CHAPTER 3

NEAR-TERM MACROECONOMIC IMPACT OF DECARBONIZATION POLICIES

Decades of procrastination have transformed what could have been a smooth transition to a more carbon-neutral society into what will likely be a more challenging one. By the end of the decade, the global economy needs to emit 25 percent less greenhouse gases than in 2022 to have a fighting chance to reach the goals set in Paris in 2015 and avert catastrophic climate disruptions. Because the energy transition needed to accomplish this has to be rapid, it is bound to involve some costs in the next few years. While there is little consensus on the expected near-term macroeconomic consequences of climate change policies, this chapter's central message is that if the right measures are implemented immediately and phased in gradually over the next eight years, the costs will remain manageable and are dwarfed by the innumerable long-term costs of inaction. Different assumptions regarding the speed at which electricity generation can transition toward low-carbon technologies put these costs somewhere between 0.15 and 0.25 percentage point of GDP growth and an additional 0.1 to 0.4 percentage point of inflation a year with respect to the baseline, if budget-neutral policies are assumed. To avoid amplifying these costs, it is important that both climate and monetary policies be credible. Stop-and-go policies and further procrastinating on the grounds that "now is not the time" will only exacerbate the toll.

Introduction

The scientific consensus recently summarized by the Intergovernmental Panel on Climate Change (IPCC 2022) suggests that to limit catastrophic climate disruptions, large-scale policy changes need to take place rapidly. Decades of procrastination have transformed what could have been a slow transition to a carbon-neutral society into what will now have to be a more abrupt one. To have a fighting chance to reach the 2015 Paris Agreement's goal of limiting global warming (relative to the preindustrial age) to well below 2°C, and preferably 1.5°C, and to achieve net carbon neutrality by 2050 requires immediate and ambitious action. By 2030, global emissions have to be reduced by at least 25 percent compared with today's emissions, which would require a combination of a sustained and large increase in greenhouse gas (GHG) emission taxes, regulations on emissions, and large investment in low-carbon technologies.[1] Advanced economies cannot accomplish the needed reduction alone; large emitters in emerging markets also have to step up the pace of their emission reduction activities (Parry, Black, and Roaf 2021).

Concerns about the energy transition's real economic costs have been a key determinant of decades-long procrastination on the policy front; while costs are often perceived as clear and present, benefits are seen as distant and uncertain, despite overwhelming evidence that any short-term costs will be dwarfed by the long-term benefits (with respect to output, financial stability, health) of arresting climate change (October 2020 *World Economic Outlook*; IPCC 2022). And hesitation in implementing the necessary climate mitigation policies seems to have even grown recently against a backdrop of rising commodity prices fueling inflation (Morawiecki 2022) and worries about energy security (see Chapter 1). In some circles, concerns have been raised that fighting climate change could cause a global inflation shock (Morison 2021), exacerbating the output-inflation trade-offs central banks currently face and increasing risks to medium-term price stability (Schnabel 2022). But are these concerns warranted?

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[1]See Black and others (2022) and Chateau, Jaumotte, and Schwerhoff (2022a) for an analysis of the equivalence between regulation on emissions and carbon taxes. Note that while incentives for investment in green technology and renewables are an important part of any climate package, they are best supplemented by carbon taxes or equivalent regulations that will help decrease demand for fossil fuels and achieve a faster transition.

There is little consensus on the expected near-term macroeconomic consequences of climate change mitigation policies, such as GHG taxes. At the most fundamental level, imposing GHG taxes amounts to putting a price on a resource—the right to pollute—that used to be free. Internalizing this negative externality increases the cost of fossil fuels—an adverse supply shock—which on the surface bears many similarities to a standard oil price shock (Pisani-Ferry 2021). But the economics of climate policy and fossil fuel price shocks have important differences. First and foremost, GHG taxes lead to lower (net-of-tax) prices for fossil fuel producers, an important deterrent to investment in this kind of energy source. Second, while fossil fuel price shocks entail a transfer of revenues to fossil fuel exporters, GHG taxes generate fiscal revenues that can be allocated in many different ways to partly alleviate their negative effect on consumption and production and to compensate low-income households, which an increase in energy prices affects the most. Depending on how these revenues are used, they can have vastly different effects on the economy. Third, while fossil fuel price shocks are usually temporary and sudden adverse supply shocks, GHG taxes are meant to be permanent and assumed to be implemented gradually (October 2020 *World Economic Outlook*, Chapter 3). Forward-looking firms and households will understand that future output and income will be durably lower than previously expected and will want to scale down investment and consumption; the balance of supply and demand effects and the net effect on output will depend greatly on other policies governments undertake. Fourth, fossil fuel price surges that do not alter relative prices according to the fuel's carbon content (those that do not increase coal prices more than gasoline prices, for example) do not provide incentives for emission reduction to the same extent as a carbon tax, in particular when the surges are expected to be temporary. Also, considerable uncertainty surrounds the pace at which electricity generation could transition to low-carbon technologies. And as this chapter shows, this has important implications for the energy transition's macroeconomic costs.

This chapter employs the IMF's novel Global Macroeconomic Model for the Energy Transition (GMMET) to inform the current policy debate. It voluntarily abstracts from issues related to long-term costs and benefits of climate policies—largely covered elsewhere[2]—and focuses on *near-term* macroeconomic costs borne by agents whose horizon is limited. The focus is also on budget-neutral climate policies exclusively.[3] This strategy makes it possible to clearly disentangle the individual impacts of climate and fiscal policies on GDP and inflation. Moreover, in the current context of high public debt, high inflation, and rising interest rates, a strong case can be made to avoid further debt-financed demand stimulation (Chapter 1).

This chapter aims to illustrate the effect of feasible climate policies that balance the need to limit output losses against the inflationary effects of higher taxes, while ensuring low-income households do not bear a disproportionate share of any costs the transition entails.[4]

Given that the resulting output-inflation trade-offs could vary a great deal depending on the design and credibility of those policies, and in particular their interaction with fiscal and monetary policy and the pace at which electricity production can be decarbonized, this chapter puts a great deal of emphasis on robustness. By shedding light on the range of possible outcomes the required transition implies over the next eight years, it will help policymakers quantify alternative options and better tailor policies to their individual situations.

[2]See Acemoglu and others (2012) and the October 2020 *World Economic Outlook*, Chapter 3, for a comprehensive discussion.

[3]The assumption of budget neutrality is in contrast to that in Chapter 3 of the October 2020 *World Economic Outlook,* which studies the effect of deficit-financed public investment on green infrastructure investment. In the context of depressed economic activity related to the COVID-19 pandemic, a fiscal stimulus was the right policy; the proposed policy mix—carbon tax and public investment—led to fiscal deficit and temporarily boosted GDP (October 2020 *World Economic Outlook*, Figure 3.6). However, in the current context of high inflation and rising interest rates, fiscal policy should avoid undermining monetary policy's efforts to tame inflation and further build up public debt.

[4]Complementing the analysis in the October 2020 WEO—where the impact of direct public investment in low-carbon technology and infrastructure was analyzed—this chapter looks at the impact of cost-effective subsidies for investment in renewables. This modeling choice makes it possible to target sectors that already have low-emission technologies, that is, renewables-based, nuclear, and hydroelectric production and electric transportation. To some extent, the difference between public investment and subsidies is a semantic issue, as these sectors are fully or partly in public hands in many countries.

More specifically, this chapter tackles the following questions:

- *Energy transition and macroeconomic costs*: How fast could countries transition toward renewable sources of energy? What would be the costs, if any, to households and firms?
- *Credibility and design of climate policies*: How do alternative policy packages fare in terms of their effects on employment, investment, consumption and output growth, inflation, and income distribution? What does a lack of policy credibility imply?
- *Challenges for monetary policy*: How great is the output-inflation trade-off arising from higher GHG taxes? How great is it likely to be if central banks lose credibility or never had it in the first place?
- *Macroeconomic cost of procrastination*: Is delaying GHG emission reduction policies a preferable option in light of the current inflation environment? Can starting later and doing it faster achieve the same emission reductions? How great would the costs be in terms of output lost and inflation?

Answers to these questions can be summarized as follows:

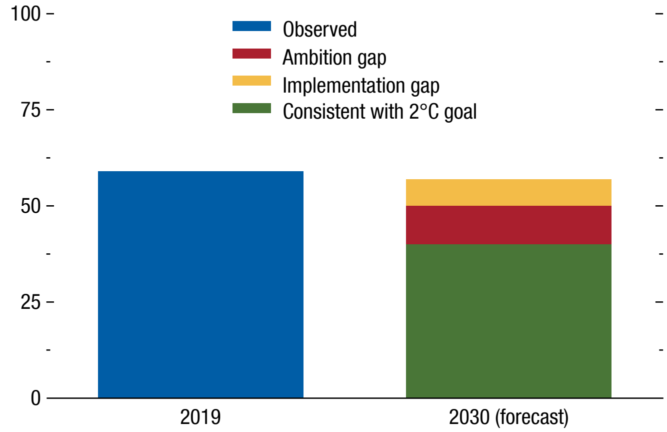
- *The energy transition will entail some costs, but they should remain manageable if countries do not delay.* The speed at which countries are assumed to be able to wean themselves off fossil fuels for electricity generation plays a key role in explaining the near-term macroeconomic costs associated with the energy transition. The more difficult it is to produce clean electricity, the more costly it will be to transition, as higher GHG taxes (or tighter regulations) will be needed to trigger the necessary drop in the use of carbon-intensive goods and services in the rest of the economy. Costs will also be variable across regions, with the block (in the model employed in this chapter) representing the rest of the world (dominated by fossil fuel exporters and carbon-intensive economies) seeing the largest transition costs (see Online Annex 3.3 for an analysis of costs when alternative policies are envisioned for these countries). To reflect the uncertainty surrounding the energy transition, this chapter considers two alternative calibrations for the elasticity of substitution between renewables and fossil fuels in electricity generation. In the most pessimistic case, a sharper increase in GHG taxes (about twice as large as in the benchmark case) will be necessary to reach the same decarbonization goal. While still manageable, the energy transition's macroeconomic costs—measured in terms of lost output and higher inflation—are expected to be about twice as large and will crucially depend on policy design. Cognizant of this uncertainty, this chapter estimates global growth could be lower by 0.15 to 0.25 percentage point annually and inflation could be 0.1 to 0.4 percentage point higher. For China, Europe, and the United States, GDP growth costs are expected to be lower and in a range between 0.05 and 0.20 percentage point annually.
- *Policy design has a major influence on climate policy's final impact on output, inflation, and income distribution.* All policy packages are assumed to be financed by GHG taxation only. Using the receipts of GHG taxes to cut *labor income taxes* reduces distortions and leads to relatively higher labor supply; higher wages net of tax; and higher consumption, investment, and output. Recycling part of the GHG tax receipts into *subsidies for investment in low-carbon technologies* (renewables, nuclear and hydroelectric, electric vehicles) facilitates the transition. The same decarbonization level can be achieved with lower GHG taxes thanks to investment in carbon-neutral technology. The impact on inflation is accordingly smaller, which reduces the potential trade-offs for monetary policy. *Transferring* tax revenues to low-income households helps increase the acceptance of climate policies but comes at a cost in terms of output growth.
- *Climate policies have a limited impact on output and inflation and thus do not present a significant challenge for central banks.* Gradual and credible implementation gives agents motive and time to transition toward a low-emission economy. Induced mild inflationary pressures require some monetary policy adjustments to ensure expectations remain anchored, but at minimal GDP costs. There may even be some room to ease in the near term to facilitate the transition. In this respect, climate policies contrast greatly with supply shocks, in which the sudden increase in the energy price creates an immediate challenge for monetary authorities. Less credible climate policies require sharper adjustments down the road and generate more inflationary pressures and more challenges for monetary authorities. Larger costs materialize only with eroded monetary policy credibility, as inflationary pressures call for more policy response.
- *Further delay would only amplify any costs associated with the energy transition.* Concerns about inflation

and energy security have prompted some to suggest that decarbonization should wait until current inflationary pressures have been overcome. But this would only amplify transition costs. This chapter's analysis shows that further delay would require GHG taxes to be raised by even more and faster than in the gradual scenario, with much larger costs (the resulting inflationary impulse is about three times stronger, and preventing it would require sacrificing roughly 1 percent of GDP over the course of four years).

This chapter starts with a general survey, stressing the urgency of cutting GHG emissions by 2030 at least to an extent that is compatible with limiting warming at the end of the century to well below 2°C. It then introduces the analytical apparatus by illustrating the impact on growth and inflation of increasing GHG taxes gradually. The next section discusses the importance of credibility and complementarity between climate and monetary policy for a successful transition. The last section quantifies the macroeconomic costs of further delay and stresses that now is the time to act.

Figure 3.1. Historical and Projected Global Emissions
(Gigatons a year)

Total projected emissions in 2030 are greater than emissions compatible with the 2°C goal.



Source: Intergovernmental Panel on Climate Change.
Note: The overhang of projected emissions in 2030 over the amount compatible with 2°C warming consists of the ambition gap (the amount by which pledged emissions exceed the 2°C-compatible amount) and the implementation gap (emissions pledged to be avoided but forecast to arise under current policies).

Decarbonizing the Economy: Now Is the Time to Become Credible

Lay of the Land

The Paris Agreement enshrined the goal of 193 countries to limit global warming by the end of the century to well below 2°C and preferably to below 1.5°C. So far, countries have collectively failed to honor their pledges, and the relentless rise in emissions following the agreement has made achieving the 1.5°C target extremely difficult. Temperatures are set to rise further, and the adverse consequences are understood to be nonlinear; every increment of warming raises the risk of crossing "tipping points" that would push the global climate system into abrupt and irreversible changes (Lenton and others 2019).[5]

Limiting global warming to below 2°C requires that emissions decline by 25 percent relative to current levels by 2030, which would mean an unprecedented acceleration in mitigation efforts, but one that is crucial to limit the extent of damage to the Earth's climate system. Unfortunately, such a regime change in climate policy remains elusive in almost all countries (UNEP and UNEP-CCC 2021; IPCC 2022; Black and others 2021). The IPCC projects that under policies currently in place, emissions in 2030 will be more than 42 percent higher than those required to reach the Paris Agreement target (Figure 3.1). Not only are existing policy pledges insufficiently ambitious (the "ambition gap" in the figure), but they are also projected to be missed under current policies (the "implementation gap"). While pledges are more ambitious among advanced economies than among countries in other economic groups, climate goals can be achieved only through a global effort (October 2020 *World Economic Outlook*, Chapter 3).

Enhancing Credibility of Climate Policy for More Effectiveness

Lack of ambition and failing implementation characterize the history of climate policy, which allows parallels to be drawn with other areas of public policy. For example, Kydland and Prescott (1977) demonstrate how central bankers concerned about inflation as well as short-term unemployment form time-inconsistent monetary policies that lead to higher inflation with no

[5]Some tipping points amplify global warming itself; for example, GHGs released by thawing permafrost or the vanishing of ice sheets, which help reflect solar heat.

gains in employment. Similarly, governments announce carbon-reducing policies but have incentives to renege on them to try to maximize output or employment or safeguard particular interests (Brulle 2018) during their terms.

With investment and research and development decisions based on long planning horizons, it is key that (to affect behaviors) new climate policy measures and commitments to future carbon-reducing policies (for example, increments in GHG taxes, regulations, and subsidies) be perceived as credible and irreversible (see "Credible Policies: Key for a Successful Transition"). As is the case for monetary policy, the credibility—and thereby effectiveness—of climate policy will be enhanced if (1) there is a clearly defined *rules-based commitment* rather than pure discretion on how future decarbonization targets will be achieved, (2) instruments and analysis of policies to reach such targets are *transparent*, and (3) the targets are implemented *independently*, insulated from the political process (Nemet and others 2017). Ideally, the third criterion would involve an institutional arrangement akin to central banks' mandates to pursue price stability as their primary goal, along with operational independence, granted by law. However, this is still a high bar, even in countries with the most advanced climate mitigation policies (such as Denmark and Sweden). To overcome the absence of institutional independence, some countries have taken explicit account of political economy constraints when designing climate policies. For instance, because the impact of GHG taxes tends to fall disproportionately on the poor in many countries, it is important to carve out some transfers for the poor from GHG tax revenues to amplify support for GHG tax policy; widespread acceptance greatly increases credibility. Pragmatic policy design may then have to sacrifice some efficiency (usually achieved by cutting distortionary taxes) for equity and allow some amount of redistribution (Box 3.2).

Climate Policies to Keep Paris within Reach

Conceptual Framework

Past experiences with GHG mitigation policies throw only a partial light on such policies' near-term macroeconomic impacts. Most empirical studies point to negligible near-term effects of mitigation policies on output and inflation (Metcalf and Stock 2020; Konradt and Weder di Mauro 2021). But the policies analyzed in these studies are much smaller in scale and scope than the policies that will be required to achieve a path consistent with reaching the Paris Agreement's goals, which limits the studies' empirical information content for the questions at hand.

The literature has long recognized this tension, and numerous large-scale general equilibrium global models have been used to analyze the impact of GHG mitigation policies on emissions and economic activity in the long term. However, very few have been designed to simultaneously incorporate enough granularity in key sectors (energy generation, transportation), model-consistent expectations, nonlinearities that reflect increasing marginal cost to the decarbonization process, and the nominal and real rigidities required to analyze the near-term consequences of large policy changes for inflation and output (see Box 3.1 for a review of the empirical literature and an indirect validation of the GMMET's quantitative properties based on a battery of large-scale models' simulations of the effect of a gradual rise in carbon tax in the United States).

This chapter relies on the new GMMET, which shares a set of key features with the IMF's workhorse Global Integrated Monetary and Fiscal (GIMF) model. Like the GIMF model, the GMMET is a multicountry, microfounded, nonlinear dynamic general equilibrium model used to simulate the transition between an initial condition and a final steady state. Households and firms are forward-looking and choose consumption, labor supply, asset holdings, and investment optimally, considering their preferences and expected lifetimes. Nominal and real frictions as well as the explicit modeling of expectations allow the analysis of cyclical fluctuations and governments' related stabilization policies. The GMMET is configured for four regions: China, the euro area, the United States, and a block representing the rest of the world.

The purpose of the GMMET is to analyze the short- and medium-term macroeconomic impact of curbing GHG emissions. Such an analysis requires a detailed description of GHG-emission-generating activities and their interaction with the rest of the economy. These activities include fossil fuel mining and trade, electricity generation using various technologies (capturing the intermittence of renewable sources, discussed in more detail in Box 3.3), transportation with electric vehicles and conventional cars (with network externalities between electric vehicles and charging stations accounted for), and energy use in the production of goods and for residential heating, as well as activities that emit non-fossil-fuel GHGs, such as agriculture. Online Annex 3.1 and Carton and others (2022) outline these activities, which are novel relative to the GIMF model.

Under the Hood: Analytical Simulations Using the GMMET

To set the stage, this section focuses on *analytical* simulations that allow the effect of key elasticities to be disentangled and different plans for recycling GHG tax revenues to be contrasted. In all exercises in this section, GHG taxes are increased gradually and globally over the next eight years, such that every region decreases its GHG emissions by about 25 percent. Each region chooses a different level for its GHG price, as each has different degrees of emission intensity in electricity generation and in its productive industries. For example, Chinese steel manufacturing relies heavily on coal, the euro area already has a large share of renewables technology for its electricity generation, and the United States has the highest level of consumer use of electricity and of fossil fuel usage for heating and transportation.[6]

A key caveat of this chapter's simulation exercises is that they implicitly compare policy scenarios against a no-catastrophe, no-action baseline that is environmentally not feasible. Forgoing mitigation action until 2030 implies irreversible jeopardization of the future of the climate system whose long-term costs are expected to be very large, even if difficult to quantify (October 2020 *World Economic Outlook*, Chapter 3; Keen and others 2021). The exercises on delayed mitigation policy presented in the following subsections address this point by comparing mitigation action today with its true alternative: rushed delayed action.

Energy Transition: How Quickly Can It Be Achieved?

The pace at which an economy can transition out of fossil fuels hinges heavily on the pace at which electricity generation can wean itself off such fuels, and, in particular, off coal. Two elasticities are key for this process in the GMMET: the elasticity of substitution of fossil fuels—especially coal—for renewables in electricity generation and the elasticity of substitution of electricity for other fossil fuels in the production of goods and services. Considerable uncertainty surrounds the value of the first elasticity. On the one hand, structural, technological, and geopolitical impediments (such as insufficient backup power and grid integration for intermittent renewables, slow technological progress in regard to electricity storage, bottlenecks in the supply of metals for renewables and the electricity grid, trade restrictions, and supply chain issues) may prevent a rapid transition to renewables-based electricity generation. On the other hand, rapid technological progress has led to massive improvements in efficiency and drops in prices of renewable energy, and the outlook for storage capacity technology is favorable (October 2020 *World Economic Outlook*, Chapter 3).[7]

Under the *benchmark* calibration, the share of renewables in electricity generation increases by 20 percentage points by 2030. This increase is broadly in line with the experiences of Germany and California but is faster than what larger countries or regions have achieved so far.[8] An *alternative* calibration assumes the pace at which electricity generation can be decarbonized to be roughly half as fast under the same policies, reflecting the experience of China and the United States over the past decade (the European Union is in between, with an increase in the share of renewables by about 15 percentage points). In this calibration, industry and consumers have to shoulder a larger part of the required decarbonization, and a sharper increase in GHG taxes (as much as twice as large) will be necessary to reach the goal of a 25 percent drop in emission by 2030.

Under the *alternative* calibration, elasticities of substitution related to the use of fossil fuels are lower (reduced to one-fourth in electricity generation, halved in the manufacturing sector; see Annex Table 3.1.2). Figure 3.2 contrasts the outcome of the two calibrations and displays the range of possible macroeconomic effects of the energy transition in two different cases. The first case assumes that tax revenues are fully rebated to households in the form of a lump-sum

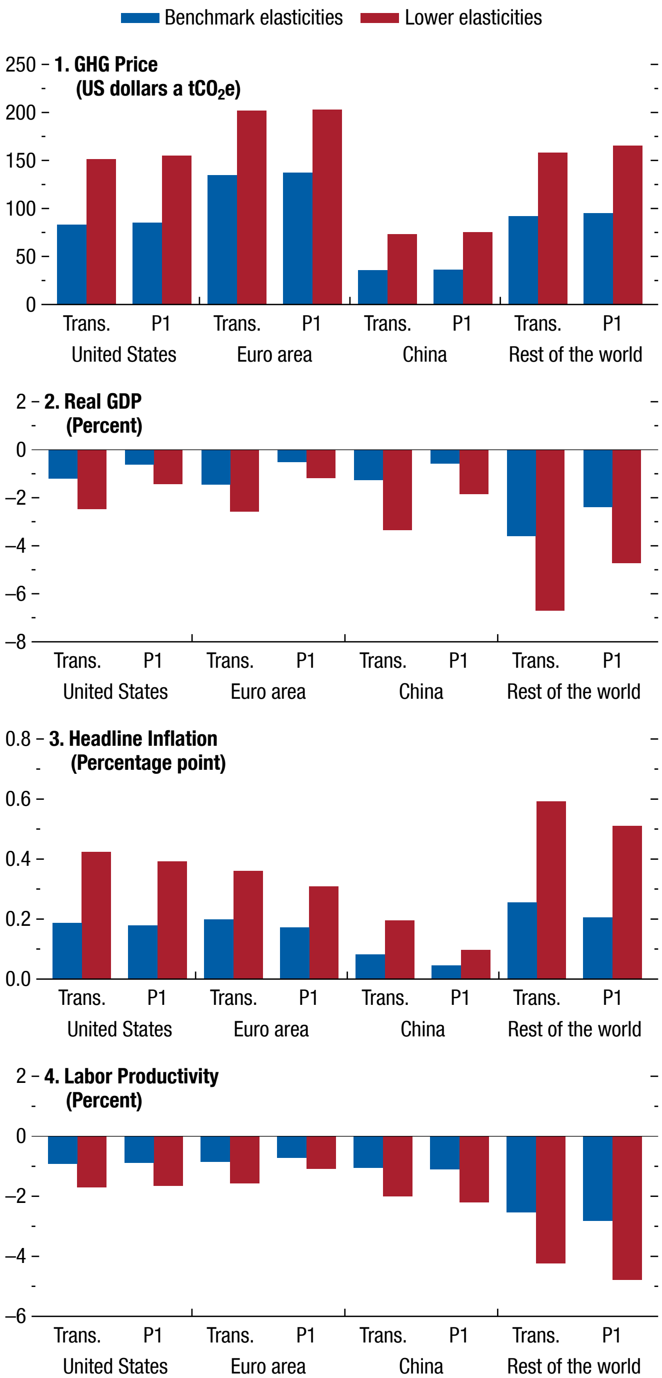
[6]To understand details on the differences in model calibration that have an impact on results in the four regions, please see "Calibrating the Energy Sectors" in Online Annex 3.1 and "Decarbonization in Different Regions: A Primer" in Online Annex 3.3.

[7]See Online Annex 3.1 for a more complete description of the energy generation sector in the GMMET, as well as key elasticities driving the pace of energy transition and its importance for investment in high- and low-carbon-intensity capital.

[8]The improvements in renewables technologies and the decline in prices since Germany and California deployed such technologies suggest a higher speed of decarbonization could be envisioned today in certain countries.

Figure 3.2. Macroeconomic Impact in 2030 of a GHG Tax under Different Calibrations of Elasticities
(Deviation from baseline)

Lower elasticities require higher GHG prices to achieve the same reduction in emissions by 2030 and magnify the macroeconomic impacts.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: P1 = Policy Package 1: two-thirds labor tax cuts and one-third transfers to households; GHG = greenhouse gas; tCO_2e = metric ton of carbon dioxide equivalent; Trans. = recycling GHG tax revenue as transfers to households.

transfer (labeled "Trans." in the figure). This isolates the effect of climate policy from fiscal policy, since fiscal policy using lump-sum transfers is nondistortionary and budget-neutral. The second case is described later in this section and assumes that tax receipts are partly recycled through a labor income tax cut (Policy Package 1, labeled "P1" in the figure). Under the alternative calibration, Policy Package 1 reduces GDP by 1–2 percent in China, the euro area, and the US by 2030.[9] These costs are roughly twice as large as those under the benchmark calibration but remain manageable; the two calibrations span a range of 0.15–0.25 percentage point of annual growth.[10] They are dwarfed by the immense risks to lives and livelihoods across the world (IPCC 2022) and very large long-term output costs associated with a business-as-usual policy potentially leading to catastrophic climate disruptions (see Chapter 3 of the October 2020 *World Economic Outlook* for estimates of averted damage).

Alternative Options to Recycle GHG Tax Revenues

A higher GHG tax, because it increases the price of energy, has been compared to an oil price shock (Pisani-Ferry 2021). But the apparent similarity can be misleading. GHG tax revenues can be redistributed domestically to alleviate some of the burden of the new tax for producers, consumers, or both.[11] Moreover, oil price shocks are often sudden, unexpected, and temporary, whereas in the simulations here, GHG taxes rise gradually from 2022 onward. A better frame of reference is the literature on productivity shocks (see, for example, Galí 2015). In this chapter's simulations, a GHG tax leads to a permanent decline in future productivity. Forward-looking agents will anticipate a drop in future profits and income due to higher expected future energy prices and will cut investment and

[9]For illustration, 1.5 percent of US GDP is about $320 billion and corresponds to the climate portion of that country's recently passed Inflation Reduction Act; the costs would be spread over eight years, or $40 billion a year.

[10]The rest-of-the-world region aggregates different economies, and drawing conclusions in regard to individual countries is not possible. The region encompasses the bulk of fossil fuel producers and is characterized by high energy intensity—in particular, high oil intensity. On net, the GDP impact is dominated by fossil fuel producers that are particularly affected during the transition as demand for fossil fuel and investment drops (see Chapter 3 of the October 2020 *World Economic Outlook* and "Decarbonization in Different Regions: A Primer" in Online Annex 3.3 for further discussions).

[11]In a supply-and-demand analogy, an oil price shock represents a shift of the supply curve, while a GHG tax is a shift along the supply curve.

consumption accordingly.[12] In the short to medium term, while the tax is still low, lower aggregate demand dominates the increase in energy costs, and a central bank focused on stabilizing core inflation will want to accommodate the shock (see Online Annex 3.3 and Chapter 2 of the *2022 External Sector Report* for a discussion of the impact on the real interest rate).[13]

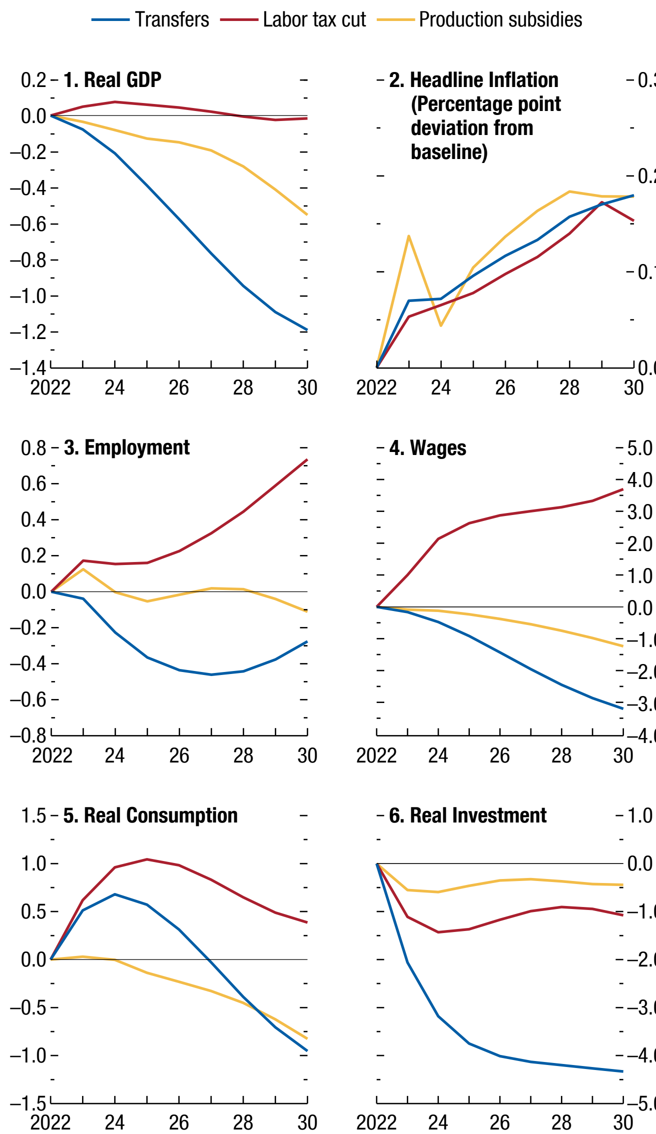
GHG taxes generate fiscal revenues that can be used to (1) help accelerate the transition, through incentives, subsidies, and public investment; (2) cushion the taxes' effect on firms' output and household income; or (3) compensate low-income households through targeted transfers. These options are part of fiscal policy, and countries will choose among them in line with their preferences and political economy considerations.[14] The following illustrates the implications of these choices for macroeconomic outcomes. Figure 3.3 contrasts three different strategies by which GHG tax revenues are recycled in the economy, by (1) reducing distortionary labor income taxes,[15] (2) subsidizing production by sector to offset the effect of the tax and provide incentives for the transition to less-carbon-intensive energy (akin to a "feebate"), or (3) simply rebating the tax's proceeds to households.

The tax has a very similar impact on inflation across the different strategies, reflecting the central bank's assumed credibility, that is, that it would respond to inflation to keep firms' and households' inflation expectations anchored. Increasing the GHG tax increases the relative price of fossil fuels and, given that other prices in the economy do not move quickly, also increases the overall price level. Absent indexation schemes, the impact is limited to the tax's first-round effect on energy prices. However, the impacts on the labor market, output, and output's use differ substantially across the three recycling strategies. While both lump-sum transfers and labor tax cuts boost consumption by transferring more income to households, only labor tax cuts, by reducing a disincentive to work, have a positive

Figure 3.3. Macroeconomic Impact of Different Recycling Options in the United States

(Percent deviation from baseline, unless noted otherwise)

Different revenue-recycling options shape the impacts of a given greenhouse gas price path on the US economy.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: Results based on benchmark elasticities.

[12]Investment in carbon-intensive capital will drop as firms adjust to the soon-to-become-obsolete capital stock. Investment in renewables and associated capital increases but not enough to offset the drop in carbon-intensive capital (see Online Annex 3.2). The price of energy in general increases. If lump-sum transfers are large, consumption increases in the short term, but the effect is short-lived. In the medium to long term, consumption declines as well owing to the tax's impact on households' permanent income.

[13]Note that the material that follows makes no attempt to derive "optimal (in the sense of welfare-maximizing) policy." The goal is to illustrate and guide, not to be normative, as the preferred policy is left to countries' authorities, given their individual situations and preferences. For discussions of optimal policy in response to an oil price shock, please refer to Blanchard and Galí (2007); Castillo, Montoro, and Tuesta (2007); Nakov and Pescatori (2010); and Natal (2012).

[14]Recycling tax revenues through lump-sum transfers is budget-neutral and nondistortionary, which averts any mixing up of the effects of climate and fiscal policy.

[15]The labor supply elasticity is 0.15, in the middle of the range of available estimates.

impact on both employment and output. Transfers compensate low-income households for higher energy prices and thereby mitigate the regressive effects of the GHG tax. Production subsidies have a beneficial effect on investment but at the expense of consumption, as they preclude transfers or tax cuts to households.

Feasible and Balanced Climate Policy Packages to Keep Paris within Reach

This subsection looks at feasible climate policy packages designed to align emissions by 2030 with the Paris Agreement while striking a balance among maximizing employment, output growth, investment in renewables, and compensating low-income households. The three policy packages examined have different objectives, but all attempt a compromise in which energy transition is realized at relatively low cost in terms of output and inflation. All packages allow for some income redistribution through transfers but combine different policy instruments and tax-recycling strategies (see Table 3.1). Policy Package 1, by using two-thirds of GHG tax revenues to cut labor income taxes, focuses on the need to engineer the required decarbonization without overly penalizing consumption. Relatively higher GHG taxes are required to provide incentives for reallocation toward less-carbon-intensive production processes, and investment declines more than in the other packages. Policy Package 3 focuses on supporting firms during the transition. The transition is then relatively smooth in terms of investment, which drops much less than in Policy Package 1. Because tax receipts are entirely rebated to firms, households bear the brunt of the tax-induced slowdown, and the consumption-to-investment ratio declines. Policy Package 2 can be seen as a combination of Policy Packages 1 and 3, as it complements measures to support households during the transition with subsidies to low-emission sectors (renewables, nuclear and hydro power plants, and purchase of electric vehicles). Subsidies support investment more than in Policy Package 1. Using the revenues for subsidies comes at the expense of consumption, as it reduces the allocations to tax cuts and transfers. Moreover, because Policy Package 2 offers incentives for investment, the required emission reduction can occur with lower GHG taxes and therefore less inflation (see Online Annex 3.3 for more details, including the external dimension). This scenario illustrates that a strategy relying on large subsidies for low-emission technologies poses little risk of inflation.

Differences across countries and regions reflect mainly different starting values in terms of energy use, proportion of fossil fuels in the consumption basket, and GHG tax increases required to reach the 25 percent decarbonization goal (Figure 3.4). Projections for inflation in China are a case in point. Because households' direct energy consumption accounts for a lower share of the consumer price index (CPI) in China, the GHG tax increase does not affect the CPI as much there as in the other regions in the simulation. As a result, the demand-contracting effect of the tax dominates and pushes the core part of the price index down. The impact on growth is much larger in the rest of the world—a residual category dominated by fossil fuel exporters and oil-intensive economies—reflecting the rapid energy transition assumed in the chapter's homogeneous reduction of emissions by 25 percent. To reflect the Paris Agreement's principle that responsibility for decarbonization efforts must be simultaneous but can be differentiated, Online Annex 3.3 analyzes the global impact on emissions, output, and inflation when the rest of the world

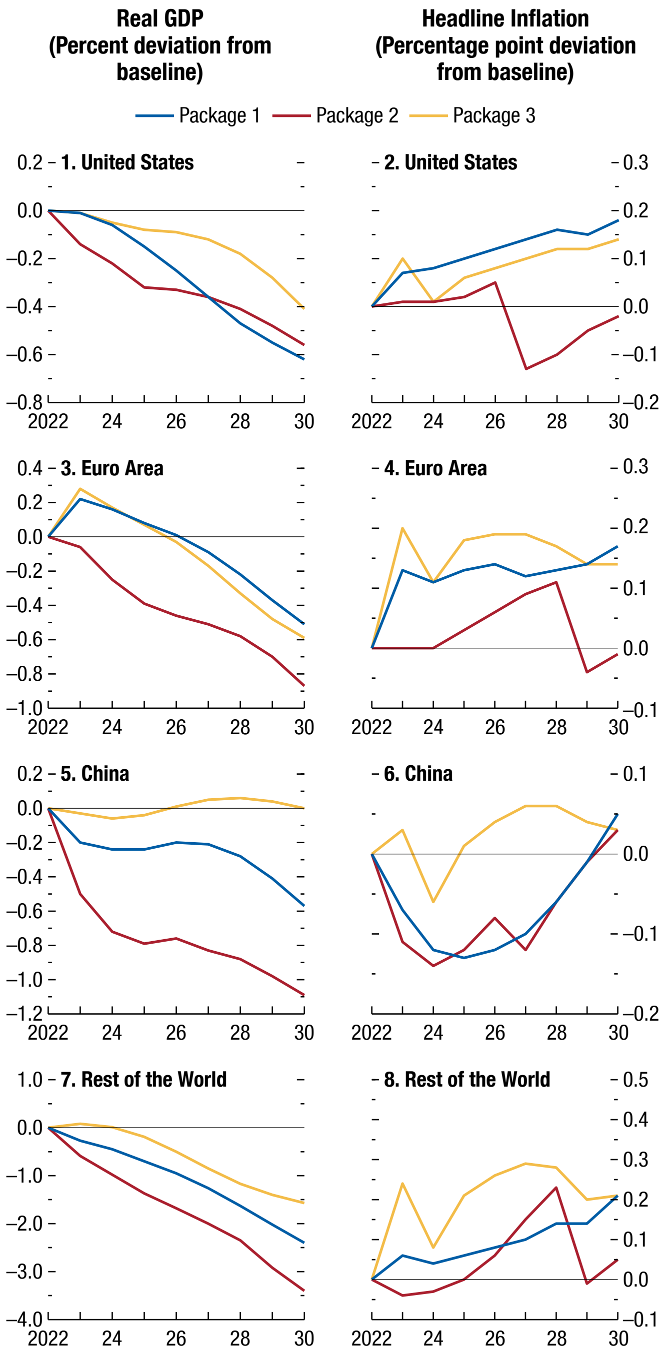
Table 3.1. Three Policy Packages Reducing Emissions by 25 Percent in 2030

Package 1	Package 2	Package 3
Gradual GHG price increase from 2023 to 2030	Gradual GHG price increase from 2023 to 2026	Gradual GHG price increase from 2023 to 2030
Two-thirds of revenue used to reduce labor taxes	One-third of revenue used to reduce labor taxes	GHG revenue rebated at the sectoral level (electricity generation, manufacturing, services)
One-third of revenue transferred to households	One-third of revenue transferred to households	GHG revenue from households' activities (residential energy and individual transportation) transferred back to households
	One-third of revenue used to subsidize low-emission sectors: • Renewables investment • Nuclear and hydro power plants • Electric-vehicle purchase	Regulation of share of electric vehicles

Source: IMF staff compilation.
Note: GHG = greenhouse gas.

Figure 3.4. Macroeconomic Impact of the Three Policy Packages in Regions in the Simulation

Green subsidies (Package 2) reduce the need for greenhouse gas price increases and result in lower inflation for the same policy rule. Production subsidies (Package 3) boost investment and GDP with little impact on inflation.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: Results based on benchmark elasticities. Policy Package 1: one-third transfers to households, two-thirds labor tax cuts; Policy Package 2: one-third transfers to households, one-third labor tax cuts, one-third green subsidies; Policy Package 3: production subsidies and transportation regulation. See Table 3.1 for a full description of the three policy packages.

does not introduce any new policy.[16] In such a case, the rest of the world's investment declines only in extraction industries, and the GDP impact is muted (see Annex Figure 3.3.3).

All simulations discussed so far have assumed perfectly credible monetary and climate policies. The next section analyzes the implications of climate policy for the macroeconomy when announced policies are less than perfectly credible.

Credible Policies: Key for a Successful Transition

Credibility of Climate Policy

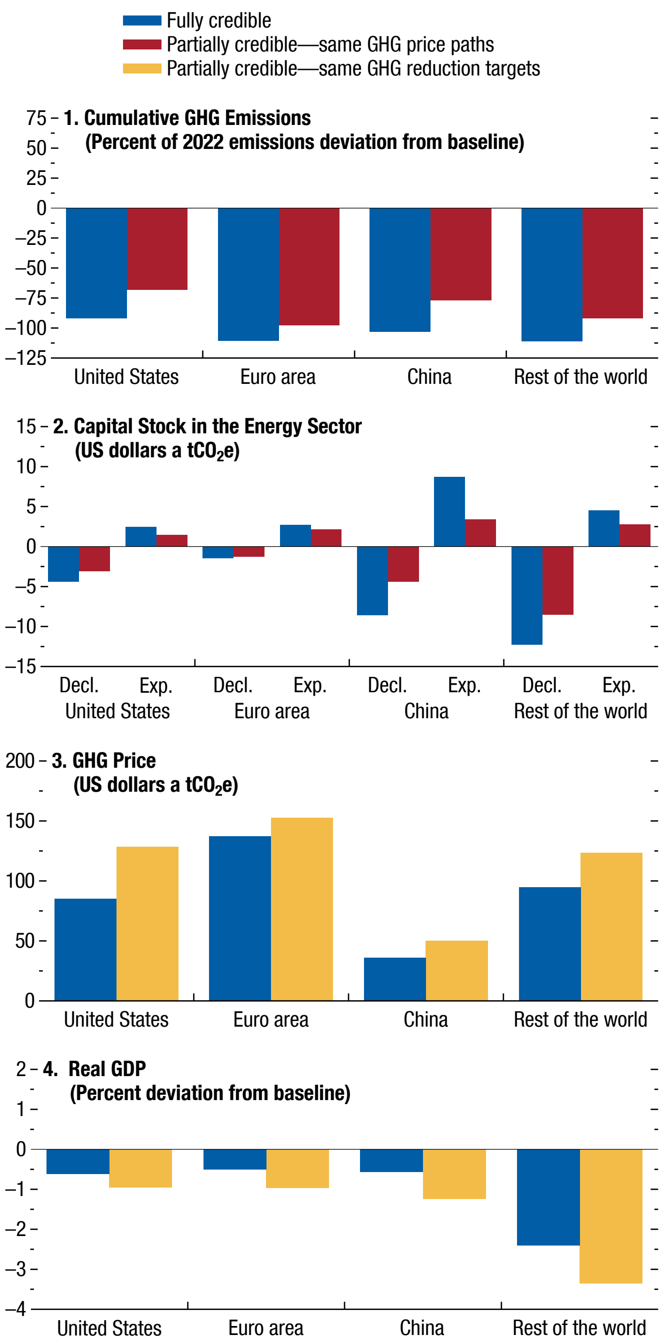
So far, the scenarios presented have assumed governments' climate policies to be fully credible: the private sector (both firms and households) takes current and future policies, including the path of the GHG price, into account to adjust its decisions. Policy Package 2, in which credible green subsidies provide powerful incentives to unleash private green investment and allow the required emission reduction with lower GHG taxes than in Policy Package 1, clearly shows the importance of credible policy. This subsection illustrates the importance of credible climate policy by relaxing the assumption of full credibility under Policy Package 1, with its gradually increasing GHG tax path. Climate policy is assumed to be believed only gradually over time (partial credibility): more specifically, each increment of the GHG tax is expected to remain in place, but future increments of the GHG price path come as a surprise, thereby having no impact on households' and firms' current decisions.

For given GHG price paths, partial credibility slows down the emission reduction process relative to the full-credibility case (the cumulative emission reduction by 2030, expressed as a share of 2022 emissions, is about 20 percent lower under partial credibility than under full credibility; see Figure 3.5), as investment in emission-intensive capital does not decline as rapidly. The key reason lies in the adjustment of investment in

[16]See Mirzoev and others (2020) for a discussion of carbon transition risks in Gulf Cooperation Council countries. For these countries, accelerating the diversification of their economies is key. Policies that seek to strengthen the non-oil sector through better business regulation, greater credit availability, reforms to the labor market, and increased sources of non-oil revenue for the government should be prioritized. In cases in which the transition involves a large drop in aggregate demand, fiscal stimulus can be envisioned, provided fiscal space is comfortable enough (see Chapter 3 of the October 2020 *World Economic Outlook* for further analysis).

Figure 3.5. Impact in 2030 of Fully and Partially Credible Mitigation Policies

Less credible policies either miss the GHG reduction target when meeting GHG price paths, owing to insufficient shifts in the capital structure, or require higher GHG prices to meet the GHG reduction targets at a higher macroeconomic cost.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: Results based on Policy Package 1 with benchmark elasticities. Decl. = declining energy sector: fossil fuel extractions and coal power plants; Exp. = expanding sectors: renewables, nuclear, hydro and fossil gas generation, electricity grid. See Table 3.1 for a full description of the three policy packages. GHG = greenhouse gas; tCO_2e = metric ton of carbon dioxide equivalent.

the electricity sector. When climate policy is fully credible, the anticipation of further GHG price increases—which will undermine future profitability—accelerates the shift of capital away from emission-intensive investments, such as coal power plants, toward low-emission alternatives.

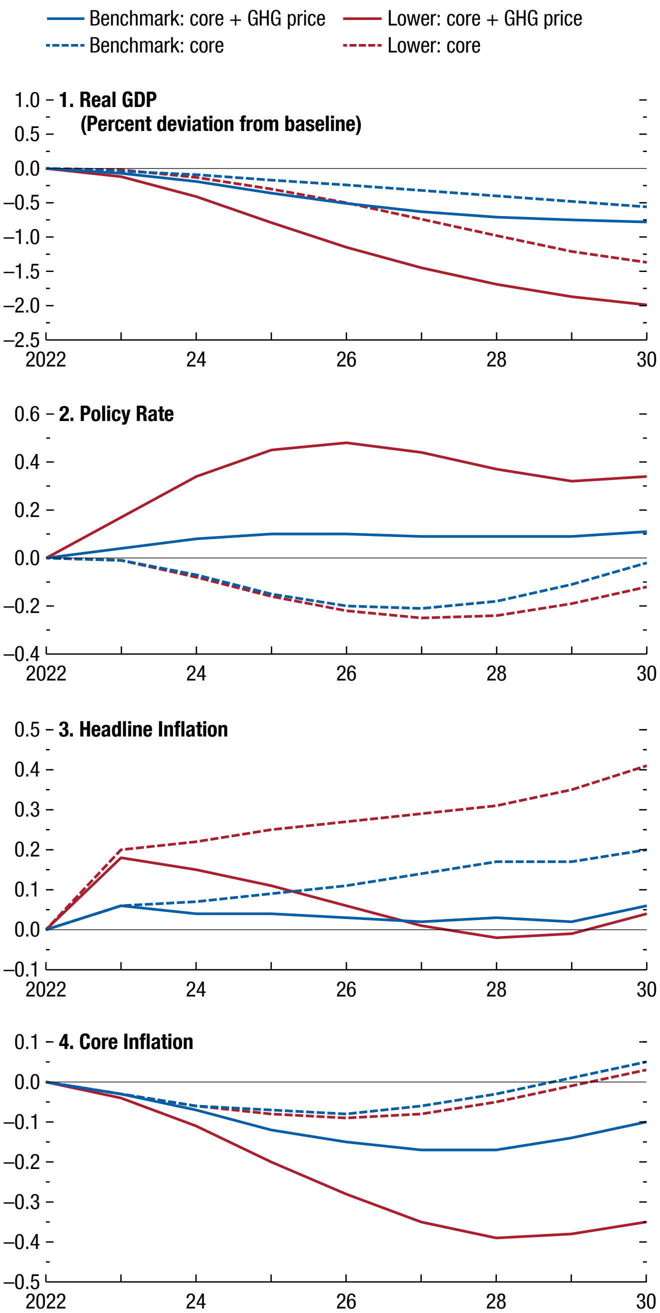
Partially credible policy requires higher GHG taxes to reach the same decarbonization goal, leading to larger GDP losses by the end of the decade (in the United States, the euro area, and China, GDP declines by 1.0, 1.0, and 1.2 percent, respectively, rather than 0.6, 0.5, and 0.6 percent).

Credibility of Monetary Policy

The current high-inflation environment has raised concerns that climate policy could create large output-inflation trade-offs, complicate the job of central banks, and potentially stoke wage-price spirals. This subsection shows that as long as central banks retain their inflation-fighting credentials, any trade-offs implied by the sort of climate policy studied in this chapter are bound to be small. As a matter of fact, climate policy, if implemented gradually, should be easier for central banks to handle than supply shocks in which the energy price increases suddenly and creates an immediate challenge for monetary authorities. If central banks lose credibility, however, trade-offs will be amplified, underscoring the importance of monetary policy credibility. Climate policy is no exception in this respect. If monetary policy is not credible, any cost-push shock is bound to entail larger trade-offs (Woodford 2003; Galí 2015). When monetary policy credibility prevents the de-anchoring of inflation expectations, a gradually implemented climate policy package will not give rise to a material output-inflation trade-off (see Figure 3.6 for results in regard to Policy Package 1). A comparison of the impact of a higher GHG tax on output and inflation under two different monetary policy rules reveals no major differences between targeting core inflation (that is, excluding energy items) and a modified version in which the targeting includes the change in GHG price (core plus GHG price). Targeting core inflation will give rise to slightly higher headline inflation because of the tax's direct impact on noncore CPI components, while targeting the modified version of core inflation (core plus GHG price) will have a larger cost in terms of lost output (necessary to bring about the required decline in marginal costs and core inflation to offset the tax's

Figure 3.6. Macroeconomic Impact of Different Monetary Policy Targets in the United States
(Percentage point deviation from baseline, unless noted otherwise)

Including the impact of the GHG price on the consumer price index has limited macroeconomic implications as long as monetary policy credibility prevents any de-anchoring of inflation expectations.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: Results based on Policy Package 1 with benchmark and lower elasticities described in Annex Table 3.1.1. See Table 3.1 for a full description of the three policy packages. GHG = greenhouse gas.

impact on noncore prices) but will drive headline inflation back to target. The difference in magnitudes remains quite small. In essence, core plus GHG price targeting keeps headline inflation close to target in the absence of shocks to other noncore components.

Of course, a great deal depends on how easily electricity generation can transition out of fossil fuels toward renewables. Larger frictions than assumed in the benchmark calibration would imply that to reach decarbonization goals, governments would have to increase GHG taxes substantially more and faster (than in the benchmark elasticity case), with implications for growth and inflation. Figure 3.6 illustrates the differences. For example, under the alternative (lower-elasticity) calibration and core plus GHG price targeting, by 2030 GDP would be about 1¼ percent lower than under the benchmark calibration.

In today's high-inflation environment, if monetary policy were to lose credibility, wages could start indexing to past inflation levels. As a result, the inflation process would become more inertial, which would result in inflation depending more on past inflation rather than being anchored to the inflation target. In such an environment, introducing climate policies, such as Policy Package 1, could potentially lead to second-round effects and larger output-inflation trade-offs. Figure 3.7 shows that in such a case, stabilizing the modified version of core inflation (core plus GHG price) would have a significantly higher cost in terms of output, while stabilizing output could trigger a wage-price spiral as the central bank stimulates the economy enough to keep labor demand and real wages in check, pushing up nominal wages and prices in a feedback loop.

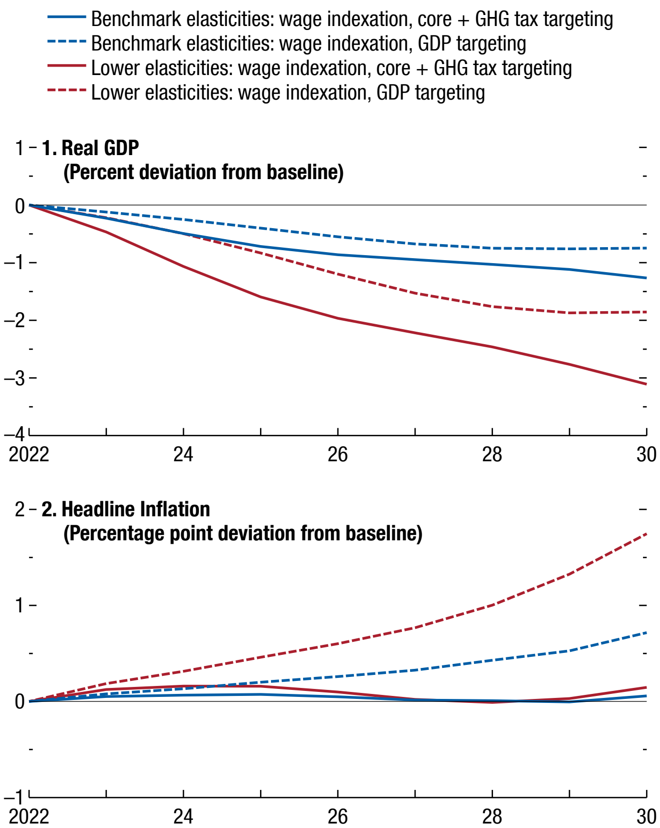
Inflation expectations have remained broadly anchored in a majority of countries and, in particular, in the large emitters that are the chapter's focus (see Chapters 1 and 2). In countries where central banks might be less credible, alternative policy packages that have a much smaller impact on prices (for example, Policy Package 2) could be favored in case concerns about the anchoring of inflation expectations are warranted.[17]

While this exercise is meant to be mainly illustrative, highlighting the unpleasant trade-offs that could

[17]In such a case, policies that entail a smaller pass-through to headline inflation may be favored, such as combining a GHG price with subsidies for low-emission technologies in electricity or transportation.

Figure 3.7. Macroeconomic Impact of Different Monetary Policy Targets under Wage Indexation

Wage indexation worsens the output-inflation trade-off.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: Results based on Policy Package 1. See Table 3.1 for a full description of the three policy packages. Panels depict alternative wage and price Phillips curves. Benchmark and lower elasticities described in Annex Table 3.1.1. GHG = greenhouse gas.

result from a lack of central bank credibility could raise the question of whether it is reasonable to wait—as some have proposed—until inflation is tamed before implementing the required climate policies. The next section shows that waiting would only complicate the transition.

Transition Costs under Further Delays

As noted earlier in this chapter, gradually phased-in climate policy packages that are rolled out without delay would have only very limited consequences in regard to inflation, provided central banks remain credible. A prominent concern at the current juncture, however, is that climate mitigation policies could de-anchor inflation expectations by raising the specter of future GHG-price-driven inflationary pressures in an already-high-inflation environment. This section asks whether delaying the necessary climate action by a few years, until inflation is brought under control, could be an option.

To assess this policy option, Policy Package 1 starting in 2023 is compared with a delayed mitigation policy package that starts in 2027 but is still compatible with the Paris Agreement's objective in that it achieves the same reduction in cumulative emissions in the long term. The results are reported only for the United States; Online Annex 3.4 presents other regions' results. The delayed package has the same composition as Policy Package 1 but is phased in more rapidly and has a higher GHG tax for some years, since a steeper decline in emissions is required to offset the unmitigated accumulation of emissions from 2023 to 2026. Both packages assume credible monetary policy.

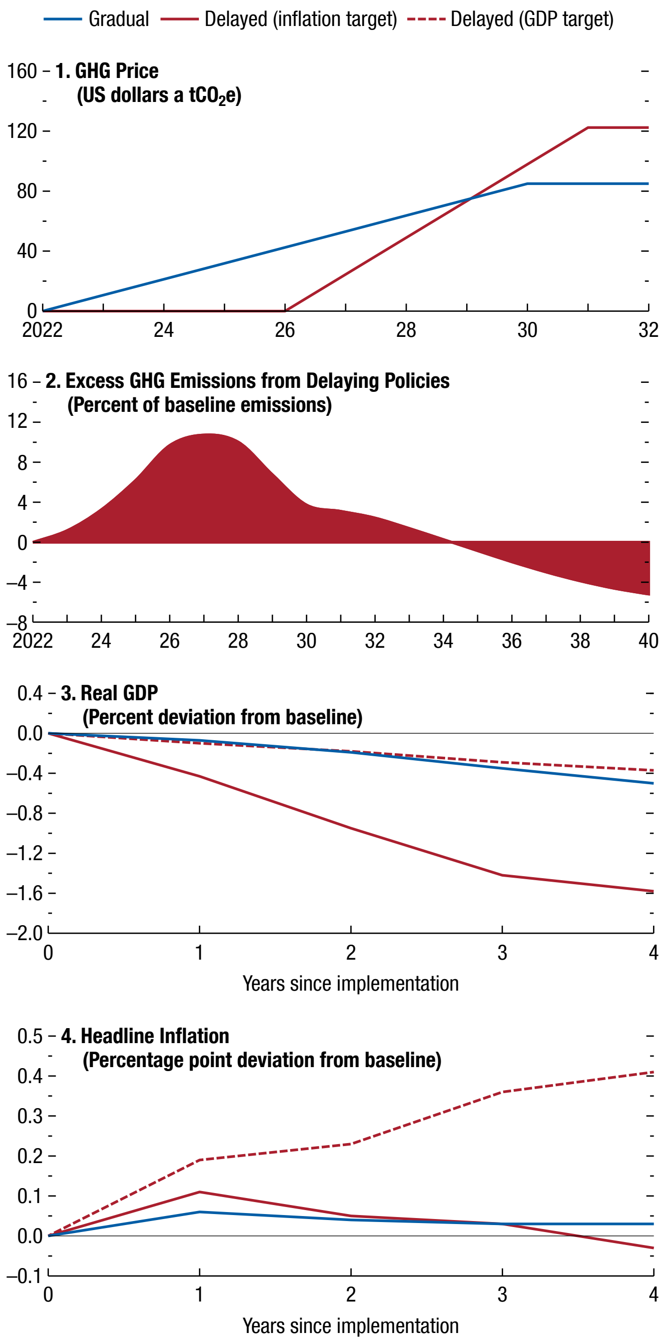
The higher speed at which the transition must take place if it is delayed significantly worsens the output-inflation trade-off (Figure 3.8). First, larger annual increments in the GHG tax directly generate larger increases in headline inflation. Second, a shorter transition period leads to a rapid fall in the utilization of capital for the production of fossil fuels, at a large cost to firms and their profitability. This is in addition to the decline in investment by all firms to allow them to shift out of any emission-intensive capital. If monetary policy targets output (to decline at the same pace as in the gradual scenario), headline inflation increases by much more than in Policy Package 1 (dashed red line); if it targets the modified version of core (core plus GHG price), output drops much faster (solid red line).

Therefore, if the concern is that higher GHG taxes may end up threatening central banks' credibility, leading to larger output-inflation trade-offs, delaying climate policy does not appear to be a reasonable option. A *risk management approach* to monetary policy might instead suggest starting to implement the necessary GHG taxes right away and leaning against their impact on headline inflation. Doing so (solid blue line in Figure 3.6) would minimize the risk that higher headline inflation will weaken the central bank's credibility and lead to widespread wage indexation and higher inflation inertia.

Comparing this policy approach with the alternative of delaying climate policy implementation to after 2026 highlights the much larger costs, in both

Figure 3.8. Gradual and Delayed GHG Mitigation Policies in the United States

Delaying mitigation policies considerably worsens the output-inflation trade-off.



Sources: Global Macroeconomic Model for the Energy Transition; and IMF staff estimates.
Note: Results based on Policy Package 1 with benchmark elasticities. Monetary policy targets Core + GHG price under "Gradual" and "Delayed"; Under "Delayed (GDP target)," monetary policy targets the same GDP as in "Gradual." GHG = greenhouse gas; tCO_2e = metric ton of carbon dioxide equivalent.

inflation and output, of the latter option. Further procrastinating requires an even more rushed transition in which inflation can be contained only at significant cost to real GDP.

Conclusions and Policy Implications

Decades of procrastination on climate policy have made it all the more urgent to act now. To keep the Paris Agreement's goal within reach, GHG emissions must decline by 25 percent, with respect to current levels, by 2030. Achieving such a result would require unprecedented global effort and would represent a serious acceleration with respect to the past decade. Rising concerns about energy independence offer the opportunity to bolster the transition in the energy sector.

How costly such efforts could be depends a great deal on how quickly electricity generation can be decarbonized. The more difficult it is to transition to clean electricity, the larger the GHG tax increase will have to be to provide incentives for larger efforts in other sectors—and the larger the macroeconomic costs in terms of growth and inflation. Different calibrations of elasticities of substitution away from fossil fuels suggest global GDP could be between 0.9 and 2.0 percent below baseline by 2030, which would amount to a slowdown of 0.15 to 0.25 percentage point in yearly growth. Inflation could increase to reach 0.1 to 0.4 percentage point above baseline. Considerable variation across regions is to be expected, with the largest effects concentrated among fossil fuel exporters.

While not trivial, these costs are manageable and dwarfed by the innumerable long-term benefits (in regard to output, financial stability, health) of arresting climate change (October 2020 *World Economic Outlook*; IPCC 2022) that have been thoroughly documented by climate science. However, the route to Paris could become more onerous if a series of conditions are not met. First, the required climate policies need to be implemented immediately. Further delaying implementation will amplify the output-inflation trade-offs that central banks may face. An immediate start will allow a gradual process whereby GHG taxes can be increased in small and predictable increments, driving private expectations and behaviors and limiting inflationary pressures. Second, it is important that new climate policy be credible. Credible climate policies offer incentives for investment and research and development in carbon-neutral technology and help accelerate the shift in consumption patterns toward low-carbon alternatives. International experience shows that rebating tax revenues to low-income households (which are bound to suffer the most from the new carbon pricing) helps bolster acceptance and reinforces such policies' credibility. Third, monetary policy credibility complements climate policy credibility and is essential to keep output-inflation trade-offs low. Doubts about central banks' price stabilization credentials could lead to more widespread wage indexation and higher inflation inertia, which would further amplify output-inflation trade-offs and the cost of future stabilization. Concerns about current high inflation offer no justification for delaying necessary actions.

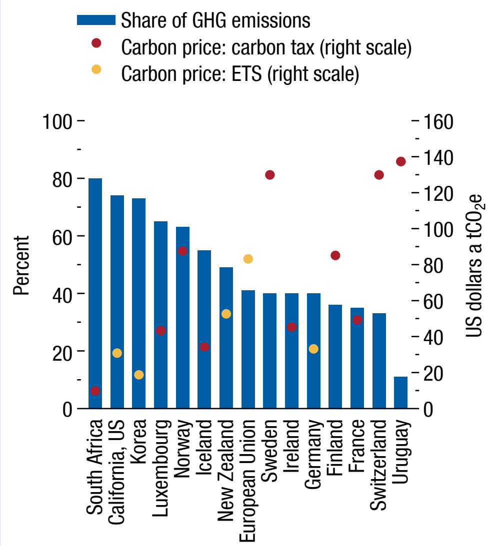
It is not too late to avert the most catastrophic climate damages, but ensuring that temperature increases remain well below 2°C at a reasonable cost will require immediate, credible, transparent, and ambitious action. Because GHGs know no borders, the effort to accomplish this goal needs to be global. The rise in geopolitical tensions related to the Russian invasion of Ukraine and the recent deterioration in China–US relationships have put global cooperation on climate goals at risk. If different international standards arose, carbon border adjustment taxes could help prevent excess leakage and accelerate the convergence of tax and regulations to the highest global standard. International coordination in GHG taxation could also allow faster decarbonization, as low-hanging fruit could be plucked in many countries that have not yet started decarbonization. Productive areas of cooperation might include bridging data gaps, improving reporting standards, and increasing access to climate finance in emerging market and developing economies (October 2022 *Global Financial Stability Report*, Chapter 2; Ferreira and others 2021).

Box 3.1. Near-Term Implications of Carbon Pricing: A Review of the Literature

Most empirical studies find that carbon-pricing programs implemented so far, even though quite modest, have led to significant reductions in emissions. Over the past two decades, a number of countries have rolled out carbon-pricing programs, with carbon tax rates and coverage of various magnitudes (Figure 3.1.1). Empirical analyses find that despite low carbon prices, emission-trading markets and carbon taxes have led to sizable reductions in emissions. For instance, the European Union (EU) Emissions Trading System (ETS)[1] has been found to have reduced EU-wide emissions by 3.8 percent between 2008 and 2016, although the market covered only 50 percent of EU carbon emissions and the price remained below €20 a ton up to 2018 (Bayer and Aklin 2020). ETS-regulated manufacturing plants have been found to have reduced emissions by close to 15–20 percent in France (Wagner and others 2014) and Germany (Petrick and Wagner 2014). An emission market introduced in the northeastern US states and targeting emissions from the power sector has also been determined to have contributed more than half of emission reductions achieved in the sector[2] in the late 2000s and early 2010s (Murray and Maniloff 2015), despite a low price averaging \$2–\$3 a ton during the time period.

Carbon pricing's macroeconomic impact remains indiscernible, however, even though effects are more tangible at the sectoral level. Recent macro empirical studies have assessed the impact of carbon taxes on GDP using cross-country panel regressions and have found no evidence that carbon taxes have led to reductions in activity. Metcalf and Stock (2020) and Konradt and Weder di Mauro (2022) focus on the economic response to carbon tax changes in EU countries, controlling for previous tax changes or GDP growth, and point to negligible near-term effects of mitigation policies on output and inflation. One of the reasons could be related to the fact that these countries were able to achieve emission reductions through investment in abatement technologies, the switching of production and demand to cleaner technologies, and energy efficiency gains.

Figure 3.1.1. Carbon Pricing in 2022 for Selected Economies



Sources: International Carbon Action Partnership; World Bank (2022); and IMF staff calculations.
Note: ETS = Emissions Trading System; GHG = greenhouse gas; tCO_2e = metric ton of carbon dioxide equivalent.

The effect of carbon pricing on activity seems easier to identify using microeconomic data. Several studies have found that the EU ETS has led firms to reduce the carbon intensity of their production through improvements in energy efficiency. An energy tax implemented in the UK resulted in energy use reductions of 23 percent in targeted manufacturing plants, leading them to cut emissions without cutting production or employment or reducing productivity (Martin, de Preux, and Wagner 2014). On the other end, carbon pricing has been shown to affect sectors differently, depending on their carbon intensity. For example, sectoral data analysis reveals that the carbon taxation implemented in British Columbia, Canada, led to a fall in employment in carbon-intensive and trade-intensive sectors (Yamazaki 2017). Studies also show that the 1970 US Clean Air Act[3] had a negative impact

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[1]The ETS is the EU's flagship climate policy, establishing in 2005 a carbon market across Europe, with more than 11,400 plants in 31 countries regulated at present.

[2]In states involved in the emission market, power sector emissions dropped by close to 25 percent between 2000 and 2011.

[3]The Clean Air Act regulates the emission of local air pollutants in the United States.

Box 3.1 *(continued)*

Table 3.1.1. Cross-Model Comparison of Changes in GDP
(Percent deviation from baseline)

	2030		
Model	Lump-Sum Rebates	Labor Income Tax Cuts	Capital Income Tax Cuts
E3	–0.8	–0.7	–0.6
DIEM	–0.4	–0.2	0.8
IGEM	–0.8	0.2	0.5
NewERA	–0.5	–0.4	0.2
RTI-ADAGE	–0.8	–0.6	0.9
ReEDS-USREP	–0.3	–0.1	0.0
Model average	–0.6	–0.3	0.3

Source: Goulder and Hafstead (2018).
Note: DIEM = Dynamic Integrated Evaluation Model; E3 = Goulder-Hafstead Environment-Energy-Economy; IGEM = Intertemporal General Equilibrium Model; NewERA = National Economic Research Associates economic consulting model; RTI-ADAGE = Applied Dynamic Analysis of the Global Economy; ReEDS-USREP = Region Energy Deployment System model–US Regional Energy Policy model.

on employment in pollution-intensive industries over the medium term: Employment in polluting sectors fell by 15 percent in the 10 years following an increase in the stringency of the regulation rolled out in the 1990s (Walker 2011).

There are limitations to how much can be inferred from past experiences to project future macroeconomic impacts of carbon pricing. First, the available empirical evidence refers to policies that were much smaller in scale and scope than those that will be required to achieve a path consistent with reaching the Paris Agreement's goals. Second, the impact of carbon pricing on output and inflation will vary depending on the way climate policies are designed and the other policies that accompany them. The multiplicity of channels through which climate policies have an impact implies that disentangling their effects (for example, on output and inflation) is empirically challenging. The literature has long recognized this tension, and numerous large-scale general equilibrium global models have been used to analyze the impact of greenhouse gas mitigation policies on emissions and economic activity. The modeling literature suggests that climate policies comparable to those needed to achieve the Paris Agreement targets have moderate adverse effects on output. It is important to note that these output costs pale in comparison with the macroeconomic risk associated with the catastrophic climate damages these policies aim to avert. Models with low elasticities of substitution between carbon-intensive and green-energy-generating technologies (NGFS 2022) and high capital adjustment costs (McKibbin and Wilcoxen 2013), limited public subsidization of the development of green technologies (Acemoglu and others 2012), and difficulty in scaling up green energy supply (IEA 2021) typically show higher output costs. The design of climate policies also matters. For instance, recycling carbon tax revenues as lump-sum transfers to households helps support consumption (Williams and others 2015; Goulder and others 2019), while using the revenues to reduce distortionary taxes, including labor income taxes, enhances growth and investment more (Chiroleu-Assouline and Fodha 2014; Caron and others 2018; McFarland and others 2018; Böhringer and others 2021).

Goulder and Hafstead (2018) compare the output costs for the US from an economy-wide carbon tax starting at $25 a ton in 2020 (and increasing by 5 percent annually until 2050) in six leading models under three common recycling plans (see Table 3.1.1). This would imply a carbon price reaching close to $38 a ton in 2030 or about half of the $75 a ton tax analyzed in this chapter across advanced economies.[4] Under a lump-sum recycling scheme, model averaging would suggest a cost of 1.2 percent of GDP by 2030 in the US, similar in scale to results from the Global Macroeconomic Model for the Energy Transition (GMMET) in advanced economies. Under a labor income tax cut, model averaging would imply a 0.6 percent loss in GDP by 2030, while the GMMET suggests essentially no loss in output over this horizon, thanks to an increase in labor supply.

[4]With a linear approximation assumed, results in Table 3.1.1 could be multiplied by 2 to reflect the impact of a carbon tax that is twice as high as in the experiment conducted in the study.

Box 3.1 *(continued)*

The use of comprehensive policy packages and coordinated approaches to drive the green transition can help reduce short-term output costs. Complementing carbon taxes with green public investments can boost aggregate demand in the short term and reduce energy supply bottlenecks (October 2020 *World Economic Outlook*, Chapter 3; Pahle and others 2022). Internationally coordinated policy action, for instance, through an international carbon price floor arrangement in which emission reduction obligations are equitably differentiated by countries' level of development, would address concerns about carbon leakage and competitiveness impacts on energy-intensive and trade-exposed industries that would arise from unilateral or uncoordinated action (Parry, Black, and Roaf 2021; Chateau, Jaumotte, and Schwerhoff 2022b). Finally, how central banks respond to the climate-policy-related supply shock can affect the magnitude of the output and inflation effects (McKibbin and others 2020).

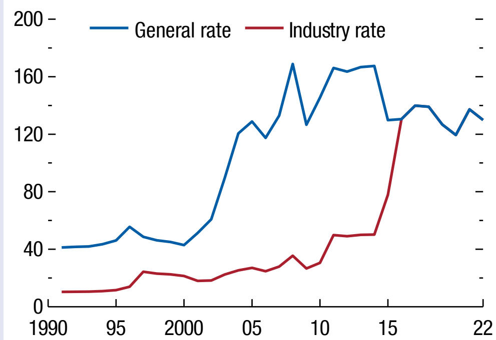
Box 3.2. Political Economy of Carbon Pricing: Experiences from South Africa, Sweden, and Uruguay

This box examines the political economy of the introduction of carbon pricing in very different countries: one advanced economy and two emerging market economies. The long-standing experience of Sweden shows that with a judicious policy design that includes *gradualism*, strong *distributional incentives,* and a *rules-based and transparent framework,* a credible mitigation strategy involving carbon pricing is possible (Nemet and others 2017). More recently, South Africa, a highly fossil-fuel-dependent economy, and Uruguay embarked on decarbonization using similar strategies. It is worth emphasizing that—for all economies—climate mitigation policies can be effective only if they are deemed credible. Sudden departures from previously announced policies—analogous to Australia's carbon tax reversal in 2014—undermine policy credibility. Also, gradual and distribution-friendly policies are more likely to overcome political resistance (France's Yellow Vests movement is a counterexample).

Sweden became, in 1991, one of the first countries in the world to introduce a carbon tax (Andersson 2019; Jonsson, Ydstedt, and Asen 2020). While environmental taxes were already part of the Swedish tax system prior to the carbon tax, strengthening political buy-in for the carbon tax required a *gradual* implementation and the use of *distributional incentives*, notably exemptions. Sweden's carbon tax rate started at a low level and increased to $130 a ton (as of 2022, and covering 40 percent of total emissions), giving society time to adapt and thereby minimizing the overall economic impact (Figure 3.2.1). The inclusion of exemptions—motivated by concerns about carbon leakage and international competitiveness—also strengthened political support for the tax by making the carbon tax regime more *robust to resistance from different sectoral interests*. For example, in its early phase, the carbon tax regime had two tiers, with some carbon-intensive and trade-exposed industries fully exempt (for example, steel), while others faced a tax rate as low as 25 percent of the general carbon tax rate (for example, mining, agriculture) (Figure 3.2.1). Most exemptions were finally removed in 2019. While the carbon tax revenues were not directly earmarked in Sweden's budget, a reduction in labor income taxes was implemented alongside the imposition of the carbon tax, in effect recycling carbon tax revenues to help improve efficiency.

The author of this box is Augustus J. Panton.

Figure 3.2.1. Carbon Price in Sweden
(US dollars a tCO_2e)



Source: World Bank (2022).
Note: tCO_2e = metric ton of carbon dioxide equivalent.

Over the years, Sweden has strengthened the credibility of its climate policy by defining a clear climate mitigation target that is *rules-based and transparent*, as articulated in the 2018 Climate Act of the Riksdag (Swedish parliament). Transitional rules-based targets (for example, 63 percent emission reduction by 2030 relative to 1990 levels) and a predefined provision for national review of progress every four years—entrusted to an independent body of scientific experts, the *Swedish Climate Policy Council*—support the national goal of reaching net-zero emissions by 2045.

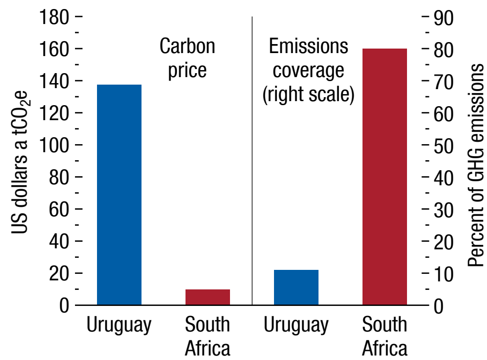
South Africa, one of the world's most fossil-fuel-dependent economies, became the first African country in 2019 to implement a formal carbon-pricing regime, with a carbon tax rate starting at $9.20 a ton of carbon dioxide and covering 80 percent of total emissions (Figure 3.2.2; World Bank 2022). The tax was largely premised on positioning the South African economy to be competitive and compliant with potential climate-related trade restrictions (for example, border carbon adjustment) (South African National Treasury 2013). The national Integrated Resource Plan, focused on decarbonizing the electricity sector, and the Green Transport Strategy complement the carbon tax, thus creating a *robust strategy* and *mix of policy instruments* to drive the green transition. Given the South African economy's high fossil fuel dependence, the need for strong political incentives to galvanize support cannot be overemphasized. As in the Swedish two-tier carbon tax regime, the transitional phase (2020–25) is characterized by *strong distributional*

Box 3.2 *(continued)*

incentives aimed at gradually transitioning people and firms to a low-carbon economy. During this phase, carbon-tax-free allowances range from 60 to 95 percent of firms' emissions, with a further 10 percent for trade-exposed firms. Other transitional incentives, such as an electricity price neutrality commitment (that is, offsets to make electricity prices carbon-tax-neutral), have been put in place to get buy-in from energy-intensive sectors (for example, steel). Also, while the tax is integrated within a carbon budget framework (that is, caps on emissions over a given period), the enforcement of carbon budgets is expected only after the transition period. While distributional incentives, including tax-free emission allowances, are critical for broadening political support in the early stages of carbon pricing, their eventual removal must be well telegraphed to anchor expectations. In this context, the extension of the transitional phase of South Africa's carbon tax to 2025 (instead of the end of 2022, as initially announced) risks weakening credibility, locking in fossil fuel investments while undermining green private investments. Furthermore, the exemption of Eskom, the state-owned power company and South Africa's largest emitter, from the carbon tax strongly weakens the carbon tax regime's effectiveness. It is also worth noting that the full implementation of South Africa's climate mitigation agenda is conditional on the country's receiving external climate finance support, including the 2021 United Nations Climate Change Conference (COP26) commitment by the European Union, France, Germany, the United Kingdom, and the United States to finance South Africa's transition away from coal. Such conditionality creates uncertainty regarding the future direction of policy, weakening credibility. The establishment in 2020 of the *Presidential Climate Commission* is a step in the right direction for strengthening credibility. Further insulating the commission from political influence would help increase *transparency* and *trust* in the green transition.

Uruguay embarked on a carbon-pricing journey earlier this year by converting its gasoline excise tax regime into a formal carbon tax, with the 2022 tax rate set at $137 a ton of carbon dioxide. Despite the lower coverage in terms of total greenhouse gas emissions, the tax covers about half of carbon dioxide emissions (Figure 3.2.2). While not resorting to exemptions—reflecting the low share of carbon emissions in total greenhouse gas emissions—Uruguay is earmarking a portion of the carbon tax revenues to be spent on a different set of *incentives*, including subsidies for purchases of electric vehicles

Figure 3.2.2. Carbon Price and Emissions Coverage, 2022



Source: World Bank (2022).
Note: GHG = greenhouse gas; tCO_2e = metric ton of carbon dioxide equivalent.

and investment in green public transport.[1] Whether these incentives are enough to broaden support for further stringency in the carbon tax—currently applied only to gasoline—remains to be seen.

Uruguay passed into law a carbon tax bill in November of last year, but challenges to the credibility of further advances in this direction remain. The lack of a rules-based mitigation path, specifically indicating how and the conditions under which the country's sectoral emission intensity targets would be adjusted, could create uncertainty for long-term private investment decisions. Uruguay's climate mitigation agenda would not be fully implemented without external climate finance support, adding to uncertainty. Finally, while the country's carbon tax framework is still in its infancy, delegating the periodic evaluation of climate policy and progress to an independent body would enhance transparency and trust.[2] Such transparency would be crucial not just locally but also internationally, given the Uruguayan government's plan for issuing sustainability-linked sovereign bonds tied to its climate mitigation agenda.

In sum, while a one-size-fits-all climate mitigation strategy does not exist, the experiences of these countries suggest that starting at a gradual pace, using targeted incentives and redistribution arrangements, can help establish a credible mitigation program and ease resistance to the use of carbon taxes for green transition.

[1]See the IMF Article IV Consultation for Uruguay (IMF 2021).
[2]Uruguay's new Sovereign Sustainability-Linked Bond Framework, launched on September 20, 2022, would help in that direction.

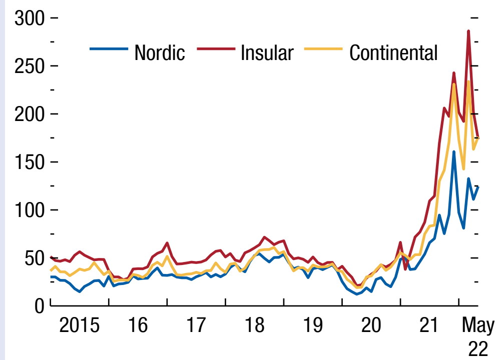
Box 3.3. Decarbonizing the Power Sector while Managing Renewables' Intermittence

Intermittent renewables, such as solar and wind, will be a key component of power sector decarbonization. Their penetration has already increased steadily over the past two decades, surpassing 20 percent in some countries, amid a favorable policy environment and rapidly falling capital costs. To bring emissions in line with the 2°C goal, simulations discussed in this chapter suggest that intermittent-renewables penetration will need to grow further and reach between 34 and 47 percent of power generation by 2030.

Intermittence presents challenges to electricity price variability and power system stability. Since storing electricity at grid scale remains very expensive, power systems need to be balanced at every point in time, with generation continuously matching fluctuating electricity demand. Power plants are turned on to satisfy demand, and priority is given to those with the lowest cost of production. Because renewables' cost of production is close to zero, as their fuel is free (for example, wind, sun), they will always be prioritized to supply electricity. Where electricity markets follow marginal pricing,[1] electricity prices will be pushed down—as costlier units are forced to turn off—and can even reach zero in the hours renewables produce enough electricity to satisfy demand and become the marginal unit.[2] Conversely, when renewables do not produce enough to satisfy demand, electricity prices can jump sharply, particularly if the sources for the marginal units that need to be turned on to satisfy demand have a high cost of production. As the availability of wind and solar varies within a day and across days and seasons, intermittence can lead to price volatility.

Several measures, including enhanced electricity grid interconnections and low-cost backup technologies, have dampened intermittence's impact on price variability so far. In Europe, price volatility from intermittence has remained limited. Before the pandemic, monthly price variability was similar in countries with high and low penetration of intermittent renewables (Figure 3.3.1). To increase the penetration of intermittent renewables while avoiding sharp swings

Figure 3.3.1. Monthly Wholesale Electricity Prices in Selected European Economies
(Euros a megawatt-hour)



Sources: European Network of Transmission System Operators for Electricity; and IMF staff calculations.
Note: Country grouping reflects the degree of grid interconnectedness. "Insular" countries (Ireland, Portugal, Spain) have limited interconnections with continental Europe and have high gas dependence (32 percent of generation in 2019) and high renewables penetration (29 percent). "Continental" countries are well interconnected, with high penetration of renewables (23 percent) and high dependence on gas (16 percent). "Nordic" countries (Denmark, Finland, Norway, Sweden) constitute a well-interconnected group and use hydro as a backup for renewables (12 percent of production), with low gas dependence (2.6 percent).

in electricity prices, countries have adopted a multipronged approach, including by ensuring greater interconnection of electricity grids, which allows surplus production from renewables to satisfy demand in neighboring countries (for example, Denmark), or by using low-cost backup technologies—such as hydro (for example, Norway) or gas power plants (for example, Spain). Indeed, low gas prices allowed backup gas power plants to run at low cost when production from renewables dropped, limiting price variability. Between 2015 and 2019, electricity prices remained low and varied little day to day, getting closer to zero when renewables accounted for larger shares of electricity generation, but staying low even on days with low renewables penetration, as the cost of backup gas units remained low (blue circles in Figure 3.3.2).

This stability contrasts with the high volatility that has come from disruption in gas supplies during Russia's recent invasion of Ukraine. Electricity prices have risen sharply on wholesale markets amid recent gas price spikes, including in countries that rely more

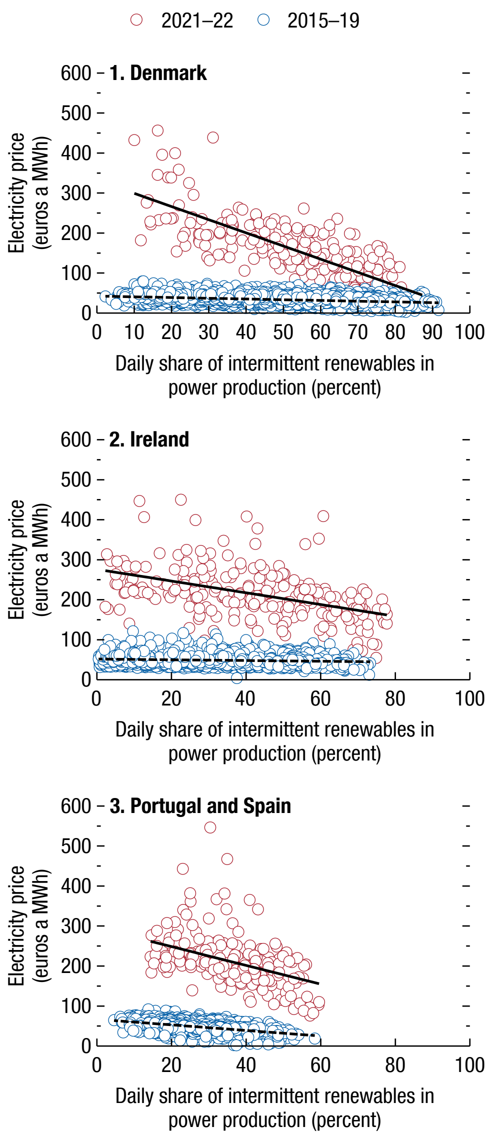
The author of this box is Mehdi Benatiya Andaloussi.

[1]In such markets, wholesale electricity prices are set equal to the operational cost of the costliest unit among those selected to satisfy demand at any point in time.

[2]An emerging body of literature documents that wind and solar generation push wholesale electricity prices down, having done so, for instance, in Australia (Csereklyei, Qu, and Ancev 2019), California (Bushnell and Novan 2018), and Europe (Halttunen and others 2020).

Box 3.3 *(continued)*

Figure 3.3.2. Daily Electricity Prices in Selected European Countries as a Function of Share of Renewables in Power Production



Sources: European Network of Transmission System Operators for Electricity; and IMF staff calculations.
Note: The solid and dashed lines represent the linear fit. MWh = megawatt-hour.

heavily on intermittent renewables, such as Denmark, Ireland, Portugal, and Spain. But where renewables are backed up by hydro (for example, Norway and Sweden), price volatility has increased only partly in response to the gas price spike (see Figure 3.3.1).[3] Furthermore, price volatility has increased sharply in countries that have high penetrations of renewables and use gas as a backup. At the end of 2021 and in 2022, as gas prices have surged, the cost of production of electricity from gas units has climbed, leading to high electricity prices when gas units have become marginal on days with low generation from renewables, while prices have pointed downward on days with high penetration from renewables (red circles in Figure 3.3.2). That has been true even where gas represents only a small share of generation, as in Denmark—where it accounts for less than 10 percent of production, whereas wind represented close to 60 percent of power production in 2021—since prices are set for the whole market by the marginal unit. Gas power plants were envisioned as becoming the choice of backup that would allow greater penetration of renewables. Yet, this choice risks exposing electricity prices to price swings in gas markets.

Looking ahead, decarbonizing the power sector will require a system-wide approach. As many sectors turn to electricity, electricity prices will become ever more central to price setting in vast swaths of the economy. Ensuring affordable and reliable electricity is thus crucial. Sector-level regulations and investment will be needed to accommodate higher intermittent-renewables penetration. These could include regulations to ensure adequate investment in backup capacity (for example, capacity markets), demand management to align peak demand with peak supply from renewables (for example, time-of-day pricing), public investment in grid interconnections, and support for research and development on storage (including from electric vehicles) and low-cost dispatchable backup technologies (for example, hydrogen, modular nuclear power plants) (see, for instance, ACER 2022; Green 2021; and Cleary, Fischer, and Palmer 2021). Further investment will also be needed to limit price volatility in gas markets (for example, liquid natural gas terminals). Finally, using a diversified mix of decarbonized power sources (for example, renewables, hydropower, and nuclear energy) will enhance power sector resilience.

[3]Pass-through to retail electricity prices has been more limited so far as a result of regulations (Ari and others, 2022).

References

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hémous. 2012. "The Environment and Directed Technical Change." *American Economic Review* 102 (1): 131–66.

Agency for the Cooperation of Energy Regulators (ACER). 2022. *Final Assessment of the EU Wholesale Electricity Market Design*. Ljublana, Slovenia.

Andersson, Julius J. 2019. "Carbon Taxes and CO_2 Emissions: Sweden as a Case Study." *American Economic Journal: Economic Policy* 11 (4): 1–30. https://www.aeaweb.org/articles?id=10.1257/pol.20170144.

Ari, Anil, Nicolas Arregui, Simon Black, Oya Celasun, Dora Iakova, Aiko Mineshima, Victor Mylonas, and others. 2022. "Surging Energy Prices in Europe in the Aftermath of the War: How to Support the Vulnerable and Speed Up the Transition away from Fossil Fuels." IMF Working Paper 22/152, International Monetary Fund, Washington, DC.

Bayer, Patrick, and Michael Aklin. 2020. "The European Union Emissions Trading System Reduced CO_2 Emissions Despite Low Prices." *Proceedings of the National Academy of Sciences of the United States of America* 117 (16): 8804–12. https://www.pnas.org/doi/10.1073/pnas.1918128117.

Black, Simon, Danielle Minnett, Ian Parry, James Roaf, and Karlygash Zhunussova. 2022. "The Carbon Price Equivalence of Climate Mitigation Policies." Unpublished, International Monetary Fund, Washington, DC.

Black, Simon, Ian Parry, James Roaf, and Karlygash Zhunussova. 2021. "Not Yet on Track to Net Zero: The Urgent Need for Greater Ambition and Policy Action to Achieve Paris Temperature Goals." IMF Staff Climate Note 2021/005, International Monetary Fund, Washington, DC.

Blanchard, Olivier, and Jordi Galí. 2007. "The Macroeconomic Effects of Oil Shocks: Why Are the 2000s So Different from the 1970s?" NBER Working Paper 13368, National Bureau of Economic Research, Cambridge, MA.

Böhringer, Christoph, Sonja Peterson, Thomas Rutherford, Jan Schneider, and Malte Winkler. 2021. "Climate Policies after Paris: Pledge, Trade and Recycle; Insights from the 36th Energy Modeling Forum Study (EMF36)." *Energy Economics* 103: 105471. https://doi.org/10.1016/j.eneco.2021.105471.

Brulle, Robert J. 2018. "The Climate Lobby: A Sectoral Analysis of Lobbying Spending on Climate Change in the USA, 2000 to 2016." *Climatic Change* 149 (3): 289–303.

Bushnell, James, and Kevin Novan. 2018. "Setting with the Sun: The Impacts of Renewable Energy on Wholesale Power Markets." NBER Working Paper 24980, National Bureau of Economic Research, Cambridge, MA.

Caron, Justin, Stuart M. Cohen, Maxwell Brown, and John M. Reilly. 2018. "Exploring the Impacts of a National U.S. CO_2 Tax and Revenue Recycling Options with a Coupled Electricity-Economy Model." *Climate Change Economics* 9 (1): 1840015. https://doi.org/10.1142/S2010007818400158.

Carton, Benjamin, Christopher Evans, Dirk Muir, and Simon Voigts. 2022. "Getting to Know GMMET: The Theoretical Structure and Simulation Properties of the Global Macroeconomic Model for the Energy Transition." Unpublished, International Monetary Fund, Washington, DC.

Castillo, Paul, Carlos Montoro, and Vicente Tuesta. 2007. "Inflation Premium and Oil Price Volatility." CEP Discussion Paper 782, Centre for Economic Performance, London School of Economics and Political Science, London, UK.

Chateau, Jean, Florence Jaumotte, and Gregor Schwerhoff. 2022a. "Climate Policy Options: A Comparison of Economic Performance." Unpublished, International Monetary Fund, Washington, DC.

Chateau, Jean, Florence Jaumotte, and Gregor Schwerhoff. 2022b. "Economic and Environmental Benefits from International Cooperation on Climate Policies." IMF Departmental Paper 2022/007, International Monetary Fund, Washington, DC.

Chiroleu-Assouline, Mireille, and Mouez Fodha. 2014. "From Regressive Pollution Taxes to Progressive Environmental Tax Reforms." *European Economic Review* 69: 126–42.

Cleary, Kathryne, Carolyn Fischer, and Karen Palmer. 2021. "Tools and Policies to Promote Decarbonization of the Electricity Sector." In *Handbook on Electricity Markets*, edited by Jean-Michel Glachant, Paul L. Joskow, and Michael G. Pollitt, 383–407. Cheltenham, UK: Elgar. https://econpapers.repec.org/bookchap/elgeechap/18895_5f14.htm.

Csereklyei, Zsuzsanna, Songze Qu, and Tihomir Ancev. 2019. "The Effect of Wind and Solar Power Generation on Wholesale Electricity Prices in Australia." *Energy Policy* 131: 358–69. https://doi.org/10.1016/j.enpol.2019.04.007.

Ferreira, Caio, David Lukáš Rozumek, Ranjit Singh, and Felix Suntheim. 2021. "Strengthening the Climate Information Architecture." IMF Staff Climate Note 2021/003, International Monetary Fund, Washington, DC.

Galí, Jordi. 2015. *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications.* 2nd ed. Princeton, NJ: Princeton University Press.

Goulder, Lawrence H., and Marc A. C. Hafstead. 2018. *Confronting the Climate Challenge: U.S. Policy Options.* New York: Columbia University Press.

Goulder, Lawrence H., Marc A. C. Hafstead, GyuRim Kim, and Xianling Long. 2019. "Impacts of a Carbon Tax across US Household Income Groups: What Are the Equity-Efficiency Trade-Offs?" *Journal of Public Economics* 175: 44–64. https://doi.org/10.1016/j.jpubeco.2019.04.002.

Green, Richard. 2021. "Shifting Supply as Well as Demand: The New Economics of Electricity with High Renewables." In *Handbook on Electricity Markets*, edited by Jean-Michel Glachant, Paul L. Joskow, and Michael G. Pollitt, 408–27. Cheltenham, UK: Elgar. https://econpapers.repec.org/bookchap/elgeechap/18895_5f15.htm.

Halttunen, Krista, Iain Staffell, Raphael Slade, Richard Green, Yves-Marie Saint-Drenan, and Malte Jansen. 2020. "Global Assessment of the Merit-Order Effect and Revenue Cannibalisation for Variable Renewable Energy." Preprint, posted December 2, 2020. https://ssrn.com/abstract=3741232.

Intergovernmental Panel on Climate Change (IPCC). 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Hans-O. Pörtner, Debra C. Roberts, Melinda Tignor, Elvira S. Poloczanska, Katja Mintenbeck, Andrés Alegría, Marlies Craig, and others. Geneva, Switzerland.

International Energy Agency (IEA). 2021. *World Energy Outlook 2021*. Paris, France. https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf.

International Monetary Fund (IMF). 2021. "Uruguay: Staff Report for the 2021 Article IV Consultation." International Monetary Fund, Washington, DC. https://www.imf.org/en/Publications/CR/Issues/2022/01/25/Uruguay-2021-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-the-512205.

Jonsson, Samuel, Anders Ydstedt, and Elke Asen. 2020. "Looking Back on 30 Years of Carbon Taxes in Sweden." Fiscal Fact 727, Tax Foundation, Washington, DC. https://taxfoundation.org/sweden-carbon-tax-revenue-greenhouse-gas-emissions.

Keen, Stephen, Timothy M. Lenton, Antoine Godin, Devrim Yilmaz, Matheus Grasselli, and Timothy J. Garrett. 2021. "Economists' Erroneous Estimates of Damages from Climate Change." arXiv preprint arXiv:2108.07847.

Konradt, Maximillian, and Beatrice Weder di Mauro. 2021. "Carbon Taxation and Greenflation: Evidence from Europe and Canada." CEPR Discussion Paper 16396, Centre for Economic Policy Research, London.

Kydland, Finn E., and Edward C. Prescott. 1977. "Rules Rather Than Discretion: The Inconsistency of Optimal Plans." *The Journal of Political Economy* 85 (3): 473–92.

Lenton, Timothy M., Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen, and Hans Joachim Schellnhuber. 2019. "Climate Tipping Points—Too Risky to Bet Against." *Nature* 575 (7784): 592–95.

Martin, Ralf, Laure B. de Preux, and Ulrich J. Wagner. 2014. "The Impact of a Carbon Tax on Manufacturing: Evidence from Microdata." *Journal of Public Economics* 117: 1–14. https://www.sciencedirect.com/science/article/pii/S0047272714001078.

Maximilian Konradt and Beatrice Weder di Mauro. 2022. "Carbon Taxation and Greenflation: Evidence from Europe and Canada." CEPR Discussion Paper No. DP16396. Centre for Economic Policy Research, London.

McFarland, James R., Allen A. Fawcett, Adele C. Morris, John M. Reilly, and Peter J. Wilcoxen. 2018. "Overview of the EMF 32 Study on US Carbon Tax Scenarios." *Climate Change Economics* 9 (1): 1840002. https://doi.org/10.1142/S201000781840002X.

McKibbin, Warwick J., Adele C. Morris, Peter J. Wilcoxen, and Augustus J. Panton. 2020. "Climate Change and Monetary Policy: Issues for Policy Design and Modelling." *Oxford Review of Economic Policy* 36 (3): 579–603. https://doi.org/10.1093/oxrep/graa040.

McKibbin, Warwick J., and Peter J. Wilcoxen. 2013. "A Global Approach to Energy and the Environment: The G-Cubed Model." In *Handbook of Computable General Equilibrium Modeling*, Vol. 1A, edited by Peter B. Dixon and Dale W. Jorgenson, 995–1068. North Holland, Netherlands: Elsevier.

Metcalf, Gilbert E., and James H. Stock. 2020. "The Macroeconomic Impact of Europe's Carbon Taxes." NBER Working Paper 27488, National Bureau of Economic Research, Cambridge, MA.

Mirzoev, Tokhir N., Ling Zhu, Yang Yang, Andrea Pescatori, and Akito Matsumoto. 2020. "The Future of Oil and Fiscal Sustainability in the GCC Region." IMF Departmental Paper 20/01, International Monetary Fund, Washington, DC.

Morawiecki, Mateusz. 2022. "Polish PM: The Green Transition Cannot Come at the Cost of European Security." *Financial Times*, July 4. https://www.ft.com/content/3d592adc-b0b0-4098-8616-9d615c9fcde5.

Morison, Rachel. 2021. "The Climate-Change Fight Is Adding to the Global Inflation Scare." Bloomberg, June 18. https://www.bloomberg.com/news/articles/2021-06-18/the-climate-change-fight-is-adding-to-the-global-inflation-scare#xj4y7vzkg.

Murray, Brian C., and Peter T. Maniloff. 2015. "Why Have Greenhouse Emissions in RGGI States Declined? An Econometric Attribution to Economic, Energy Market, and Policy Factors." *Energy Economics* 51: 581–89.

Nakov, Anton, and Andrea Pescatori. 2010. "Monetary Policy Trade-Offs with a Dominant Oil Producer." *Journal of Money, Credit and Banking* 42 (1): 1–32.

Natal, Jean-Marc. 2012. "Monetary Policy Response to Oil Price Shocks." *Journal of Money, Credit and Banking* 44 (1): 53–101.

Nemet, Gregory F., Michael Jakob, Jan Christoph Steckel, and Ottmar Edenhofer. 2017. "Addressing Policy Credibility Problems for Low-Carbon Investment." *Global Environmental Change* 42: 47–57.

Network for Greening the Financial System (NGFS). 2022. "Running the NGFS Scenarios in G-Cubed: A Tale of Two Modelling Frameworks." NGFS Occasional Paper, Banque de France, Paris, France. https://www.ngfs.net/sites/default/files/medias/documents/running_the_ngfs_scenarios_in_g-cubed_a_tale_of_two_modelling_frameworks.pdf.

Pahle, Michael, Oliver Tietjen, Sebastian Osorio, Florian Egli, Bjarne Steffen, Tobias Schmidt, and Ottmar Edenhofer. 2022. "Safeguarding the Energy Transition against Political Backlash to Carbon Markets." *Nature Energy* 7 (3): 290–96. https://doi.org/10.1038/s41560-022-00984-0.

Parry, Ian, Simon Black, and James Roaf. 2021. "Proposal for an International Carbon Price Floor among Large Emitters." IMF Staff Climate Note 2021/001, International Monetary Fund, Washington, DC. https://www.imf.org/-/media/Files/Publications/Staff-Climate-Notes/2021/English/CLNEA2021001.ashx.

Petrick, Sebastian, and Ulrich J. Wagner. 2014. "The Impact of Carbon Trading on Industry: Evidence from German Manufacturing Firms." Kiel Working Paper 1912, Kiel Institute for the World Economy, Kiel, Germany. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2389800.

Pisani-Ferry, Jean. 2021. "Climate Policy Is Macroeconomic Policy, and the Implications Will Be Significant." Policy Brief 21-20, Peterson Institute for International Economics, Washington, DC.

Schnabel, Isabel. 2022. "A New Age of Energy Inflation: Climateflation, Fossilflation and Greenflation." Speech delivered at "Monetary Policy and Climate Change" panel, 22nd "The ECB and Its Watchers" Conference, Frankfurt am Main, March 17. https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220317_2~dbb3582f0a.en.html.

South African National Treasury. 2013. "Reducing Greenhouse Gas Emissions and Facilitating the Transition to a Green Economy." Carbon Tax Policy Paper, Pretoria. http://www.treasury.gov.za/public%20comments/Carbon%20Tax%20Policy%20Paper%202013.pdf.

United Nations Environment Programme (UNEP) and UNEP Copenhagen Climate Centre (UNEP-CCC). 2021. *Emissions Gap Report 2021: The Heat Is On; A World of Climate Promises Not Yet Delivered*. Nairobi, Kenya.

Wagner, Ulrich, Mirabelle Muûls, Ralf Martin, and Jonathan Colmer. 2014. "The Causal Effects of the European Union Emissions Trading Scheme: Evidence from French Manufacturing Plants." Paper presented at the IZA Institute of Labor Economics workshop "Labor Market Effects of Environmental Policies," Bonn, Germany, September 4–5. https://conference.iza.org/conference_files/EnvEmpl2014/martin_r7617.pdf.

Walker, W. Reed. 2011. "Environmental Regulation and Labor Reallocation: Evidence from the Clean Air Act." *American Economic Review* 101 (3): 442–47.

Williams III, Roberton C., Hal Gordon, Dallas Burtraw, Jared C. Carbone, and Richard D. Morgenstern. 2015. "The Initial Incidence of a Carbon Tax across Income Groups." *National Tax Journal* 68 (1): 195–213. https://doi.org/10.17310/ntj.2015.1.09.

Woodford, Michael. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton, NJ: Princeton University Press.

World Bank. 2022. "Carbon Pricing Dashboard." Washington DC. https://carbonpricingdashboard.worldbank.org/map_data.

Yamazaki, Akio. 2017. "Jobs and Climate Policy: Evidence from British Columbia's *Revenue-Neutral* Carbon Tax." *Journal of Environmental Economics and Management* 83: 197–216.