long term. More detailed information for more experienced users is provided in Section IV (including on the use of the GDP deflator). If there is no Central Bank inflation target, a practical approach is that a user could consider an average inflation rate from neighboring countries or regional economic blocs.

Interest rate assumptions and the Interest Rate worksheet

The interest rate assumptions need to be entered by the user. Country expertise is important to develop credible assumptions for long-term interest rate developments, particularly with respect to the availability of concessional loans, sovereign risk premia, and the maturity of domestic financial sectors. Q-CRAFT offers three options for making interest rate assumptions: the nominal interest rate remains constant from 2029 (that is, after the WEO horizon); the (nominal) interest growth differential remains constant from 2029; or the real interest rate, which could be aligned with a country's estimated neutral rate of real interest (also called r-star), remains constant from 2029

- Constant nominal interest assumption. Selecting this assumption might be the simplest approach. This implies that the nominal interest rate remains constant at the last year of the projections in the Macro-fiscal worksheet. However, in the previous the section, if the productivity assumptions imply that the country is converging to OECD level of productivity by end century, it may be better to taper the nominal interest rate by using a constant interest growth differential instead of keeping it fixed. This is because, as productivity improves, economic conditions evolve, and maintaining a constant nominal interest rate might not accurately capture the likely changes in growth and inflation. Adjusting the rate with a differential allows for a more realistic reflection of how interest rates would behave in a converging, more advanced economy.

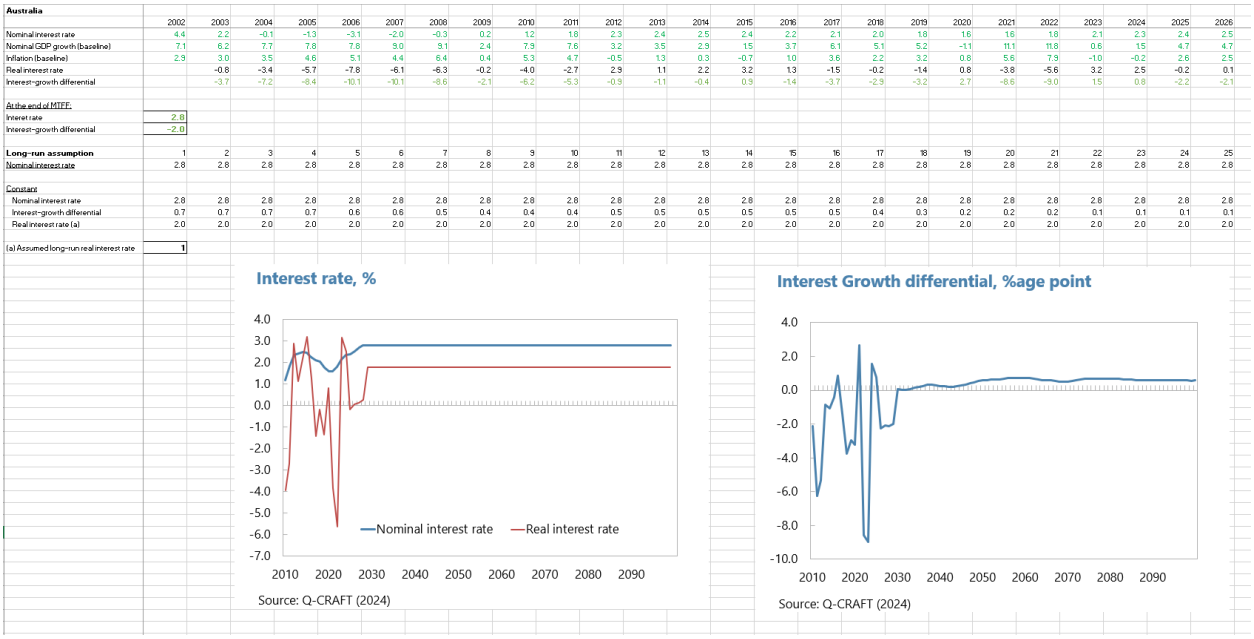
- Constant (nominal) interest growth differential assumption. When using this assumption, the user assumes that the difference between the growth rate of the economy and the interest rates within that economy remains constant. This approach can provide a more nuanced projection than assuming a constant nominal interest rate. However, more advanced users are advised to carefully consider potential effects of demographic changes on the interest-growth differential.[9]

[9] For more advanced users, it is important to consider factors such as a declining population, which can widen the interest-growth differential. As noted in the IMF Staff Discussion Note "The Fiscal Consequences of Shrinking Populations" (Clements et al., 2015), demographic shifts like shrinking populations can lead to slower economic growth. Therefore, users should take demographic trends into account, as a constant differential may not accurately reflect future economic conditions in countries facing significant demographic changes.

However, if the first two options result in a prolonged period of negative real interest rate—that is, if the long-term nominal interest rate falls below the projected inflation rate—then the constant real interest rate option could be chosen. In this case, the user needs to make a further assumption about the long-term real interest rate.

Given the assumption selected, Q-CRAFT projects a profile for nominal interest rate, interest-growth differential, and real interest rate (Figure 6). Detailed information for more experienced users is provided in Section IV.

Figure 6. The Interest Rate Worksheet



Australia	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Nominal interest rate	4.4	2.2	-0.1	-1.3	-3.1	-2.0	-0.3	0.2	1.2	1.8	2.3	2.4	2.5	2.4	2.2	2.1	2.0	1.8	1.6	1.6	1.8	2.1	2.3	2.4	2.5
Nominal GDP growth (baseline)	7.1	6.2	7.7	7.8	7.8	9.0	9.1	2.4	7.9	7.6	3.2	3.5	2.9	1.5	3.7	6.1	5.1	5.2	-1.1	11.1	11.8	0.6	1.5	4.7	4.7
Inflation (baseline)	2.9	3.0	3.5	4.6	5.1	4.4	6.4	0.4	5.3	4.7	-0.5	1.3	0.3	-0.7	1.0	3.6	2.2	3.2	0.8	5.6	7.9	-1.0	-0.2	2.6	2.5
Real interest rate		-0.8	-3.4	-5.7	-7.8	-6.1	-6.3	-0.2	-4.0	-2.7	2.9	1.1	2.2	3.2	1.3	-1.5	-0.2	-1.4	0.8	-3.8	-5.6	3.2	2.5	-0.2	0.1
Interest-growth differential		-3.7	-7.2	-8.4	-10.1	-10.1	-8.6	-2.1	-6.2	-5.3	-0.9	-1.1	-0.4	0.9	-1.4	-3.7	-2.9	-3.2	2.7	-8.8	-9.0	1.5	0.8	-2.2	-2.1
At the end of MTFF:																									
Interet rate	2.8																								
Interest-growth differential	-2.0																								
Long-run assumption	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Nominal interest rate	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Constant																									
Nominal interest rate	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Interest-growth differential	0.7	0.7	0.7	0.7	0.6	0.6	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Real interest rate (a)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
(a) Assumed long-run real interest rate	1																								

The fiscal rule assumption and the baseline scenario

The baseline scenario

A baseline scenario is generated automatically once the relevant choices are made in the Dashboard and reflects methodological assumptions. The baseline scenarios are summarized in a set of charts in the Output Baseline-worksheet. The initial macro-fiscal projections in the baseline scenario reflect the following methodological relationships and assumptions (Figure 7). The intuition behind the methodology is described in detail in Section IV.

- *Employment*: After the end of the IMF WEO horizon, employment is assumed to grow by the projected growth in working age (15-64 year) population.[10]

- *Nominal GDP*: Nominal GDP projections are calculated using employment growth together with assumptions for productivity growth and inflation as made by the user in the Dashboard-worksheet. Specifically, the Nominal GDP growth is approximated as the sum of employment growth, productivity growth, and inflation.

- *Government Revenue*: Revenue is assumed to remain constant as a share of nominal GDP (that is, it grows in line with productivity, inflation, and working age population) after the end of the WEO horizon.

- *Primary expenditure*: Primary expenditure excludes government interest payments and is assumed to grow by productivity, inflation, and total population after the end of the WEO horizon, and therefore changes as a share of GDP, which is different than the assumption for government revenue.

Figure 7. The Baseline Worksheet

	Counter	Notes			
	Years		2009	2010	2011
Inputs from blue tabs; calculations as describe					
Input (Demography)	Working age (15-64) population	Level	=Demography!BJ4	=Demography!BK4	=Demography!BL4
Input (Demography)	Total Population	Level	=Demography!BJ5	=Demography!BK5	=Demography!BL5
Input (Macrofiscal)/Calculation (after 2029)	Real GDP	Level	=Macrofiscal!L2	=Macrofiscal!M2	=Macrofiscal!N2
Input (Macrofiscal)/Calculation (after 2029)	Nominal GDP	Level	=Macrofiscal!L3	=Macrofiscal!M3	=Macrofiscal!N3
Input (Macrofiscal)/Calculation (after 2029)	GDP deflator	Level	=Macrofiscal!L4	=Macrofiscal!M4	=Macrofiscal!N4
Calculation	Employment growth	Per cent	=(D15/100-D14/100)/(1+D14/100)*100	=(E15/100-E14/100)/(1+E14/100)*100	=(F15/100-F14/100)/(1+F14/100)*100
Input (Productivity)	Labour productivity growth	Per cent	=Productivity!J5	=Productivity!K5	=Productivity!L5
Input (Macrofiscal)/Calculation (after 2029)	Real GDP growth	Per cent	=Macrofiscal!L12	=Macrofiscal!M12	=Macrofiscal!N12
Input (Macrofiscal, Dashboard)	GDP deflator growth	Per cent	=Macrofiscal!L14	=Macrofiscal!M14	=Macrofiscal!N14
Input (Macrofiscal)/Calculation (after 2029)	Nominal GDP growth	Per cent	=Macrofiscal!L13	=Macrofiscal!M13	=Macrofiscal!N13
Calculation	Population growth	Percent	=Demography!BJ5/Demography!BI5*100-100	=Demography!BK5/Demography!BJ5*100-100	=Demography!BL5/Demography!BK5*100-100
Input (Macrofiscal)/Calculation (after 2029)	Revenue	%age NGDP	=Macrofiscal!L15	=Macrofiscal!M15	=Macrofiscal!N15
Calculation	Total expenditure	%age NGDP	=D28/D10*100	=E28/E10*100	=F28/F10*100
Calculation	Interest expenditure	%age NGDP	=D29/D10*100	=E29/E10*100	=F29/F10*100
Input (Macrofiscal)/Calculation (after 2029)	Primary expenditure	%age NGDP	=Macrofiscal!L16	=Macrofiscal!M16	=Macrofiscal!N16
Input (Macrofiscal)/Calculation (after 2029)	Primary balance	%age NGDP	=Macrofiscal!L20	=Macrofiscal!M20	=Macrofiscal!N20
Input (Macrofiscal)/Calculation (after 2029)	Overall balance	%age NGDP	=Macrofiscal!L19	=Macrofiscal!M19	=Macrofiscal!N19
Input (Macrofiscal)/Calculation (after 2029)	Revenue	Level	=Macrofiscal!L5	=Macrofiscal!M5	=Macrofiscal!N5
Input (Macrofiscal)/Calculation (after 2029)	Total expenditure	Level	=Macrofiscal!L6	=Macrofiscal!M6	=Macrofiscal!N6
Input (Macrofiscal)/Calculation (after 2029)	Interest expenditure	Level	=Macrofiscal!L10	=Macrofiscal!M10	=Macrofiscal!N10
Input (Macrofiscal)/Calculation (after 2029)	Primary expenditure	Level	=Macrofiscal!L11	=Macrofiscal!M11	=Macrofiscal!N11

Q-CRAFT projects debt-to-GDP ratio to 2099 using the debt dynamics equation. The debt dynamics equation is the formula used to calculate how the level of government debt changes over time, taking into account an initial level for government debt (based on WEO data), the interest rate

[10] Employment growth is derived for the period till the end of WEO horizon as a residual between the WEO real GDP growth and the productivity growth trajectory calculated above. This derived employment growth will likely differ from the authorities' own employment growth figures because of the short run influence of the business cycle. See Section IV for further discussion.

at which a country borrows money to finance its debt, the primary balance of a government and nominal GDP growth. The intuition behind the debt dynamics equation is to understand how interest rates, economic growth, and primary fiscal balances affect the trajectory of public debt:

- When the rate of economic growth is lower than the interest rate, it indicates that the economy is expanding at a slower pace than the cost of borrowing money. As a result, the debt-to-GDP ratio, which is a measure of a governments debt relative to its economic output, tends to increase over time. Conversely, when economic growth is higher than the interest rate, the debt-to-GDP ratio tends to decrease. This relationship demonstrates that a decline in economic growth can lead to worsening debt dynamics, as the government's debt burden becomes relatively larger compared to its ability to generate income. The negative impact of climate change on economic output can exacerbate unfavorable debt dynamics, or render a favorable debt dynamic unfavorable, by hindering economic growth and making it more difficult for countries to manage their debt obligations.

- Also, a primary surplus will reduce the debt-to-GDP ratio and a primary deficit will raise it, all else equal.

- This 'debt dynamics equation' is detailed for the advanced users in Section IV. Q-CRAFT uses the equation to generate debt-to-GDP ratio over the long-term.

Q-CRAFT calculates the debt-stabilizing primary balance, which is the necessary primary balance to maintain stable debt levels, for every year to 2099. The debt dynamics equation can be used to derive the primary balance needed to keep debt stable relative to GDP over time. This calculation can be used to assess whether current fiscal policy is consistent with a stable debt-to-GDP ratio and indicate how much budgetary effort is required to achieve a stable debt ratio. Declining economic output resulting from climate change increases the required effort of a government to maintain stable debt levels. Further details are provided for the advanced users in Section IV.

The fiscal rule

If the user wants to compare the evolution of the debt-to-GDP ratio with a fiscal rule for debt-to-GDP, they need to choose the fiscal rule assumption.[11] The following steps need to be done:

[11] Since Q-CRAFT is a partial equilibrium model, it does not estimate the GDP effects of the fiscal adjustments needed for the government to meet the debt-to-GDP target. The stable inflation assumption suggests that a fully rational household sector expects authorities to comply with the fiscal rule and the central bank to maintain macroeconomic stability. As a result, households will smooth their consumption, preventing any negative impact from the consolidation. Although this is a strong assumption, it conceptually aligns with the stable inflation premise.

- Initially, the option "no" should be selected, and 0 should be entered for the debt target.
- If the user wants to apply a fiscal rule debt target, they should select the option "yes" and then enter the appropriate level for debt-to-GDP in the dashboard worksheet.

C. GENERATING THE CLIMATE SCENARIOS

Climate change scenarios

Q-CRAFT simulates the fiscal consequences for six different climate scenarios. The six scenarios are briefly summarized below, with further details for advanced users in Section IV B.

- **Paris**: based on the SSP1-2.6 IPCC scenario where international commitments from the 2015 Paris summit are met. This scenario assumes significant cuts in emissions, keeping global temperature increase above its preindustrial level below 2°C at the end of the century.
- **Moderate**: based on the SSP2-4.5 IPCC scenario. Emissions continue increasing in line with the continuation of present trends and stabilize at the end of the century, with temperature increase similar to the 1960-2014 trend. This scenario assumes that climate mitigation policies continue along the observed trend, but countries do not take more aggressive actions to fulfill their Paris commitments.
- **High**: based on the high-emissions SSP3-7.0 IPCC scenario. Rather than intensifying climate mitigation efforts, countries start scaling back their implemented policies in a fragmented world with limited energy efficiency improvements and continued use of fossil fuels.
- **Hot**: emissions are as in the "high" scenario, but it uses the 90th percentile of temperature increases among all climate models that used SSP3-7.0 emissions, instead of the median of temperature projections in this scenario.
- **Hot adapted**: same temperature increases as in the hot scenario, but countries adapt to it more quickly.
- **Hot un-adapted**: same temperature increases as in the hot scenario, but countries adopt very slowly to climate change.

Macro-fiscal effects of climate change

Q-CRAFT uses existing empirical data about the potential impact of climate change on the GDP levels to 2099 under different climate scenarios. Q-CRAFT calculates the macroeconomic impacts of climate change under different scenarios by using updated estimates of slow-moving warming impacts on GDP per capita growth in Kahn et al (2021) as generated by the FAD Climate

Policy Division. These estimates are provided for 171 economies in the Climate Data-worksheet (Figure 8).[12] The estimation methodology to generate the empirical data is detailed in Section IV.

Figure 8. The Climate Worksheet

Q-CRAFT assumes that fiscal projections will be affected by climate change scenarios starting in 2030. This assumption is used to distinguish the long-term impacts of climate change, on which Q-CRAFT analysis focuses, from other macroeconomic shocks that buffet an economy in the near and medium term.[13]

The results from the climate scenarios are generated automatically reflecting certain methodological assumptions. The outputs for each climate scenario are summarized in a set of tables and charts in the Output Scenarios worksheet. The macro-fiscal projections in these scenarios reflect the following methodological assumptions. The intuition behind these assumptions is further detailed in Section IV.

- In each scenario, the revenue-to-GDP ratio remains same as the baseline, and government revenue is therefore lower than the baseline as GDP will decrease because of the impacts of climate change.

- In contrast, in each scenario, primary expenditure is initially assumed to remain rigid at the baseline level in local currency terms. As GDP declines with climate change, the primary expenditure-to-GDP ratio rises.

[12] At the time of current publication, climate estimates are not available for the following economies: Andorra; Antigua and Barbuda; Aruba; Bahrain; Barbados; Dominica; Hong Kong SAR; Kiribati; Kosovo; Macao SAR; Maldives; Malta; Marshall Islands; Micronesia; Nauru; Palau; Seychelles; Singapore; St Kitts and Nevis; St Lucia; Taiwan Province of China; Timor-Leste; Tonga; Tuvalu; West Bank and Gaza.

[13] See Aligishiev, Bellon, and Massetti, 2022 for further discussion on how adaptation measures can be integrated in macro-economic frameworks over the short to medium-term.

With reduced revenue but unchanged primary expenditure (see next section on expenditure rigidity), primary balance worsens with climate change. This raises debt and worsens the overall deficit. Over time, the debt-to-GDP ratio can therefore become much higher in the climate scenarios than that in the baseline. Further, even if the debt-to-GDP ratio is stable in the baseline scenario, the ratio can start rising inexorably under climate change.

The Expenditure Rigidity parameter

Users can adjust the expenditure rigidity parameter in the dashboard. As noted above, primary expenditure is assumed to remain unchanged in the face of smaller GDP under climate change. This reflects a value of 1 for the Expenditure Rigidity parameter in the dashboard. This means that the governments take a passive stance and does not adjust its expenditure in light of decreasing revenues. At the other extreme, a value of 0 for the parameter means that government reprioritizes expenditure to maintain the same primary expenditure to GDP ratio as that in the baseline. However, users should know that Q-CRAFT does not accommodate any potential GDP effects of the expenditure cuts. Users can choose any value between 0 and 1 in the dashboard.

Discrete Risks and Natural Disasters

Users can register materialization of discrete fiscal risks or fiscal impact of natural disasters as rises in primary expenditure or losses of revenue. In addition to macroeconomic risks, climate change is likely to heighten fiscal risks including more frequent and severe natural disasters as well as risks to state owned enterprises, sub-national governments and public-private partnerships. Realization of fiscal risks can result in losses of government revenue and/or increases in primary expenditure, and, without adaptation, through their repeating nature result in persistent costs. Q-CRAFT allows users to manually enter, as percentage of GDP in the Discrete Risks-worksheet, fiscal impacts of the materialization of these risks under different climate change scenarios.

The choice of discrete risks to be registered should reflect country-specific factors. Discrete fiscal risks are generally idiosyncratic to countries. For such analysis, a basic practice would be that governments use data from their historical experience —how often did these risks materialize in the past and what were their typical fiscal impacts — and assume that both the likelihood and impact of these risks will increase with successively worse climate change scenario. The more advanced practice would be that the Ministry of Finance work together with weather and climate change experts to develop quantitative expectations about the costs of climate change. Users should note that the inputs for discrete risks only focus on revenues and expenditure and any potential impact on GDP growth is not factored in. Figure 9 provides an illustrative example for a hypothetical country where:

- Historically fiscal risks from a natural disaster materialized once a decade, resulting in a one-off 0.5 percent of GDP rise in primary expenditure in the impact year and a one-off 0.5 percent of GDP loss of revenue in the following year;

- The same pattern is assumed to hold in the Paris scenario (with the first impact year assumed to be 2030);
- The same likelihood of materialization is assumed in the moderate scenario, with the fiscal impacts rising to 0.7 percent of GDP (with 2030 being the first year of impact);
- In the high scenario, risks are assumed to materialize once every five years, with 0.7 percent of GDP fiscal impacts (again, 2030 being the first year of impact);
- In the hot scenario, risks are assumed to materialize once every five years with 1 percent of GDP fiscal impacts; and
- In the hot adapted scenario, risks are still assumed to materialize once every five years, but fiscal impacts are assumed to be 0.8 percent of GDP.

Figure 9. The Discrete Risks Worksheet

Climate scenario	Fiscal effects %GDP	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
Paris	Revenue		-0.5										-0.5										-0.5		
	Primary expenditure	0.5										0.5										0.5			
Moderate	Revenue		-0.7										-0.7										-0.7		
	Primary expenditure	0.7										0.7										0.7			
High	Revenue		-0.7					-0.7					-0.7					-0.7					-0.7		
	Primary expenditure	0.7					0.7					0.7					0.7					0.7			
Hot	Revenue		-1					-1					-1					-1					-1		
	Primary expenditure	1					1					1					1					1			
Hot adapted	Revenue		-0.8					-0.8					-0.8					-0.8					-0.8		
	Primary expenditure	0.8					0.8					0.8					0.8					0.8			

III. Illustrative Example

An illustrative example of an imaginary country is used demonstrate the use of Q-CRAFT. The fictional data used to generate these examples are provided to help understand the mechanics of the tool. Aurelium is an advanced economy with strong institutions and policy settings but is prone to natural disasters which are likely to worsen in severity and magnitude with climate change.

Baseline Scenario

The following assumptions are made in the dashboard to generate the baseline scenario for Aurelium, these assumptions are explained in more detail in subsequent paragraphs:

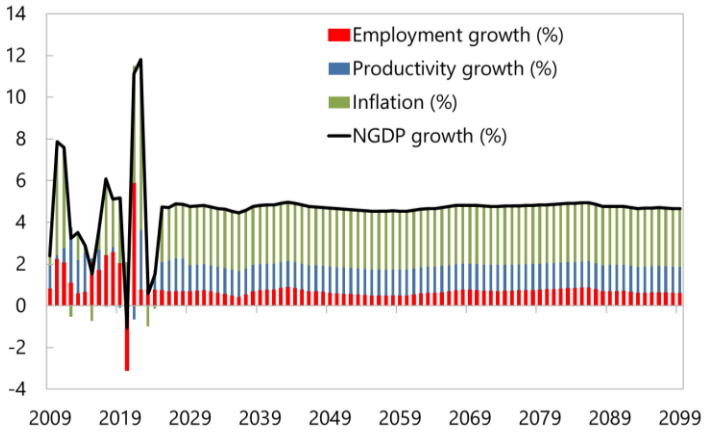
- A high demography scenario;
- A constant productivity growth rate assumption of 1.25 percent a year reflecting historical experience;
- A constant inflation assumption of 2.75 percent reflecting the Central Bank's target;
- An expenditure rigidity of 1;
- A constant nominal interest rate assumption at the end of the WEO horizon; and
- And no fiscal rule.

In the baseline scenario, Aurelium's long-term nominal GDP growth is expected to remain relatively stable at around 4.5 percent a year (Figure 14). The contribution of demography and productivity assumptions to nominal GDP growth are outlined below.

- The 'High' scenario of demographic projections is chosen to generate the baseline, reflecting strong migration intakes and strong fertility rates that are expected to continue. Nonetheless, the working age-share of total population is expected to decline in the third quarter of the century as the population grows older.

- Aurelium is expected to continue having a productivity level slightly higher than the OECD average, as it has in the past.

Figure 14. Nominal GDP Growth in Aurelium



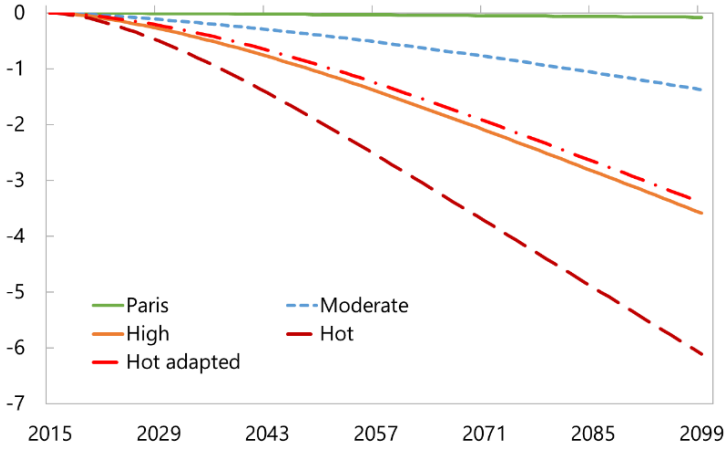
Source: Q-CRAFT (2024)

Aurelium is projected to experience a rise in debt-to-GDP ratio over the long term in the baseline scenario. While the revenue-to-GDP ratio is projected to remain constant, primary expenditure is projected to grow from the mid-century by productivity, inflation, and total population. Primary and overall deficits are projected to widen consequently, with debt rising relative to GDP.

Climate Scenarios

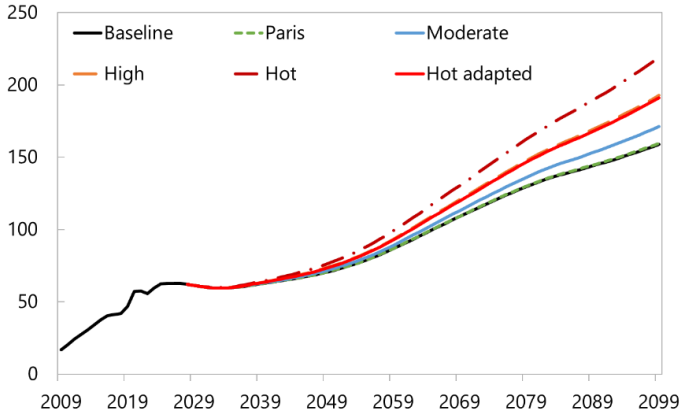
Climate change could impose significant fiscal pressures on Aurelium. In the worst-case scenario in Q-CRAFT, Aurelium might lose nearly 6 percent of GDP relative to the baseline (Figure 15). Nominal GDP level and growth rates decline because of climate change, resulting in lower government revenue which are calculated as percentage of nominal GDP. However, as primary expenditure is assumed to be rigid, the gap between revenue and expenditure grows and primary deficits widen with climate change. By the end of the century, climate change could increase Aurelium's debt by 60 percent of GDP relative to the baseline (Figure 16).

Figure 15. Climate Change Effects on GDP level in Aurelium



Source: Q-CRAFT (2024)

Figure 16. Climate Change Effects on Aurelium's Debt-GDP ratio



Sources: Q-CRAFT (2024)

Explicitly registering possible materializations of discrete fiscal risks will worsen Aurelium's fiscal outlook in different climate change scenarios. Aurelium is already prone to natural disasters, which has historically increased primary expenditures on reconstruction efforts and reduced tax revenue reflecting government support measures. Recognizing that climate change will likely make these natural disasters more frequent and more severe, discrete fiscal risks profiles along the line illustrated in Figure 9 above were registered in the Discrete Risks worksheet. These one-off events add to primary deficits on impact, which raise debt and interest expenditure in the subsequent years and thus leave lasting fiscal footprints.

IV. Detailed Discussion of the Methodology

Q-CRAFT is grounded in macroeconomic and fiscal concepts and identities as well as empirical relationships. A simple production function underpins the macroeconomic projections, and the fiscal projections are generated using the debt-dynamic equation. The effects of climate change on

GDP under different climate scenarios reflect observed empirical relationships between the temperature increases and the economy. These concepts are detailed in this section. Some of the material covered in this section is not in Q-CRAFT, but should inform and guide the analysis and interpretation of scenarios simulated by the tool. Long-term macro-fiscal projections in developing countries present a set of challenges that are further discussed in Box 1.

Box 1. Long-Term Fiscal Sustainability Analysis in Developing Economies

Long-term fiscal sustainability (LTFS) analysis is an important part of a countries fiscal risk toolkit. They are useful for: informing policymaking and tradeoffs involving long term commitments which will compete with other priorities; identifying and quantifying long-term fiscal pressures such as demographics and climate change; informing areas for deeper analysis; and in developing economy context, assessing the realism of authorities' long-term development aspirations.

The IMF considers it a good practice for countries to 'regularly publish multiple scenarios for the sustainability of the main fiscal aggregates and any health and social security funds over at least the next 30 years using a range of macroeconomic assumptions' (*Fiscal Transparency Handbook*, pp. 108-109). Many advanced economies (for example, the United Kingdom and Australia) regularly publish LTFS statements, and some emerging economies (South Africa and Kazakhstan, for example) have recently started to do so. However, similar analyses are still relatively rare among developing economies, partly reflecting methodological challenges.

Long-term macroeconomic and fiscal projections are grounded in assumptions on employment, productivity, and prices. For advanced economies, historical trends in these variables are often a good starting point for projecting a long-term baseline against which alternative fiscal scenarios can be assessed. For emerging economies, convergence to advanced economy over the long-term can be a reasonable baseline assumption.

However, for countries at an earlier stage of development trajectory, convergence to advanced economy may not be a realistic assumption. In these economies, starting with an analysis of recent trends in employment, production and prices at a sectoral level, in conjunction with cross-country comparisons with other similar economies could be more fruitful.

Fiscal scenarios that are relevant for the LTFS analysis in developing economy context maybe different from those in advanced and emerging economies. Population ageing is a key long-term fiscal pressure in advanced and most emerging economies. In contrast, developing economies are at an earlier age of the demographic transition than advanced and emerging economies. Reaping the benefits of this potential demographic dividend will require investment in human capital, with fiscal implications. Facilitating the structural transformation of the economy may also require public expenditure.

Finally, long-term fiscal projections are particularly sensitive to assumptions on interest rates, and cross-country comparisons can be helpful, particularly in economies with less developed capital markets.

Source: IMF staff

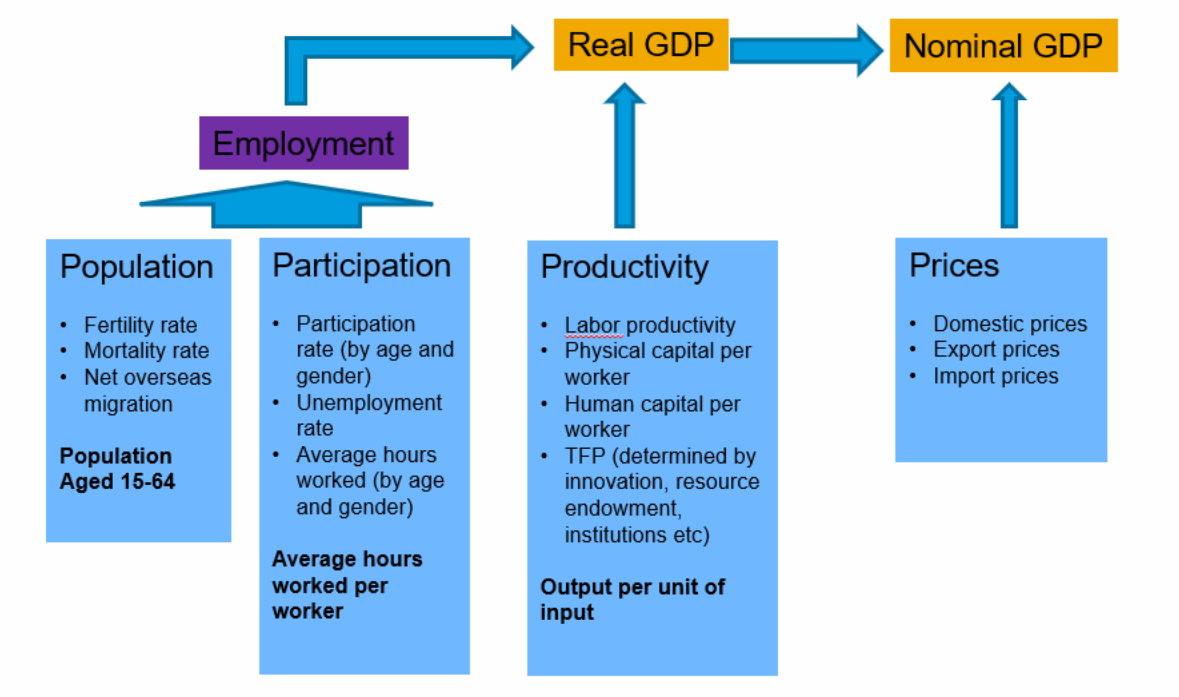
A. THE BASELINE SCENARIO

Nominal GDP breakdown

The nominal GDP projection is derived from the projected growth in employment, productivity, and the GDP deflator. Nominal GDP measures the values of all goods and services produced in the economy in a given period, say a year. Fiscal aggregates such as revenue, expenditure, and debt are usually represented relative to nominal GDP. Nominal GDP can be decomposed into the prices of the goods and services (measured by the GDP deflator, see the section on inflation), and real GDP (which measures the quantity of goods of services produced in the economy). Real GDP, in turn, reflects employment (the number of workers in the economy) and labor productivity (how productive each worker is).

The nominal GDP decomposition can also be expressed formally in a simple production function. Let *N* represent nominal GDP. $N = Y * P$ where *Y* is real GDP and *P* is the GDP deflator. For *Y*, we assume a production function of the form $Y = A * L$, where *L* represents employment and *A* represents all factors that affect labor productivity over time, including land productivity; physical and human capital; innovation and technological progress; sectoral composition of the economy and its resource endowment; and history and institutions. Since $N = Y * P = A * L * P$, growth in nominal GDP (*Y*) is approximately the sum of growth in productivity, employment, and GDP deflator. Figure 19 summarizes the various factors that affect nominal GDP over time.

Figure 19. A Simple Breakdown of Nominal GDP



Demography and employment

Demography plays the key role in driving employment growth in the long run. In the short run, employment growth is influenced by factors such as stage of the business cycle, which includes periods of economic expansion and contraction, and the unemployment rate, where high unemployment rates suggest a weak economy with fewer job opportunities. In the medium term, changes in the labor force participation rate also affect employment, with a higher participation rate increasing the supply of labor. Not less important, in developing countries, the presence of large informal sectors makes it difficult to analyze the labor market. However, the effects of the business cycle and changes in labor force participation on the labor market may lessen over time, leaving the ratio of employment-to-working-age (for which Q-CRAFT uses the age range of 15-64 years old) population stable. Informality is likely to decrease as countries develop, but also here it is likely to not fundamentally change that ratio, with the effect of reduced informality likely to be captured in overall productivity changes. In Q-CRAFT, this trend is assumed to be reached by the end of the medium-term covered in the IMF WEO (2028 currently). Consequently, employment is projected to grow in line with the UN's projections for working age population under three scenarios —medium, high, and low— from 2029 onwards.

Demographic changes will have significant long-term macroeconomic and fiscal effects that, in many countries, will likely play out over the same time as the effects of climate change are felt. Box 2 provides a brief discussion on these demographic issues.

Box 2. Long-Term Macro-Fiscal Effects of Demography

In each of the three demographic scenarios used in Q-CRAFT, the share of the elderly (over 65) in the total population is expected to rise and the growth in working-age population is expected to slow globally over the century. These demographic projections are, therefore, mechanically expected to weigh down global economic growth by slowing down employment growth.

Demographic projections, however, vary considerably across the world, with important country-specific policy implications. Some countries are already experiencing stagnation or a decline in working age population. In other countries, however, the growth in working age population is yet to peak. Neither the demographic drag on economic growth nor the potential demographic dividend are, however, automatic. For example, changes to retirement age or pensions can induce the elderly to remain in the labor market, delaying or lessening the demographic drag on economic growth. Likewise, to reap the potential demographic dividend of rising share of working age people, countries require supportive microeconomic policies as well as investment in human capital.

That is, for developing countries, reaping the potential demographic dividend and achieving strong productivity growth to converge towards the advanced economies will likely have fiscal implications. The fiscal risks emanating from an ageing society would be critical elsewhere. Public finances are likely to worsen with and ageing population, with expenditures on health, aged care, and pensions likely to rise. Ageing of the population may also erode a country's revenue base, while the revenues tend to rise relative to GDP as a country develops.

Source: Amaglobeli, D., and Shi, W. (2016), "How to assess fiscal implications of demographic shifts: a granular approach, IMF.

Productivity

Over time and across countries, differences in GDP per capita and standard of livings tend to reflect differences in productivity. Productivity measures output produced per used input. The broadest measure of productivity, and the one used in Q-CRAFT, is GDP (output) per employed person (input).

Assumptions needed for long-term labor productivity growth projections require detailed country expertise. Unlike demographic projections, there is no long-term off-the-shelf productivity growth projection, requiring country authorities to make their own projections. Specifically, authorities need to assume a realistic end period structural labor productivity growth rate. This is described below.

Historical productivity performance can be used to consider structural productivity growth. Recall that labor productivity is defined as GDP per person employed. The WB publishes historical labor productivity data for the 1991-2021 period for most countries and according to various country groupings. Q-CRAFT automatically calculates average productivity growth using the WB data for: 1991-2022 (the entire period covered in the dataset); 2007-19 (between the cyclical peaks before the Global Financial Crisis and the pandemic); and 2014-19 (five years to the pre-pandemic cyclical peak) for both the reference country as well as number of country groupings that can be used as benchmark.

However, extending recent performance to the end of the century might not be realistic. Economic theory and historical experience in many countries suggest that poorer countries can experience faster productivity growth as they adopt production processes and techniques from more advanced economies, but productivity growth slows down as an economy becomes more developed and relatively 'low hanging fruits' of the so-called catch-up growth are plucked.

Users have to form a judgment about the productivity growth rate the country will converge to by the end of the century. To assist with this 'end period' productivity convergence assumption, Q-CRAFT calculates productivity growth rate over the 1991-2021 period according to World Bank country groupings. For example, a country might be expected to become a middle-income economy by the end of the century, and thus the historical productivity growth rate of middle-income countries might be an appropriate end period assumption.

Productivity level relative to the OECD is an important realism check for productivity growth projections in Q-CRAFT. Given the start and end period productivity growth assumptions, Q-CRAFT calculates a productivity growth path and the implied productivity level relative to the OECD (assuming that OECD productivity continues to grow at the historical average rate of 1.2 percent). While detailed country circumstances will vary, as a general guide, it may not be realistic if the projected productivity growth rates imply a currently developing or emerging economy becoming significantly more productive than the OECD average by the end of the century.

Inflation

Nominal GDP projections are needed for fiscal analysis, as it is the broadest measure of the tax base and a government's ability to carry debt. While real GDP growth projections can be derived from employment and productivity growth projections, inflation projections are needed to derive nominal GDP. Q-CRAFT uses the GDP deflator as this may better reflect the full tax base of a country.[14]

Inflation is assumed to be stable in line with the Central Bank's target in the long run. To derive nominal GDP projections, Q-CRAFT assumes that countries will have stable inflation that is consistent with the Central Bank's target over the long term. The growth in GDP deflator and consumer price inflation can diverge in the near to medium term reflecting terms of trade shocks. Adjustment to external imbalances, for both capital importing and exporting countries, may require exchange rate adjustments, which could affect inflation. However, with the external and monetary sectors exogenous, Q-CRAFT abstracts from these possibilities.

Revenue, primary expenditure, and primary balance

In Q-CRAFT, revenue and primary expenditures, and therefore the primary balance, reflect a passive fiscal policy setting of the government. Long-term projections of these variables, under 'no policy change' assumptions, is useful for assessing the sustainability of a country's fiscal settings. Further, primary balance is a key driver of how debt evolves over time. Q-CRAFT calculates these fiscal indicators under certain assumptions which have been described above and are further explained below.

Revenue is assumed to remain constant relative to nominal GDP in the long run. That is, from the end of the period covered by the WEO, revenue grows by: the assumed inflation; the projected productivity growth; and the projected employment growth (which equals the UN's projection for the growth in the working-age population). Intuitively, nominal GDP can be considered as the broadest tax base for a government, and the constant revenue-to-GDP ratio assumption implies the tax policy setting remains unchanged in the long run.

In the long run, real primary expenditure per capita grows in line with productivity, inflation, and total population. That is, from the end of the period covered by the WEO, primary expenditure grows by: the assumed inflation; the projected productivity growth; and the UN projected growth in *total* population (as opposed to the projected growth in the working-age population, which is used to grow nominal GDP and revenue). The intuition for this assumption is as follows:

[14] Q-CRAFT uses GDP deflator and, for the long run and in the baseline scenario, assumes stable economic conditions and no structural breaks, so that CPI inflation and the GDP deflator converge because inflationary pressures across sectors tend to balance out.

- let nominal primary expenditure G be the basket of goods and services the government provides to its citizens;

- growing G in line with inflation and total population growth reflects a 'no policy change' assumption—that is, in the long run, the government does not alter the real value of G provided to each citizen;

- however, G also benefits from the economy-wide productivity gains, and in Q-CRAFT it is assumed that G grows in line with productivity.

Demographic changes can affect primary expenditure over the long-term. A corollary of the primary expenditure assumption is that in countries where the working age population is projected to grow faster than total population—that is, a country reaping a potential demographic dividend—primary expenditure will be falling relative to GDP over time. Conversely, the ratio of primary expenditure to GDP will be rising where the working age population is projected to grow slower than total population—for example in countries experiencing a demographic drag from ageing.

To isolate the impact of climate change in the analysis, the long-term trajectory of the primary balance reflects the above 'no policy change' assumptions, and thus can be indicative of long-term fiscal sustainability. Particularly, suppose a country is projected to experience widening primary deficits over the long term. This indicates an unsustainable fiscal trajectory. Conversely, suppose a country is projected to experience widening primary surpluses in the long run. This would imply the country never using its fiscal space, which is not credible in the long run.

Q-CRAFT methodology abstracts from financing issues that could affect fiscal policy settings in the long run. Q-CRAFT assumes that a country can avail budget financing in a manner that is consistent with macroeconomic stability. This may well be a strong assumption if the primary deficit widens inexorably in the long run.

Fiscal rule assumptions are used to maintain a stable debt-to-GDP ratio in the baseline. The default fiscal rule assumption is 'none'. If the debt-to-GDP ratio is not credible under this assumption, the 'debt ceiling' assumption should be used. However, the user can use the 'debt ceiling' option to simulate a baseline where debt is stabilized at a certain percent of GDP that is consistent with the country's fiscal framework. This is achieved in the 'debt ceiling' assumption by cutting primary expenditure, with the tool presenting the magnitude of adjustment needs in the baseline scenario. The user should be aware that there is no feedback loop in Q-CRAFT between fiscal consolidation needed to maintain a stable debt-to-GDP ratio and the impact of this fiscal consolidation on GDP growth. The mechanics of these assumptions are as below:

- Suppose the debt ceiling (floor) is reached at time T;

- Q-CRAFT calculates the fiscal gap that would need to be closed to stabilize debt relative to GDP at time T under the debt ceiling assumption (or the fiscal space that is available while keeping debt stable relative to GDP at time T under the debt floor assumption);
- Primary expenditure at time T+1 is reduced (increased) by the fiscal gap (space) thus calculated;
- The process is repeated for the years of the projection horizon.

As the process of fiscal adjustment involves lags, the debt ceiling target is never precisely achieved.

Interest rates

Long-term fiscal projections are highly sensitive to the interest rate assumptions, and there are considerable uncertainties around them. Interest rates in the advanced economies have been declining for the past few decades, and the recent post-pandemic increases notwithstanding, there are grounds for expecting them to remain low into the future.[15] For developing economies, convergence towards the OECD levels of productivity would imply a reduced ability to avail concessional lending, exerting an upward pressure on interest rates. While a more developed economy will have the ability to borrow from the market, there may be significant risk premia on any foreign currency-denominated debt. Somewhat offsetting these factors may be a more developed financial market, which could increase domestic savings and thus lower domestic interest rates. Further, in the long run, the real interest rate tends to track productivity growth, and thus if an economy converges to a slower productivity growth trajectory, its interest rates might decline too.

Assumptions need to be made on the weighted average nominal interest rate. Conceptually, the weighted average nominal interest rate on a country's debt reflects its sovereign debt profile. Calculating it from a granular analysis would require a detailed knowledge of the length, yield, and the currency of each instrument as well as making an assumption on the expected trajectory of the exchange rate. A much simpler approach is taken in Q-CRAFT whereby the user can choose between constant: nominal interest rate; (nominal) interest growth differential; or real interest rate (for more information see section "Interest rate assumptions and the Interest Rate worksheet").

Debt dynamics

The debt-dynamics equation is used to derive the long-term trajectory of the debt-to-GDP ratio. Q-CRAFT uses a basic version of the debt-dynamics equation, this excludes, for example, exchange rates and stock-flow adjustments. The projected primary balance, in conjunction with the WEO projected stock of gross debt and the interest rate assumptions, are used to derive the baseline projection of the debt-to-GDP ratio. Given nominal GDP growth of g, nominal interest rate of i, and

[15] For further details, see: Chapter 2: The Natural Rate of Interest: Drivers and Implications for Policy, IMF WEO, April 2023.

primary balance (as percentage of nominal GDP) of *pb*, the debt-to-GDP ratio (*D*) evolves according to:

$$D_{t+1} = D_t * [(1+ i) / (1+g)] - pb_t$$

This equation is a key concept used in Q-CRAFT, and its intuitions and corollaries are outlined below.

- Assuming all else remains unchanged: a larger primary surplus or a smaller primary deficit leads to a lower debt-to-GDP ratio; a higher initial debt leads to a higher debt-to-GDP ratio; a higher interest rate leads to a higher debt-to-GDP ratio; and a faster GDP growth rate leads to a lower debt-to-GDP ratio.

- The primary balance is the only variable in the equation that a government can control in the near to medium term through fiscal policy.

- The difference between the interest rate paid on government debt and the growth rate of the economy is called the interest rate – growth differential. This is represented by the variables Dt * [(1+ i) / (1+g)] in the equation. This is also called the "automatic debt dynamics," because interest rate i and economic growth g are factors outside the control of the government in the near to medium term.

- For $i > g$, the automatic debt dynamics are "unfavorable" as the economy is growing slower than the costs of borrowing. The higher the difference, the larger the adjustment of the primary balance should be to reduce the debt-to-GDP ratio.

- If $i < g$, the automatic debt dynamics are "favorable" as the economy is growing faster than the costs of borrowing.

Q-CRAFT also calculates debt-stabilizing primary balance at each year to help users assess a country's fiscal settings. If debt is rising over time, then a country will need to reduce its primary deficit (or run a larger primary surplus) to stabilize debt. The difference between the projected primary balance and the debt-stabilizing primary balance in this case will be the fiscal task facing the authorities to stabilize debt. If the debt stabilizing primary deficit (surplus) is larger (smaller) than the projected primary balance, then the country has fiscal space in the sense that it can afford to loosen fiscal policy settings without debt starting to rise.

B. CLIMATE SCENARIOS

Six climate change scenarios in Q-CRAFT

Q-CRAFT focusses on five key climate scenarios[16] for assessing macro-fiscal risks. Global mean temperature is projected to increase between 0.7 and 3.5°C by the end of the century with respect to present levels (Table 1) in these IPCC climate scenarios that cover both uncertainty in future emissions (*scenario uncertainty*), and uncertainty in the response of the climate system (*model uncertainty*).

- Paris: based on the SSP1-2.6 IPCC scenario where international commitments from the 2015 Paris summit are met. This scenario assumes significant cuts in emissions, keeping global temperature increase above its pre-industrial level below 2°C at the end of the century.

- Moderate: based on the SSP2-4.5 IPCC scenario. Emissions continue increasing in line with the current trends and stabilize at the end of the century, with temperature increase similar to the 1960-2014 trend. This scenario assumes that climate mitigation policies continue along the observed trend, but countries do not take more aggressive actions to fulfill their Paris commitments.

- High: based on the high-emissions SSP3-7.0 IPCC scenario. Rather than intensifying climate mitigation efforts, countries start scaling back their implemented policies in a fragmented world with limited energy efficiency improvements and continued use of fossil fuels.

- Hot: emissions are as in the high scenario, but it uses the 90th percentile of temperature increase among all climate models that used SSP3-7.0 emissions, instead of the median of temperature projections.

- Hot adapted: same temperature increases as in the hot scenario, but countries adapt to it more quickly.

- 'Hot Un-Adapted', same temperature increases as in the hot scenario, but countries adapt to it more slowly.

[16] The data for scenarios used in Q-CRAFT comes from the FADCP Climate Dataset and this dataset does not include the SSP5-8.5 scenario as this not included because uses emission scenarios unrealistically high developed for scientific reasons, to study the climate response to extremely high emissions-scenarios. See also: Hausfather and Peters (2020); Pielke and Ritchie (2021); Bellon and Massetti (2022); Massetti and Tagklis (2024).

Table 1. IPCC Global Mean Surface Temperature Change (°C) wrt Present

	2021–2046		2046–2065		2081–2100	
Scenario	**Best Estimate**	**Very Likely range**	**Best Estimate**	**Very Likely range**	**Best Estimate**	**Very Likely range**
Global (land and ocean)						
Paris (SSP1-2.6)	0.4	0.1 to 0.7	0.6	0.2 to 1.1	0.7	0.2 to 1.3
Moderate (SSP2-4.5)	0.4	0.1 to 0.8	0.9	0.5 to 1.4	1.6	1.0 to 2.4
High (SSP3-7.0)	0.4	0.1 to 0.9	1.0	0.6 to 1.5	2.5	1.7 to 3.5
Hot (SSP3-7.0 90th perc.)	0.7		1.5		3.5	

Source: Global temperature change from Arias and others (2021, Cross-Section Box TS.1). Notes: Global Mean Surface Temperature Change (°C) does not include 1.1°C of global warming up to present time. Global temperature increase includes downward corrections of climate scenarios output to account for other empirical evidence.

Macroeconomic effects of climate change in Q-CRAFT

To quantify the effects of climate change on the macroeconomy, Q-CRAFT uses updated estimates of Kahn et al (2021). The authors estimate the long-term macroeconomic effects of climate change using data from 174 countries over the period 1960-2014. According to their estimates, a persistent increase in average global temperature by 0.04 degrees Celsius per year, in the absence of mitigation policies, would reduce world real GDP per capita by 7 to 13 percent by 2100. Box 4 provides further details. The Kahn et al (2021)'s counterfactuals have been updated for 171 countries for the five scenarios described above.

The effect of climate change on real GDP is captured in Q-CRAFT as a slowdown in productivity growth. The econometric estimates of Kahn et al (2021) establish a link between changing climate and GDP per capita, but does not explicitly elaborate on transmission channels through which the former affects the latter. Some possible mechanisms, with varying degrees of relevance in an individual country, are discussed in Section V.

Inflation is assumed to remain unchanged in different climate scenarios, and the decline in labor productivity directly reduces nominal GDP. As noted above, monetary and external sectors are exogenous and are not considered in Q-CRAFT. Climate change could cause spikes in inflation through natural disasters and other supply chain disruptions, but even in the one-off natural disaster sheet this is not endogenized. Further, climate change may also affect a country's external balances, presenting another potential inflation risk.

Box 4. Summary of Kahn et al (2021)

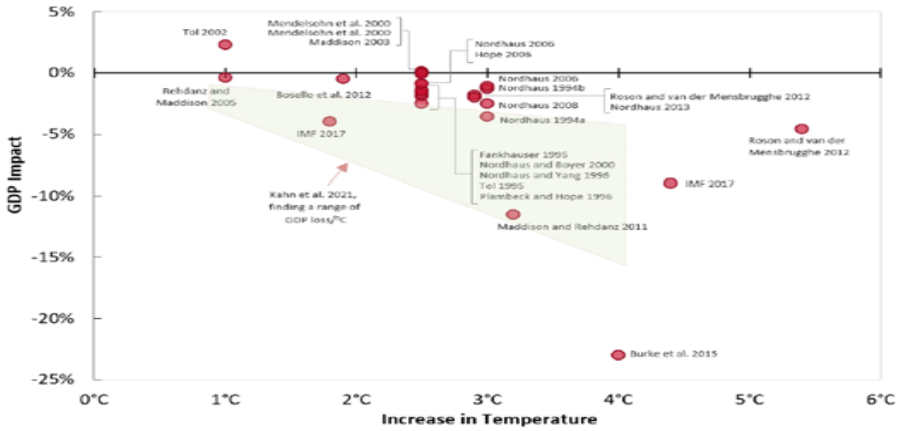
The authors estimate the long-term effects of weather patterns transformed by climate change on economic activity across countries. They begin with a theoretical growth model that links "deviations" of temperature and precipitation (that is, weather) from their long-term moving-average historical norms (that is, climate) to growth in real GDP per capita. This theoretical model is then estimated by using data from 174 countries over 1960-2014. Their econometric technique allows for dynamics, nonlinearity, an implicit model for adaptation to climate change, and accounts for the effects on economic activities of changes in the distribution of weather patterns—that is, both averages and variability of temperature and precipitation. They further explore the efficacy of adaptation by tracking the elasticity of per capita GDP to climate variables over time. The key findings include the following.

- Per-capita real output growth is adversely affected by persistent changes in the temperature above or below its historical norm.
- A persistent increase in average global temperature by 0.04 degrees Celsius per year, in the absence of mitigation policies, reduces world real GDP per capita by around 7 percent by 2100 compared to a baseline in which temperatures increase according to their 1960-2014 trends.
- The estimated losses would increase to 13 percent globally if country-specific variability of climate conditions were to rise commensurate with annual temperature increases of 0.04 degrees Celsius. Climate change alters the frequency, intensity, and patterns of climate variability (El Niño events, Pacific Decadal Oscillation, and the Atlantic Multidecadal Oscillation).
- Abiding by the Paris Agreement goals, thereby limiting the temperature increase to 0.01 degrees Celsius per year, reduces the loss substantially to about 1 percent.
- While adaptation to climate change can reduce these negative long-run growth effects, it is highly unlikely to offset them entirely.

The authors do not estimate country-specific impact of temperature on GDP. Rather, temperature projections vary between countries, leading to different GDP impacts.

Figure A compares the authors' results with other loss estimates from rising temperatures.

Figure A. Estimates of GDP Impact from Increases in Temperature



Source: Kahn M.E., Mohaddes K., Ng R.N.C., Pesaran M.H., Raissi M., and Yang J-C, 2019, *Long-Term Macroeconomic Effects of Climate Change: A Cross-country Analysis*, Energy Economics, 104, pp. 105624/1–13.

Fiscal effects of climate change in Q-CRAFT

As nominal GDP decreases, tax revenues experience a corresponding decline, with the severity of climate change scenarios further exacerbating the reduction in revenue. Under each of the climate change scenarios, revenue is assumed to decline in line with nominal GDP, and thus the revenue-to-GDP ratio remains unchanged from the baseline scenario. The intuition behind this assumption is that in the face of slow-building climate change, governments do not adjust tax policy and the effective tax rate represented by the revenue-to-GDP ratio remains constant.

In contrast, primary expenditure is assumed to be rigid, and held unchanged from the baseline. Again, this assumption reflects unchanged policy settings in the face of slow-building climate change. With the level of primary expenditure remaining same as that of the baseline, but nominal GDP declining, the ratio of primary expenditure to GDP rises in climate change scenarios.

Recognizing the effects of climate change, authorities may wish to recalibrate primary expenditure. This possibility is built into Q-CRAFT through a parameter that allows for different degrees of spending flexibility. That is, it allows the expenditure rigidity assumption to be relaxed. This parameter varies between 0 (fully flexible) and 1 (completely rigid). As primary expenditure becomes more flexible (the parameter approaches 0), real primary expenditure per capita reduces to a point where the primary expenditure to GDP ratio becomes the same as that in the baseline, and primary expenditure in the local currency terms is significantly lower than the baseline.

Declining revenue and unchanged primary expenditure (in the rigid setting) results in worsening primary and overall balance in climate change scenarios. Primary balance deteriorates in both local currency unit terms and relative to GDP. Worsening primary balance has an adverse effect on the debt-to-GDP ratio, which raises interest expenditure and worsens the overall balance.

Q-CRAFT users can manually include additional fiscal costs of climate change risks, for example of the costs of natural disasters, under the different climate change scenarios. Climate change is likely to increase the severity and magnitude of extreme natural disasters, and it is possible that the fiscal implications of these are not fully captured in the econometric estimates underpinning the climate scenarios. In addition, climate change could increase the likelihood of the materialization of discrete fiscal risks such as those associated with power purchasing agreements, public private partnerships, state-owned enterprises, or subnational governments. The simple approach adopted in Q-CRAFT is to assume that these 'fiscal shocks' either raise primary expenditure or lower revenue upon materialization, and they will occur more frequently and with greater magnitude with climate change.

Q-CRAFT results show how climate change can reduce fiscal space for a country, potentially leading to unfavorable or unsustainable fiscal trajectories for severely affected countries. Even if a country's debt-to-GDP ratio is stable in the long run in the baseline scenario, under climate change scenarios, slower economic growth and worsening primary balance can cause debt to spiral

out of control relative to GDP. Further, climate change could make the 'fiscal task' of stabilizing debt significantly more onerous.

Faster adaptation to climate change can ameliorate the long term macroeconomic and fiscal effects of climate change. Implicit in the Kahn et al (2021) empirical framework is an adaption parameter (*m*) that assumes countries will adapt to higher temperatures over the course of 30 years. This parameter can be adjusted, with a lower value reflecting faster adaption, which reduces the macroeconomic impact of persistent increases in temperature on growth. However, the dataset does not have any estimates of climate adaptation spending. From an economic modeling standpoint, the projected spending will not exceed the expenditure levels anticipated in the baseline scenario for any country. This scenario has significant macroeconomic implications, as it may necessitate governments to reallocate funds, increasing spending on adaptation measures while reducing allocations to other areas, such as education. A decrease in education spending could, in turn, diminish productivity, potentially leading to a lower GDP growth rate than initially projected in the baseline scenario. However, it is important to note that these indirect effects, or second-order effects, are not accounted for in the model.

In the 'Hot Adapted' scenario, this parameter is set to 20. That is, countries adapt to higher temperature in 20 years rather than 30. Macroeconomic effects of climate change in the Hot Adapted scenario are less severe than that in the Hot scenario, but are still significant. Further, faster adaptation to climate change is likely to require significant public and private investment. There is yet no econometric empirical analysis linking adaptation investment with macroeconomic and fiscal outcomes that could be applied in Q-CRAFTs framework.

In the 'Hot Un-Adapted' scenario, the m parameter is set to 50. This means that countries adapt to higher temperatures in 50 years rather than 30 years. Macroeconomic effects of climate change in the Hot Un-Adapted scenario are more severe than that in the Hot scenario.

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