INTERNATIONAL MONETARY FUND

Public Debt Dynamics during the Climate Transition

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WP/24/71

2024
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WORKING PAPER

 WP/24/71

IMF Working Paper
Fiscal Affairs Department

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Authorized for distribution by W. Raphael Lam
March 2024

ABSTRACT: Managing the climate transition presents policymakers with a tradeoff between achieving climate goals, fiscal sustainability, and political feasibility, which calls for a fiscal balancing act with the right mix of policies. This paper develops a tractable dynamic general equilibrium model to quantify the fiscal impacts of various climate policy packages aimed at reaching net zero emissions by mid-century. Our simulations show that relying primarily on spending measures to deliver on climate ambitions will be costly, possibly raising debt by 45-50 percent of GDP by 2050. However, a balanced mix of carbon-pricing and spending-based policies can deliver on net zero with a much smaller fiscal cost, limiting the increase in public debt to 10-15 percent of GDP by 2050. Carbon pricing is central not only as an effective tool for emissions reduction but also as a revenue source. Delaying carbon pricing action could increase costs, especially if less effective measures are scaled up to meet climate targets. Technology spillovers can reduce the costs but bottlenecks in green investment could unwind the gains and slow the transition.

RECOMMENDED CITATION: Daniel Garcia-Macia, W. Raphael Lam, and Anh Dinh Minh Nguyen. 2024. "Public Debt Dynamics during the Climate Transition", International Monetary Fund Working Paper No. 2024/71.

JEL Classification Numbers:	E10, H30, H50, H60, Q54
Keywords:	Climate change; mitigation; public debt; carbon pricing; subsidies; public investment; industrial policies; dynamic general equilibrium.
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[1] We are grateful for the comments and discussion from Simon Black, Benjamin Carton, Era Dabla-Norris, Ruud de Mooij, Vitor Gaspar, Florence Jaumotte, Ian Parry, Christine Richmond, Gregor Schwerhoff, and Karlygash Zhunussova, and participants from the IMF Fiscal Monitor workshop and from internal discussions at the IMF's Fiscal Affairs department.

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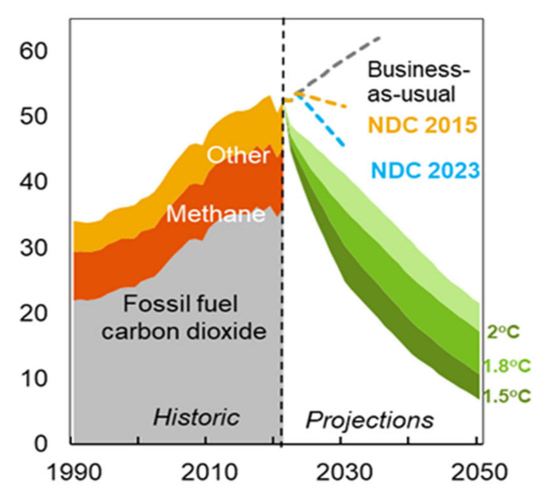
I. Introduction

The year 2023 was the warmest on record. The likelihood of climatic "tipping points" increases with global warming, bringing potentially catastrophic consequences (IPCC 2021; McKay and others 2022; Ditlevsen and Ditlevsen 2023). Countries have recognized the need for urgent action to address global warming. In addition to the 2015 Paris Agreement, countries have also committed to longer-term targets for net-zero emissions—cutting greenhouse gas emissions to as close to zero as possible by about midcentury. Despite progress in many countries, including the largest emitters, large gaps in ambition and implementation remain (Figure 1).[1]

Achieving temperature goals will require a fundamental transformation of production, consumption, and investment by households, firms, and governments over the coming years. Ongoing developments in green sectors could result in new products and processes with lower greenhouse gas emissions (GHG) (Aghion and Howitt 2005; Stern and Valero 2021). But the transition costs could be spread unevenly across people and firms (Mercure and others 2018; Gourinchas, Schwerhoff, and Spilimbergo, 2023). At the same time, adapting to climate change will require public investment in green technologies, adding to other sustainable development goals (SDGs) and putting pressure on many fiscally-constrained developing countries.

Figure 1. Annual Global Greenhouse Gas Emissions, 1990–2050

(Billions of tons of carbon dioxide emissions equivalence)



Sources: Intergovernmental Panel on Climate Change (2022); Black and others (2023).
Note: The figure shows estimates from projection using using the IMF–World Bank Climate Policy Assessment Tool. NDC = nationally determined contributions.

Such transformation necessitates careful management of public finances. On the one hand, governments need to design appropriate fiscal policies to incentivize decarbonization and facilitate the green transition. On the other hand, they need to balance policy tradeoffs and ensure equitable burden sharing of transition costs across households, while safeguarding fiscal sustainability. A key question is how governments can encourage firms and households to decarbonize while respecting government budget constraints. At the same time, many countries—notably low-income countries and small developing states—have multiple competing development needs alongside the imperative to adapt to climate change.

[1] The current largest emitters, including *China, the European Union, India*, and *the United States,* together account for more than 60 percent of global emissions by 2030. The share of emerging market economies is expected to reach almost 70 percent by 2035, signifying their importance for global mitigation efforts. The set of countries classified as the largest emitters and respective share would vary depending on the timeframe.

Therefore, assessing the fiscal implications of policies to achieve climate objectives is crucial. Furthermore, long-standing tradeoffs in tackling climate change are amplified at a time when many countries face elevated debt levels, high inflation, and weak growth prospects following the pandemic and energy crisis. A push for energy security is prompting countries to pursue a faster, but likely bumpy, green transition. Protectionist measures also exacerbate the risks of geopolitical fragmentation and could impede technology diffusion across borders.

Against this backdrop, this paper develops a dynamic general equilibrium model to investigate the fiscal impacts of environmental policy choices during the climate transition. Our main contributions are twofold. First, we quantify the dynamic implications for deficits and public debt of various policy packages to achieve net zero emissions for two country groups—advanced and emerging market economies. Second, we assess the evolving desirable mix of climate instruments from a macro-fiscal perspective.

Specifically, we analyze six scenarios where policies achieve net zero emissions by around midcentury: (i) *Scaled-up sending*: countries primarily scale up spending through, for instance, green subsidies and public investment to reach climate goals; (ii) *Reliance on carbon pricing:* climate policies rely primarily on carbon pricing; (iii) *Balanced policy mix:* a balanced mix of revenue and expenditure measures is adopted, considering both climate targets and public debt sustainability; (iv) *Cost of delaying carbon pricing*; (v) *Technology spillovers*; and (vi) *Investment Bottlenecks*.

We find that heavily relying on spending measures to achieve climate goals will be costly, potentially increasing debt by 45-50 percent of GDP by mid-century. In contrast, a balanced approach combining carbon pricing with spending-based policies can achieve net-zero goals at a significantly lower fiscal cost, limiting the rise in public debt to 10-15 percent of GDP by 2050. In this balanced policy mix, carbon pricing plays an essential role not only as an effective means of reducing emissions but also as a source of revenue. Postponing action on carbon pricing is costly. While technology spillovers can help reduce the costs, investment bottlenecks could hinder the transition and cause debt-to-GDP ratios to rise further.

The paper is structured as follows. Section II discusses our contributions in relation to the literature. Section III presents the main features of model framework and calibration. Section IV illustrates the implications for public finances if countries either a) scale up spending mostly, or b) rely primarily on carbon prices to reach climate goals. Then the paper presents simulations of an appropriate policy mix that reduces fiscal costs and improves macroeconomic outcomes and political feasibility.[2] The section also discusses the implications for debt dynamics under alternative scenarios: delayed climate action, considering technological spillovers, and with bottlenecks in green investment. Sensitivity analyses are provided to illustrate the uncertainty surrounding the estimates. Section V concludes with policy implications from these quantitative results.

[2] Political feasibility could vary over time and across countries. A number of countries have adopted carbon pricing, but with carbon prices on average at low levels and covering relatively limited sectors (see IMF 2023). The adoption of carbon pricing in one country makes it easier for others to adopt it (Linsenmeier, Mohommad, and Schwerhoff 2023). Nevertheless, overcoming political hurdles is still challenging, making it difficult to raise carbon prices significantly or expand coverage to broader economic activity.

II. Related Literature

Our paper aims to build a bridge between two different streams of the literature. First, it contributes to the extensive body of research on modelling fiscal policy using New-Keynesian models. Similar to Traum and Yang (2015), our model incorporates a comprehensive set of fiscal instruments, both on revenue and expenditure sides, as well as the evolution of public debt. The model also differentiates two types of households: savers and non-savers (also known as liquidity-constrained households), which allows to model of targeted transfers to the latter group. Additionally, we follow Mian, Straub, and Sufi (2022) to model the feedback effect of public debt on interest rate, particularly relevant for countries where the borrowing cost is sensitive to debt dynamics.

Second, our paper is closely related to the climate-macro literature, particularly studies using dynamic general-equilibrium models to examine the effects of environmental policies. For instance, Fischer and Springborn (2011) and Heutel (2012) explore the interaction between environmental policy and economic responses to productivity shocks in a real business cycle model with a pollution externality. Annicchiarico and Di Dio (2014) investigate the conditioning role of different environmental policy regimes on the response to nominal and real shocks in a New Keynesian model. Barrage (2019) quantifies optimal carbon taxes in a dynamic general equilibrium climate-economy model with distortionary fiscal policy. Ferrari and Landi (2020) study the effects of green quantitative easing in a DSGE model that distinguishes between two production sectors (similar to with Acemoglu and others (2012, 2016)): a polluting brown sector and a non-polluting green sector. Barrett (2021) argues that the most effective policy package in emissions-reducing regions is a research subsidy funded by a carbon tax. Our paper distinguishes itself from these studies by analyzing the implications of climate policies on public debt dynamics using a dynamic general equilibrium model equipped with a rich set of fiscal instruments.

Our modelling setup differs from other climate models such as the IMF-WB Climate Policy Assessment Tools and computable general equilibrium (CGE) models by accounting for intertemporal behavioral responses to expected changes in climate policies. These are important for examining the decisions on consumption and investment, as well as the implications for public debt dynamics. Price rigidities are necessary to generate realistic transition dynamics from short term to long term. However, our model focuses on a closed economy and so is not equipped to analyze cross-border issues such as carbon-border adjustments or international spillovers of climate policies, which can be captured in large-scale models such as GMMET (Carton and others, 2023). Despite this limitation, our model's computational tractability allows us to retain potential nonlinear dynamics, which can be challenging in solving multi-country models.

III. Model Framework and Calibration

We develop a model that integrates the standard New Keynesian dynamic general equilibrium model equipped with a rich set of fiscal policies as in Traum and Yang (2015) with a climate module, featuring green energy and brown energy in production, as motivated by Acemoglu and others

(2012, 2016). Our analysis assumes perfect foresight, and solves the transition dynamics nonlinearly, which matters given the large magnitudes of potential changes in the energy sector.

The model inherits standard features of the two-agent New Keynesian model with a fiscal block, similar to Traum and Yang (2015):

1. There are two types of households: savers and non-savers. The non-savers do not have access to financial or capital markets and consume all of their income (wages and transfers) each period. The forward-looking savers have access to complete asset and capital market.
2. The final good's price is subject to nominal rigidity (à la quadratic adjustment costs). Also, investment is subject to adjustment costs.
3. The large set of fiscal instruments includes a consumption tax, labor and capital income taxes, government expenditure, and transfers. Debt is stabilized by changes in lump-sum tax on savers.
4. Monetary policy follows a Taylor rule responding to inflation gap and output gap.

Given the purpose of the exercise, we integrate two features into this standard setting. First, energy is used in the production of final goods and generated from both green and brown sources. Each energy source employs specific private capital and labor, as well as public capital in the case of green energy (for example, electricity grids) and private investment subject to adjustment costs. Second, fiscal policy tools are extended to include carbon pricing, green subsidies, public investment, and targeted transfers.

The following equations focus mainly on the additional climate and technology features of the model relative to Traum and Yang (2015). Final goods are produced combining intermediate energy y_t^E and non-energy inputs y_t^F with a Constant Elasticity of Substitution (CES) function with elasticity η_f and energy share ς_f:

$$y_t = \left((1 - \varsigma)^{1/\eta_f}(y_t^F)^{(\eta_f - 1)/\eta_f} + \varsigma^{1/\eta_f}(y_t^E)^{(\eta_f - 1)/\eta_f}\right)^{\eta_f/(\eta_f - 1)}.$$

The non-energy input y_t^F is produced by using generic capital and labor inputs in a standard Cobb-Douglas production function. Energy itself is also produced with a CES bundle of green and brown sources of energy, with elasticity η and brown energy share ω:[3]

$$y_t^E = \left((1 - \omega)^{1/\eta}(y_t^G)^{(\eta - 1)/\eta} + \omega^{1/\eta}(y_t^B)^{(\eta - 1)/\eta}\right)^{\eta/(\eta - 1)}.$$

Carbon emissions are directly proportional to the brown energy output, with unit elasticity. Each energy source $i = \{G, B\}$ employs private capital k^i and labor h^i, with productivity A^i, as well as public capital k^{Gi} in the case of green energy (for example, electricity grids). The production function for green energy source G is thus:

$$y_t^G = A_t^G \left(\left((1 - w_G)^{1/\eta_G}(k_{t-1}^G)^{(\eta_G - 1)/\eta_G} + w_G^{1/\eta_G}(k_{t-1}^{GG})^{(\eta_G - 1)/\eta_G}\right)^{\eta_G/(\eta_G - 1)}\right)^{1 - \alpha_G} (h_t^G)^{\alpha_G},$$

[3] Carton and others (2023) feature a granular modelling of electricity generation, transportation, and fossil fuel mining, therefore increasing the likelihood of capturing the actual obstacles of the energy transition. This could be a potential extension for our model.

where the share of public capital is set to zero for brown energy—a simplifying assumption that does not affect key results.

In addition, productivity in each energy source benefits from learning-by-doing externalities. It grows in proportion to the existing capital stock:

$$\log\left(A_t^i\right) = \alpha^i \log\left({k_{t-1}^i}/{k_{SS}^i} \right) + \epsilon_t^i,$$

where k_{SS}^i indicates the steady-state capital level and ϵ_t^i is an exogenous trend.

Private investment is subject to adjustment costs, capturing potential bottlenecks for green investment, such as scarcity or supply disruptions of critical minerals, including from rising geopolitical fragmentation, and/or bottlenecks in divesting stranded brown assets. Adjustment costs grow quadratically in proportion to the deviation of the investment ratio in each capital stock i_t^j / k_{t-1}^j from the depreciation rate, thus imposing a cost on both sharp capital accumulation and divestment. The capital accumulation function for each capital stock j (private green, private brown, public green, or generic) is:

$$k_t^j(1 + g)(1 + n) = (1 - \delta)k_{t-1}^j + i_t^j - \frac{\gamma_j}{2}\left(\frac{i_t^j}{k_{t-1}^j} - \delta\right)^2 k_{t-1}^j,$$

where g is the balanced-growth-path in output per capita, n is the population growth, δ is the depreciation rate, and γ_i is the adjustment cost parameter.

Sovereign interest rates are increasing in the debt-to-GDP ratio to capture the downward-sloping demand for safe assets, which is particularly relevant for countries with less fiscal space. Specifically, the functional form follows Mian, Straub, and Sufi (2022), with the convenience yield of holding government debt equal to:

$$\widehat{CY}_t = -\varphi \frac{b_t - \bar{b}}{\bar{b}}.$$

where $\widehat{CY}_t$ is the convenience yield in deviation from the steady state, φ is the debt elasticity, and b_t is the level of debt ($\bar{b}$ in the steady state). Higher government debt increases interest rates as liquidity and safety premiums on government debt diminish (Krishnamurthy and Vissing-Jorgensen 2012).

Data and Calibration

The simulations compare a "business-as-usual" baseline based on current policies with policy scenarios that reduce emissions by 80 percent by 2050 in advanced economies and by 2060 in emerging market economies. The baseline paths for output, population, and government debt are based on IMF World Economic Outlook database projections, long-term projections by the Organisation for Economic Co-operation and Development, and the UN population projection, while the emissions path and initial carbon prices are consistent with analyses using the Climate Policy Assessment Tool and initial energy shares from the US Energy Information Administration and

Table 1. Calibration of Model Parameters

Parameters	Symbol	Value	Sources
Energy-related Parameters			
Elasticity of energy in final goods production	η_f	0.21	Labandeira, Labeaga, and López-Otero (2017)
Elasticity between green and brown energy	η	3.5	Acemoglu and others (2012)
Elasticity between private green capital and public green capital	η_G	0.9	See text for discussion
Share of energy in final goods production	ς_f	0.07	Känzig (2023)
Share of brown source in energy production	ω	0.8 (AE)/0.9 (EM)	IEA's World Energy Balances, also see text for discussion
Share of public green capital in the green capital	w_G	0.16	Based on Traum and Yang (2015)
Macroeconomic Parameters			
Discount factor	β	0.99	Standard value
Intertemporal elasticity of substitution	σ	1	Standard value
Depreciation rate	δ	0.025	Standard value
Inverse Frisch elasticity		2	Standard value
Share of labor in green, brown, and non-energy production	α_i	0.68	Standard value
Debt elasticity	φ	0 (AE)/0.003 (EM)	See text for discussion
Price elasticity	ϵ_p	10	Standard value
Capital adjustment cost	γ_i	4	Standard value, also see text for further discussion
Price adjustment cost	κ	52.9	Match the average frequency of price changes (every three quarters)
Consumption tax rate	τ^c	12 percent	Standard value
Labor income tax rate	τ^w	20 percent	Standard value
Capital income tax rate	τ^k	20 percent	Standard value
Lump-sum tax: Response to debt-to-GDP ratio	ϕ_B	0.01	Gomes, Jacquinot, and Pisani (2012), see text for discussion
Taylor rule: smoothing	ρ	0.5	Standard value
Taylor rule: response to inflation	γ_π	2	Standard value
Taylor rule: response to output gap	γ_y	0.125	Standard value
Inflation target	$\bar{\pi}$	2 percent (AE)/4 percent (EM)	Standard value

Source: Authors' compilations.

Note: Standard values are based on Smets and Wouters (2007), Christiano, Eichenbaum, and Evans (2005), Gomes, Jacquinot, and Pisani (2012), and Traum and Yang (2015). AE = advanced economies; EM = emerging market economies; IEA = International Energy Agency.

International Energy Agency. The model is calibrated to a representative advanced economy based on the *Group of Seven* and a representative emerging market is an average of countries including *Argentina, Brazil, China, India, Indonesia, Mexico, South Africa,* and *Türkiye*. The initial carbon price is set to $40 for a representative advanced economy and $5 for a representative emerging market.

Key parameters of the model are in line with the literature (Table 1). The share of public capital (w_G) in green capital is set to 0.16, matching generic public capital in Traum and Yang (2015). The elasticity between private green capital and public green capital is set to 0.9, close to but slightly smaller than the unit elasticity used in the case of generic public investment, reflecting the specific need of public investment in green production. The share of liquidity constraints households is 30 percent in advanced economies (Kaplan, Violante, and Weidner 2014; Kumhof and others 2010; Gomes, Jacquinot, and Pisani 2010) and 50 percent in emerging market economies (Kumhof and others 2010).

The capital adjustment cost is set to the standard value of 4. At the steady state, the adjustment cost is always zero regardless of the adjustment cost parameter. In the preferred net zero emission package of advanced economies, the ex post annual cost on output is very small, about 0.03 percent of GDP to 2050 on average (or 0.8 percent in total between 2023–50).

The debt elasticity of the convenience yield (φ) is set to zero for the advanced economies, while representative emerging market economies are calibrated so that the equilibrium interest rate increases by 20 basis points when government debt increases by 10 percent (Mian, Straub, and Sufi 2022).[4]

IV. Results

The paper presents simulation results across different scenarios for a representative advanced economy and a representative large emerging market economy as noted above. We first examine the impact on public finances if countries scale up spending to reach climate goals without ambitious carbon pricing measures (Scenario 1). Then, the second scenario considers the impact on public finances and the macroeconomy if the primary instrument to reach net zero emissions by midcentury is a large and rapid increase in carbon prices (Scenario 2). Third, the paper considers a mix of climate instruments including both revenue and spending measures to reach the net zero goal (Scenario 3). The fourth scenario studies the cost of delayed carbon pricing (Scenario 4). The last two scenarios consider the role of technology spillovers and investment bottlenecks (Scenarios 5 and 6).

A. Scenario 1: Scaling up spending to meet climate goals.

Countries have pursued different policy mixes to curb emissions. While an increasing number of countries have put an explicit carbon price on greenhouse gas emissions, which is the most effective and efficient policy instrument in responding to the pollution externality, those prices are low on

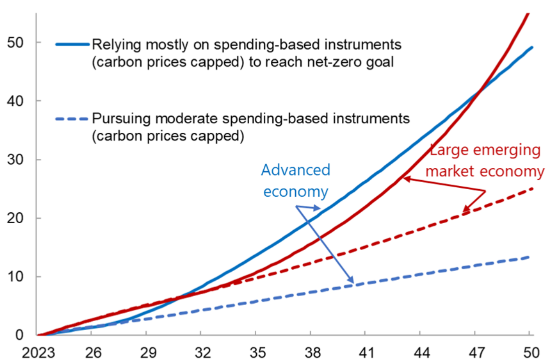
[4] In addition, to focus on the impact of climate policy on debt, the debt stabilization channel is suspended in the model until 2050 (for advanced economies) and 2060 (for emerging market economies), and henceforth a lump-sum tax is set to gradually increase in response to debt to GDP to ensure the government’s intertemporal budget constraint is met.

average (at $20 a ton) and cover only one-quarter of global emissions (Black et al., 2022a). Instead, several large economies have instead relied on less-optimal spending-based measures, such as green public investment and subsidies (or tax expenditures) in their decarbonization strategies. For example, the Inflation Reduction Act of 2022 represents the largest federal green policy to date in the *United States* (costing nearly $400 billion over 10 years) and envisages investment in clean energy and electric vehicles (Bistline, Mehrotra, and Wolfram 2023).

Our simulation first considers a policy package that combines spending on mitigation that scale up public investment and subsidies (an additional of 2 percent of GDP per year on average) to reach the net zero emission goal by midcentury, while reaching a modest carbon price of $75 a ton by 2030 for a representative advanced economy, maintained at that level until 2050. In response to these government incentivizing policies, private sector investment increases and therefore accounts for a large share of the total green investment needed for decarbonization.

Figure 3 presents two simulations of spending policies: a substantial scaling up of green investment and subsidies to reach the net-zero goal (solid blue line), and a moderate increase in such spending to contain the rise in debt (dashed blue line). The former simulation entails a much larger fiscal cost, a significant rise in the debt-to-GDP ratio (by 45 percentage points by 2050), and an associated pickup in government borrowing costs. Rising debt levels of the magnitude projected in the scenario are likely unsustainable. The analysis shows that relying largely on expenditure measures to achieve net-zero emissions by midcentury would raise public debt-to-GDP ratios sharply and put debt sustainability at risk. Our results are consistent with literature findings that expenditure policies are not always cost-effective, although they could contribute toward reducing emissions. For example, the carbon price equivalent for sectoral policies varies significantly, implying that countries could have achieved the same mitigation goal at lower cost (Black et al., 2022b).

Figure 3. Illustrative Debt Dynamics When Expenditure-Based Climate Policies Are Expanded
(Percent of GDP)



Source: Authors' simulations.
Note: Figure shows cumulative change relative to a "business-as-usual" scenario, based on simulations from a dynamic general equilibrium model (see Online Annex 1.2 for details). The lines for the advanced economy (large emerging market economy) cap the carbon price at $75 ($45) a ton. The solid lines scale up green public investment and subsidies (at 2 percent of GDP a year on average) to meet the net-zero-emissions target by 2050 (2060 for the emerging market economy), while the dashed lines have the same profile on carbon prices and a moderate rise in investment and subsidies, in line with International Energy Agency estimates.

In the case of a more moderate increase in expenditures (an additional ½ percent of GDP per year on average for advanced economies), however, emissions would only fall by about 40 percent by 2050 relative to current levels, far from the net-zero target (dashed lines).

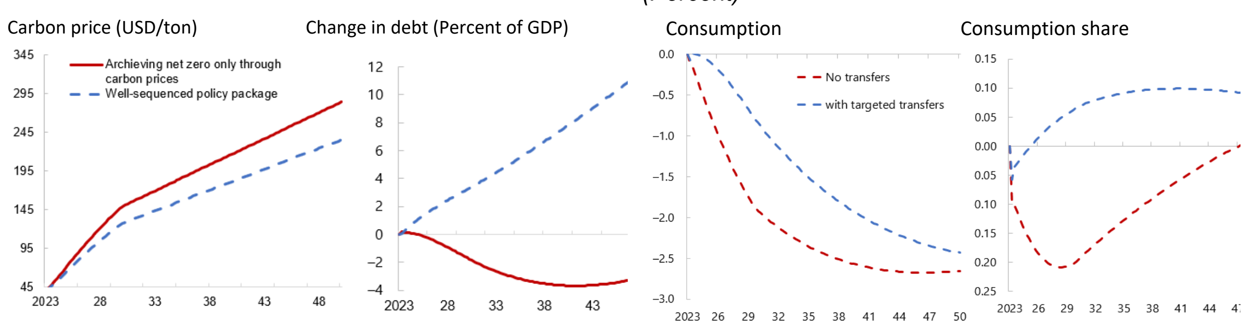
For emerging market and developing countries, the green transition would likely entail additional fiscal costs, especially if they rely on expenditure measures. A comparable simulation for a representative large emerging market economy considers a cap on carbon prices at $45 a ton during 2030–50, together with a substantial increase in green investment and subsidies to reach net-zero goals by 2060. Results of the simulation show that such a package would lead to an unsustainable surge in the debt-to-GDP ratio of more than 50 percentage points by 2050 (solid red line in Figure 3), with an associated sharp rise in borrowing costs. In the scenario with a more moderate increase in spending, emissions will only fall by 10 percent from current levels and will not be sufficient to achieve the net-zero target (dashed red).

B. Scenario 2: Relying primarily on carbon pricing.

To benchmark the model against the literature, a scenario achieving net zero emissions with carbon pricing as the only climate policy is presented for the advanced economy (Figure 4). The scenario shows that this would require raising carbon prices to $150 per ton by 2030 and $280 per ton by 2050 (panel 1). The increase in carbon pricing would generate revenue and reduce deficits, which reduces the real interest rate and the debt ratio, but such high level of carbon prices is likely to be politically unpalatable in many countries (Metcalf 2023; Känzig 2023). Although carbon pricing is an effective tool to reduce emissions and generate revenues, such high levels could lower output and lead to uneven transition costs among households (panel 2), with some facing a disproportionate decline in consumption, calling for targeted transfers to mitigate the adverse impact.

Figure 4. Illustrative Debt Impact when Climate Policy Packages Involve Only Carbon Pricing: Advanced Economy

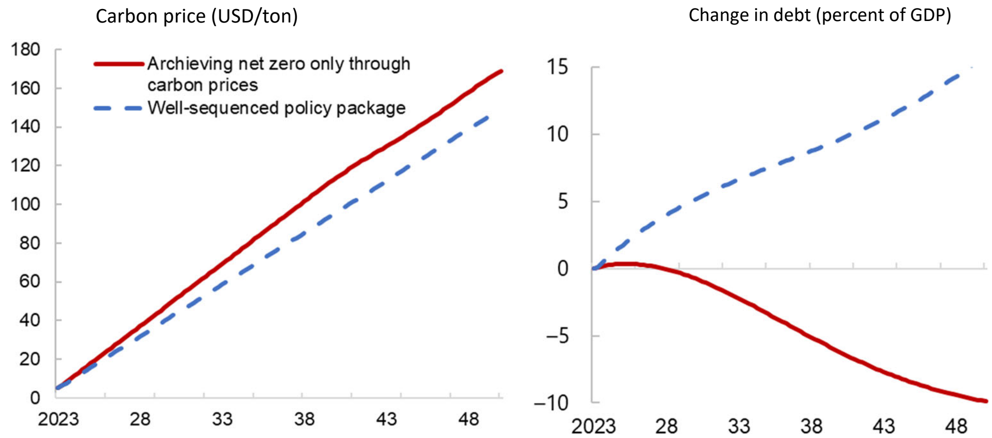
1. Public Debt Implications *2. Consumption of Liquidity Constrained Households (Percent)*



Source: Authors' simulations.
Note: Simulations based on a representative large advanced economy with carbon pricing as the only climate instrument to reach net zero target.

For a representative large emerging market economy, a similar scenario is conducted to use primarily carbon pricing to achieve net zero emissions. The scenario assumes no green subsidies and modest public investment for mitigation at ¼ percent of GDP per year. In this case, carbon prices would need to raise to $165 per ton by 2050 (Figure 5, red line). The increase in carbon pricing would generate revenue and lead to a small primary surplus of 0.4 percent of GDP, which reduces debt ratio, but at the expense of smaller output and an uneven decline in consumption across households.

Figure 5. Illustrative Debt Impact when Climate Policy Packages Involve Primarily Carbon Pricing: Emerging Market Economy



Source: Authors' simulations.
Note: Simulation based on a representative large emerging market economy with primarily carbon pricing as the only climate instrument to reach net zero target.

C. Scenario 3: Combination of Well-Sequenced Policy Instruments.

The scenario considers a mix of policy instruments in a well-sequenced package to achieve net-zero emissions by midcentury. The package combines revenue and expenditure measures, including carbon pricing (to reduce emissions efficiently and generate fiscal revenues), green public investment (to complement green private capital), green subsidies (to encourage innovation and deployment of clean energy), and targeted transfers (to mitigate adverse impacts on households during the green transition). These policies help incentivize the private sector to scale up their investment for decarbonization. The analysis operationalizes the net-zero-emissions target as an 80 percent reduction in 2023 emission levels by 2050 for advanced economies and by 2060 for emerging market economies, with the assumption that carbon capture and storage will offset the remaining emissions (Black et al., 2022a; IMF 2021).

The effects of the policy package also depend on how fiscal instruments affect growth and interest rates. For instance, carbon pricing will increase government revenues but reduce near-term output. Expenditure measures will support output in the short term, while higher public capital will add to the economies' productive capacity, boosting long-term output. However, higher expenditures raise budget deficits and add to the pressures on interest rates and government borrowing costs by raising the demand for capital (macroeconomic channel) and increasing the supply of government debt (fiscal channel). The balance between carbon-pricing and expenditure measures in the overall package, as well as the endogenous effects on output and interest rates, determine the debt dynamics between today and 2050. In the simulations, the effect of inflation on debt dynamics is captured in the real interest rate contribution. The policy package has a moderate inflationary impact during the transition, as higher carbon pricing tends to increase production costs, while the expansion of green energy production reduces the price of green energy.

Advanced Economies

In a representative *advanced economy*, annual green public investment is assumed to increase permanently by 0.4 percent of GDP (with a frontloaded trajectory) compared to the business-as-usual baseline. This assumption aligns with the estimates from the International Energy Agency (IEA 2021), the assumption of the *United Kingdom*'s Office for Budget Responsibility (2021), and European Commission (2020). For example, the European Commission (2020) estimates an annual total investment need of 1.6–2.3 percent of GDP. Given the share of public investment is around 20–25 percent of the total, the public investment needs are about 0.4 percent of GDP. The annual green subsidy is 0.2 percent of GDP higher relative to the baseline scenario until 2030, and then gradually fades away. This calibration falls within the range of the estimate in the Inflation Reduction Act of the *United States* (a total of $270 billion of tax credit, or 1 percent of GDP in total, until 2031). Fiscal transfers to protect vulnerable households are assumed to be equivalent to 30 percent of carbon revenue (Känzig 2023). The initial carbon price is set to $40. The emission trajectory aims to achieve a decline of 40–50 percent by 2030 and 80 percent by 2050 relative to 2023 (IMF 2021; Black et al., 2022a).

This policy package would require an ambitious increase in carbon pricing from the current levels—reaching $130 per metric ton by 2030 and $235 per metric ton by 2050, respectively in line with the net zero emission scenario in IEA (2021) estimates—but smaller than the $280 per metric ton by 2050 needed if carbon pricing was the only instrument.

Revenues from higher carbon prices are projected to peak around 2030 because the gradual decarbonization of the economy would reduce the tax base of carbon and other fuel taxes, unless taxes are shifted to other bases (such as vehicle mileage, instead of fossil fuel use) (Figure 6.3). Hence, despite increasing carbon prices, carbon revenues as a share of GDP decline during 2030–50.

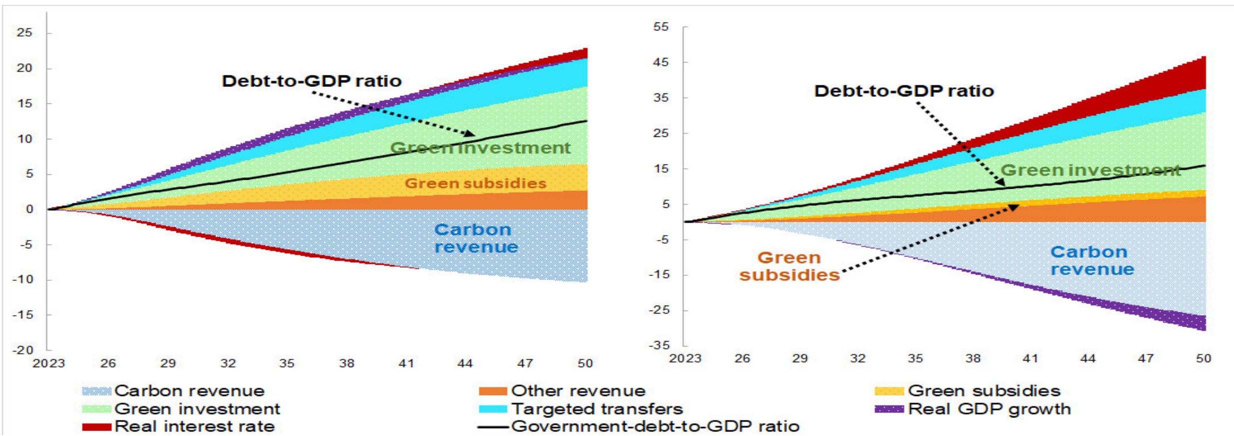
The policy package incentivizes private sector investment in green energy production, doubling the green private capital stock relative to the business-as-usual scenario. This is partly owing to the crowd-in effects from the complementary role of public capital. The endogenous green investment by the private sector accounts for the majority of total green investment in the decarbonization efforts. The simulations for both advanced and emerging market economies assume no earmarking of carbon revenues to specific spending, to distinguish the macro-fiscal effects of climate policies from other fiscal policies, except for a transfer (30 percent of carbon revenues) targeted to hand-to-mouth households.

Figure 6. Implications of Net-Zero Policy Packages on Debt and Primary Balance, Relative to "Business-as-Usual" Baseline, by Fiscal Component

(Percent of GDP)

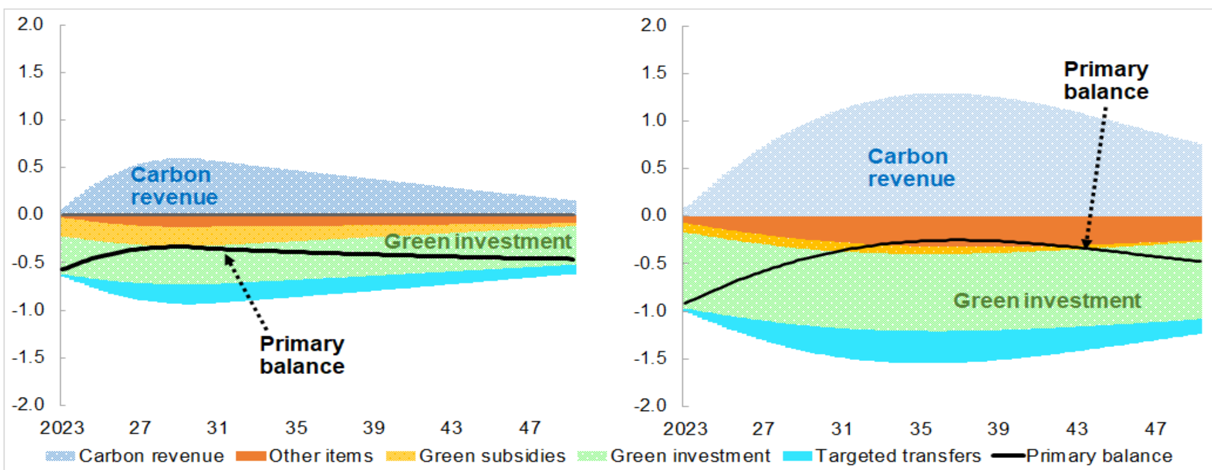
Cumulative Change in Government Debt

1. Advanced Economy
2. Emerging Market Economy



Change in Primary Balance

3. Advanced Economy
4. Emerging Market Economy



Source: Authors' simulations.

Note: For advanced economies, parameters and fiscal instruments are calibrated to a representative large advanced economy (that represents the average of data for Group of Seven economies). The policy package is designed to achieve net-zero emissions in 2050. The value for public investment is consistent with the upper range of estimates by the International Energy Agency (2022). Green subsidies are assumed to be front loaded and phased out after 2030, and targeted transfers are assumed to be proportional (at 30 percent) to carbon revenues. Given later emission peaks in emerging market economies, the policy package for those economies is designed to achieve net-zero emissions by 2060. "Other revenue" includes taxes from capital, labor, and consumption, which vary owing to endogenous effects from macroeconomic variables even though tax rates are held the same. Parameters and fiscal instruments are calibrated to a representative emerging market economy that is assumed to reflect the weighted average of data for Argentina, Brazil, China, India, Indonesia, Mexico, South Africa, and Türkiye. The value for public investment is consistent with the upper range of International Energy Agency estimates for emerging market economies. Green subsidies are assumed to be front-loaded and phased out after 2030, and targeted transfers are assumed to be proportional (at 30 percent) to carbon revenues.

The simulation shows that, on balance, the debt-to-GDP ratio in this representative advanced economy increases by 10–15 percentage points by 2050, with the primary deficit rising moderately, by 0.4 percent of GDP a year, relative to the "business-as-usual" baseline in this scenario (Figure 6, panels 1 and 3). Interest rate effects would be relatively muted and lower demand for capital in brown sectors would partly offset the higher demand for capital in the green sector. Some advanced economies may have fiscal space to pursue such a combination of fiscal policies to meet the net-zero emissions goal while maintaining debt sustainability. Countries can also raise revenues from other taxes or reduce other spending to contain the rise in debt.

Emerging Market and Developing Economies

A similar simulation is conducted for a representative large emerging market economy, but with several differences compared to the representative advanced economy. First, most emerging markets currently have a lower share of green energy than advanced economies and will have a lower carbon price during the initial phase of decarbonization—assumed in the simulation to reach $45 a ton by 2030, gradually rising to $150 a ton by 2050. Yet this lower carbon price yields greater carbon revenue than the case in an advanced economy for a longer period and leads to a later peak in emissions and carbon revenue (Figure 6 panels 2 and 4). Second, green investment needs in emerging market economies are larger (at ¾ percent of GDP per year), owing to different ownership structures and less private investment in mitigation, consistent with International Energy Agency (2022) estimates. The increase in the green subsidy in emerging market economies is half the value in advanced economies, due to limited innovation capacity. Third, emerging market economies also face a higher risk premium—that is, greater sensitivity of borrowing costs to rising debt levels. Transfers to vulnerable households are assumed to be 30 percent of carbon revenue, the same as the scenario for advanced economies.

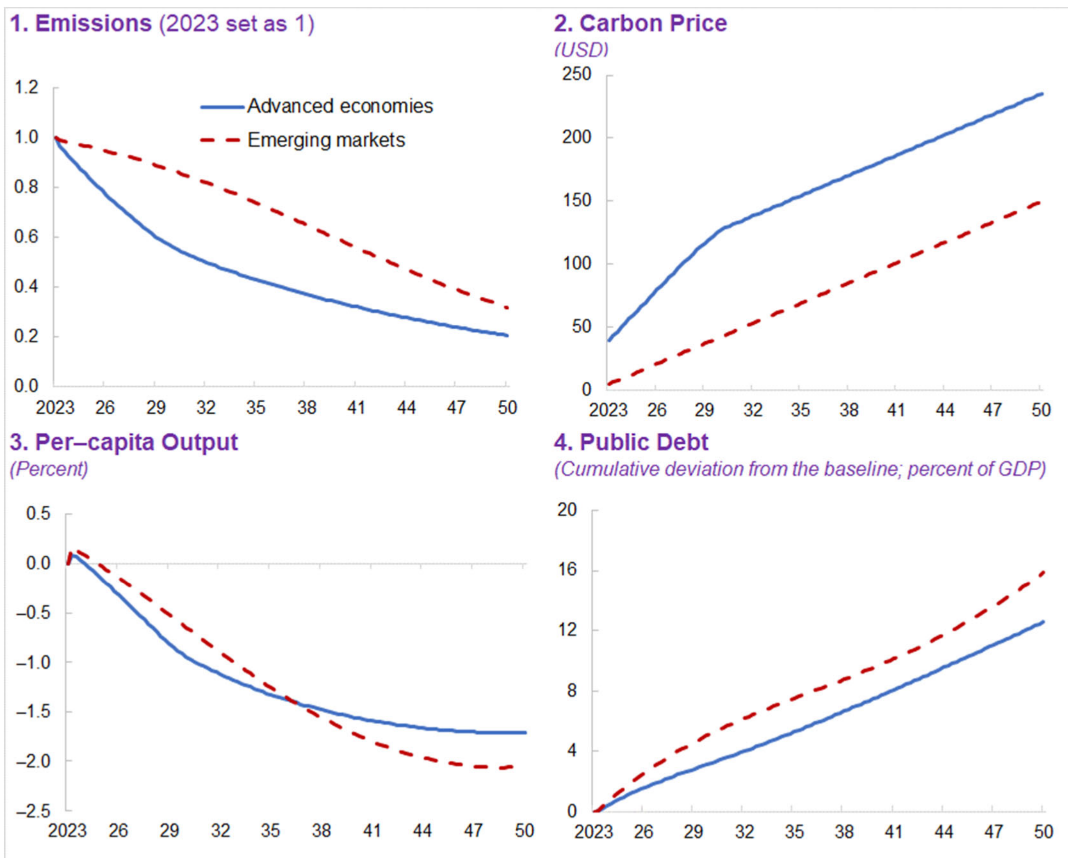
As shown in Figure 7, emission reduction efforts in emerging markets are backloaded, achieving net zero emissions by 2060, to reflect their need to prioritize development. As in the advanced economies, the policy package encourages private green investment, tripling the green private capital stock by 2050.

Incorporating these distinctive features and specific assumptions, the model simulation of this illustrative scenario suggests that public debt would increase by about 15 percent of GDP by 2050 in these economies relative to the business-as-usual baseline, equivalent to a rise in primary deficits by 0.4 percentage points a year on average (Figure 6, panel 4). The simulated rise in debt is subject to a wide range of 8–25 percent of GDP by 2050, depending on public investment, subsidies, and targeted transfers, as well as whether countries are fossil-fuel producers as will be shown below. While the increase in debt-to-GDP ratio is comparable to advanced economies, the composition is different, with larger contributions from interest costs and higher public investment needs, while carbon revenues are higher.

Many emerging market economies would find the increases in debt and deficits challenging, especially those already experiencing high debt, as rising borrowing costs lead to higher interest payments and account for a sizable part of the deteriorating debt dynamics. As a result, they would be unable to afford a large redistribution of carbon revenues or meet their public investment needs. These call for improving spending efficiency and mobilizing alternative sources of finance, including other domestic tax revenues (Benitez and others 2023), and a greater role for private financing. A well-calibrated fiscal strategy could crowd-in private investment and financing to jumpstart growth, critical for emerging markets with limited fiscal space. The precise mix of measures would vary across countries accounting for their macroeconomic conditions and political feasibility. Low-income developing countries should prioritize reducing energy intensity and adapting to climate change, given limited access to financing and modest contributions to global emissions. Reconciling climate challenges with growth and development needs in emerging market and developing economies therefore calls for efforts to mobilize domestic revenues.

Figure 7. Policy Package Combining Different Fiscal Instruments

(Cumulative impact relative to the business-as-usual baseline)



Source: Authors' simulations.
Note: The policy package is designed to achieve net zero emissions by 2050 in advanced economies (blue line) and by 2060 in emerging market economies (red line). Parameters and fiscal instruments are calibrated to a representative advanced economy (average of Group of Seven) and a representative emerging market economy, assumed to be the weighted average of large emerging market economies (Argentina, Brazil, China, India, Indonesia, Mexico, South Africa, Türkiye).

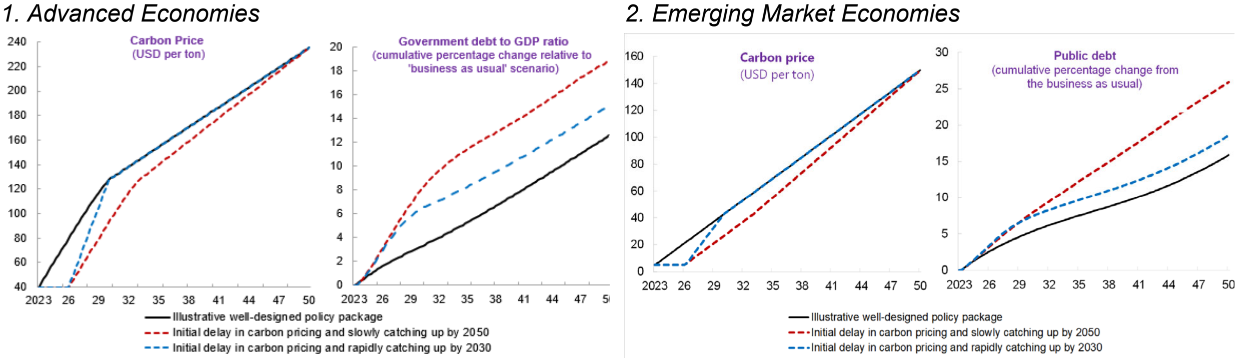
D. Scenario 4: Delays in Carbon Pricing.

We also consider the case of delayed implementation of carbon pricing and how it affects debt sustainability and emission reductions. The simulation assumes the carbon pricing action is postponed by three years relative to the policy package outlined above, with public investment and subsidies boosted to achieve the same emission reduction path as before. Two simulations are envisaged: 1) carbon prices are raised quickly after the initial 3-year delay to catch up with the path in the preferred package by 2030 (Figure 8 dashed blue line); and 2) carbon prices do not fully catch up with the baseline price path until 2050 (Figure 8 dashed red line). Both cases show that debt would increase in advanced economies, by 3 percentage points of GDP by 2050 in the former and almost 6 percentage points in the latter. In emerging market economies, debt worsens substantially if the carbon price fails to catch up promptly after the delay, and by slightly less than in advanced economies otherwise.

Figure 8. Debt Implications of Delaying Climate Action on Carbon Prices

(Relative to the business-as-usual scenario)

1. Advanced Economies *2. Emerging Market Economies*



Source: IMF staff simulations.
Note: Delay refers to a postponement of carbon pricing by three years (from 2023 to 2026) relative to the preferred policy package.

Each year of delay in raising carbon prices is found to increase public debt by 0.8–2.0 percentage points of GDP in advanced economies, depending on how quickly carbon prices adjust after the initial delays and assuming that spending-based policies are scaled up to deliver the same level of emission reductions by 2050 (Figure 8). Although carbon revenues are projected to peak later for emerging market economies, delays would still increase debt in a notable way (about 0.9 percentage point), even when carbon prices catch up quickly following the initial delay. The longer countries wait to make the shift to a greener future, the costs will likely be larger.

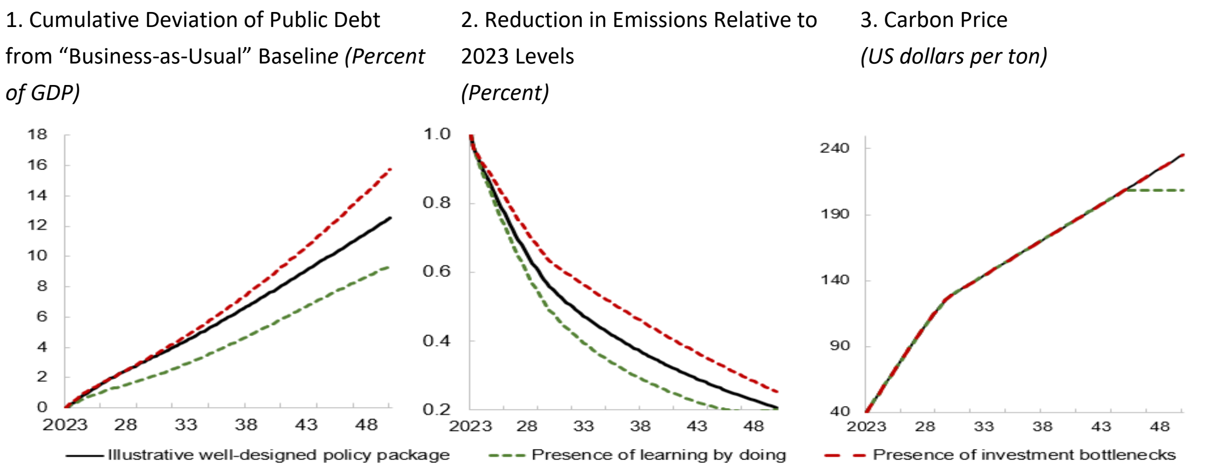
E. Scenarios 5 and 6: Technology Spillovers and Investment Bottlenecks.

The calibration is extended to cover two sources of technological developments. In the first scenario, we investigate the effect of learning-by-doing externality on firm incentives (Scenario 5), assuming that a 1 percent increase in energy capital is assumed to raise total factor productivity by 0.1 percent in the energy sector, in accordance with Chang, Gomes, and Schorfheide (2002) and Dietz and Stern

(2015). In the second scenario with investment bottlenecks, the adjustment cost parameter is increased to 100. This implies that under the same set of climate policies as in the preferred package, the annual adjustment cost would rise to 0.25 percent of GDP on average, and the green capital stock would only grow by half as much by 2050. Hence, stronger policy action would be needed to achieve the net zero target (Scenario 6).

The effectiveness of green subsidies will depend on how firms respond to fiscal incentives and how easily they can shift to, or invest in, low-carbon technologies. Model simulations show that green subsidies will be more effective if learning-by-doing effects in clean technologies are present, allowing a faster reduction in emissions and limiting the associated output costs, while keeping public debt contained (dashed green line in Figure 9). However, bottlenecks to green investment, such as limited institutional capacities and disruptions in supply chains for critical minerals because of geoeconomic fragmentation, could limit the potential for rapid uptake of green technology. Stranded assets in brown sectors—assets that need to be written down prior to the end of their economic life, such as old coal plants—could also be costly to divest or phase out. Such bottlenecks, if they take form of adjustment costs imposed on investment, would slow the shift toward renewable energy, making green subsidies less effective and causing debt-to-GDP ratios to rise further (dashed red line in Figure 9). This also implies that emission targets may not be reached unless more forceful action through other measures, such as higher carbon prices, is taken.

Figure 9. Impact of Technology Spillovers and Investment Bottlenecks on Debt Dynamics



Source: IMF staff simulations.
Note: The figure assumes carbon prices are the same across scenarios and is calibrated to a representative advanced economy (that reflects the average of the data for Group of Seven economies). When learning-by-doing is present, a 1 percent increase in energy capital is assumed to raise total factor productivity by 0.1 percent in the energy sector, in accordance with Chang, Gomes, and Schorfheide (2002) and Dietz and Stern (2015).

We further extend our analysis to illustrate, technology spillovers from advanced to emerging market economies. Given the closed economy specification, we conduct this simulation by assuming that each 1 percentage point of total factor productivity increase in the advanced economy's energy sector spill over to a 0.1 percentage point increase in the same sector in emerging market economies (Adler and others 2017), and then simulate the technological growth in the emerging market economy's energy sector given the corresponding path in the advanced economy's energy sector This would lead to a positive spillover in green production and a negative one in brown production. Second, a smaller amount of learning-by-doing takes place in emerging markets' energy sectors, with a 2 percent elasticity of total factor productivity to capital accumulation (lower than the 10 percent assumed for advanced economies given weaker innovation capacity in developing countries (Awate and others 2012)). Technological spillovers can help emerging markets to achieve net zero with a smaller increase in carbon price, mitigating the output loss and decline in consumption.

F. Additional Sensitivity Analysis and Robustness

Simulation results are subject to many sources of uncertainty, including model parameters that are subject to a large uncertainty, the size of investment and subsidies, and the extent of compensatory transfers to households.

Table 2. Sensitivity of Debt Dynamics to Parameters and Scenarios

Scenario	**Carbon Price in 2050** (USD per ton)	**Change in Debt Ratio** Relative to "Business-as-Usual" Baseline by 2050 (percent of GDP)
Policy Package to Reach Net Zero Emission Goal (benchmark)	$235 (advanced economy)	12.5 (advanced economy)
· Lower elasticity of substitution between green and brown energy $\eta = 2$	$660	–1.6
· Lower elasticity of substitution between green and brown energy $\eta = 2$ limiting carbon pricing at $350, but scaling up investment and subsidies	$350	29
· Higher green investment (0.6 percent of GDP, or 0.2 percentage point higher than benchmark)	$215	24
· Higher green subsidies (0.4 percent of GDP, or 0.2 percentage point higher than benchmark)	$215	19
· Advanced economy simulation: Higher transfers (50 percent of carbon revenues; relative to 30 percent in the benchmark)	$235	15

Source: Authors' simulation results.
Note: Values for a representative advanced economy (average of Group of Seven countries).

Debt dynamics vary with alternative assumptions on the elasticity of substitution between energy sources and fiscal outlays on green investment and subsidies (Table 2). A lower elasticity of substitution between green and brown energy is found to require a much higher carbon price (US$660 compared with US$235 in the main scenario).[5] Higher carbon prices would lead to more

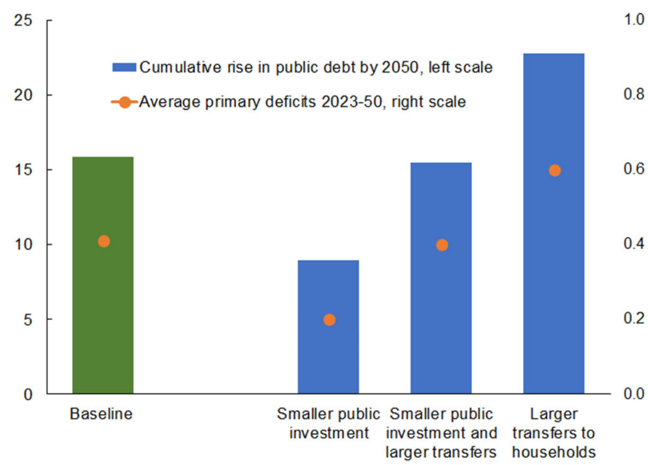
[5] In contrast, a smaller increase in carbon price is likely required in case of higher elasticity, for instance due to the availability and the easiness of scaling up green energy production.

revenue and less debt accumulation. If the increase of carbon price is capped, for instance, at US$350, then green investment and subsidies need to be higher, resulting in greater debt accumulation. Higher investment and subsidies also raise debt, but the required carbon price is smaller and therefore the output cost too. Meanwhile, higher transfers (50 percent of carbon revenues) would slightly increase debt compared to the main scenario.

Public investment needs in emerging market are subject to large uncertainty and varies across countries. For example, estimates in IEA (2022) suggest additional mitigation investment needs by 2030 would be greater for South Asia than other regions. Countries may also reduce fossil fuel investment while scaling up green investment, leading to a lower net public investment on mitigation, particularly for those fossil-fuel-producing countries.

Figure 10. Sensitivity of Public Debt to Public Investment and Transfers for Emerging Market Economies

(Percent of GDP relative to the business-as-usual scenario)



Source: IMF staff compilation.
Policy packages are set to reach net zero emissions by 2060. Parameters and fiscal instruments are calibrated to a representative emerging market, assumed to be the weighted average of large emerging market economies (*Argentina, Brazil, China, India, Indonesia, Mexico, South Africa, and Türkiye*). The baseline is the well-sequenced policy package discussed in the chapter, which consists of transfers at 30 percent of carbon revenues and public investment at about ¾ percent of GDP. Alternative scenarios explore sensitivity on the size of transfers (higher at 50 percent of carbon revenues) and public investment (lower at ½ percent of GDP per year).

Similarly, the extent of transfers to compensate on households depends on the financial constraints, informality of the economy, and strength of the social safety nets, which vary considerably across emerging markets. These suggest public investment needs and transfers may be greater or smaller than the one assumed in the baseline. Sensitivity analysis shows that if government transfers are 50 percent of the revenue from carbon taxes, debt would rise by 25 percentage points of GDP by 2050, with an increase in primary deficits of 0.6 percentage point of GDP a year on average. If instead public mitigation investment and subsidy are reduced by about ¼ percent of GDP per year, debt would increase by 8 percentage points of GDP. Overall, sensitivity analyses suggest that the simulated rise in debt for emerging markets is in the range of 8-25 percent of GDP by 2050 for transfers at 30-50 percent of carbon revenues and public investment about ½ and ¾ percent of GDP (Figure 10).

V. Policy Implications and Conclusions

Climate action is a global imperative, presenting policymakers with a tradeoff between achieving climate goals, fiscal sustainability, and political feasibility. Prolonging the business-as-usual path and taking only moderate action will not contain global warming, leaving the world vulnerable to potential catastrophic consequences. Relying mostly on spending-based policies to achieve the net-zero-emissions goal will lead to fast-rising debt beyond the currently projected rising path, exacerbating risks to fiscal sustainability. Relying solely on carbon pricing to reach net zero, on the other hand, is likely to be politically unpalatable.

This paper quantifies the implications of various climate policy packages on public finances, focusing on the medium-term debt dynamics. It shows that striking a balance among the three objectives of achieving climate goals, fiscal sustainability, and political feasibility will require a carefully calibrated mix of revenue- and spending-based mitigation instruments. Carbon pricing is necessary but on its own likely not the viable approach to reach the net-zero emission goals given political constraints. Other complementary measures, such as transfers, green subsidies and investment, and regulatory measures are needed in the policy mix.

Climate policies to decarbonize economies will likely entail a net fiscal cost, which varies considerably across countries depending on size of investment needs, revenues from carbon pricing, and borrowing costs. Advanced economies with sufficient fiscal space could likely accommodate a small increase in debt if needed. Yet many emerging market and developing economies with high debt will find it more challenging to accommodate rising debt, especially as many face pressing priorities on climate adaptation and other development goals. This calls for action to enhance domestic revenue mobilization and improve spending efficiency, combined with efforts to catalyze private financing and undertake structural reforms to accelerate growth.

Delaying action on carbon pricing is costly. Policy sequencing matters—combining fiscal instruments strategically can limit the rise in debt. For instance, the initial rise in carbon tax revenues could be timed to coincide with front-loaded green subsidies, containing the impact on deficits.

The policy mix of fiscal instruments in mitigation should account for technology spillovers and investment bottlenecks. Our results show that the presence of positive externalities or spillovers can raise the effectiveness of green subsidies, enabling lower decarbonization cost. But investment bottlenecks such as trade or supply-chain frictions could make decarbonization more costly.

Projected debt levels are subject to considerable uncertainty, depending on the size of investment needs, assumptions about the elasticity of substitution between energy sources and the economic impact of fiscal policies. The uncertainty about the debt path highlights the need to develop further tools to incorporate climate policies into debt sustainability analysis. It is important to recognize the interrelationship between climate policies and macro-fiscal conditions. Identifying the optimal mix of climate policies for individual countries and its implication of debt dynamics will be useful for further research.

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PUBLICATIONS

Public Debt Dynamics during the Climate Transition
Working Paper No. WP/2024/071