EXECUTIVE BOARD MEETING

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September 12, 2019

To: Members of the Executive Board

From: The Secretary

Subject: **October 2019 Fiscal Monitor**

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Tentative Board Date:	**Thursday, October 3, 2019**
Publication:	Yes, it is intended that the Fiscal Monitor will be released to the public at the time of the Fiscal Monitor press conference, tentatively scheduled for **Wednesday, October 16, 2019**.
Questions:	Mr. Mauro, FAD (ext. 37718) Ms. Pattillo, FAD (ext. 37319) Mr. Parry, FAD (ext. 39724)
Additional Information:	The paper will be revised for publication in light of the Executive Board discussion. If Executive Directors have additional comments, they should notify Mr. Mauro, Ms. Pattillo, and Mr. Parry by **5:30 p.m. on Monday, September 30, 2019**.

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HOW TO MITIGATE CLIMATE CHANGE

Prepared by the Fiscal Affairs Department
In consultation with the other departments
Approved by Vitor Gaspar
September 12, 2019

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EXECUTIVE SUMMARY

Global warming is threatening our planet and living standards around the world, and the window of opportunity for containing climate change to manageable levels is closing rapidly. Carbon dioxide (CO_2) emissions are a key driver of this alarming trend. Fiscal policy has an important role to play. This issue of the *Fiscal Monitor* argues that policymakers need to act urgently to mitigate climate change and thus reduce its damaging and deadly effects, including rising sea levels and coastal flooding, more frequent extreme weather events, and disruption to our food supply—key issues affecting all people globally.

Action to date has been inadequate. The 2015 Paris Agreement goes in the right direction, but the commitments countries have made fall well short of those needed to limit global warming to the level considered safe by scientists—2°C, at most, above preindustrial temperatures. Furthermore, it remains uncertain whether countries are reducing emissions as agreed. The longer policy action is delayed, the more emissions will accumulate in the atmosphere and the greater the cost of stabilizing global temperatures—let alone of failing to do so. A better future is possible. The technological and policy means are available to switch from coal and other polluting fossil fuels to cleaner energy while maintaining robust economic growth and creating jobs. For the needed transformation to take place, a key challenge is to distribute its costs and benefits in a manner that can muster enough political support—both domestically and internationally.

Fiscal Policies to Mitigate Climate Change

This *Fiscal Monitor* argues that, of the various mitigation strategies to reduce fossil fuel CO_2 emissions, carbon taxes—levied on the supply of fossil fuels (for example, from oil refineries, coal mines, processing plants) in proportion to their carbon content—are the most powerful and efficient, because they allow firms and households to find the lowest-cost ways of reducing energy use and shifting toward cleaner alternatives. The burden of the tax in proportion to household consumption is moderately larger for lower-income households than for higher-income households in some countries (for example, China and the United States), but roughly equal or slightly smaller in others (Canada, India).

This chapter analyzes the carbon prices countries must impose to implement their mitigation strategies and the tradeoffs with other mitigation instruments. Limiting global warming to 2°C or less requires policy measures on an ambitious scale, such as an immediate global carbon tax that will rise rapidly to $75 a ton of CO_2 in 2030. Under such a scenario, over 10 years electricity prices would rise, on average, by 45 percent cumulatively and gasoline prices by 15 percent, for households, compared with the baseline (no policy action). The revenue from such a tax (1.5 percent of GDP in 2030, on average, for the Group of Twenty (G20) countries) could be redistributed, for example, to assist low-income households, support disproportionately affected workers or communities (for example, coal-mining areas), cut other taxes, fund investment in clean energy infrastructure or United Nations Sustainable Development Goals, reduce fiscal deficits, or pay an equal dividend to the whole population. This *Fiscal Monitor* compares such uses of the revenues in terms of economic efficiency and impact on income distribution. For example, carbon pricing combined with an equal dividend to the whole population rather than an income tax cut redistributes income to favor lower-income groups but forgoes gains in economic efficiency. An intermediate approach compensating, say, the poorest 40 percent of households, as well as vulnerable workers and communities, leaves three quarters of the revenues for other goals such as productive investments or cuts in income taxes.

The shift from fossil fuels will not only transform an economy but also profoundly change the lives of households, businesses, and communities. Importantly, the shift would generate additional and immediate domestic environmental benefits, such as lower mortality from air pollution (725,000 fewer premature deaths in 2030 for a $75 tax for G20 countries alone). Businesses that deploy new technologies would earn profits and create jobs, which in the renewables sector already reached 11 million globally in 2017.

If carbon taxation is not feasible, emission trading systems (auctioning or allocating emission permits that are then traded) would be equally effective if applied to as wide a range of economic activities. If neither of these mitigation strategies is available on the necessary scale, "feebates" (systems of fees and rebates on products or activities with above or below average emissions intensity) or regulations (for example, standards for emission rates and energy efficiency) could generate two thirds of the CO_2 reduction opportunities of carbon taxation. Feebates and regulations prompt people and firms to switch to greener energy but do not discourage activities that use energy. To deliver the full scale of necessary emission reduction, feebates or regulations would need to be used more aggressively, causing greater disruption to existing production processes. The economic costs of mitigating climate change through less-than-optimal tools would still be lower than the devastating effects of global warming.

International Cooperation for a Shared Future

Some advanced and emerging market economies already use carbon taxes and emission trading systems, but insufficiently. Indeed, the average price on global emissions is currently $2 a ton, a tiny fraction of what is needed for the 2°C target. An early start to reinforce the Paris process could be made through a carbon price floor arrangement among countries with the largest emissions. This would provide a transparent target based on a common measure and reassurance against losses in international competitiveness from higher energy costs. If the top three emitters (China, United States, India) participated, such an agreement would already cover more than half of global emissions. Low-income and emerging economies could be provided with a lower floor or international transfers. The arrangement could accommodate different policy approaches (for example, national level emission trading systems, feebates, or regulatory approaches) with agreement on verification procedures.

Meeting temperature stabilization goals does not mean that overall global energy investment must increase much further, but it does imply an urgent need to shift energy supply investment toward low-carbon sources. This is because the infrastructure built today will determine emission levels for decades. Additional policies are needed, such as incentives for research and development, temporary fiscal incentives to promote demand for low-emission technologies until they yield sufficient economies of scale, and green bond markets to facilitate access to private capital. Businesses that are considering longer term investments, such as for power generation, must be certain about future tax and regulatory policies, so policymakers should lock in mitigation policies for as long as possible, including making commitments to the global community.

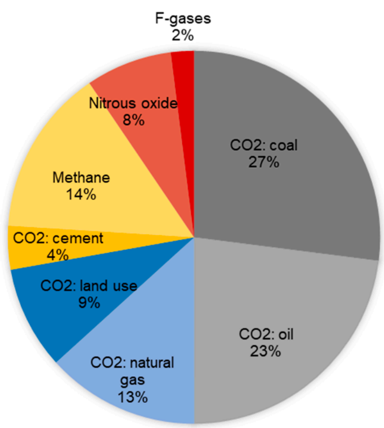
Different policy tools have pros and cons, but the climate crisis is urgent and existential, calling on key stakeholders to deploy all appropriate policy measures. Finance ministers can confront this crisis by undertaking carbon taxation or similar policies, making climate change mitigation more acceptable through complementary tax or expenditure measures, ensuring adequate budgeting for clean technology investment, and coordinating strategies internationally.

I. Introduction

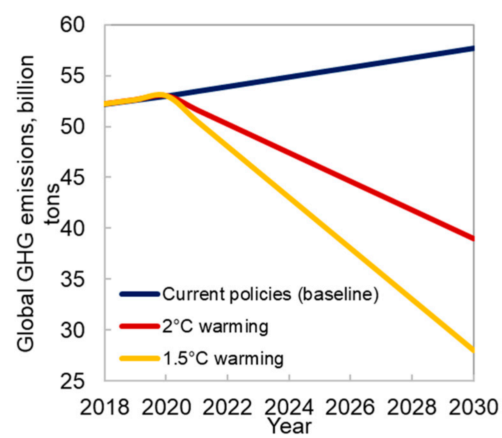
Without substantial mitigation of greenhouse gas emissions, global temperatures are projected to rise by around 4°C above pre-industrial levels by 2100 (they have already increased by 1°C since 1900).[1] Global warming causes major damage to the global economy and the natural world and engenders risks of catastrophic and irreversible outcomes such as rising sea levels, extreme weather events (already more frequent) leading to loss of life, and the possibility of much higher warming scenarios.[2] Carbon dioxide (CO_2) emissions from fossil fuel combustion account for a dominant (63 percent) and growing share of global greenhouse gas emissions and are the most immediately practical to control (Figure 1.1, panel 1).[3] Policy action is thus urgently needed to curtail emissions. The longer action is delayed, the greater the accumulation in the atmosphere, and the more abrupt and costly will be the necessary action to stabilize global temperatures.

Figure 1.1. The Global Mitigation Challenge

1. Global GHG Emissions Share, 2016



2. Emission Pathways and Warming Goals



Sources: Panel 1: Le Quéré and others (2018); Tollefson (2018). Panel 2: CAT (2018) (based on scientific studies of the relationship between emissions, atmospheric GHG concentrations, and temperature summarized in IPCC 2018).
Note: In panel 1 oil includes international aviation and maritime emissions. Methane emissions are from extractive industries, landfills, and agriculture; nitrous oxide from agriculture and industrial processes; and fluorinated (F-) gases used, for example, in refrigerants and aerosols. Land use refers to net CO_2 emissions from forestry and agricultural practices. GHG = greenhouse gas.

The transition toward cleaner energy sources and reduced energy consumption requires overcoming externalities both at home and internationally. (Externalities occur when individuals affect others through their actions but do not pay a price for doing so.) Domestically, firms and households are not charged for the greenhouse gases they release through the combustion of fossil fuels and other sources. Likewise, greenhouse gases released by individual countries affect the global climate, and no country can solve the problem alone. Domestic policies are thus needed to give people and businesses greater incentives

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[1] For temperature projections see Stocker and others (2013), who predict warming of 3.4°C to 5.6°C by 2100 in a scenario of high future emissions growth, and Nordhaus (2018).

[2] See, for example, IPCC (2018), Murray (2019), NAS (2018), Nordhaus (2018), and WEF (2019). Kahn and others (2019) show that all regions (cold or hot, advanced or developing) would experience a major decline in GDP per capita by 2100 in the absence of mitigation policies. The poor would be disproportionately hurt (IMF 2017, Hallegatte and others 2017, World Bank 2012). Rising sea levels, storm surges, and droughts and lower water availability, would cause hundreds of millions of people to migrate both within countries and across borders (World Bank 2018, IOM 2003, IPCC 2014).

[3] See Online Annex 1.1 as well as IMF (2019c) for CO_2 emission projections for 135 countries.

(through pricing or other means) to reduce emissions, without de-railing economic growth. And international cooperation is key to ensure that all countries do their part. Supporting the case for such cooperation, curbing fossil fuel use is also desirable on domestic grounds, for example, to reduce deaths from local air pollution saving millions of lives: as this *Fiscal Monitor* shows, for many countries, including large emerging market economies, the gains from fewer premature deaths caused by air pollution outweigh the costs of mitigation policies.

The shift from fossil fuels will not only transform economic production processes, it will also profoundly change the lives of many people and communities. Firms and their employees in energy-dependent sectors (such as aluminum, glass, chemicals, plastics, petroleum refining, pulp and paper, and steel), as well as people living in areas poorly served by public transportation, are vulnerable to higher energy prices. Some coal-mining communities and regions are especially at risk because of a lack of other jobs and sources of fiscal revenues. Industries, workers, and communities whose livelihood depends on fossil fuels may thus oppose reforms to mitigate climate change. Policymakers should design appropriate assistance and measures to build a better future for groups especially affected by drastic changes associated with mitigation policies.

Beyond finding ways of cooperating in the common interest and building domestic political consensus, mitigating climate change requires greater attention to the future. National governments, subject to short-term political cycles, may lack incentives to act, because the benefits of temperature stabilization extend beyond their horizon. Taking a long-term view is also challenging for voters who live paycheck to paycheck, and the gains from policies that limit global warming may seem imperceptible, at least in the near term. Businesses considering longer-term investments, such as for power generation, need certainty about future tax and regulatory policies. Stabilizing global temperature calls for an urgent shift of energy supply investments toward low-carbon sources, because the infrastructure built today will determine emissions levels for several decades (Box 1.1). Policymakers thus need to consider ways of locking-in mitigation policies for as long as possible, including commitments to the global community.

The long-term goal of the 2015 Paris Agreement is to limit projected global warming to 2°C, with an aspirational target of 1.5°C, the level deemed safe by the Intergovernmental Panel on Climate Change (IPCC 2018). Meeting even the 2°C goal requires starting to reduce greenhouse gases immediately, bringing them to a third below baseline levels by 2030 (Figure 1.1, panel 2). As a first step, 190 parties submitted climate strategies (Nationally Determined Contributions) containing mitigation targets for the Paris Agreement (Online Annex 1.2 provides more details on mitigation aspects of the agreement). Many developing economies pledged more aggressive action contingent on external financial and technical support, and it is essential that advanced economies honor their commitments under the Paris Agreement to mobilize, from 2020 onwards, $100 billion a year from public and private sources for climate projects (both mitigation and adaptation) in developing economies.[4] However, even if current mitigation commitments are fully implemented—many countries are not on track to achieve these targets and the United States intends to withdraw from the Paris Agreement in 2020—these commitments are consistent with warming of 3°C (UNEP 2018): emission reductions by 2030 would be one-third of those required for 2°C. Implementation of existing commitments is therefore a first-step priority, but mechanisms to boost action at the global level are urgently needed.[5]

[4] Quantifying financial flows is difficult, however, not least because they may partially substitute for other forms of official development assistance. For further details on the Paris Agreement see UNFCCC (2016, 2018) and Stern (2018).

[5] The next opportunity for parties to make their mitigation pledges more ambitious is in 2020 when they must submit revised Nationally Determined Contributions (Online Annex 1.2).

The key role of fiscal policies in climate change mitigation is increasingly recognized, and this chapter suggests how to design, and enhance the acceptability, of such policies and scale them up at the domestic and global level.[6] Specifically, this chapter:

- Provides a conceptual and quantitative framework for understanding the environmental, fiscal, and economic impacts of carbon taxation and the trade-offs between carbon taxes and alternative mitigation instruments. The chapter argues that fiscal policies are a key tool to mitigate climate change, and that a higher price tag on carbon emissions is the most powerful and efficient way to do so; it gives people and businesses an incentive to find ways to conserve energy and switch to greener sources (see Policies to Reduce Fossil Fuel CO_2 Emissions).
- Discusses how to facilitate international agreement on more ambitious targets, by proposing a carbon price floor arrangement among large emitters (see How to Increase Ambition in Global Mitigation Targets).
- Discusses strategies for enhancing the domestic acceptability of mitigation policy and estimates how accompanying fiscal measures can alleviate the overall burden of mitigation policy on key groups (see Making Mitigation Policy Acceptable in Domestic Politics);
- Recommends support (for example, technological and financial) for the policies necessary to mobilize investment in clean energy (see Supporting Policies for Clean Technology Investment and Chapter 6 in the October 2019 *Global Financial Stability Report*).

II. Policies to Reduce Fossil Fuel CO_2 Emissions

Carbon taxes—charges on the carbon content of fossil fuels—and similar arrangements to increase the price of carbon, are the single, most powerful and efficient tool to reduce domestic fossil fuel CO_2 emissions (Parry and others 2012, 2015a; Farid and others 2016; Akerlof and others 2019; CAE and GCEE 2019). (For greenhouse gases stemming from sources other than domestic use of fossil fuels, see Box 1.2). Raising the price of coal and other fossil fuels is desirable not only to mitigate climate change but also to reduce local problems such as air pollution.[7] Carbon pricing can: provide across-the-board incentives to reduce energy use and shift toward cleaner fuels; mobilize a valuable source of new revenue; and be straightforward administratively if it builds on fuel tax systems. Many countries and subnational governments have implemented carbon pricing initiatives (Table 1.1). Even so, the global average carbon price is $2 a ton (based on World Bank 2019), a tiny fraction of the estimated $75 a ton price in 2030 consistent with a 2°C target (discussed later in this section). Without consensus to raise the carbon price

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[6] Growing interest in sharing experiences and promoting collective action in fiscal policies is reflected, for example, in the Finance Ministers Coalition for Climate Action, launched in April 2019 (www.worldbank.org/en/news/press-release/2019/04/13/coalition-of-finance-ministers-for-climate-action). Beyond mitigation, fiscal policies for adaptation and resilience building in countries vulnerable to climate impacts are also needed: these are discussed in IMF (2019b, c).

[7] In most countries, the price of fossil fuels is lower than desirable (and thus subsidized) owing to various factors: fuel and electricity prices in some countries are provided at prices below cost recovery; prices should be higher to reduce global warming and local problems such as air pollution as well as traffic congestion and accidents; and the consumption of fossil fuels is sometimes not taxed as much as other goods. The combined value of underpricing from all these sources for all countries globally has been estimated at $5.2 trillion for 2017, with coal and oil accounting for 85 percent of the subsidy (Coady and others 2019). The quantitative analysis in this *Fiscal Monitor* considers the need for higher carbon pricing only from the perspective of global warming.

to the necessary level, other less effective instruments should complement carbon pricing to reduce domestic fossil fuel CO_2 emissions.[8]

Which Mitigation Policies Work Best?

Policymakers can use various fiscal tools, as well as regulatory policies, to encourage firms and households to reduce CO_2 emissions. The most effective and efficient policies make it costlier to emit greenhouse gases and allow businesses and individuals to choose how to conserve energy or switch to greener sources through a range of opportunities. These opportunities include reducing the emission intensity of power generation (for example, switching from high-carbon-intensive coal to intermediate-carbon-intensive natural gas or coal with carbon capture and storage,[9] and from these fuels to carbon-free renewables or, with appropriate safeguards, nuclear); curbing electricity demand (for example, through adoption of energy-efficient appliances, air-conditioners, and machinery and less use of products using electricity); limiting demand for transportation fuels (for example, through better fuel economy of gasoline and diesel vehicles and increased use of electric and alternative-fuel vehicles and less driving); and less direct fuel use in homes and industry (mainly for heating).

Table 1.1. Selected Carbon Pricing Arrangements, 2019

Country/region	Year introduced	Price 2019, \$/ton CO_2	Coverage of GHGs 2018	
			Million tons	Percent
Carbon taxes				
Chile	2017	5	47	39
Colombia	2017	5	42	40
Denmark	1992	26	22	40
Finland	1990	65	25	38
France	2014	50	176	37
Ireland	2010	22	31	48
Japan	2012	3	999	68
Mexico	2014	1-3	307	47
Norway	1991	59	40	63
Portugal	2015	14	21	29
South Africa	2019	10	360	10
Sweden	1991	127	26	40
Switzerland	2008	96	18	35
Emissions trading systems				
California	2012	16	378	85
China	2020	na	3,232	
EU	2005	25	2,132	45
Korea	2015	22	453	68
New Zealand	2008	17	40	52
RGGI*	2009	5	94	21
Carbon price floors				
Canada	2016	15	na	70
UK	2013	24	136	24

Sources: Stavins (2019); World Bank (2019); and IMF staff calculations.
Note: * = Regional Greenhouse Gas Initiative (a market-based program in 9 states in the eastern part of the United States); CO_2 = carbon dioxide; GHGs = greenhouse gases; na = not available.

A carbon tax—a tax on the supply of fossil fuels (for example, from oil refineries, coal mines, processing plants) in proportion to their carbon content—leads people and firms to use all such avenues to reduce emissions, conserve energy, or switch to greener power sources because it is passed forward into higher prices for carbon-based fuels and electricity. People and firms will identify which changes in behavior reduce emissions—for example, purchasing a more efficient refrigerator versus an electric car—at the lowest cost. Carbon tax paths can be set in line with mitigation objectives based on projections of fuel consumption and estimates of how consumption responds to higher prices. Online Annex 1.3

[8] Proposals for decarbonizing the economy far more rapidly than currently envisioned are being debated in the United States under the banner of a "Green New Deal." Other countries are considering, or have already enacted (for example, France, Norway, Sweden, United Kingdom), zero net emissions targets for the middle of the century—a valuable roadmap that should inform, but not detract from the need for immediate action. Regulations, such as banning new coal plants and sales of gasoline or diesel vehicles, are often more prominent than pricing in such approaches. Even under such approaches, however, carbon pricing could play a role—for example, in promoting retirement of existing (emissions intensive) capital and allowing firms to pay out-of-compliance fees if regulatory requirements are costlier than anticipated.

[9] Carbon capture and storage is the process of separation, cleaning, and compression of carbon from fuel combustion and industrial processes and its permanent storage underground (IEA 2013).

explains how the emission reductions and economic costs of the tax relate to its impact on fuel and electricity markets.

Table 1.2. Features of Alternative Mitigation Approaches

	Carbon Tax	Emissions Trading Systems	Feebates	Regulations
Potential for exploiting mitigation opportunities	Full, if applied comprehensively (in practice may contain exemptions)	Full, if applied comprehensively (in practice often limited to power/large industry)	Similar to regulations	Can exploit some key opportunities but not all (for example, reductions in vehicle use)
Use of price/market mechanism	Yes	Yes	Yes	No
Efficiency across mitigation responses induced by policy	People and firms choose most efficient way of reducing emissions	People and firms choose most efficient way of reducing emissions	People and firms choose most efficient approach only within one activity	No automatic mechanism
Energy price impacts and acceptability	Higher energy prices can be challenging politically	Higher energy prices can be challenging politically	Avoiding significant energy price increases may enhance acceptability	Avoiding significant energy price increases may enhance acceptability
Price predictability	Yes (if clearly specified trajectory)	No (unless includes price floors or similar mechanisms)	Yes (if clearly specified trajectory)	No (implicit prices vary with technology costs, energy prices, etc.)
Revenue generation	Yes (though exemptions may limit revenue base)	Maybe (if allowances auctioned, but revenue base may be limited)	No (recommended design is revenue neutral)	No
Administrative burden	Small (if builds on existing fuel or royalty tax systems)	New capacity needed to monitor CO_2/trading markets	New capacity needed (for example, to apply fees/rebates to power generators)	New capacity needed (for example, to monitor and enforce emission rate standards for power generators)

Source: IMF staff.

Alternative mitigation instruments, whose features are summarized in Table 1.2, include the following:

- Emission trading systems in which firms must hold an allowance for each ton of their emissions and the government sets a cap on total allowances or emissions; market trading of allowances establishes the emissions price. If the system comprehensively covers emissions, and the government charges for the initial allowances (for example, by issuing them through an auction), emissions and revenues are in principle the same as under an equivalent carbon tax. In practice, the coverage of emission trading systems has usually been limited to power generators and large industrial firms.[10]
- "Feebates," which impose a sliding scale of fees on products and activities with above average emission rates (per unit of energy or miles driven) and provide rebates (subsidies) on a sliding scale for products or activities with below average emission rates. Under a feebate, for example, power generators would pay a fee (or receive a rebate) in proportion to their output times the difference between their emission rate per kilowatt hour (averaged across their plants) and the industry average emission rate. The structure of fees and rebates would usually be set to make the system

[10] Although carbon taxes sometimes include exemptions, their overall coverage of emissions is often greater than that of emission trading systems. See Goulder and Parry (2008), Hepburn (2006), and Stavins (2019) for a general discussion of similarities and differences between carbon taxes and emission trading systems.

revenue-neutral (self-financing). Online Annexes 1.4 and 1.5 explain how feebates can be implemented in practice (thus far they have been applied to vehicles in several countries) and how they differ from carbon taxes.

- Regulations—for example, standards for the emission rates of vehicles and power generators, or for the energy efficiency of electricity-using products, or minimum requirements for the use of renewables in power generation.

These mitigation policies work in different ways and may be compared as follows:

- *Range of emission mitigation mechanism and impact on end-user energy prices:* Carbon taxes and emission trading systems lead people and firms both to shift to greener energy and to cut back on the use of energy-consuming products or capital. Feebates and regulations, however, do not discourage activities that use energy. Fossil-fuel energy producers pass the cost of a carbon tax (or of tradable emission permits) to end-users through higher prices for, say, electricity or gasoline.[11] In contrast, a feebate consisting of an extra fee on vehicles with lower-than-average fuel efficiency and a rebate on more efficient vehicles would lead consumers to purchase more efficient vehicles, but it would not reduce vehicle miles driven. Likewise, although a feebate would lead power generating firms to shift to lower emission technologies, there would be little impact on energy consumption (Online Annex 1.3). Thus, to deliver the entire emissions cut by switching to greener energy while continuing to use approximately the same amount of energy, feebates or regulations would need to be used more aggressively. The ensuing greater disruption to choices of energy source would imply larger economic costs than those incurred through carbon pricing, which allows people to identify and exploit all available avenues to reduce emissions in the most efficient way (Online Annex 1.3).[12]

- *Use of the price mechanism:* In addition to carbon taxes and emission trading systems, feebates also rely on the market system, though within a narrower set of activities. For example, under a feebate that charges power generating firms a fee (or gives them a rebate) for each kilowatt hour that emits more (less) than the industry average, firms will use the most efficient technology.[13] In contrast, regulations might not leave sufficient flexibility for households and firms to find least-cost options. Moreover, regulations must keep up with rapidly-changing technology. Excessive reliance on a regulatory approach could also motivate firms to collude with officials to alter or evade the regulations.[14]

- *Likely political opposition:* In the absence of accompanying measures, carbon pricing may face stiffer opposition from energy-using industries and the public at large, compared with arrangements, such as feebates and regulations, which have a much smaller impact on energy prices. (All approaches

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[11] The cost of the carbon tax is largely passed forward because domestic fuel supply curves tend to be elastic relative to demand curves, not least because most countries are price takers in international fuel markets.

[12] Firms and households would cut back on emissions as soon as a carbon tax is introduced, but increasing the tax gradually allows them time to adapt and be less opposed to change. Emission trading systems likewise have an immediate impact, which often leads governments to give some free permits to incumbents to ease their adjustment. Whereas a feebate for power generation could be applied quickly, in many areas—such as for vehicles—feebates would realistically be applied to new products and equipment only, so it would take years for their effect to fully permeate existing fleets and capital stocks.

[13] To maintain efficiency across feebate programs (for example, power generation versus vehicle choice) fees and rebates would need to be set in a way that harmonizes the incremental cost of emissions reductions across sectors (Online Annex 1.4).

[14] The flexibility of regulations can be enhanced by combining them with pricing mechanisms, for example, allowing firms that exceed a standard to sell credits to firms that fall short of the standard.

may face resistance from carbon-intensive energy producing firms, workers, and regions.) If a comprehensive and equitable strategy to make carbon pricing more acceptable is not politically feasible, a less efficient strategy would be less ambitious carbon taxes or emission trading systems complemented by, or even substituted with, more forceful use of feebates or regulations.

- *Predictability of prices and fostering investment in green energy:* To mobilize investment (for example, in renewable energy plants) with high upfront costs and long-range payoffs, a transparent pricing plan for the years ahead is necessary (as well as supporting policies—see Supporting Policies for Clean Technology Investment). With carbon taxes and feebates, such a plan is possible. With emission trading systems, prices vary with energy market conditions (although volatility can be contained, for example, by combining emission trading systems with price floors—as in California, where allowances are auctioned to the market with a minimum price—see, for example, Flachsland and others 2018). Regulations may offer the weakest investment incentives because they do not reward investment that exceeds the standard (for example, Fischer and others 2003, Jaffe and Stavins 1995).

- *Ability to raise revenues:* From the standpoint of mobilizing general revenues, a carbon tax with no exemptions will have the broadest tax base. In principle, governments could collect the same amount of revenues by charging for emission trading permits. In practice, however, revenue available for general use under emission trading systems could be diminished by (1) the narrower base for emissions pricing; (2) the possibility that the government would allocate some permits for free—for example, initial allocations to incumbent firms; and (3) potential earmarking of revenues from allowance auctions.[15] Regulations do not raise revenues, and feebates are generally revenue neutral (Online Annex 1.3). The revenues collected through a carbon tax (or, to a lesser extent, the sale of emission permits) could be redeployed through cuts in other taxes or additional investment or assistance to improve economic efficiency and enhance political acceptability of mitigation measures. The overall benefits of carbon pricing are greater the more productively and efficiently these revenues are used (for example, cutting taxes that discourage work effort and investment and promote informality and other tax-sheltering behavior, or funding socially productive investments for United Nations Sustainable Development Goals, such as education, health and infrastructure).

- *Ease of administration:* Carbon taxes can be integrated into existing fossil fuel taxes, or possibly into fiscal regimes for extractive industries.[16] For emission trading systems, new government capacity is needed to monitor trading markets and firms' emissions: in some countries, this could be impractical given capacity constraints and limited trading. Feebates could be integrated into existing vehicle tax systems in many countries (Online Annex 1.4), but new institutions may be needed to apply them more extensively (for example, to appliance distributors and power generators). Many countries already have some energy efficiency regulations and building codes (IEA 2018), though the administrative workload and complexity would rise to apply them more extensively. Although the coverage of feebates and regulations could be expanded, it would be administratively challenging to apply them to the full range of energy-consuming products or types of equipment.

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[15] Globally, 63 percent of emission trading system revenues have been used for environmental spending, 16 percent for general funds, and 21 percent for development—the corresponding percentages for carbon tax revenues are 23, 59, and 4 respectively, while a further 10 percent have been used for tax cuts and 4 percent for transfers (World Bank 2019b).

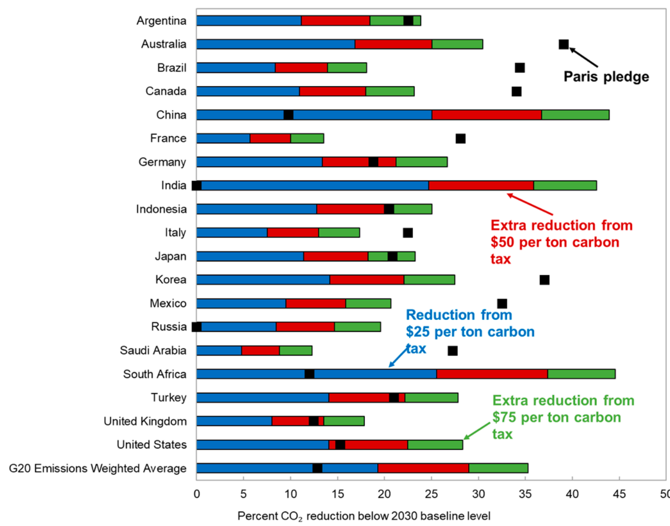
[16] For a discussion of administrative modalities, see Calder (2015) and Metcalf and Weisbach (2009).

On balance, carbon pricing approaches seem to be the most promising, although mitigation through other approaches is better than inaction. The efficiency costs of different mitigation policies, and the burden of these policies across income groups, are discussed later in this section and in Section IV Making Mitigation Policy Acceptable in Domestic Politics, respectively.

Quantitative Analysis: Cross-Country Assessments of Carbon Pricing and Other Mitigation Approaches

To analyze how fiscal policy tools can help deliver mitigation commitments, emissions projections under baseline scenarios (with no new mitigation measures) are compared with those under current pledges and with carbon tax scenarios. CO_2 emission reductions below baseline levels in 2030 that will meet countries' Paris mitigation pledges range widely, from essentially zero to 40 percent (Figure 1.2).[17] As noted, current pledges globally are consistent with warming of 3°C.

Figure 1.2. Reduction in Fossil Fuel CO_2 from Carbon Taxes, 2030



Source: IMF staff calculations.
Note: Paris pledges indicate the percent reduction in CO_2 emissions below the baseline (that is, no mitigation) levels in 2030 implied by meeting countries mitigation pledges submitted for the Paris Agreement. Bars indicate the percent reduction in CO_2 emissions below baseline levels under carbon taxes with alternative tax levels.

To illustrate the extra effort needed by each country to attain current, or more ambitious, mitigation targets by using only carbon taxes, and to trace the implications for firms and household budgets, three scenarios are considered, with tax rates of $25, $50, and $75 a ton of CO_2 in 2030.[18] The $75 tax is estimated by the IMF staff to lead to the amount of emissions scientists (see Figure 1.1, panel 2) estimate will lead to 2°C warming (if applied globally and combined with investment policies—see Supporting Policies for Clean Technology Investment—as well as measures for non-fossil CO_2 emissions).[19] The less ambitious scenarios, $25 and $50, are also analyzed given the lower prices consistent with many countries' mitigation pledges and the possibility that less ambitious carbon tax pricing may be combined with other instruments.[20]

Considering the estimated cut in emissions from uniform carbon prices of $25, $50, and $75 a ton for the G20 countries individually and as a group (Figure 1.2), three results stand out:

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[17] See IMF (2019c) for details on how these reductions were calculated.

[18] These tax amounts are in addition to any pre-existing energy taxes addressing fiscal or domestic environmental considerations. All monetary figures throughout the chapter are in constant 2017 US dollars.

[19] Stern and Stiglitz (2017) estimated global carbon prices consistent with 2°C at $50–$100 a ton in 2030.

[20] Projecting the impact of carbon taxation on emissions requires assumptions about how much people and firms would cut back on energy use and switch energy sources. Since carbon taxation has generally been low in the past, such assumptions are more uncertain the higher the level of tax. It is especially difficult to predict how rapidly low-emission technologies would be deployed in response to higher carbon prices. These uncertainties should be kept in mind.

- *First*, uniform carbon prices of $25, $50, and $75 a ton reduce CO_2 emissions by 19, 29, and 35 percent, respectively, for the G20 group (with countries weighted by their future emission shares).
- *Second*, whereas a $25 price would be more than enough for some countries (for example, China, India, Russia) to meet their Paris Agreement pledges, in other cases (for example, Australia, Canada) even the $75 a ton carbon tax falls short. This dispersion reflects cross-country differences in the stringency of mitigation pledges, as well as in the price responsiveness of emissions—for example, emissions are more responsive to pricing in coal-reliant countries like China, India, and South Africa than in other countries.
- *Third*, the large cross-country differences in carbon prices consistent with individual country pledges underscore the case for greater international price coordination.

Table 1.3. Impacts of Carbon Taxes on Energy Prices, 2030

	Coal		Natural gas		Electricity		Gasoline	
Country	**Baseline Price, $/GJ**	**% Price Increase**	**Baseline Price, $/GJ**	**% Price Increase**	**Baseline Price, $/kWh**	**% Price Increase**	**Baseline Price, $/liter**	**% Price Increase**
$75 Carbon Tax								
Argentina	3.0	297	3.0	133	0.10	48	1.4	13
Australia	3.0	263	9.6	44	0.11	75	1.3	15
Brazil	3.0	224	3.0	131	0.12	7	1.4	13
Canada	3.0	251	3.0	128	0.10	11	1.1	17
China	3.0	238	9.6	41	0.09	64	1.2	13
France	5.0	123	8.3	49	0.12	2	1.8	9
Germany	5.2	132	8.4	52	0.12	18	1.8	8
India	3.0	230	9.6	25	0.09	83	1.3	13
Indonesia	3.0	239	9.6	36	0.12	63	0.6	32
Italy	5.3	134	8.3	50	0.14	18	2.0	9
Japan	3.0	230	9.6	48	0.13	42	1.4	11
Korea	3.0	220	9.6	47	0.16	42	1.5	6
Mexico	3.0	226	3.0	132	0.10	74	1.0	18
Russia	3.0	169	7.0	54	0.14	25	0.9	12
Saudi Arabia	3.0	234	7.0	56	0.22	40	0.6	28
South Africa	3.0	205	7.0	23	0.08	89	1.2	16
Turkey	3.0	232	7.0	59	0.09	40	1.5	9
United Kingdom	6.1	157	8.3	51	0.13	16	1.7	8
United States	3.0	254	3.0	135	0.08	53	0.8	20
Simple Average	3.5	214	7.0	68	0.12	43	1.3	14
$50 Carbon Tax								
Simple Average	3.5	142	7.0	45	0.1	32	1.3	9
$25 Carbon Tax								
Simple Average	3.5	71	7.0	23	0.1	19	1.3	5

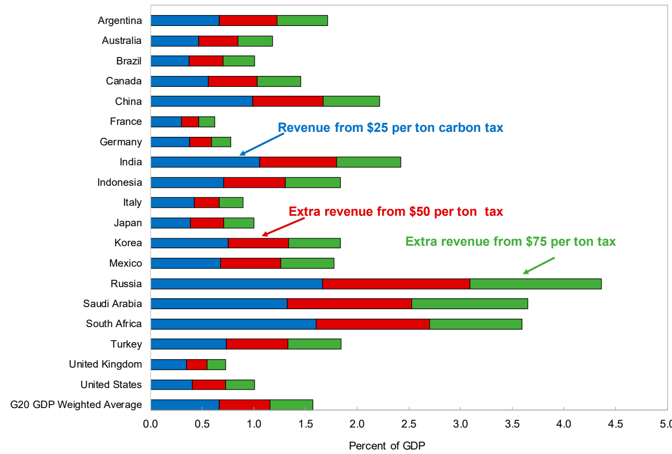
Source: IMF staff calculations.

Note: Baseline prices are retail prices estimated in Coady and others (2019) and include preexisting energy taxes. Baseline prices for coal and natural gas are based on regional reference prices. Baseline prices for electricity and gasoline are from cross-country databases. Impacts of carbon taxes on electricity prices depend on the emission intensity of power generation. Carbon tax prices are per ton. GJ = gigajoule; kWh = kilowatt hour.

Under carbon taxation on a scale needed to mitigate climate change, the price of essential items in household budgets, such as electricity and gasoline, would rise considerably but such increases have been experienced in the past. With a $75 a ton carbon tax, coal prices would typically rise by more than 200 percent above baseline levels in 2030, because coal has a high carbon content and its baseline price per unit of energy is currently low (Table 1.3). This is indeed the purpose of a carbon tax: promoting a switch away from carbon-rich fuels by making them costlier. But coal is largely an intermediate product rather than one consumed by households. The price of natural gas, which is used not only for power generation but also directly by households (mostly for heating and cooking) would also rise significantly, by 70 percent on average; the proportionate impact would be larger in North and South America, where baseline prices are much lower, compared with prices in Europe and Asia. The proportional increase in retail electricity prices would vary across countries depending on the emissions intensity of generation: less than 30 percent in Canada and several European countries, where the use of coal has already declined compared with a few decades ago and ranging between 70 and 90 percent in Australia and several large emerging market economies, which reflects how heavily they rely on coal-fired generation. Gasoline prices would rise by 5–15 percent in most countries. For retail electricity and gasoline, price changes of this size are well within the bounds of price fluctuations experienced during the past few decades.[21] As shown in Table 1.3, the impact on prices is lower under less ambitious scenarios. For the remainder of the chapter, most of the analysis will use the $50 tax scenario as an illustration.

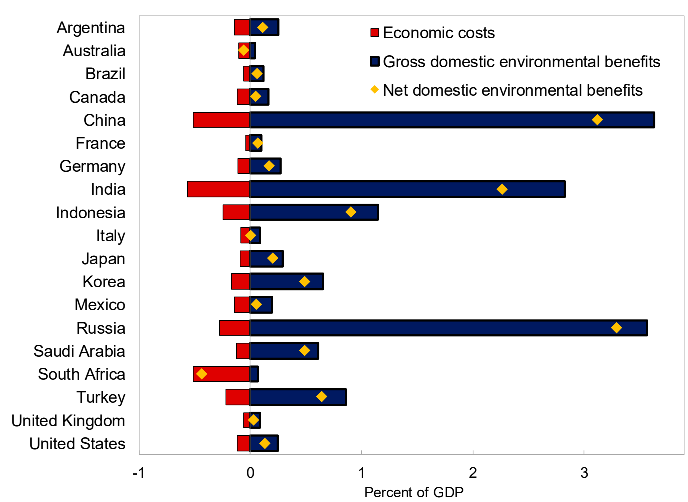
Carbon taxes (on domestic fuel consumption) can mobilize significant new revenues, ranging widely across countries (between ½ and 3 percent

Figure 1.3. Revenue from Comprehensive Carbon Taxation, 2030



Source: IMF staff calculations.

Figure 1.4. Unilateral Costs and Domestic Net Benefits of a $50 Carbon Tax, 2030



Source: IMF staff calculations.

[21] For example, real electricity prices in the United States declined 30 percent between 1993 and 2003; real gasoline prices in increased 75 percent between 2003 and 2006 (calculated from Haver Analytics and IMF, International Financial Statistics).

of GDP for the G20 countries for the $50 tax in 2030—see Figure 1.3), depending on factors such as reliance on coal, efficiency in using energy, and importance of energy between sectors in the economy.

Analyzing the merits of different mitigation policies requires estimating their costs on economic efficiency. (For the purpose of this discussion, the term "economic efficiency costs" excludes the global climate and domestic environmental impacts of mitigation policies.) Economists (and many governments around the world) measure such costs by how much worse off people are as a result of the policy action, excluding the benefits it brings (Online Annex 1.3). In the case of mitigation policies, the costs occur because the policies cause (1) a shift to cleaner but costlier technologies and equipment than people or firms would otherwise prefer; and (2) a decline in overall economic activity because of higher energy

Table 1.4. Comparing other Mitigation Policies with Carbon Taxes, 2030

	CO_2 reduction from other policies as a fraction of CO_2 reduction under $50 carbon tax (for same carbon price)		Mitigation cost of other policies relative to cost of $50 carbon tax (for same CO_2 reduction)	
Country	**Feebate/regulatory combination**	**ETS/feebate/regulatory hybrid**	**Feebate/regulatory combination**	**ETS/feebate/regulatory hybrid**
Argentina	0.51	0.66	1.95	1.51
Australia	0.66	0.90	1.51	1.11
Brazil	0.59	0.67	1.70	1.49
Canada	0.57	0.62	1.74	1.60
China	0.69	0.88	1.44	1.13
France	0.50	0.55	2.01	1.83
Germany	0.71	0.82	1.41	1.21
India	0.69	0.93	1.45	1.07
Indonesia	0.62	0.85	1.62	1.18
Italy	0.61	0.73	1.64	1.38
Japan	0.59	0.80	1.69	1.24
Korea	0.66	0.82	1.52	1.21
Mexico	0.50	0.76	1.98	1.32
Russia	0.53	0.65	1.87	1.54
Saudi Arabia	0.36	0.70	2.78	1.42
South Africa	0.64	0.84	1.56	1.19
Turkey	0.63	0.78	1.58	1.27
United Kingdom	0.64	0.71	1.56	1.41
United States	0.64	0.81	1.56	1.24
Simple Average	0.60	0.76	1.71	1.33

Source: IMF staff calculations.
Note: Feebate and regulatory policies promote reductions in emission rates in power generation and transportation and two-thirds of other opportunities for higher energy efficiency. CO_2 = carbon dioxide; ETS = emission trading systems.

prices.[22] The estimated economic efficiency costs of mitigation responses induced by carbon taxes are first compared with the domestic environmental benefits and then with the costs of other mitigation instruments.

[22] This aggravates distortions in labor and capital markets created by broader taxes on the returns to work effort and investment (Online Annex 1.3).

The economic efficiency costs of a $50 carbon tax[23] are equivalent to less than 0.5 percent of GDP in 17 countries (Figure 1.4). For most G20 countries, these costs are lower than the domestic environmental benefits stemming from the same measure—fewer deaths from air pollution as well as reductions in traffic congestion and accidents—before even counting climate benefits. The domestic environmental benefits are especially large for countries with especially severe air pollution, such as China, India, and Russia (Figure 1.4). In fact, for G20 countries together, a $50 carbon tax would prevent 600,000 premature air pollution deaths in 2030 (60 percent of them in China); a $75 tax would prevent 725,000 premature deaths. Despite uncertainty in measuring the size of the domestic environmental benefits, carbon pricing benefits many countries because it reinforces efforts to address the aforementioned domestic environmental problems.[24]

The economic efficiency costs of carbon taxes are considerably lower than those of other mitigation instruments, such as (1) feebates or regulations promoting reductions in the emission intensity of power generation and vehicles, as well as the main opportunities for improving energy efficiency across the household, industrial, and electricity-consuming sectors; and (2) an emission trading system applied to power generation and large industry combined with feebates and regulations for the household and transportation sectors (Table 1.4).

For the left-hand columns in Table 1.4, the policies are scaled so as to provide the same incentive for reducing CO_2 by an extra ton as under a $50 carbon tax (for the emission sources each policy affects). In this case, the feebate/regulation and hybrid packages achieve emission reductions of 50–70 percent and 65–80 percent, respectively, of those under the carbon tax. For the right-hand columns, the policies are scaled so as to achieve the same economy-wide emission reduction as under a $50 carbon tax. In this case, the costs of mitigation responses are 50–100 percent and 20–40 percent larger, respectively, for the feebate/regulation and hybrid packages. The mitigation cost is lower for the carbon tax because the emission reduction can be achieved by switching to cleaner technologies for a wider range of products and activities, as well as by consuming less energy. In contrast, under the feebate package, for example, the burden of adjustment is not spread as widely, and it becomes more and more difficult to attain emission savings through a narrower range of actions.

III. How to Increase Ambition in Global Mitigation Targets

The success of the Paris Agreement in meeting its long-term temperature goals will hinge critically on substantially scaling up mitigation efforts above what is currently pledged. This section discusses how an international carbon price floor could muster consensus among key countries on greater mitigation ambition.[25]

[23] Measured by the shift to cleaner but costlier technologies and equipment. Costs from the decline in overall economic activity are calculated for the United States in Making Mitigation Policy Acceptable in Domestic Politics.

[24] The estimates in Figure 1.5 make some allowance (for example, through declining air pollution emission rates) for future initiatives to address domestic environmental problems. See Coady and others (2019) and Parry and others (2014, 2015b) for further discussion. Another potential cobenefit of carbon mitigation, not counted in Figure 1.5, is reduced dependence on volatile energy markets.

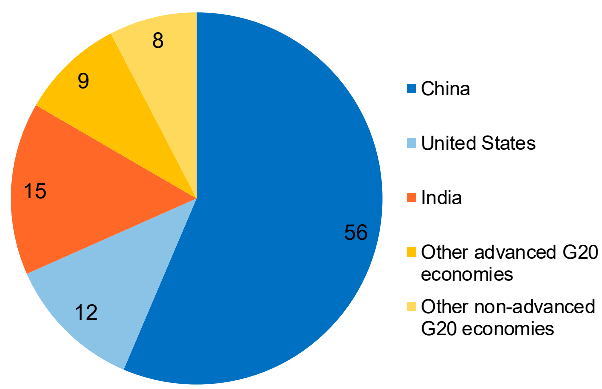
[25] Global mitigation policies will cause large declines in revenues for fossil-fuel-rich countries—estimated in Online Annex 1.10. A complementary, more tentative proposal is thus put forward in that annex, calling for further analysis of how fossil-fuel-rich countries can share in the revenues from carbon taxation by increasing royalty payments, so as to encourage these countries to support an international carbon price floor.

Promoting an International Carbon Price Floor

Any mechanism to induce scaling up of global mitigation needs to address three obstacles:

- First, a country may be reluctant to be the only one to scale up ambition, not only because the benefits accrue mostly to other countries but also because it may be concerned that higher energy costs would harm its firms' international competitiveness.
- Second, current mitigation pledges are not expressed using a common measure for all countries, thus hindering international comparisons.[26]
- Third, most future low-cost mitigation opportunities are in large, rapidly growing emerging market economies, especially those that rely heavily on coal. For example, with a globally uniform $25 carbon price in 2030 China and India would account for an estimated 56 and 15 percent, respectively, of CO_2 reductions (compared with baseline levels) from G20 countries, the United States for 12 percent, and all other G20 countries combined for 18 percent (Figure 1.5). However, advanced economies may have greater responsibilities for mitigation.[27] Indeed, on a per capita basis, projected baseline emissions in India in 2030 are only one-seventh those for the United States (Online Annex 1.1).

Figure 1.5. Country Shares of G20 CO_2 Reductions below Baseline under a Uniform $25 Carbon Price, 2030
(Percent)



Source: IMF staff calculations.
Note: CO_2 = carbon dioxide; G20 = Group of 20.

An international carbon price floor for high emitting countries (given the concentration of emissions in those countries), as a complement to the Paris process, might address these obstacles:

- An internationally coordinated approach would provide reassurance against losses in competitiveness and address free-rider issues—in fact, country participants may support robust floor prices as this reduces the emissions of other participants, thereby conferring collective benefits for all (for example, Cramton and others 2017, Weitzman 2016).
- A common emission price requirement improves the transparency of countries' actions.

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[26] Current pledges vary (for example, IMF 2019c, Appendix I) in terms of (1) target variables (for example, emissions, emission intensity, clean energy shares); (2) nominal stringency (for example, percent emission reductions); and (3) baseline years against which targets apply (for example, historical versus projected baseline emissions).

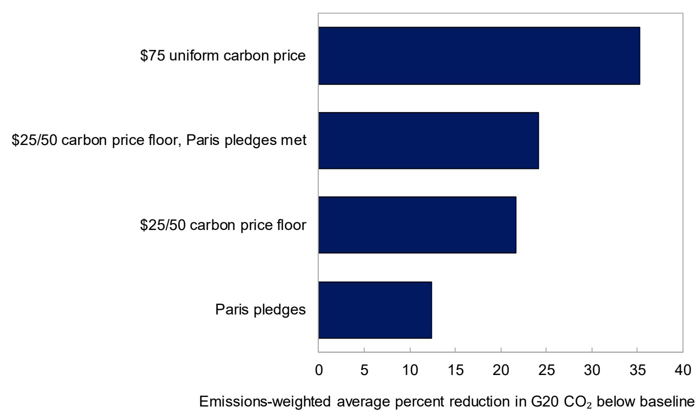
[27] Under the principle of "common but differentiated responsibilities," countries have varying responsibility for their contributions toward global greenhouse gas mitigation in recognition of their economic status and respective capabilities (UN 1992, Article 3.1).

- A common price floor (ideally a global price floor) is most efficient because emissions are cut where it is cheapest to do so on a global scale.[28] If the floor is lower for countries where it is cheaper to reduce emissions than for countries where cutting emissions is more expensive, many opportunities to cut emissions at the lowest cost could be missed.
- Despite the efficiency case for a uniform price an option to ensure equity would be for advanced economies to be subject to a higher floor price. An alternative (or complementary) option would be for advanced economies to provide enhanced financial or technological support to emerging market economies in exchange for their commitment to more ambitious targets. The latter mechanism would be more efficient, because the emerging market economies have more opportunities to reduce emissions at low cost, although agreeing on international transfers might be more challenging.

Although an international floor price approach would require meeting operational challenges, such as monitoring and ensuring sustained participation (Box 1.3), it presents several advantages:

- It retains flexibility for countries to exceed the floor if they need to do so to meet their Paris mitigation pledges or other policy targets.
- It may encourage nonparticipants, and participants for which the minimum price is not binding, to raise carbon prices (for example, Kanbur and others 1995).
- It can be designed to accommodate strategies based on emission trading systems and feebates and regulations. Although the price floor is most naturally met through carbon taxes, emission trading systems could be accommodated (for example, by setting the emission cap such that the expected emission price is at least equal to the required price, or by including a mechanism that withdraws allowances from the system if prices would otherwise fall below the floor). Feebate and regulatory approaches could also be accommodated if the floor price were converted to an emission target for each country (that is, what emissions would be with the price floor).

Figure 1.6. CO_2 Reduction for G20 Countries under Alternative Ambition Scenarios, 2030



Source: IMF staff calculations.
Note: Carbon prices are per ton. For some emerging market economies (advanced economies) the $25 ($50) floor is not enough to meet the Paris pledges. In the second scenario from the top, countries meet the price floor or the Paris pledge, whichever is more stringent; in the third scenario from the top, all countries meet their respective price floor, but some may fail to comply with their Paris pledges. CO_2 = carbon dioxide; G20 = Group of 20.

Precedents for cooperation over price floors suggest that this approach is feasible. For example, under federal requirements introduced in Canada in 2016, provinces and territories are required to phase in a minimum carbon price, rising to Can$50 (US$38) a ton by 2022 using a carbon tax or an emission

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[28] Following similar logic, CAE and GCEE (2019) have recently made the case for a common price floor in Europe.

trading system.[29] More broadly, some progress has been made in combating excessive competition for internationally mobile tax bases through tax floor arrangements, for example, for excises on gasoline, cigarettes, and alcohol in the European Union.

Under a floor arrangement in which advanced and nonadvanced G20 member countries were, for illustration, subject to minimum prices of $50 and $25 a ton, respectively, on their domestic CO_2 emissions in 2030, combined G20 CO_2 emission reductions would be 24 percent below baseline levels (if either the floor prices or current mitigation commitments, whichever are more stringent, were met), doubling emission reductions over and above those implied by meeting current pledges (Figure 1.6). Under that scenario, however, mitigation would still fall a third short of consistency with the 2°C target, so other measures, or higher price floors—an estimated $75 a ton across all G20 country emissions—would still be needed.

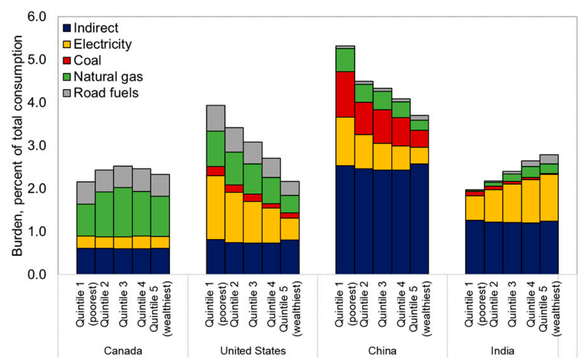
IV. Making Mitigation Policy Acceptable in Domestic Politics

At a domestic level, implementing mitigation policy will likely require a comprehensive strategy that confronts the political challenges to enact and keep a high and broad-based carbon tax or similar measures. This section discusses common obstacles to reform and general strategies for overcoming them; the distributional burden of carbon pricing across household and industry groups in selected countries; options for use of carbon pricing revenue, considering their impact on income distribution; and measures to assist vulnerable groups.

Obstacles and Potential Solutions

Voters and particular groups often oppose carbon pricing because it increases their costs for energy and their cost of living. They may also oppose carbon pricing because of the misperception that these taxes impose a very disproportionate burden on low-income households; will not be effective in reducing emissions; and are a backdoor way to increase the size of government (Carattini, Carvalho, and Fankhauser 2017). Energy-intensive firms, especially those in trade-exposed sectors (that cannot easily pass on higher energy costs in product prices), labor groups, and regions that depend on energy production are often the most forceful opponents of carbon taxation.

Figure 1.7. Burden of Carbon Taxation on Households by Income Quintile, $50 Carbon Tax in 2030, Selected Countries



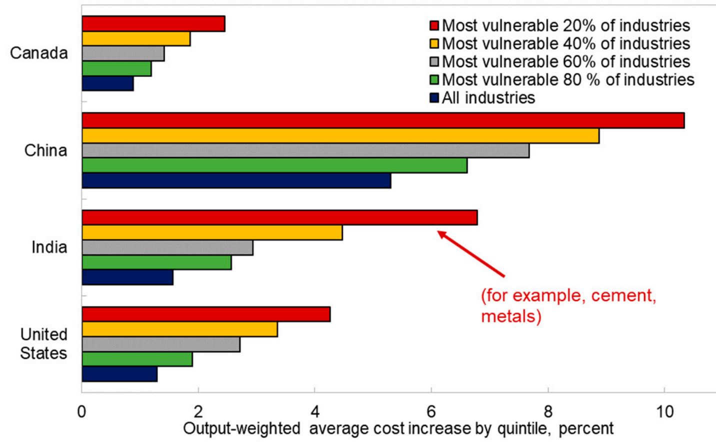
Source: IMF staff calculations.
Note: See Online Annex 1.8 for methodology and data sources. “Indirect” refers to the increase in price of consumer goods in general from higher energy costs. Burdens are estimated prior to use of carbon tax revenue and assume full pass-through of taxes to consumer prices.

[29] The federal government will step in, where needed, to ensure regional governments meet the requirement (Government of Canada 2018a, b; Parry and Mylonas 2018). The system is currently under legal challenges from some provincial governments.

Past attempts to introduce carbon pricing and energy pricing reform more generally point to the importance of four elements in successful strategies:[30]

- Increasing carbon prices in the near term and locking in subsequent price hikes through legislation to provide clarity and certainty (thereby allowing time for firms and households to adjust through, for example, energy efficiency investments);
- Extensive consultations with stakeholders to garner support and a public communication campaign that provides the facts underlying the case for reform and addressing possible misperceptions;
- Transparent, equitable, and productive use of revenues; and
- An up-front package of targeted assistance for vulnerable households, firms, workers, and disproportionately affected communities.

Figure 1.8. Burden of Carbon Taxation by Industry, $50/ton Carbon Tax, 2030



Source: IMF staff calculations (see Online Annex 1.8).
Note: Figure shows production cost increases from higher energy prices as a result of the carbon tax (assuming no pass-through of higher costs to producer prices).

For example, Sweden successfully implemented a tax on carbon emissions starting at $28 a ton in 1991 and progressively rising to $127 a ton in 2019. The tax was introduced as part of a broader reform including the reduction of taxes on energy, labor, and capital. Higher social transfers and reductions in the basic rate of income taxes helped to offset burdens for low- and middle-income households, while competitiveness concerns were addressed through a lower initial rate for industries (progressively phased out by 2018). Businesses and other stakeholders were involved in the decision-making process through public consultations. In France, on the other hand, the rapid ramping up of a similar carbon tax was suspended in 2018 at $50 a ton, following public backlash against the perceived unfairness of the tax, which was introduced at the same time as broader tax reductions seen as benefiting the wealthy. Online Annex 1.7 summarizes additional experiences with carbon taxation.

Beyond these general elements, overcoming the political challenge may require building a broad enough coalition in favor of reform; for example, by using a portion of the revenues to finance policies that will mobilize support from environmental groups, green industrial interests, and households. Where this is not feasible, avoiding higher energy prices in favor of feebate and regulatory policies may be more practical, even if less effective.[31]

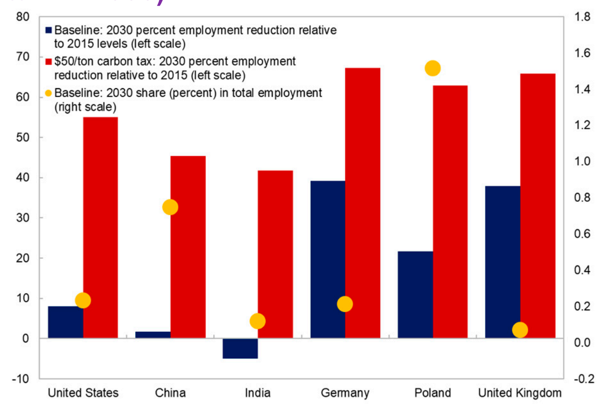
[30] For more detail on suggested reform strategies see Clements and others (2013) and Coady, Parry, and Shang (2018).

[31] This would be more likely, for example, if political opposition to higher energy prices is especially severe, raising energy prices is at odds with promoting energy access, energy prices are already high compared with neighboring countries, or emissions respond modestly to prices (which is the case, for example, if they come mostly from the transportation sector).

The Distribution of Income across Households and Businesses

Before considering the use of revenues from carbon pricing, carbon taxes would undoubtedly add to the cost of living for all households, and the burden as a share of total household consumption would range from moderately regressive to moderately progressive in selected countries. (A regressive policy imposes a larger burden as a share of consumption on lower-income households than on higher-income households; a progressive policy does the opposite.) Carbon taxes would be moderately regressive in China and the United States, distribution-neutral in Canada, and moderately progressive in India for a $50 carbon tax in 2030 (Figure 1.7). The reason is that in China and the United States, the poor spend a greater share of their budget for electricity, but the opposite applies in India.[32] In most countries, one-third to one-half of the burden of increased energy prices on households comes indirectly through higher general prices for consumer products, and these burdens are approximately proportional to total consumption across households (so distributed evenly across consumption quintiles). The absolute burden on the bottom consumption quintile ranges from 2.2 percent of household consumption in Canada to 5.3 percent in China. Moreover, in all four countries 90 percent of the total burden is borne by the top four consumption quintiles. Underpricing energy associated with carbon emissions is therefore an inefficient way to help low-income households, because most of the benefits accrue to wealthier groups.

Figure 1.9. Impact of Carbon Pricing on Employment in the Coal Sector ($50 a ton tax in 2030)



Source: IMF staff calculations.
Note: Employment includes coal mining and related activities, primarily coal transport and processing. Baseline assumes no new mitigation measures.

Although, over the longer term, efficient allocation of an economy's scarce resources implies that firms unable to compete when energy is efficiently priced (including to address emissions) should be allowed to go out of business, impacts of higher energy prices on firms, especially those in energy-intensive, trade-exposed sectors, is a political concern with carbon pricing.[33] Carbon taxes have uneven impacts across countries and economic sectors (Figure 1.8). The average impact on industry costs of a $50 a ton tax in 2030 ranges between 0.9 percent in Canada and 5.3 percent in China. However, the most energy-intensive industries can be affected significantly: cost increases for the 20 percent of most vulnerable industries in China are 10.3 percent and 6.8 percent in India.

Carbon mitigation might also have large impacts on certain groups of workers and regions. Coal-related employment is projected to decline in many countries under baseline policies. A $50 carbon tax in 2030 would substantially accelerate this process; for example, increasing estimated job losses in this sector relative to 2015 levels from 8 to 55 percent in the United States and up (from small changes) to 42–45

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[32] In India, the burden of carbon pricing would be somewhat larger for urban households than for rural households because of lower availability of, and less spending on, electricity in rural areas.

[33] A related concern is that if domestic firms reduce emissions, firms abroad could increase emissions as they gain competitive advantage. However, estimates suggest when emissions are cut by 100 units at home, they increase abroad by no more than 5–20 units (Böhringer, Carbon and Rutherford 2012, Burniaux, Chateau, and Duval 2013).

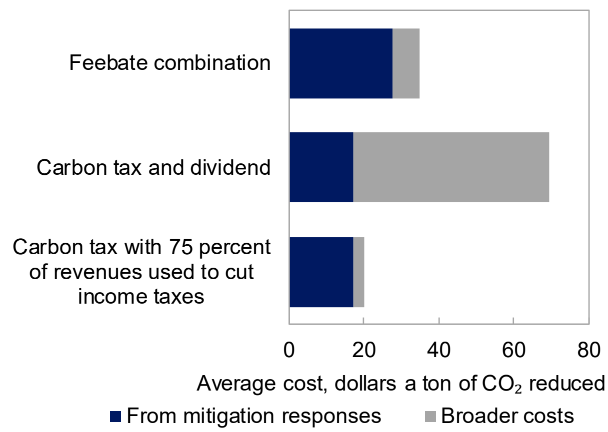
percent in China and India (Figure 1.9). These job losses would amount to 0.3–0.9 percent of economy-wide employment in China and Poland and less than 0.15 percent in other countries; employment would increase in other sectors, such as renewables, but—in the absence of specific policies—the new jobs would likely become available in other regions.[34]

Typically, coal- (or fossil-fuel-) related jobs are highly geographically concentrated, accounting for a disproportionately large share of local employment in a few regions in a country (Online Annex 1.6). Winding down production in these regions would lastingly reduce output and employment prospects for local communities. In addition, extractive activities may cause scarred local landscapes and impaired waterways, and bankrupt extraction firms may be unable to meet their obligations to clean up the abandoned mines, reducing prospects for attracting new industries (Morris 2016).

Options for Use of Carbon Tax Revenue

For carbon pricing reforms to be economically and politically viable, and for the burden of adjustment to be distributed in a fair manner, policymakers need to consider how to best allocate the revenues considering both economic efficiency and implications for income distribution. Key considerations will usually include fiscal needs for environmental or general spending or deficit reduction, the existing income distribution, and the effectiveness of transfer programs, as well as the design, efficiency, and progressivity of the broader tax system.

Figure 1.10. Efficiency Costs of Alternative Carbon Mitigation Instruments for the United States ($50 carbon tax), 2030



Source: See Online Annex 1.3, updating Parry and Williams (2010).
Note: All policies reduce economy-wide CO_2 emissions 22 percent below baseline levels. Cost estimates exclude global climate and domestic environmental benefits from carbon mitigation.

For example, universal transfer payments (that is, equal dividends to all households regardless of income) might help with political acceptability but would forgo potentially sizable efficiency benefits from productive revenue use. Environmental investments (low-carbon infrastructure, energy networks, R&D) may also be favored by voters as part of a package; however, these investments would need to be balanced against competing investment priorities and scrutinized to ensure high quality, as with other important investments (for example, basic education and health). As regards options for lowering other taxes, cutting personal and corporate income taxes likely provides significant efficiency gains for the economy (through better incentives for work effort, investment, and lowering incentives for tax sheltering behavior) though benefits tend to be skewed towards better off households (for example., poor households may not pay income taxes). Reducing payroll or consumption taxes can also promote some of these efficiency gains

[34] In 2017, global employment in the renewables sector was 11 million (Roberts 2019). Although jobs in renewables require more specialized skills in general, those jobs have lower educational requirements and better pay than the national averages (for example, fewer than 20 percent of workers in clean energy production and energy efficient occupations have college degrees—Muro and others 2019).

and would benefit households roughly in proportion to their income. See Table 1.5 for a summary of options.

Figure 1.10 illustrates some of the efficiency trade-offs for the United States in 2030 for a $50 carbon tax, with all revenues returned to everyone in the population as an equal dividend, the same tax with three-quarters of revenues used for labor income tax cuts and one-quarter for assistance to lower-income groups, and a feebate package achieving the same economy-wide emission reduction as the carbon tax. Accounting for the broader costs of higher energy prices on economic activity and the economic efficiency benefits from use of carbon tax revenues—in addition to the costs of mitigation responses (discussed in Policies to Reduce Fossil Fuel CO_2 Emissions)—on balance, the carbon tax is the least costly approach overall, with costs of $20 a ton of CO_2 reduced, if three-quarters of the revenues are deployed to cut existing income taxes, which have their own efficiency costs.

Table 1.5. Options for Use of Carbon Tax Revenues

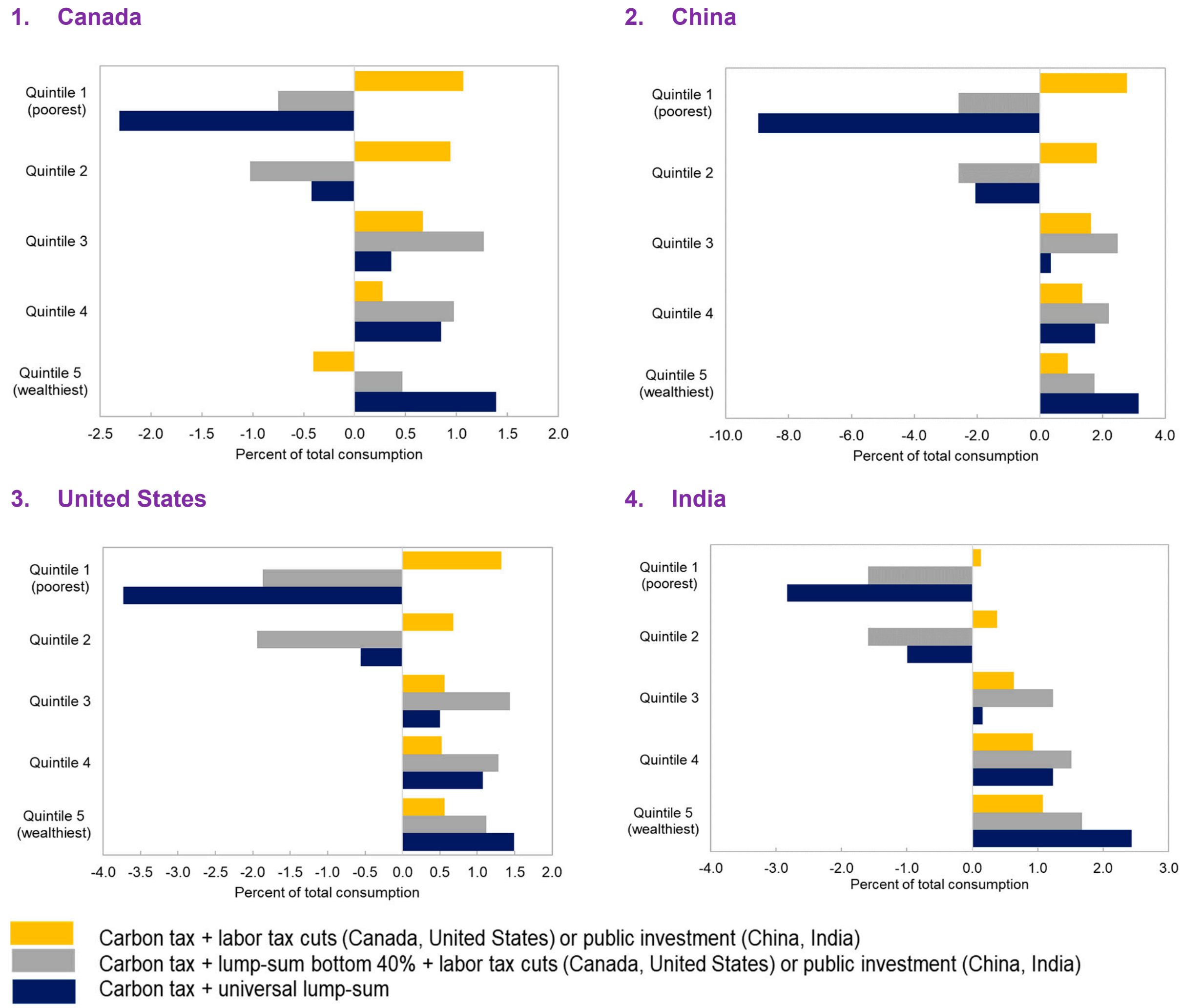
Instruments		Metric		
		Impacts on Income Distribution	Impact on Economic Efficiency	Administrative Burden
General Revenue Uses	Environmental investment	May disproportionately benefit low-income households (for example, if reduces their vulnerability to natural disasters)	Risk that may be less efficient than broader uses of revenue	Modest
	General investments	May disproportionately benefit low-income households (for example, if provides basic education, health, infrastructure)	Potentially significant	Modest
	Universal transfers	Highly progressive (disproportionately benefits the poor relative to income)	Forgoes efficiency benefits[1]	New capacity needed (but should be managable)
	Payroll tax	Benefits are largely proportional across working households	Improves incentives for formal work effort	Minimal
	Personal income tax	Typically benefits are skewed to higher-income groups	Improves incentives for formal work effort and saving, reduces tax-sheltering	Minimal
	Consumption tax	Largely proportional to household consumption	Reduces incentives for untaxed goods and activities	Minimal
	Corporate income tax	Benefits skewed to higher-income groups	Improves incentives for investment	Minimal
	Deficit reduction	Benefits accrue to future generations	Lowers future tax burdens and macro-financial risk	Minimal
Targeted Assistance	Means-tested cash, in-kind transfers	Effective at helping low-income groups if social safety nets are comprehensive	Efficiency impacts unclear but likely modest[1]	Low if builds on existing capacity, otherwise significant
	Assistance for household energy bills	Provides partial relief for all households (for example, does not help with indirect pricing burden)	Modest reduction in environmental effectiveness	Low if builds on existing capacity, otherwise significant

Source: IMF staff.
[1] Transfers to low-income households could lead to a small increase in human capital investment.

The carbon tax with revenues funding equal dividends for the entire population has much larger efficiency costs—estimated at $70 a ton of CO_2 emission reduction, twice as high as under the feebate (which has limited impacts on energy prices) and 3½ times as high as a carbon tax with three-quarters of revenues used to lower income taxes. The size of the gap in economic efficiency costs between using carbon tax revenues for equal dividends versus income tax cuts depends on country circumstances and might be larger, for example, in countries where tax systems lead to greater avoidance or evasion behavior, such as informal sector activities (see Online Annex 1.3 for details on the methodology).

When analyzing distributional effects, it is important to consider the impact on all income groups because carbon pricing affects all households. Indeed, opposition to reform often comes from groups of people who are closer to the median of the income distribution—members of the middle class. Still, reform packages will usually need to include assistance to lower-income households as well as assistance and compensation to workers and communities experiencing widespread job losses. In some cases, support to groups of disproportionately affected firms may be appropriate, although in this area measures are often inefficient.

Figure 1.11. Burden of a $50 Carbon Tax in 2030 under Alternative Revenue Uses



Source: IMF staff calculations.
Note: Negative figures for total consumption imply a gain and positive numbers imply losses.

Imposing carbon taxes with revenue returned in equal dividends to everyone is a highly progressive policy, with the bottom two consumption quintiles better off on net and the top two quintiles worse off for all countries in Figure 1.11. Alternatively, using the revenues to enhance economic efficiency—reducing labor taxes in Canada and the United States and funding public investment in China and India—is a regressive policy on net, aside from in India, though net burdens on each household group are reduced considerably (compared with Figure 1.7) as a result of the revenue use. An intermediate approach, in which the bottom two quintiles are compensated for higher energy prices through equal dividends, and the remaining revenue—60–70 percent of the total—is used for public investment (China and India) or reductions in labor taxes (Canada and the United States) is also highly progressive and can still generate large gains in economic efficiency.[35]

A political consideration in favor of combining carbon taxation with equal dividends is that such an approach creates a large constituency in favor of enacting and keeping the plan (because about 40 percent of the population gains, and gains rise if the carbon price increases over time) and the public may feel that the government does not have the option to "waste" the carbon tax revenues. Policymakers will have to consider the weight of the arguments against the backdrop of their country's particular economic and political circumstances. From a practical standpoint, however, to give investors, firms and households certainty and predictability, it would seem appropriate to lock-in a gradual increase in carbon taxation—over a decade or more, if possible—ideally backed by an international commitment. An equal dividend could be provided on distributional grounds and to enhance political acceptability. In subsequent years, further reforms to other taxes would likely take place and, as always, would be informed by the new economic and distributional pattern resulting from the carbon tax and dividend approach as well as by many other developments in the meantime.

Targeted Assistance

Assistance to lower-income households: Several options are available to alleviate the impact of carbon pricing on the poor (Table 1.5). In principle, targeted assistance (for example, cash or food vouchers following means-testing) is an efficient way to help lower-income households. However, if administrative capacity is not up to the task, targeting can be inaccurate—leading some poor households to be excluded or non-poor households to be included. Providing relief for household energy bills through a lifeline (discounted price for basic energy needs of poor households) can also help, although it would not offset the significant indirect burden from generally higher consumer prices. Expanded eligibility for support that provides incentives to find and retain a job (for example, the Earned Income Tax Credit in the United States) also helps people remain in the labor force and maintain basic job skills. Compared with targeted assistance, universal transfers would close coverage gaps and perhaps build broader support for reform, but they would be much costlier for the public finances.[36]

Support for displaced workers and coal-mining regions: In view of the major economic transformation experienced by workers and communities whose livelihood depends on fossil fuels, assistance will be appropriate to help them transition to a better future and to enhance the political viability of carbon pricing. While the exact design would depend on country circumstances, measures for displaced workers could center around extended unemployment benefits, training and reemployment services, and financial assistance related to job search, relocation, and health care. Potentially useful features include outreach to increase awareness and take-up of the program, tailoring of job training to the needs of coal-related sector workers, and wage insurance or tax credits, especially for older workers. For the success of the program, beyond good design, the scale of support needs to be sufficiently generous. Even so, the estimated cost of programs providing comprehensive benefits is less than 2 percent of carbon tax revenues for China, India, the United Kingdom, and the United States under a $50 a ton carbon tax. (Online Annex 1.6). Support to affected regions needs to go beyond assistance to displaced workers, because mine closures often take a toll on communities with limited alternative employment opportunities, and declining home values make it difficult for people to move. Assistance for reclaiming abandoned mining and drilling sites and temporary budget support for local governments could help to

[35] All households face a small burden under a package of indirect pricing policies like feebates, but the burdens are less than 1 percent of consumption for all groups in Canada, India, and the United States.

[36] For further discussion of universal transfers versus targeted assistance, see IMF (2019a).

create jobs and to bridge the transition for adversely affected communities.[37] Additional investments or other geographically targeted policies (such as subsidies or grants to individuals or firms in the affected regions) may also be warranted to help the regions engage in economically viable and sustainable opportunities (WB 2018).[38]

Table 1.6. Instruments for Offsetting Burdens on Trade-Exposed Firms

	Rebates for Direct/Indirect Emissions	Output-Based Rebate	Border Carbon Adjustments	General Corporate Tax Cut	International Carbon Price Floor
Effectiveness at Addressing Competitiveness of Trade Exposed Industries	Effective	Effective	Effective	Poorly targeted at exposed industries	Effective
Preserving Mitigation Incentives for Trade Exposed Industries	Removes all incentives	Maintains incentive for reducing emission intensity	Maintains all incentives	Maintains all incentives	Maintains all incentives
Revenue Loss from Instrument	Moderate	Moderate	Increases revenue	Large cost	na
Added Administrative Burden	Moderate	Need to indentify industries and monitor their output	Need to identify imported products and measure their embodied carbon	na	Monitoring by international organization required
Compatibility with World Trade Organization Rules	Compatible if carefully designed	Compatible if carefully designed	Compatible if carefully designed	Compatible	Compatible if carefully designed
Compatability with Paris Agreement	Compatible	Compatible	May penalize countries using indirect pricing	Compatible	Compatible

Source: IMF staff.
Note: na = not applicable.

Assistance to firms: Absent agreement on an international carbon price floor—the best way to preserve international competitiveness—policymakers could consider several options to cushion the blow to domestic firms from higher energy prices, especially for energy-intensive, trade exposed firms (Table 1.6). However, these options are for the most part inefficient and their design may need careful attention. A general cut in corporate income taxes would reach all firms, not just energy-intensive, trade-exposed firms. Border carbon adjustments, levying charges on the unpriced carbon emissions embodied in imports (and perhaps remitting domestic carbon taxes on exports) might be judged compatible with World Trade Organization (WTO) rules if they are viewed as meeting environmental (rather than protectionist) objectives.[39] They would, however, require significant administrative capacity (for example, to assess the carbon embodied in products imported from various countries) and might work against the spirit of the Paris Agreement if they penalize countries implementing their mitigation pledges through non-pricing means. Providing rebates to trade-exposed firms in proportion to their output preserves their incentive to reduce emissions per unit of output, but this also requires additional administrative capacity.

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[37] For example, China established a restructuring fund in 2015 (0.15 percent of GDP), mainly for training and job search assistance, to facilitate the shutdown of coal mines and other overcapacity for sectors.

[38] Germany, for example, is planning to allocate €40 billion over the next 20 years to coal-mining regions to support activities such as developing infrastructure; expanding public transportation; and promoting R&D, science, and innovation. Reclaiming mining sites and protecting retiree benefits of coal-related sectors are estimated at a one-time cost 0.03 percent of GDP in the United States (Morris 2016).

[39] For more discussion on compatibility issues see Flannery and others (2018) and Trachtman (2017).

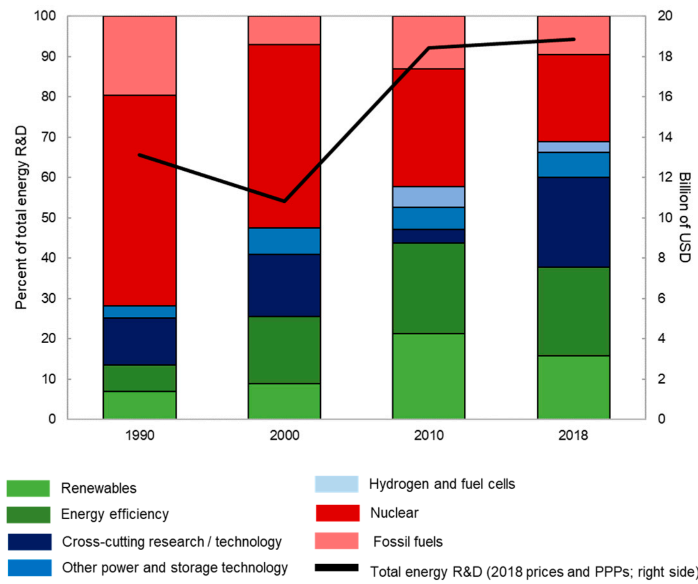
V. Supporting Policies for Clean Technology Investment

Even with robust carbon pricing, investment in low-carbon technologies—essential for the transition to the cleaner energy systems necessary for lower emissions—may be insufficient because of various technology-related market failures and impediments, including the following:[40]

- Knowledge spillovers from R&D and technology diffusion that may prevent firms from capturing the full social benefits of developing and using new technologies;[41]
- Scale economies that may deter firms from investing in a clean technology until they are confident about the size of the market;
- Network externalities where additional infrastructure needed for one investor (for example, to connect a remote renewables site to the power grid) could potentially benefit other firms;
- Market distortions that might impede low-carbon investment (for example, regulated energy pricing, incomplete property rights that hinder land acquisition for renewable plants); and
- Financial market imperfections reflecting limited financial instruments for low-carbon investments and the shorter-term horizons of investors.

Figure 1.12. Composition of Global Public Energy R&D Expenditure

(Percent of total [left scale] and billions of US dollars [right scale])



Source: IEA (2018).
Note: PPP = purchasing power parity.

Approaches for addressing these market impediments include public R&D support (IMF 2016), targeted fiscal incentives (for example, capital grants, tax credits, per-unit subsidies, feed-in tariffs), and regulations (for example, on renewable generation shares) to deal with knowledge spillovers and provide more certainty over the demand for clean technologies; public infrastructure investment (for example, on charging stations for electric vehicles) to tackle network externalities; price liberalization and land reforms to reduce market distortions; and financial sector policies. Over the past three decades, public R&D spending in the energy sector in advanced economies has increasingly shifted from fossil fuels and nuclear to cross-cutting research and technologies, renewables, and energy efficiency (from 25 percent of total energy R&D spending in 1990 to 61 percent in 2018 (Figure 1.12).

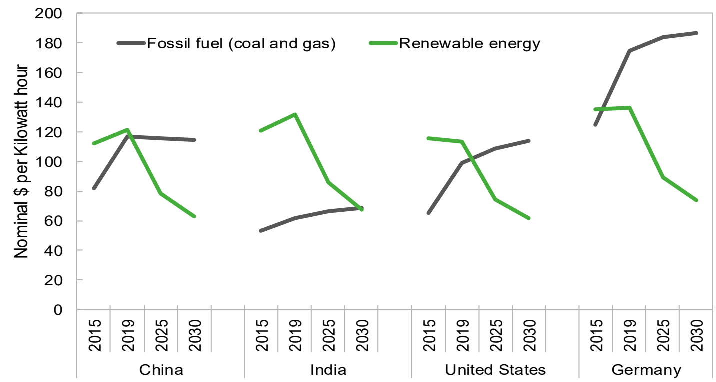
[40] For further discussion of non-pricing measures to complement carbon pricing and the underlying rationale, see Stern and others (2017) and Stiglitz (2019). These studies emphasize the importance of strategic choices in investment in public transportation infrastructure and urban planning, as well as the governance of the energy system; they also point, for example, to the success of regulations in promoting the development of cheap LED by banning incandescent light bulbs and the reduction in lead-based pollution by banning lead in gasoline.

[41] These spillovers are common to emerging technologies across all sectors of the economy and to some extent may be addressed by intellectual property protection, but the deterrent may be especially severe for long-lived, low-carbon technologies whose future returns are uncertain because of changing mitigation policies. See, for example, Fischer and Preonas (2010), Newell (2015), de Serres, Murtin, and Nicoletti (2010), Acemoglu and others (2012).

Supporting policies should be part of a comprehensive strategy to promote supply-side investment in low-carbon technologies and demand-side energy-efficiency measures—including carbon pricing (Ang and others 2017); fiscal incentives that are appropriately scaled, targeted, and designed; and direct public infrastructure investment. In this regard,

- Governments should increase R&D support now and then gradually reduce support over time when technologies are widely deployed and used by firms and households (Acemoglu and others 2012, 2016). For example, some have called for a gradual doubling of public spending on energy R&D in advanced economies ($10 billion in 2018),[42] focused on needed technologies currently furthest from the market that have strong social benefits (for example, carbon capture and storage, smart grids, infrastructure for electric vehicles, and batteries to store intermittent renewable power). Subsidies that promote widespread deployment and use of new technologies by firms and households should also be temporary—for example, as the electricity generated from renewables approaches cost parity with fossil-fuel-generated power (Figure 1.13), subsidies could be shifted from R&D to deployment and then progressively phased out (as in the phasing out of subsidies for solar power in China; see Online Annex 1.9).

Figure 1.13. Electricity Cost by Energy Source of Production



Source: Bloomberg New Energy Finance.

- Production-based fiscal incentives, such as fixed subsidies per kilowatt hour of renewable energy, are more flexible than (1) investment-based incentives (see Online Annex 1.9 on India); (2) regulations that force in the adoption of new technologies regardless of their future costs; and (3) (commonly used) feed-in tariffs guaranteeing minimum prices per kilowatt hour that do not permit supply responses to changing market conditions (Löschel and Schlenker 2017). Many countries, including Germany, Mexico, South Africa, and the United Kingdom, have moved away from pre-defined feed-in tariffs and have adopted tendering processes to reduce costs. Moreover, some regulations might deter low-carbon investment from new entrants because they impose disproportionately higher costs on them relative to incumbent firms—such as the 2015 rule in Canada that requires investment in carbon capture and storage in new coal plants while allowing a long adjustment period for existing firms (OECD 2017). Moreover, studies find that policies that support upstream development and manufacturing of clean technologies can be more cost effective than policies to support downstream consumption, because upstream providers face less competition (Requate 2005, Fischer 2016). And provisions in corporate income tax codes, such as the amount and duration of loss carryovers, should be appropriately calibrated to account for the upfront costs of renewable investments (OECD 2017).
- The current dominance of carbon-based systems may perpetuate incentives for R&D in fossil fuel technology. Escaping the carbon lock-in can be facilitated by public funding of R&D in renewables, as well as by public infrastructure investment to tackle network externalities (for example, funding of

[42] For example, Newell (2015), Dechezleprêtre and Popp (2017), IEA (2019).

smart electricity grids to accommodate an intermittent supply of renewables) and removing market distortions for low-carbon private investment.

- Policies in the financial sector can help mobilize financing for climate change mitigation. Recent proposals have focused on fostering the financing of green projects and companies through (1) the establishment of standards, prototype green bond contracts, and benchmark indices of securities that meet environmental norms; (2) amendment of prudential regulations and collateral eligibility criteria; and (3) shifts in the portfolio choices of central banks and institutional investors (Online Annex 1.12).

Policy inconsistencies and redundancies should be avoided. For example, many countries currently subsidize renewables and fossil fuels at the same time.[43] Incentives for energy efficiency and renewables have no impact on emissions when imposed on top of an emission trading system with a binding emissions cap; similarly, tax incentives for electric vehicles may have no effect on average vehicle emission rates in the presence of binding fuel economy standards (Krupnick and others 2012). Fossil fuel generators are sometimes awarded long-term purchase agreements that insulate them from the improving competitiveness of renewables. Uncertainty about renewable investment policies could also impede investment. For example, the US tax preferences related to fossil fuels are permanent features of the tax code, while most of the incentives for R&D, and investment in renewables and energy efficiency are temporary and will continue to be available only if extended. Providing more predictability on R&D tax credit policies could bolster incentives for innovation. And policy inconsistencies sometimes arise at different levels of government. Thus, greater coordination would be appropriate across ministries, levels of government, and other public sector agents.[44]

The shift of investment composition toward renewables also creates new job opportunities. Global employment in the renewables sector reached about 11 million in 2017 (IEA/IRENA 2017; Roberts 2019), the bulk of which was in solar energy. More than 40 percent of worldwide jobs created in the renewables sector since 2012 have been in China. Employment in the renewables sector is projected to grow to 24 million by 2030 under a 2°C scenario (IRENA 2018; IEA/IRENA 2017).

VI. Conclusions

Climate change is threatening the planet and the global economy, calling for urgent policy action to secure a better future. Promoting the transition to low-carbon growth is a challenge faced by all countries and there is much to be done in designing the right incentives at the domestic and international levels and navigating the practical obstacles to putting them in place. This *Fiscal Monitor* emphasizes the critical role of fiscal policies in climate change mitigation with emphasis on improving their social and political acceptability (for example, through judicious use of revenues) and effectiveness (for example, through international carbon price floors and supporting technology policies).

Carbon taxation or other systems that use price signals provide the most powerful and efficient incentives for households and firms to reduce CO_2 emissions. If these instruments are not feasible on the

[43] Globally, subsidies for fossil fuels (measured by underpricing for supply costs) were estimated at $270 billion in 2016 compared to $150 billion for renewables (Coady and others 2019, IEA 2016). In addition, other forms of subsidies are important albeit more difficult to quantify. For example, despite coal's adverse impact on greenhouse gas emissions and local air pollution, a recent study indicates that government support to the production and consumption of coal through investment by state-owned enterprises and financing by the public sector (including state-owned banks) is sizable among G20 countries (Gençsü and others, 2019).

[44] OECD (2015). For example, federal production tax credits for renewables in the United States may have no impact in states where generators are already subject to binding requirements on renewable generation shares.

scale that is needed, alternative instruments such as feebates and regulations could be used. These instruments would have to be implemented more aggressively to achieve the same emission reductions, implying little increase in energy prices, but greater inefficiency and disruption. Still, the cost of achieving emissions reductions through these approaches would be lower than the costs to people and the planet from climate change. Finance ministers can play a key role by undertaking carbon taxation or similar pricing, adjusting broader tax and expenditure policy as part of a comprehensive strategy, ensuring adequate budgeting for investment in R&D and support for cleaner technologies, and coordinating strategies internationally. Actions in high emitting countries are especially urgent, not just for their own sake but also for their potentially catalyzing impact in other countries. These actions also bring domestic benefits such as lower mortality from air pollution. Finance ministers in all countries are central to designing and implementing policies to meet emissions reductions in the most efficient, equitable, and socially and politically acceptable way.

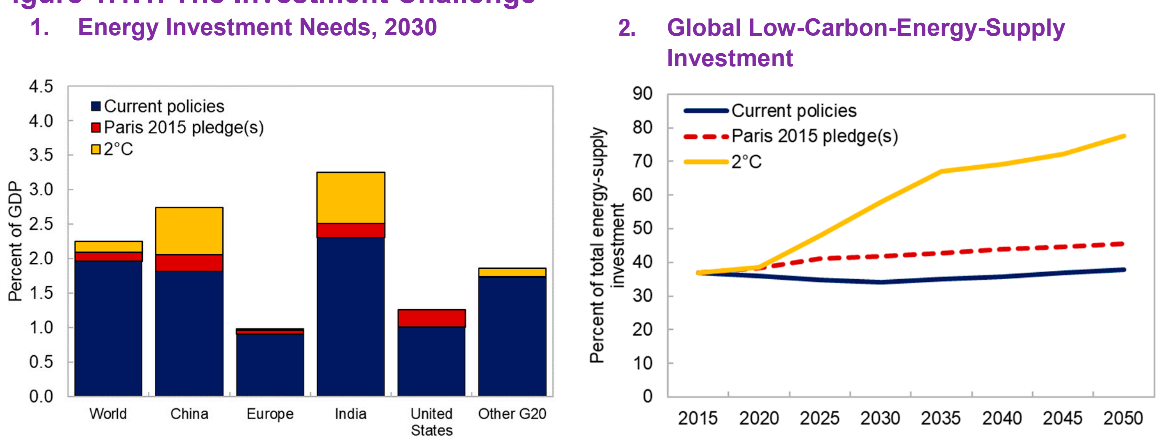
Box 1.1. Investment Needs for Clean Energy Transitions

Model estimates suggest that reducing emissions to a level consistent with a 2°C temperature target would require increasing the projected global energy investment in 2030 (encompassing both public and private) from 2.0 percent of GDP to 2.3 percent of GDP, with most of the increase concentrated in China and India (Figure 1.1.1 panel 1). [1]

The more important challenge for all countries, however, is to overhaul the composition of new investment, with the share of low carbon energy supply (renewables, nuclear, improved transmission and distribution networks, carbon capture and storage in power generation) rising from 40 percent in 2020 to 70 percent in 2035 and 80 percent in 2050 (Figure 1.1.1 panel 2). Energy infrastructure—for example, power plants and power grids—has an expected lifetime of 30–60 years. Choices made today will thus determine emissions for decades. This is especially important for rapidly growing emerging market economies, where new infrastructure will be built or expanded in the coming decades. Sizable extra investment in energy efficiency is also needed for buildings (for example, design, heating, cooling, appliances), transportation (for example, electric cars), and industry (Online Annex 1.9). These demand-side investments can speed up the reduction in carbon emissions because of their shorter life cycles compared with energy infrastructure (IEA 2018). Online Annex 1.9 elaborates on investment needs for individual G20 countries. Shifting investment to low carbon energy supply would help ensure that more carbon remains in the ground.

Incremental investment needs would be even greater if they also covered transportation and other infrastructure (water, sanitation, and telecommunication) that are essential to deliver the Sustainable Development Goals (SDGs), including SDG7 on clean energy access, and enhance the adaptive capacity to climate change (OECD 2017, IPCC 2018, and NCE 2018).

Figure 1.1.1. The Investment Challenge



Source: IMF staff calculations based on McCollum and others (2018).
Note: Paris 2015 pledges are those made by each country as part of the Paris Agreement in 2015. 2°C is the more ambitious scenario of keeping global warming below 2°C.

[1] These numbers represent multi-model averages and are subject to large uncertainty. The faster the transition to low-carbon technologies, the higher the risk of stranded assets and investment costs.

Box 1.2. Fiscal Instruments to Reduce Broader Sources of Greenhouse Gases

Fiscal instruments could promote many greenhouse gas mitigation opportunities beyond those for reducing domestic fossil fuel CO_2 emissions. Potential applications include the following (for general discussions see IMF 2019c, Calder 2015, Metcalf and Weisbach 2009):

- *CO_2 emissions from fuel use in the international aviation and maritime sectors:* The UN agencies overseeing these industries are responsible for developing and implementing strategies to mitigate their emissions. A tax on the carbon content of fuels, administered by these agencies, could form the centerpiece of these efforts while also raising sizable revenue—for example, for climate finance (for example, Keen, Parry, and Strand 2013).
- *Net CO_2 emissions from the forestry sector:* These could be reduced through slowing deforestation and planting new trees to increase the amount of carbon stored in forests. In countries where property rights are reasonably well established at the forestry and agricultural border, a national-level feebate program could be introduced. It would tax landowners who store less carbon on their property relative to storage in a baseline year and give rebates to landowners who increase carbon storage (Parry 2019).
- *Methane leakage during the extraction, processing, and transport of petroleum and coal:* Technologies for monitoring these emissions are evolving, but in the meantime fuel extraction could be taxed in proportion to a default leakage rate, with rebates for firms that demonstrate a leakage rate below the default rate.
- *Fluorinated (F-) gases:* These are highly potent greenhouse gases are used primarily in refrigerants, foams, aerosols, and fire extinguishers. Some countries (for example, Denmark, Norway, Poland, Spain) have introduced taxes on these gases with rates of about $5–$40 a ton of CO_2 equivalent emissions (for example, Brack 2015).
- *CO_2 emissions released during the production of clinker* (from limestone): Clinker is used to manufacture cement. Taxes could be levied on clinker production in proportion to a default emission rate (van Ruijven and others 2016).
- *Agricultural greenhouse gases, which include methane emissions from cows, nitrous oxide emissions from soil and fertilizer practices, and CO_2 emissions from forest clearance for agriculture:* Taxes could be imposed per head of cattle, on fertilizer inputs, and on profits for farming involving deforestation (for example, where ill-defined property rights preclude direct pricing of forestry emissions (Batini 2019)). Administration, however, might be limited to large-scale operations.

There are precedents for successful international cooperation over reducing these types of gases. The 1987 Montreal Protocol set up a framework that essentially eliminated, by the mid-1990s, production of chlorofluorocarbons (CFCs) and other substances that had been depleting the ozone layer, thereby elevating risks of cancer from ultraviolet light (Hammitt 2010). F-gases were largely developed in response to the phaseout of CFCs. Unlike other greenhouse gases in the Paris Agreement, however, F-gases are subject to other international negotiations—under the 2016 Kigali Agreement, all countries are required to largely phase out these chemicals over the next 25 years (Mulye 2017).

Box 1.3. Operationalizing International Carbon Price Floors

Turning an international carbon price floor into reality would require agreement among participants, preparatory work, and independent monitoring in several areas, such as the following.

Ensuring that carbon prices are measured using a consistent approach across countries: Some countries may provide favorable rates to selected (perhaps politically sensitive) emission sources, or they may partially offset carbon taxation by reducing preexisting energy taxes. To ensure cross-country comparability of effort, the arrangement might thus focus on countries' "effective" carbon prices. These can be calculated by (1) expressing existing fuel taxes on a CO_2-equivalent basis (that is, dividing them by the fuel's CO_2 emission factor); and (2) weighting CO_2-equivalent fuel taxes, and any direct carbon pricing, by their relative effectiveness at reducing CO_2 emissions compared with a comprehensive carbon price and then aggregating across these tax and pricing systems. First-pass estimates of effective carbon prices for 135 countries are provided in IMF (2019c).

Recognizing past efforts: There is little efficiency basis for equating effective carbon prices across countries since these vary, for example, according to fiscal needs and the share of economy-wide emissions from fuels subject to excise. Instead, the arrangement could focus on a required uniform *increase* in countries' effective carbon prices relative to prices in an earlier year—for example, before the recent proliferation of carbon pricing programs to avoid penalizing those who have already acted.

Ensuring sustained participation—carrots? Besides granting them a lower price floor, participation in the agreement among emerging market economies might be encouraged through side payments, technology transfers, or credit trading opportunities. The Paris Agreement (UNFCCC 2016, Article 6.2) recognizes internationally transferred mitigation outcomes across national governments. Countries needing prices lower than the floor price to meet their mitigation pledges could benefit from setting the floor price and selling internationally transferred mitigation outcomes at this price to other countries (for which the floor price would be insufficient to meet their pledge).

Ensuring sustained participation—sticks? Some authors have suggested that nonparticipants could be coerced into joining the agreement through trade sanctions (for example, Nordhaus 2015) or border carbon adjustments (levying charges on the unpriced carbon emissions embodied in imports from nonparticipant countries to match the domestic carbon tax). Ideally these penalties should account for progress on meeting mitigation commitments (through pricing and other measures) in nonparticipating countries. This approach would likely impose a considerable administrative burden.

References

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

Acemoglu, Daron, Ufuk Akcigit, Douglas Hanley, and William Kerr. 2016. "Transition to Clean Technology." *Journal of Political Economy* 124 (1): 52–104.

Akerlof, George, and others. 2019. "Economists' Statement on Carbon Dividends." www.econstatement.org.

Ang, G., D. Rottgers, and P. Burli. 2017. "The Empirics of Enabling Investment and Innovation in Renewable Energy", OECD Environment Working Paper No.123, May 2017.

Batini, Nicoletta, 2019. "Transforming Agri-Food Sectors to Mitigate Climate Change: The Role of Green Finance", in Challenges and opportunities of "Green Finance", edited by Claudia Kemfert, Dorothea Schäfer, Willi Semmler and Alexander Zaklan, Quarterly Journal of Economic Research, 2(3).

Bento, Antonio, Mark Jacobsen, and Antung A. Liu. 2018. "Environmental Policy in the Presence of an Informal Sector." *Journal of Environmental Economics and Management* 90:61–77.

Böhringer, Christophe, Jared C. Carbone, and Thomas F. Rutherford. 2012. "Unilateral Climate Policy Design: Efficiency and Equity Implications of Alternative Instruments to Reduce Carbon Leakage." *Energy Economics* 34 (Supplement 2): S208–S217.

Brack, Duncan. 2015. "National Legislation on Hydrofluorocarbons." Institute for Governance and Sustainable Development report, Washington, DC.

Bunch, David S., David L. Greene, Timothy Lipman, Elliot Martin, and Susan Shaheen. 2011. "Potential Design, Implementation, and Benefits of a Feebate Program for New Passenger Vehicles in California." Report prepared for the State of California Air Resources Board and the California Environmental Protection Agency.

Burniaux, Jean-Marc, Jean Chateau, and Romain Duval. 2013. "Is There a Case for Carbon-Based Border Tax Adjustment? An applied General Equilibrium Analysis." *Applied Economics* 45:2231–40.

Calder, Jack. 2015. "Administration of a U.S. Carbon Tax" In *Implementing a U.S. Carbon Tax: Challenges and Debates*, edited by Ian Parry, Adele Morris, and Roberton C. Williams III. New York: Routledge.

Carattini, Stefano, Maria Carvalho, and Sam Fankhauser. 2017. "How to Make Carbon Taxes More Acceptable." Grantham Research Institute on Climate Change and the Environment, London School of Economics, London.

Carney, Mark, François Villeroy de Galhau and Frank Elderson. 2019. "The Financial Sector Must be at the Heart of Tackling Climate Change." The Guardian, April 17. https://www.theguardian.com/commentisfree/2019/apr/17/the-financial-sector-must-be-at-the-heart-of-tackling-climate-change.

Clements, Benedict, David Coady, Stefania Fabrizio, Sanjeev Gupta, Trevor Alleyne, and Carlos Sdralevich, eds. 2013. *Energy Subsidy Reform: Lessons and Implications.* Washington, DC: International Monetary Fund.

Climate Action Tracker (CAT). 2018. *CAT Emissions Gaps*, Climate Action Tracker. https://climateactiontracker.org/global/cat-emissions-gaps.

Coady, David, Ian W. H. Parry, Nghia-Piotr Le, and Baoping Shang. 2019. "Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates." IMF Working Paper 19/89, International Monetary Fund, Washington, DC.

Coady, David, Ian W.H. Parry, and Baoping Shang. 2018. "Energy Price Reform: Lessons for Policymakers." Review of Environmental Economics and Policy 12: 197–219.

Council of Economic Analysis (CAE) and German Council of Economic Experts (GCEE). 2019. "A Uniform Carbon Price for Europe." Joint Statement of the CAE and the GCEE. http://www.cae-eco.fr/Communique-commun-des-conseils-economiques-francais-et-allemand-Joint-statement.

Cramton, Peter, David MacKay, Axel Ockenfels, and Steven Stoft, eds. 2017. *Global Carbon Pricing: The Path to Climate Cooperation*, 13–30. Cambridge, MA: MIT Press.

de Serres, Alain, Fabrice Murtin, and Giuseppe Nicoletti. 2010. "A Framework for Assessing Green Growth Policies." OECD Economics Department Working Paper 774, Organisation for Economic Co-operation and Development, Paris.

Dechezleprêtre, Antoine, and David Popp. 2017. "Fiscal and Regulatory Instruments for Clean Technology Development in the European Union." In *Energy Tax and Regulatory Policy in Europe: Reform Priorities*, edited by Ian Parry, Karen Pittel, and Herman Vollebergh, 167–214. Cambridge, MA: MIT Press.

Farid, Mai, Michael Keen, Michael Papaioannou, Ian Parry, Catherine Pattillo, and Anna Ter-Martirosyan. 2016. "After Paris: Fiscal, Macroeconomic, and Financial Implications of Climate Change." IMF Staff Discussion Note 16/01, International Monetary Fund, Washington, DC.

Fischer, Carolyn. 2016. "Strategic Subsidies for Green Goods." Resources for the Future Discussion Paper 16–12, Washington, DC.

———, Ian W. H. Parry, and William A. Pizer. 2003. "Instrument Choice for Environmental Protection when Technological Innovation is Endogenous." *Journal of Environmental Economics and Management* 45:523–45.

Fischer, Carolyn., and Louis Preonas. 2010. "Combining Policies for Renewable Energy: Is the Whole Less than the Sum of its Parts?" *International Review of Environmental and Resource Economics* 4:51–92.

Flachsland, Christian, Michael Pahle, Dallas Burtraw, Ottmar Edenhofer, Milan Elkerbout, Carolyn Fischer, Oliver Tietjen, and Lars Zetterberg. 2018. "Five Myths about a European Union Emissions Trading System Carbon Price Floor." Resources for the Future, Washington, DC.

Flannery, Brian, Jennifer A. Hillman, Jan W. Mares, and Matthew Porterfield. 2018. "Framework Proposal for a US Upstream Greenhouse Gas Tax with WTO-Compliant Border Adjustments." Georgetown University Law Center report, Washington, DC.

Gençsü, Ipek and others. 2019. "G20 coal subsidies: Tracking government support to a fading industry," Report by Overseas Development Institute (ODI), Natural Resources Defense Council (NRDC), International Institute for Sustainable Development (IISD), and Oil Change International (OCI).

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

Goulder, Lawrence H., Ian W. H. Parry, Roberton C. Williams, and Dallas Burtraw. 1999. "The Cost-Effectiveness of Alternative Instruments for Environmental Protection in a Second-Best Setting." *Journal of Public Economics* 72:329–60.

Goulder, Lawrence H., and Ian W. H. Parry. 2008. "Instrument Choice in Environmental Policy." *Review of Environmental Economics and Policy* 2:152–74.

Government of Canada. 2018a. The Greenhouse Gas Pollution Pricing Act. https://www.parl.ca/LegisInfo/BillDetails.aspx?Language=E&billId=9727472.

———. 2018b. "Government of Canada Fighting Climate Change with Price on Pollution." https://pm.gc.ca/eng/news/2018/10/23/government-canada-fighting-climate-change-pricepollution.

Hallegatte, Stephane, Adrien Vogt-Schilb, Mook Bangalore, and Julie Rozenberg. 2017. *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. Washington, DC: World Bank.

Hammitt, James. 2010. "The Successful International Response to Stratospheric Ozone Depletion." In *Issues of the Day: 100 Commentaries on Climate, Energy, the Environment, Transportation, and Public Health Policy*, edited by I. Parry and F. Day. Washington, DC: Resources for the Future.

Hepburn, Cameron. 2006. "Regulating by Prices, Quantities, or Both: An Update and Overview." *Oxford Review of Economic Policy* 22:226–47.

Intergovernmental Panel on Climate Change (IPCC). 2014. "Climate Change 2014: Synthesis Report—Contribution of Working Groups I, II and III to the Fifth Assessment Report. Geneva.

———. 2018. *Global Warming of 1.5°C*. Geneva.

International Energy Agency (IEA). 2013. *Technology Roadmap—Carbon Capture and Storage*. Paris.

———. 2016. *World Energy Outlook*. Paris.

———. 2018. *Policies and Measures Databases*. Paris.

———. 2019. *World Energy Outlook*. Paris.

———, and International Renewable Energy Agency (IRENA). 2017. *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System*. Paris.

International Monetary Fund 2016. Acting Now, Acting Together. Fiscal Monitor, Washington, DC.

———. 2017. World Economic Outlook, October 2017, Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges (Washington).

———. 2019a. "A strategy for IMF Engagement on Social Spending." IMF Policy paper 19/016, June 2019, International Monetary Fund, Washington, DC.

———. 2019b. Building Resilience to Natural Disasters. Washington, DC.

———. 2019c. "Fiscal Policies for Paris Climate Strategies—From Principle to Practice." Washington, DC.

Inter-Governmental Panel on Climate Change (IPCC). 2018. *Global Warming of 1.5°C.*, Geneva. IOM. 2009. *Migration, Environment and Climate Change: Assessing the Evidence*. International Organization for Migration, Geneva, Switzerland.

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

———. 2018. *Global Warming of 1.5°C*. Geneva.

IRENA. 2018. *Global Energy Transformation: A roadmap to 2050*. International Renewable Energy Agency, Abu Dhabi.

Jaffe, Adam B. and Robert N. Stavins. 1995. "A Dynamic Incentives of Environmental Regulation: The Effects of Alternative Policy Instruments on Technology Diffusion." *Journal of Environmental Economics and Management* 29: S43–S63.

Kahn, M. E., K. Mohaddes, R. N. C. Ng, M. H. Pesaran, M. Raissi, and J. Yang. Forthcoming. "Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis" Working Paper 26167. National Bureau of Economic Research

Kanbur, Ravi, Michael Keen, and S. Van Wijnbergen. 1995. "Industrial Competitiveness, Environmental Regulation, and Foreign Direct Investment," In I. Goldin and L. A. Winters (eds.) The Economics of Sustainable Development, CEPR and Cambridge University Press, pp. 289–302.

Keen, Michael, Ian W.H. Parry, and Jon Strand. 2013. "Ships, Planes, and Taxes: Charging for International Aviation and Maritime Emissions," Economic Policy, Vol. 28, pp. 701–49.

Kriegler, Elmar, and others. 2015. "Diagnostic Indicators for Integrated Assessment Models of Climate Policy," Technological Forecasting and Social Change, Vol. 90, pp. 45–61.

Krupnick, Alan J., Ian W.H. Parry, Margaret Walls, Tony Knowles and Kristin Hayes. 2010. Toward a New National Energy Policy: Assessing the Options (Washington: Resources for the Future and National Energy Policy Institute).

Le Quéré, Corinne, Robbie M. Andrew, Pierre Friedlingstein, Stephen Sitch, Julia Pongratz, Manning, Andrew C., Jan Ivar Korsbakken, and others. 2018. "Global Carbon Budget 2017," Earth System Science Data, Vol. 10, pp. 405–48.

Löschel, Andreas and Oliver Schlenker. 2017. "On the Coherence of Economic Instruments: Climate, Renewables, and Energy Efficiency Policies." In Ian Parry, Karen Pittel and Herman Vollebergh (eds.), Energy Tax and Regulatory Policy in Europe: Reform Priorities, pp. 167–214 (Cambridge: MIT Press).

Maliszewski, Wojciech, Serkan Arslanalp, John Caparusso, José Garrido, Si Guo, Joong Shik Kang, W. Raphael Lam, T. Daniel Law, Wei Liao, Nadia Rendak, Philippe Wingender, Jiangyan Yu, and Longmei Zhang, 2016. "Resolving China's Corporate Debt Problem". Working paper 16–203, IMF, Washington, DC.

McCollum DL, Zhou W, Bertram C, de Boer H-S, Bosetti V, Busch S, Despres J, Drouet L, Emmerling J, Fay M, Fricko O, Fujimori S, Gidden M, Harmsen M, Huppmann D, Iyer G, Krey V, Kriegler E, Nicolas C, Pachauri S, Parkinson S, Poblete-Cazenave M, Rafaj P, Rao N, Rozenberg J, Schmitz A, Schoepp W, van Vuuren D, Riahi K. 2018. "Energy Investment Needs for Fulfilling the Paris Agreement and Achieving the Sustainable Development Goals." Nature Energy 3: 589–99.

Metcalf, Gilbert E. and David Weisbach. 2009. "The Design of a Carbon Tax." *Harvard Environmental Law Review*, 3, 499–556.

Morris, Adele. 2016. Build a better future for coal workers and their communities. Brookings Institution, Washington, DC.

Mulye, Manjiri. 2017. “Kigali Agreement: Simplified,” Cearias.com. Available at: www.clearias.com/kigali-agreement.

Muro, M., A. Tomer, R. Shivaram, and J. Kane. 2019. “Advancing Inclusion through Clean Energy Jobs’, Metropolitan Policy Program, Brookings Institute, April 2019.

Murray, Jessica. 2019. “Climate Change: Emerging Markets to Carry the Burden.” J.P. Morgan, Europe Economic Research.

National Academy of Sciences (NAS). 2018. Rapid Climate Change Special Feature. Proceedings of the National Academy of Sciences, Vol. 15.

NCE. 2018. *Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action in Urgent Times*. The New Climate Economy. The Global Commission on Energy and Climate.

Network for Greening the Financial System (NGFS). 2019. “A Call for Action: Climate Change as a Source of Financial Risk”, NGFS First Comprehensive Report, April 2019.

Newell, Richard. 2015. “The Role of Energy Technology Policy Alongside Carbon Pricing,” In Implementing a U.S. Carbon Tax: Challenges and Debates, edited by I. Parry, A. Morris, and R. Williams (New York: Routledge).

Nordhaus, William D. 2018. “Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies,” *American Economic Journal: Economic Policy* 10, 333–60.

———., 2015. “Climate Clubs: Overcoming Free-riding in International Climate Policy.” *American Economic Review* 105: 1339–70.

Organization of Economic Cooperation and Development (OECD). 2015. “Scaling Up Low-carbon Investment and Finance”, in chapter 2 of Aligning Polices for a Low-carbon Economy, OECD Publishing.

Organization of Economic Cooperation and Development (OECD). 2017. “Policies for Scaling Up Low-Emission and Resilient Investment” chapter 5 in Investing in Climate, Investing in Growth, OECD Publishing 2017.

Parry, Ian W.H. 2011. Reforming the Tax System to Promote Environmental Objectives: An Application to Mauritius. Discussion paper 11/124, International Monetary Fund, Washington, DC.

———. 2019. “The Rationale for, and Design of, Forest Carbon Feebates,” Unpublished manuscript (Washington: International Monetary Fund).

———., and Victor Mylonas. 2018. “Canada’s Carbon Price Floor.” Working paper 18/42 (Washington: International Monetary Fund).

———., Adele Morris and Roberton Williams. 2015. Implementing a US Carbon Tax: Challenges and Debates (London: Routledge).

———., Chandara Veung and Dirk Heine. 2015b. “How Much Carbon Pricing is in Countries Own Interests? The Critical Role of Co-Benefits,” Climate Change Economics, Vol. 6, pp. 1550019- 1-26.

———., Dirk Heine, Shanjun Li, and Eliza Lis. 2014. *Getting Energy Prices Right* (Washington: International Monetary Fund).

———., Ruud de Mooij, and Michael Keen. 2012. Fiscal Policy to Mitigate Climate Change: A Guide for Policymakers, International Monetary Fund, Washington, DC.

———., and Roberton Williams. 2010. "What are the Costs of Meeting Distributional Objectives for Climate Policy?" B.E. Journal of Economic Analysis & Policy 10, Issue 2 (Symposium), Article 9.

———., and Antonio M. Bento. 2000. "Tax Deductions, Environmental Policy, and the "Double Dividend" Hypothesis." *Journal of Environmental Economics and Management* 39: 67–96.

Requate, T. 2005. Timing and commitment of environmental policy, adoption of new technology, and repercussions on R&D. Environmental and Resource Economics 31: 175–99.

Roberts, D. 2019. "The Global Transition to Clean Energy", Vox, Jun 26, 2019.

Stavins, Robert. 2019. "The Future of US Carbon-Pricing Policy." NBERD Working paper 25912, National Bureau of Economic Research, Cambridge, MA.

Stiglitz, Joseph E. 2019. Addressing Climate Change through Price and Non-Price Interventions. Working Paper 25939. National Bureau of Economic Research.

Saez, Emmanuel, Joel Slemrod, and Seth H. Giertz. 2012. "The Elasticity of Taxable Income with Respect to Marginal Tax Rates: A Critical Review." *Journal of Economic Literature* 50: 3–50.

Stern, Todd. 2018. The Paris Agreement and its Future (Washington: Brookings Institution).

Stern, Nicholas and Joseph Stiglitz. 2017. "Report of the High-Level Commission on Carbon Pricing," Paper of the Carbon Pricing Leadership Coalition of the World Bank Group (Washington).

Stocker, Thomas F., Dahe Qin, Gian-Kasper Plattner, Melinda M. B. Tignor, Simon K. Allen, Judith Boschung, Alexander Nauels, et al., eds. 2013. Climate Change 2013: The Physical Science Basis: Working Group 1 Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Trachtman, Joel. 2017. "Law Constraints on Border tax Adjustment and tax Credit Mechanisms to Reduce the Competitive Effects of Carbon Taxes." National tax Journal 70: 469–94.

Tollefson, Jeff. 2018. "Carbon's Future in Black and White," Nature 556: 422–425.

UNEP. 2018. *Emissions Gap Report 2018*, UN Environment Programme (since renamed UN Environment), (Nairobi, Kenya).

UN.1992. United Nations Framework Convention on Climate Change. United Nations, New York City, NY.

UNFCCC. 2016. Paris Agreement, United Nations Framework Convention on Climate Change (New York City, NY). https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

________. 2018. Nationally Determined Contributions (NDCs). United Nations Framework Convention on Climate Change (New York City, NY). https://unfccc.int/process/the-parisagreement/nationally-determined-contributions/ndc-registry#eq-4.

van Ruijven, Bas J. Detlef, P. van Vuuren, Willem Boskaljon, Maarten L. Neelis, Deger Saygin, and Martin K. Patel. 2016. "Long-Term Model-Based Projections of Energy Use and CO_2 Emissions from the Global Steel and Cement Industries," Resources, Conservation, and Recycling, Vol. 112, pp. 15–36.

Weitzman, Martin, L. 2016. "Voting on Prices vs. Voting on Quantities in a World Climate Assembly." Research in Economics 71(2).

World Bank. 2012. *Turn down the Heat: Why a 4°C Warmer World Must Be Avoided*. Washington, DC.

________. 2018. *Groundswell: Preparing for Internal Climate Migration*. World Bank, Washington, DC.

________. 2019a. *State and Trends of Carbon Pricing 2019*. World Bank, Washington, DC.

________. 2019b. *Using Carbon Tax Revenues*. World Bank, Washington, DC.

World Economic Forum (WEF). 2019. *The Global Risks Report 2019*. Geneva.

Online Annex 1.1. Baseline CO_2 Emission Projections by Country

The *Fiscal Monitor* uses a spreadsheet tool providing standardized analyses, on a country-by-country basis, of carbon pricing and other mitigation instruments.[1] The model uses recent data on the use of fossil and other fuels for the power generation, transportation, household, and industrial sectors and projects fuel use forward in a baseline scenario of CO_2 emissions. No mitigation measures beyond those previously enacted and reflected in historical fuel consumption data are assumed.

These projections are based on assumptions regarding (1) future GDP growth; (2) how higher GDP affects the demand for energy products; (3) rates of technological change (for example, changes that improve energy efficiency); and (4) future international energy prices. The change in fossil fuel use and CO_2 emissions from mitigation policies, relative to the baseline, depends on (1) the change in fuel and electricity prices; (2) switching among fuels in power generation (coal, natural gas, oil, renewables, nuclear); and (3) the price responsiveness of demand for electricity and fuel in other sectors (capturing changes in both energy efficiency and product use). Electricity and fuel price elasticities are assumed to be between –0.5 and –0.8, based on cross-country empirical evidence and results from more detailed energy models. The model is applied here to the Group of Twenty (G20) countries, which collectively are projected to account for 80 percent of baseline CO_2 emissions in 2030.[2]

Fossil fuel CO_2 emissions are projected to increase significantly between 2017 and 2030 in the baseline case (Figure 1.1.1). For G20 countries combined, (emission weighted) GDP expands 78 percent over the period (by more than 100 percent in China and more than 150 percent in India). However, the energy intensity of GDP falls by 20–40 percent over the period[3] with generally modest changes in the CO_2 intensity of energy.[4] The net result is that CO_2 emissions (shown by the black squares in Figure 1.1.1) for the G20 countries combined increase by 28 percent, though emission growth is much larger in, for example, India, at 73 percent. The levels of projected emissions per capita in 2030, however, are largest in Australia, Canada, and the United States (about 14 tons per capita) and lowest in Brazil, India, and Indonesia (about 2 tons per capita). In absolute terms, projected 2030 emissions are highest in China (13.3 billion tons), the United States (5.0 billion tons), and India (3.6 billion tons).

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[1] The tool has been applied to 135 countries. See IMF (2019c).

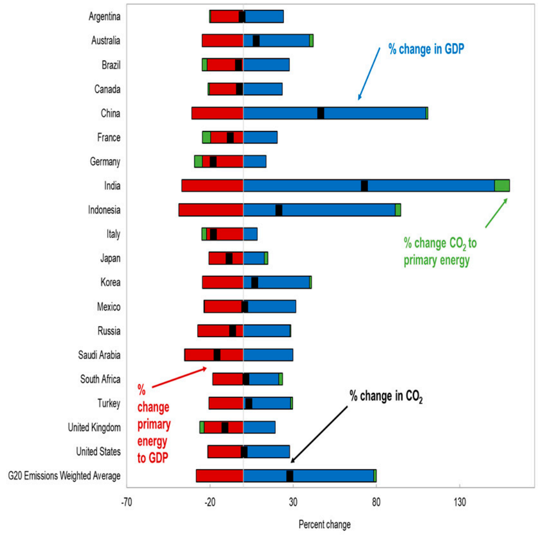
[2] See IMF (2019) for more extensive country results and details on data and methodology. (The current analysis updates GDP and international energy price data). The model is streamlined in various ways. For example, it does not account for trade linkages nor for the dampening effect on fuel price responsiveness in the nearer term stemming from gradual turnover of capital stocks. Moreover, the impact of higher energy prices on the deployment of emerging, low-carbon technologies remains uncertain.

[3] This reflects improving energy efficiency, an assumption that the proportionate increase in demand for energy products is less than the proportionate increase in GDP, and the dampening effect on energy demand from gradually rising international energy prices.

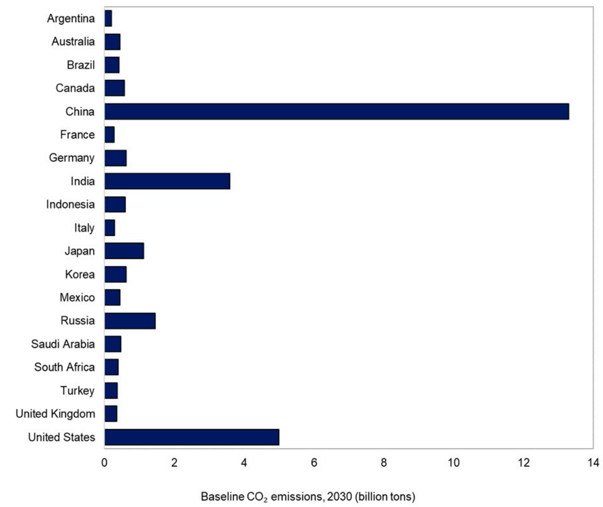
[4] CO_2 intensities would fall more in the longer term with greater substitution of renewables for (long-lived) fossil fuel capital.

Online Annex Figure 1.1.1. Baseline Projections of Fossil Fuel CO_2 Emissions

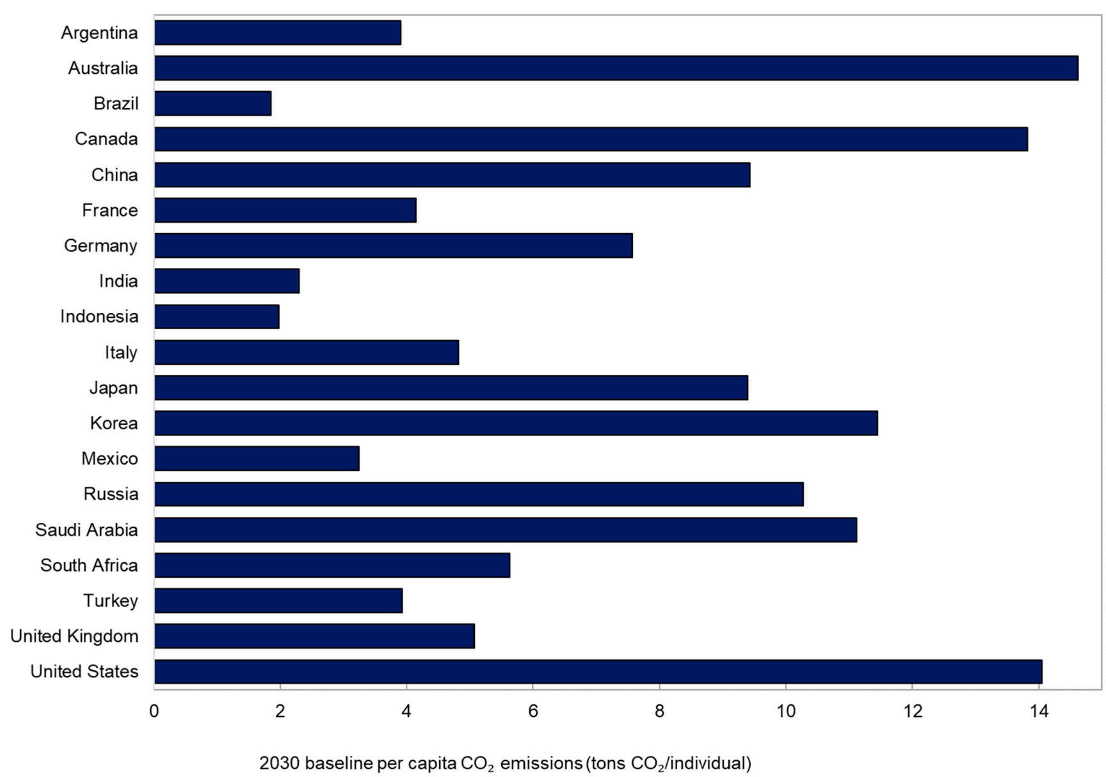
1. Change in Emissions, 2017–30



2. Total Emissions, 2030



3. Emissions Per Capita, 2030



Online Annex 1.2. Mitigation Aspects of the Paris Agreement

One hundred and ninety-seven parties are members of the UN Framework Convention on Climate Change (UNFCCC), an international environmental treaty adopted in 1992. The framework outlines how international agreements or protocols may be negotiated to specify action to progress on the objective of stabilizing atmospheric greenhouse gas concentrations to prevent dangerous climate change. The parties to the convention have met annually since 1995 in Conferences of the Parties (COPs) to assess progress in dealing with climate change. At COP 21, in 2015, the Paris Agreement was adopted and signed by 195 parties and went into effect in 2016 following ratification by a sufficient number of countries (to date 185 parties have ratified the agreement). The central goal of the Paris Agreement is to limit future global warming to 2°C above preindustrial levels, with an aspirational target of 1.5°C.[1]

One hundred and ninety parties submitted climate strategies, now referred to as "Nationally Determined Contributions" (NDCs), for the Paris Agreement. NDCs contain mitigation objectives and (in 140 cases) adaptation goals.[2] Mitigation pledges are difficult to compare because they vary in terms of (1) target variables (for example, emissions, emission intensity, clean energy shares); (2) nominal stringency (for example, percent emission reductions); (3) baseline years against which reduction targets apply (for example, historical versus projected baseline emissions); and (4) whether pledges are contingent on external finance and other (for example, technical) support.

Parties are required to submit revised NDCs every five years starting in 2020, with mitigation pledges that are expected to be progressively more stringent. Parties are required to report their emissions, and their progress in reducing them, to the UNFCCC every two years starting in 2024, based on the latest emission accounting guidelines from the Intergovernmental Panel on Climate Change (IPCC 2019).

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[1] See IPCC (2018) comparing the climate impacts of warming of 1.5°C and 2°C. The United States has announced its intention to withdraw from the agreement in 2020.

[2] Mitigation pledges are summarized in IMF (2019), WBG (2019), and at http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx.

Online Annex 1.3. The Effects of Carbon Mitigation Policies: A Diagrammatic Treatment

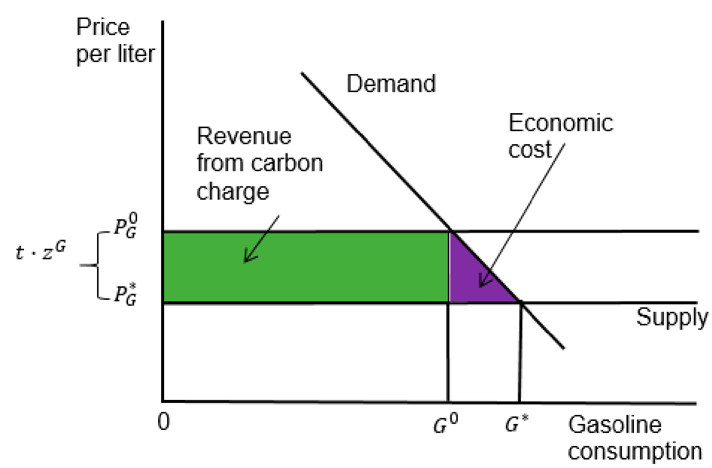
This annex uses a series of diagrams to explain the approach underpinning estimates of the emission, cost, price, and revenue impacts of carbon pricing presented in the *Fiscal Monitor*. The subsections below discuss the impacts of carbon pricing in energy markets, the impacts of alternative mitigation instruments, and the broader costs of carbon mitigation policies arising from their impacts on factor markets.

Impacts of Carbon Pricing on Energy Markets

Consider first, a tax on the supply of fossil fuels in proportion to their carbon content.

Gasoline Market: Figure 1.3.1 indicates the impact on the gasoline market: the height of the demand curve reflects the value to fuel users of an extra unit of consumption; the height of the supply curve reflects the cost of producing and distributing an extra unit of gasoline. The supply curve is drawn as flat, which is usually a reasonable longer-term approximation given that countries can purchase fuel from, or sell fuel to, global markets at a fixed price. Initially, the consumer and producer fuel price is P_G^* and consumption is at the economically efficient level G^*, in which the benefit to consumers from an extra unit of gasoline is equal to the cost of supplying that unit (the implications of preexisting fuel taxes are noted later).

Online Annex Figure 1.3.1. Gasoline Market

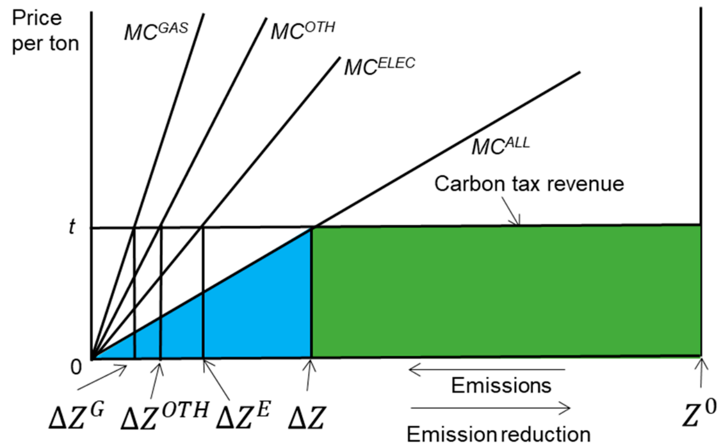


Source: IMF staff.

Suppose a per unit carbon charge of $t \cdot z^G$ is introduced on gasoline, in which *t* is a tax per ton on CO_2 emissions and z^G is the emission factor for gasoline (tons of CO_2 generated per unit of fuel use). The tax drives a wedge of $t \cdot z^G$ between the price paid by the consumer (now equal to P_G^0) and the price received by the producer (which remains at P_G^*) and reduces gasoline consumption to G^0. The tax causes an economic welfare loss indicated by the purple triangle, which can be interpreted as the loss of benefits to fuel users (the area under the demand curve between G^0 and G^*) minus saved supply costs (the area under the supply curve between G^0 and G^*). The former reflects losses to motorists from driving less, and using less-emission-intensive vehicles, than they would prefer. Revenues raised by the tax equal the tax rate times the new level of gasoline consumption G^0.

In Figure 1.3.2, MC^{GAS} is the marginal abatement cost schedule for reducing emissions from gasoline use—the height of this curve is the economic cost of reducing CO_2 emissions from gasoline consumption by an extra ton. The carbon tax t reduces CO_2 emissions from gasoline consumption by $\Delta Z^G = z^G(G^* - G^0)$; that is, CO_2 per gallon of fuel times the reduction in gasoline use and the area under the MC^{GAS} integrated over this emission reduction corresponds to the shaded triangle in Figure 1.3.1.

Online Annex Figure 1.3.2. Marginal Abatement Cost Curves for Reducing CO_2

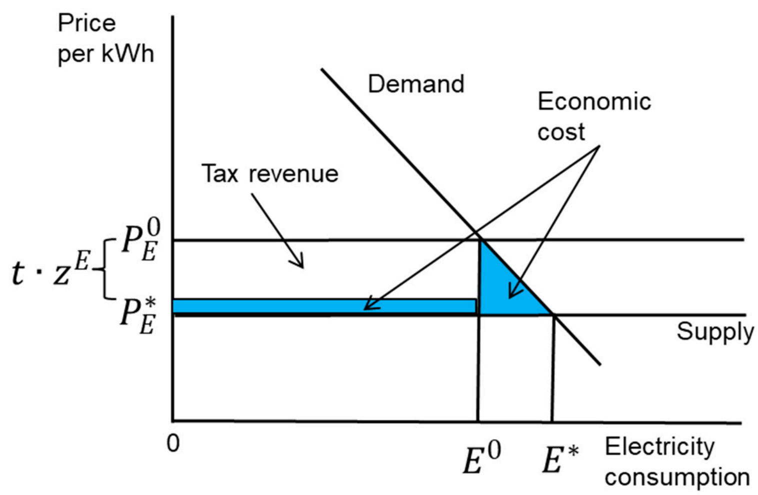


Source: IMF staff.

Next, consider the electricity market, as shown in Figure 1.3.3, in which the height of the demand curve is the value to firms or households of an extra unit of consumption, and the supply curve (drawn as flat for simplicity) is the cost of generating and distributing an extra unit of electricity from the marginal fuel source (for example, coal, natural gas, wind, solar). Initially, the consumer and producer price of electricity is P_E^* , and consumption is E^*, again the efficient level at which the benefit from incremental consumption to electricity users equals the incremental supply cost.

Suppose a tax on the carbon content of power generation fuels—or, equivalently, of power generation emissions—is introduced. The electricity price for consumers increases to P_E^0 , and this increase has two components. First, unit production costs increase to the extent generators react by switching from carbon-intensive fuels like coal to zero- or lower-carbon—but costlier—fuels to lower their average CO_2 emissions per unit of generation and these higher costs are passed on in higher electricity prices.[1] Second, generators must pay a tax on the remaining CO_2 emissions, causing a price increase equal to the (new) CO_2 emission rate per unit of generation z^E times the per ton CO_2 tax.

Online Annex Figure 1.3.3. Electricity Market



Source: IMF staff.
Note: kWh = kilowatt-hour.

The economic cost of the tax in Figure 1.3.3 has two components. One is the blue triangle, reflecting forgone benefits from the reduction in consumption to E^0 (the area under the demand curve between E^0

[1] It is assumed that, in the absence of a carbon tax, generators would choose their fuel mix to minimize generation costs.

and E^*) minus supply cost savings (the area under the supply curve between E^0 and E^*), in which the former reflects consumers' less intensive use of electricity-consuming products and increased reliance on more efficient (but costlier) products and technologies than they would prefer. The second cost is the blue rectangle, reflecting the higher average resource costs involved in producing the new level of output. Revenue from the tax is the carbon tax rate times CO_2 emissions per unit of output times the new output level E^0.

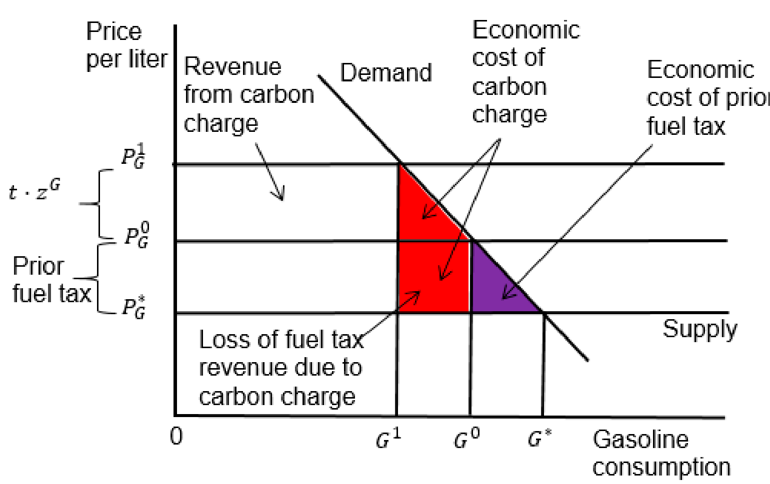
In Figure 1.3.2, MC^{ELEC} is the marginal abatement cost schedule for reductions in power sector emissions—the height of this curve is the economic cost of reducing CO_2 emissions from the power sector by an extra ton. The carbon tax *t* reduces CO_2 emissions from the power sector by ΔZ^E; that is, the product of the initial emission rate and initial output minus the product of the new emission rate and new output and the area under the MC^{ELEC} integrated over this emission reduction corresponds to the sum of the shaded blue areas in Figure 1.3.2.

Also shown in Figure 1.3.2 is MC^{OTH}, which summarizes the marginal abatement cost schedule from reducing CO_2 from all other (energy-related) sources, such as direct industrial and household fossil fuel use, diesel vehicles, and other transportation—the emission reduction from these sources is denoted ΔZ^{OTH}. MC^{ALL} in Figure 1.3.2 is the envelope or horizontal summation of all the marginal cost curves, in which emissions fall by $\Delta Z = \Delta Z^G + \Delta Z^E + \Delta Z^{OTH}$ under the tax of *t* per ton of CO_2. The total economic welfare cost of the tax is the area under the MC^{ALL} curve, given by

$$\frac{t \cdot \Delta Z}{2}. \qquad (1.3.1)$$

Total revenues raised by the carbon tax (from all emission sources), indicated by the green rectangle in Figure 1.3.2, are $t \cdot (Z^0 - \Delta Z)$, in which Z^0 is emissions in the absence of mitigation.

Online Annex Figure 1.3.4. Gasoline Market with Prior Fuel Tax



Source: IMF staff.

Suppose now that in the gasoline market in Figure 1.3.4 there is a preexisting fuel tax that causes initial fuel consumption G^0 to be below the efficient level G^*, resulting in an initial economic cost indicated by the purple triangle. Imposing the carbon charge increases the gasoline price to P_G^1, which reduces consumption to G^1, resulting in an additional economic cost indicated by the red trapezoid—again this is the loss of consumer benefits (the area under the demand curve between G^1 and G^0) minus production costs saved (the area under the supply curve between G^1 and G^0). The carbon charge raises revenues equal to the tax per unit of fuel use times G^1, but it also reduces the amount of revenue that would have been collected from the preexisting fuel tax by the red box in Figure 1.3.4.

Impacts of Other Mitigation Instruments

Suppose instead that the same emission reduction ΔZ was obtained by an emission trading system applied to power generators in a downstream program that prices emissions at the point of fuel combustion. In this case, the cost of the policy is given by the relevant area under the MC^{ELEC} curve in Figure 1.3.2 (rather than the area under MC^{ALL}). By similar triangles, the slope of this curve is equal to $\Delta Z / \Delta Z^{E}$ times the slope of the MC^{ALL} curve.

Alternatively, consider an emission standard for the power sector under which all generators are subject to a maximum allowable rate of CO_2 per kilowatt-hour (kWh). This policy promotes fuel switching in the same way a carbon pricing policy does. However, it avoids a large transfer of tax revenue to the government or the introduction of allowance rent, the main cause of higher electricity prices and reduced electricity demand under a carbon tax or emission trading system. Firms lower their average emission rate without paying taxes on, or acquiring allowances to cover, their remaining emissions.[2] Assuming the policy has a minor impact on electricity demand, and following the same logic as above, the slope of the marginal cost curve for this policy would equal the slope of the MC^{ALL} curve divided by the share of economy-wide emission reductions (under economy-wide emission pricing) that comes from fuel switching in the power sector.

Links between Carbon Mitigation Policies and the Broader Fiscal System

Broader taxes in the fiscal system—primarily taxes on personal and corporate income, payrolls, and consumption—create two sorts of distortion to economic activity.

First, the tax system distorts factor markets, thereby reducing the overall *level* of economic activity. By lowering the net-of-tax return from working—and therefore discouraging labor force participation, effort on the job, investment in human capital, and so on—taxes on labor income reduce work effort below what would otherwise maximize economic efficiency. Similarly, by lowering the net-of-tax returns on capital investments, taxes on corporate income and personal savings reduce capital accumulation below economically efficient levels.

Taxes also distort the *composition* of economic activity. Taxes encourage more activity in the informal sector, where productivity tends to be lower than in the formal sector. They also generate a bias toward other tax-sheltered activities or goods—for example, tax preferences for owner-occupied housing cause people to spend more on housing and less on ordinary goods than they would prefer. Tax exemptions for fringe benefits such as employer-paid medical insurance imply that workers receive excessive compensation in the form of fringe benefits at the expense of ordinary wage income.

Public finance economists have emphasized the importance of considering the full range of behavioral responses—the composition as well as the level effect—when evaluating the economic costs of distortions caused by the tax system.[3]

Figure 1.3.5 takes a closer look at tax distortions in the (economy-wide) labor market. Here the height of the demand-for-labor curve reflects the value of the output from extra work effort—this curve is drawn as flat, which is a reasonable approximation when returns to scale are constant (that is, doubling the amount of labor and capital input doubles output). In a competitive market, the wage paid by firms tends to reflect the value of extra output from additional work effort.

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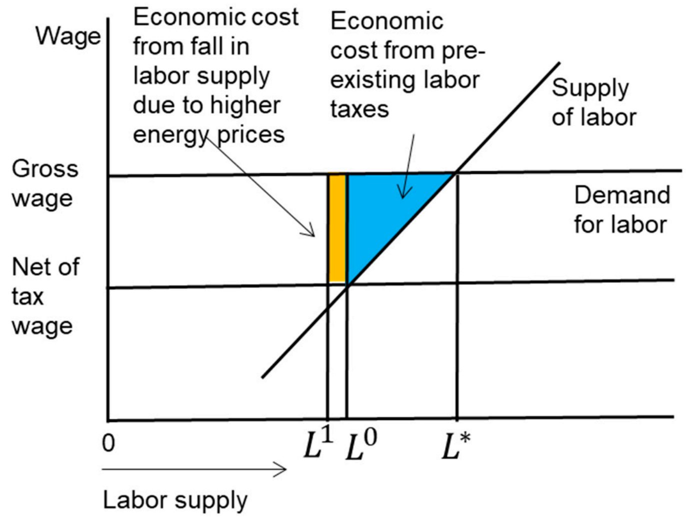
[2] Since there is no cap on total emissions, there is no creation of scarcity rents.

[3] For example, Saez and others (2010).

Online Annex Figure 1.3.5. Tax Distortions in the Labor Market



Source: IMF staff.

The supply-of-labor curve is drawn as sloping upward as higher wages tend to cause responses that increase work effort (for example, people putting in more effort or hours on the job, taking a second job, or delaying retirement or secondary workers in the household joining the labor force). According to economic theory, households will tend to supply labor until the wage they receive compensates them for the value of time forgone (in leisure activities, child rearing, schooling, volunteering, and so on). In the absence of taxes (or other distortions, such as institutional wage setting) the employer and household wage would be the same, and with the market in equilibrium employment would be at L^* in Figure 1.3.5. This is the economically efficient employment level as it is where the value of the extra output from additional work effort equals the cost to households from supplying additional effort.

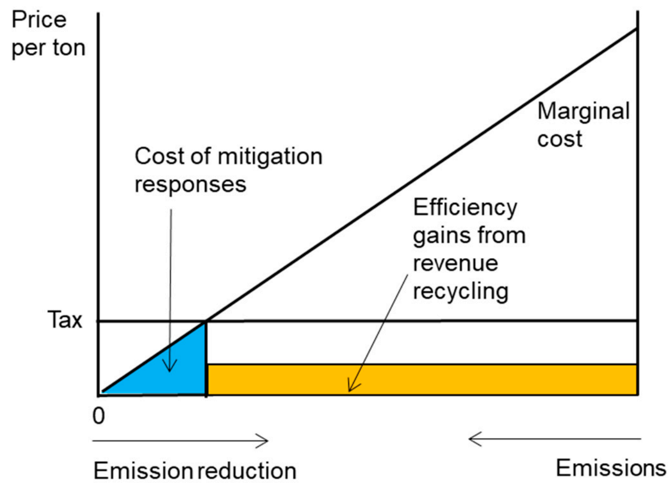
However, a variety of taxes—including payroll taxes paid by employers and employees, personal income taxes, and consumption taxes—combine to drive a large wedge between the wage paid by firms and the net-of-tax wage to households (in terms of how much consumption they can afford). As a result, the equilibrium level of employment is below the efficiency level at L^0, and there is an economic cost indicated by the blue triangle. This cost is the value of the output forgone (the area under the demand curve between L^0 and L^*) minus the value of the extra time for households as a result of supplying less labor (the area under the supply curve between L^0 and L^*). Cutting labor taxes therefore produces an economic efficiency gain as it reduces the tax wedge and pushes labor supply to move closer to its efficient level.

Carbon taxes or emission trading systems interact with the broader fiscal system in two important ways.

First, large gains in economic efficient can be generated when revenues are used to lower other distortionary taxes. In terms of Figure 1.3.6, these gains are indicated by the yellow rectangle, or the amount of revenue raised—the carbon price times emissions—multiplied by the efficiency gain per dollar of revenue used to cut distortionary taxes. More generally, the revenue-recycling benefit is similar if instead revenues are used to fund investments (for example, for United Nations Sustainable Development Goals) that might benefit the economy significantly more than the investment costs.

Second, however, there is a counteracting economic cost. Higher energy prices tend to compound the distortions from taxes in factor markets by reducing (via a slight contraction in overall economic activity) work effort and capital accumulation. If higher energy prices lead to a reduction in labor supply to L^1 the resulting economic cost is measured by the yellow rectangle in Figure 1.3.5, with the base equal to the reduction in labor supply ($L^0 - L^1$) and the height equal to the tax wedge, or the difference between the value to firms per unit of work effort and the cost to households per unit of labor supply.

Online Annex Figure 1.3.6. Economic Efficiency Gains from Revenue Recycling



Source: IMF staff.

To a point, and leaving environmental benefits aside, there can be a net economic gain from shifting taxes from labor and capital to fossil fuels (that is, the first effect above can overshadow the second). This is because cutting broader taxes helps reduce distortions both to the level of economic activity (through more incentives for work effort and investment) and to the composition of economic activity (through fewer incentives to shift spending toward tax-favored goods and assets). Although higher energy prices can reduce economic activity, they do not necessarily increase distortions in the composition of economic activity.[4]

The more important point, however, is that if revenue opportunities are not exploited—for example, if allowances are freely allocated in an emission trading system rather than auctioned or if carbon tax revenues are returned as lump-sum transfers (which do not encourage work effort and investment)—fiscal linkages can considerably increase the overall costs of carbon pricing policies. This follows because such policies fail to offset the second source of economic cost (in Figure 1.3.6) with economic efficiency benefits from revenue recycling.

Feebate and regulatory approaches generally do not raise revenue and therefore do not reap the efficiency benefit shown in Figure 1.3.6. At the same time, however, they have a much weaker impact on energy prices (Figure 1.3.3) and therefore tend to cause much smaller reductions in labor supply, in Figure 1.3.5, compared with those under carbon pricing. As a result, feebates and regulations can be less costly overall (for a given economy-wide reduction in emissions) than carbon pricing approaches that do not exploit the efficiency benefits of revenue recycling.[5]

Details on Cost Calculations

The economic efficiency benefits from recycling carbon pricing revenues is given by the following equation:

$$t \cdot (Z^0 - \Delta Z) \cdot M^R, \qquad (1.3.2)$$

[4] For example, Parry and Bento (2000), Bento and others (2018).

[5] For example, Goulder and others (1999).

in which M^R is the efficiency gain per \$1 of revenue; for example, from reducing taxes that distort the level and composition of economic activity or from funding productive investments. The calculation in The *Fiscal Monitor* uses an illustrative value of M^R = \$0.35 for the United States based on estimates (albeit uncertain) of behavioral responses to taxes,[6] although the calculation assumes 75 percent of revenues are used for this purpose and 25 percent for transfer payments with no economic efficiency benefits (but necessary to address, for example, burdens on lower-income households).

The economic cost of the increased distortion in the labor market induced by higher energy prices under carbon taxes is given by[7]

$$t \cdot \left(Z^0 - \frac{\Delta Z}{2}\right) \cdot M^L \cdot \left(\frac{1+M^R}{1+M^L}\right), \qquad (1.3.3)$$

in which M^L is the efficiency cost of labor taxes per \$1 of extra revenue, accounting for impacts in the labor market alone (that is, not including distortions to the composition of economic activity). M^L is taken to be 0.23.[8] Finally, the economic efficiency cost of a feebate policy in the labor market is given by

$$M^L \cdot \frac{t \cdot \Delta Z}{2}. \qquad (1.3.4)$$

Equations (1.3.1)–(1.3.4) are used to compute the costs in Figure 1.10 of the *Fiscal Monitor*, which focuses on a \$50 carbon tax for the United States in 2030. According to calculations from the IMF spreadsheet model, this implies CO_2 emission reductions 22 percent below baseline levels.

A Closer Look at Some Underlying Assumptions

Comparing (1.3.2) and (1.3.3), if $M^R = M^L$; that is, if labor taxes cause distortions only in labor markets, there is a net cost from interactions with the tax system. However, to the extent that $M^R > M^L$, the efficiency benefit from cutting income taxes is larger because income taxes distort other margins of behavior rather than just labor markets and, in this case, there can be a net economic benefit from interactions with the tax system.

The environmental tax literature has explored various modifications to the basic analysis above. For example, suppose that, instead of using 75 percent of carbon tax revenues to cut income taxes, these revenues were used to fund (general or environmental) public investments. Then the efficiency gains from revenue use would be larger or smaller than in equation (1.3.2), depending on whether these investments generate larger or smaller economic efficiency gains than from cutting distortionary taxes.

In addition, some analyses have studied links between carbon taxes and the broader fiscal system in dynamic models that capture the distortive effects on investment from taxes on the return to capital. In these models the efficiency costs of taxes on capital tend to exceed those of taxes on labor; therefore using the revenues from carbon taxes to cut capital taxes yields larger efficiency gains and strengthens the prospect of a net efficiency gain from links with the tax system (though the benefits from cutting capital taxes are skewed toward the better-off).[9]

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[6] Parry and Williams (2010).

[7] The equations below are based on Parry and Williams (2010).

[8] Parry and Williams (2010).

[9] For example, Goulder and Hafstead (2018).

Online Annex 1.4. Rationale for Feebates and the Impact of Applying them to Key Energy Sectors

There are several rationales for feebates. Potentially they

Are *effective* at reducing energy use, if they are applied across major energy-using products—vehicles, washing machines, light bulbs, air conditioners, refrigerators, and so on—and set to provide continuous (rather than discrete) rewards for higher efficiency (see below), and are appropriately scaled;

Are *cost-effective*, if there is a uniform reward for reducing energy, or more precisely emissions, across different types of products;

Limit administrative burdens, to the extent they can be incorporated into existing procedures for collection of excises on imported or domestically produced goods, though their application to power generators likely involves new capacity for monitoring emission rates and administering fees and rebates; and

Limit burdens on vulnerable households and firms, as they do not involve a first-order pass-through of new tax revenues to higher fuel, electricity, or product prices.

Application to Transportation

Many excise tax systems for new or imported vehicles classify the vehicles according to engine size (a proxy for fuel consumption rates) and then apply higher tax rates to vehicle categories with larger engines. These tax systems do not reward other vehicle characteristics, such as smaller cabin size, lighter body materials, or better aerodynamics, that can also lower fuel consumption and emission rates. And they offer no reward for a shift to lower-emission-rate vehicles within a classification (all vehicles within a tax bracket are subject to the same tax rate). Moreover, as people shift toward smaller vehicles this reduces the amount of revenue collected from the tax system.

The above problems can be addressed by a shift toward a vehicle excise tax system with an ad valorem, and a feebate, component.[1] The proportional tax in the ad valorem component can be set to meet a revenue target and does so without distorting the choice among different vehicles (because it leaves the relative price of different vehicles unaffected).

A feebate levies a tax on fuel-inefficient vehicles in proportion to the difference between their fuel consumption rate (that is, the inverse of fuel economy) and a "pivot point" fuel consumption rate. Conversely it subsidizes efficient vehicles in proportion to the difference between the pivot point and their fuel consumption rate; equivalently, fees and rebates can be levied on CO_2 emission rates. That is, a vehicle receives a fee or rebate according to the formula $t \cdot (CO_2/mile - \overline{CO_2/mile})$, in which the bar denotes the pivot point emission rate per mile and *t* is a charge per ton of CO_2 per mile.

The feebate component can be made (approximately) revenue-neutral by setting the pivot point emission rate equal to the average emission rate of vehicles sold in the previous year and updating it over time as the average emission rate of the vehicle fleet progressively declines. The tax or subsidy rates in the feebate can be set as aggressively as needed to encourage shifting to more efficient vehicles without eroding the revenue base (which depends on vehicle prices). Implementing this tax system would require data on the fuel per mile (the inverse of fuel economy) for different models.[2] Emission rates per mile can be inferred from the emission factors and fuel consumption rates per mile. Alternatively, the tax or

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[1] See for example Parry (2011).

[2] For example, from www.fueleconomy.gov.

subsidy rates can be levied on differences between a vehicle's CO_2 emissions per mile and a pivot point CO_2 per mile. Fuel economy can be converted to CO_2 per mile by inverting (from miles per gallon to gallons per mile) and multiplying by CO_2 per gallon—8,850 grams of CO_2 per gallon for gasoline and 10,250 grams per gallon for diesel.

A number of countries have recently introduced feebates, including Denmark, France, the Netherlands, and Norway (and many others have elements of feebates). The pivot points in these systems are typically equivalent to between 200 and 250 grams of CO_2 per mile, although the feebate prices differ significantly. For example, $10 per gram of CO_2 in France and up to $155 in Norway.[3] For illustration, a feebate with a pivot point of 250 grams of CO_2 per mile, and a price of $100 per gram of CO_2, would provide a subsidy of $5,000 to a vehicle with fuel economy of 45 miles per gallon and would impose a tax of $10,000 on a vehicle with fuel economy of 25 miles per gallon.

Electricity Sector

An excise analogous to the one described above for vehicles, with both ad valorem and feebate components, could be applied to sales of appliances and other electricity-using capital. Again, the ad valorem component could remain at any existing excise tax rate to maintain revenue. The feebate would involve taxes on products with relatively low energy efficiency in proportion to the difference between their electricity consumption rate and a pivot point consumption rate and conversely provide a subsidy to relatively efficient models in proportion to the difference between the pivot point and their consumption rate. For example, refrigerators might receive a fee or rebate according to the formula $t \cdot (kWh/(cubic\ foot\ cooled) - \overline{kWh/(cubic\ foot\ cooled)})$, in which kWh/(cubic foot cooled) is the electricity consumption rate, a bar denotes the pivot point consumption rate, and *t* is the charge per kWh/(cubic foot cooled).

To illustrate, if the pivot point consumption rate is 5 kWh/month and the feebate price is $30 per kWh/month, then a refrigerator with an energy consumption rate of 8 kWh/month would be subject to a tax of $90; a refrigerator with an energy consumption rate of 2 kWh/month would receive a $90 subsidy.[4] And again the feebate component can be made (approximately) revenue-neutral by setting the pivot point equal to the average electricity consumption rate of models within a product class sold in the previous year, with updates as the consumption rate progressively declines. To minimize the cost of reducing electricity use across a range of different product classes, the same incremental reward on kWh (that is, the tax rate *t*) should be uniform across electricity-using products.

Feebates could be applied to power generators. Generators would pay a fee (or receive a rebate) in proportion to their output times the difference between their emission rate per kilowatt-hour (averaged across their plants) and the industry average emission rate.

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[3] Bunch and others (2011), 59–61. In some cases, however (for example, Denmark), the implicit price of CO_2 is substantially higher for vehicles receiving rebates than for vehicles subject to fees, which results in net revenue losses from the feebate and violates the principle of providing the same reward for reducing emissions across all vehicle classes.

[4] As another example, the fee or rebate for air conditioners would be $t \cdot (kWh/(BTU\ of\ heat\ removed) - \overline{kWh/(BTU\ of\ heat\ removed)})$, where BTU is British Thermal Unit.

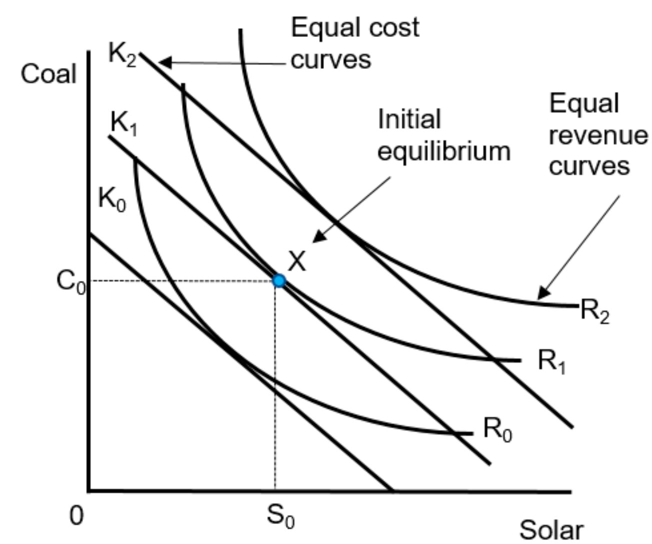
Online Annex 1.5. Carbon Taxes versus Feebates: A Closer Look

This annex offers further explanation of the difference between carbon taxes and feebates, as applied to the power generation sector, using a diagrammatic approach. The different impacts on firm-level choices, economic efficiency costs, revenue, and distributional burdens are discussed in turn.

Impact on Firm Choices

Consider Figure 1.5.1, which depicts the choice of output level, and input mix, for a power generation firm. The firm can choose between coal generation, which produces CO_2 emissions, and solar generation, which does not.

Figure 1.5.1. Firm Optimization over Input Mix and Output Level



Source: IMF staff.

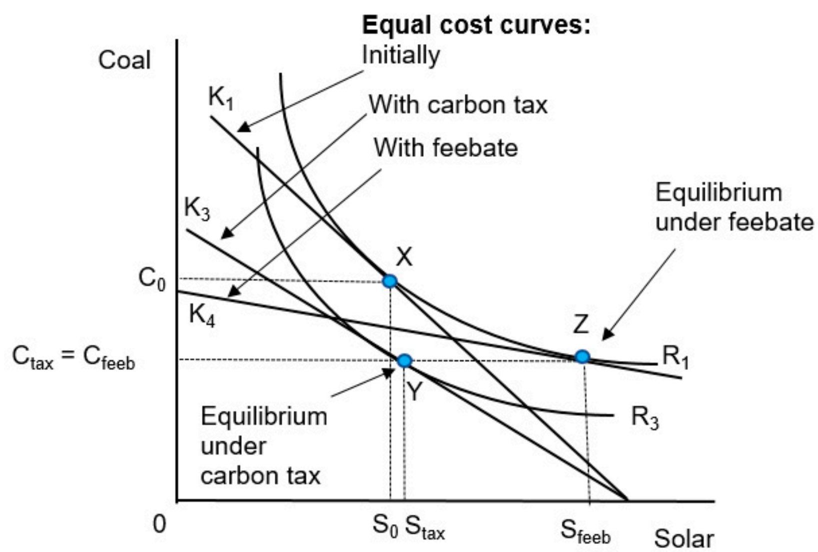
The downward sloping lines labeled K_0, in this figure are equal cost curves; that is, a given curve shows different combinations of coal and solar power inputs that would result in the same total production cost to the firm. The slope of these curves is the ratio of the cost per unit of solar generation to the firm to the cost per unit for coal generation.

The curves labeled R_0, in Figure 1.5.1 are equal revenue curves; that is, a given curve shows different combinations of coal and solar power inputs that would result in the same revenue to the firm. These curves are convex to the origin, because it is increasingly difficult to substitute one input for the other—for example, as the most productive sites for solar generation are used up, a progressively larger investment in solar is needed to progressively increase output by an extra unit. Increasing the quantity of both inputs by 10 percent boosts revenue by less than 10 percent—this could reflect the impact of greater supply at the industry level on reducing the market price of electricity and/or diminishing returns to scale (that is, the declining addition to output from progressive increases in coal and solar investments as the most productive sites are used up). In contrast, increasing the quantity of both inputs by 10 percent leads to a 10 percent increase in total production costs.

The firm chooses point X, where the equal revenue curve R_1 is tangential to the equal cost curve K_1. At this point, the level of output is optimized by the firm—expanding output by an extra unit beyond X would bring in less additional revenue than the extra cost; conversely, reducing output by a unit below X would lose more revenue than it would save in costs. In addition, the mix of inputs at point X, C_0 level of coal and S_0 level of solar, minimizes costs to the firm. A revenue-preserving increase in solar generation, and a reduction in coal generation, would move the firm along the R_1 curve to the right of point X. This would shift the firm to a higher cost curve. (Similarly, increasing coal input and reducing solar input to preserve revenue would move the firm along the R_1 curve to the left of point X, again shifting the firm to a higher cost curve.)

Now consider Figure 1.5.2, which compares the outcome just described with outcomes under either a carbon tax or a feebate. A carbon tax increases the unit cost of coal generation to the firm, thereby flattening the equal cost curves—specifically, the total production cost from a given quantity of inputs will increase in proportion to the increase in the cost of coal generation times the share of coal generation in total production costs. The new equilibrium is depicted by point Y, where the equal revenue curve denoted R_3 is tangential to the equal cost curve K_3, and the new quantities of coal and solar generation are C_{tax} and S_{tax}, respectively. Coal use falls for two reasons. First, the increase in the cost of coal generation relative to solar generation will cause a shift away from coal toward solar for any given level of output—a movement along the equal revenue curve R_1 to the right of point X. Second, at the market level consumer demand for electricity will fall as coal tax revenue is passed forward in higher electricity prices, and the representative generator will respond by reducing output, as represented by the shift to the lower equal revenue curve R_3, which in turn implies less use of both coal and solar inputs. Coal use falls while net carbon-free generation could increase or decrease.

Figure 1.5.2. Firm Optimization under Carbon Tax and Feebate



Source: IMF staff.

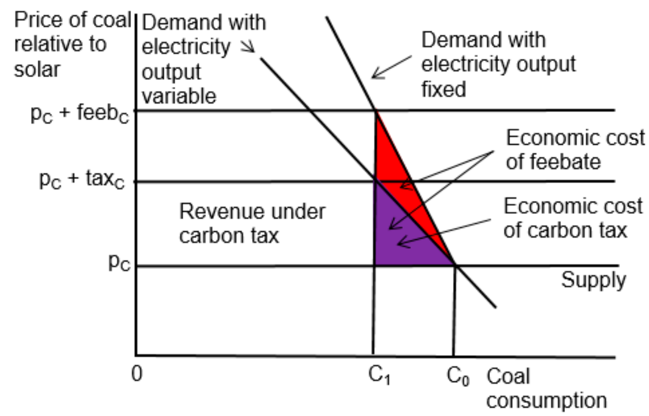
The feebate policy is defined as revenue-neutral and is designed to deliver the same decline in coal use as under the carbon tax. The feebate increases the unit cost of coal generation to the firm and reduces the unit cost of solar, but without (approximately speaking) a reduction in industry output (there is no net tax payment passed forward in higher electricity prices). In terms of Figure 1.5.2, the policy induces a movement along the initial equal revenue curve to point Z at the point of tangency with the new equal cost curve K_4, which has a flatter slope than the initial equal cost curve. As drawn in Figure 1.5.2, coal generation is the same as under the carbon tax. Solar generation is greater, however, as all the reduction in coal use results from switching toward the zero-carbon fuel—none of it reflects a general reduction in use of all inputs in response to less total electricity generation.

To achieve the same emission reduction as under a carbon tax—that is, to induce the same reduction in coal generation—the feebate policy must bring about a greater increase in the cost of coal generation relative to solar generation. This can be seen from Figure 1.5.2, in which the equal cost curve K_4 has a flatter slope than K_3 to compensate for its failure to reduce output and shift the firm to a lower equal revenue curve.

Economic Efficiency Costs

To compare the economic efficiency costs (excluding environmental benefits) of carbon taxes and feebates applied to the power sector, consider Figure 1.5.3, which shows the industry-wide market for coal used as an input in power generation. The lower, downward sloping curve is the demand for coal, and the height of this curve at any point is the value to generators (or profit) from using an extra unit of coal. The height of the supply curve reflects the cost of producing an extra unit of coal and, for simplicity, this is taken to be constant and equal to p_C, the supply price for coal. In the absence of policy intervention, the coal market is taken to be in equilibrium with coal consumption, given by C_0.

Figure 1.5.3. Economic Costs of Carbon Tax and Feebate in the Coal Market



Source: IMF staff.

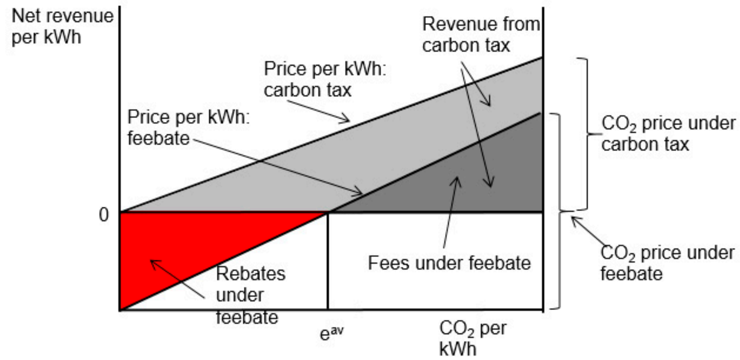
Now suppose a per unit tax of tax_C is imposed on coal use, corresponding to a carbon tax. The market price of coal will rise to $p_C + tax_C$ and coal use will fall to C_1, reflecting both shifting to the zero-carbon fuel and reductions in the overall level of electricity production. The resulting efficiency cost is given by the area under the demand curve between C_1 and C_0 (the benefits forgone from less coal use) minus the area under the supply curve between C_1 and C_0 (the supply cost savings).

Under a feebate policy, the demand for coal falls due to switching to solar, but (as an approximation) there is no reduction in overall electricity production. The relevant input demand curve for this policy therefore has a steeper slope than the corresponding demand curve under the carbon tax. Consequently, achieving the same reduction in coal use to C_1 (and therefore the same reduction in emissions) involves a higher efficiency cost as indicated by the red triangle in Figure 1.5.3—this extra cost arises because the feebate policy pushes excessively on fuel switching to compensate for not reducing electricity production.

Revenue Impacts

Finally, Figure 1.5.4 compares the revenue implications of carbon taxes and feebates applied to the power sector and allowing now for the possibility that firms have different mixes of fuels in their portfolio of generation plants. The industry-wide average CO_2 emission per kilowatt-hour (kWh); that is, total CO_2 emissions produced by the industry divided by total generation from the industry, is denoted as e^{av}.

Figure 1.5.4. Revenue Impacts of Carbon Tax and Feebate Applied to Power Generation



Source: IMF staff.
Note: kWh = kilowatt-hour.

Under the feebate policy, e^{av} is taken to be the pivot point emission rate, below or above which rebates or fees apply. Generators with emission rates below e^{av} (for example, those with relatively high shares of renewables and nuclear in their portfolios) will receive rebates per unit of generation equal to the CO_2 price times the difference between e^{av} and the average emission rate for their portfolio. Generators with emission rates above e^{av} (for example, those with relatively high shares of coal or diesel plants in their portfolios) will pay taxes per unit of generation equal to the CO_2 price times the difference between the average emission rate for their portfolio and e^{av}. The lower curve in Figure 1.5.4 shows the net revenue paid per unit of generation under the feebate—this curve has a negative intercept equal to e^{av} times the emission price in the feebate and slope equal to the emission price. Total rebates paid to firms with below average emission rates are indicated by the red triangle, while total taxes paid by firms with above average emission rates are indicated by the darker gray triangle. Total fees equal total rebates because the feebate is designed to be self-financing. And (as in Figure 1.5.3) the emission price under the feebate is larger than under the tax, because the feebate is designed to promote more switching between coal and solar.

Under a carbon tax all generators (aside from those with exclusively zero-emission portfolios) will pay taxes per unit of generation equal to the CO_2 price under this policy times their average emission rate. The upper curve in Figure 1.5.4 shows the revenue paid per unit of generation—this curve has a zero intercept and slope equal to the emission tax. Total taxes paid are indicated by the sum of the lighter and darker gray shaded areas.

Distributional Burdens

Under a carbon tax, most of the tax payments are likely passed forward in higher electricity prices to households and other electricity consumers, though a minor portion might come at the expense of rents for coal and electricity producers. Clean energy can benefit under both policies, but more so under the feebate. In this regard the feebate may garner more support from clean energy producers, and face less opposition from electricity and coal producers, though carbon taxes also raise revenues that can be used in ways to garner political support.

Online Annex 1.6. The Concentration of Coal-Related Employment within Countries

Reducing carbon emissions from coal is key if countries are to scale up efforts to tackle climate change. Yet in many countries, including some of the world's largest producers, coal activity is concentrated in a few regions, making it politically difficult to reduce the role of coal because that would generate sizable job losses in those regions. The regional implications of climate change mitigation policies thus need to be considered.

The top five regions on average account for about three-quarters of nationwide coal production for a sample of eight countries including China, the Czech Republic, India, Germany, Poland, and the United States (Table 1.6.1). Moreover, these coal-intensive regions often have lower per capita GDP (at about 60–90 percent the national average). Those regions also may have fewer alternative jobs and less diversified economies, as shown in the greater shares of the energy sector in regional GDP and coal-related jobs in total employment (Table 1.6.1; Figure 1.6.1). Coal workers often face longer spells of unemployment after layoffs and a permanent wage cut by as much as 30 percent in new jobs that often require relocation (Bollinger and others 2018; Johnson and Gosselin 2018). Communities that shut down coal mines also tend to face a sharp drop in labor force participation rates.

Online Annex Table 1.6.1. Regional Coal-Related Production and Employment (2015–17)
(Percent, unless otherwise stated)

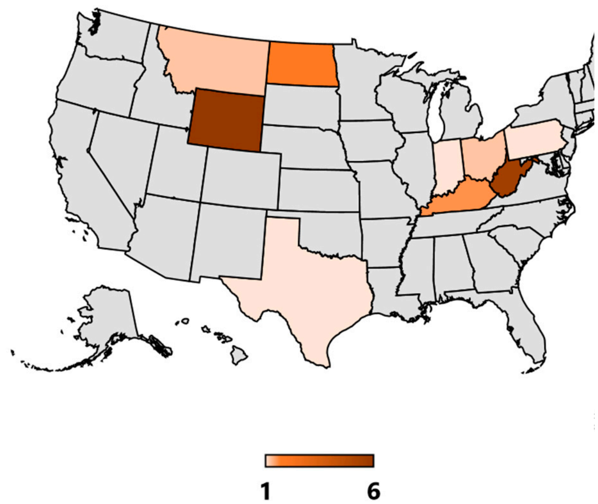
Country/Region 2/	Regional Share of National Coal Production (percent)	Coal to Total Regional Employment 1/ (percent)	Coal Production Per Capita (tons)	Regional Share of National Capacity of Coal-Fuel Power Plants (percent)	Energy Share of Regional GDP (percent)	Regional Per Capita GDP (percent of nationwide level)	Regional Population (percent of national population)
United States Coal Intensive Regions	85	1.6	46	46	7	92	25
Illinois	6	0.2	4	5	2	109	4
Indiana	4	0.5	5	6	2	91	2
Kentucky	5	1.1	9	5	3	77	1
Montana	5	0.8	34	1	4	77	0
Ohio	1	0.8	1	6	3	94	4
Pennsylvania	6	0.3	4	4	4	98	4
Texas	5	0.1	1	11	9	100	9
West Virginia	12	5.1	51	6	14	69	1
Wyoming	41	5.9	540	3	21	114	0
China Coal Iintensive Regions	76	6.7	17	n.a.	n.a.	83	12
Guizhou	5	2.1	5			64	3
Inner Mongolia	26	5.8	36			108	2
Shanxi	25	18.2	24			71	3
Shaanxi	16	5.1	15			97	3
Xinjiang	5	2.2	7			76	2
Germany Coal Intensive Regions	53	0.3	7	39	5	85	31
Brandenburg	19	0.4	14	10	6	72	3
North Rhine Westphalia	19	0.2	2	18	4	98	22
Saarland	0	0.5		5	4	92	1
Saxony	15	0.3	7	6	5	76	5
India Coal Intensive Regions	71	19.7	3	n.a.	n.a.	62	14
Chhattisgarh	20	19.4	5			73	2
Jharkhand	19	36.3	4			52	3
Madhya Pradesh	13	15.4	1			64	6
Odisha	19	7.8	3			62	3

Sources: Alves Dias and others (2018); CEIC; India's statistics office; US Bureau of Economics Analysis; and IMF staff estimates.
Note: Regions within countries are listed in alphabetical order. Coal-intensive regions are selected based on the shares of regional coal mines, the capacity of regional coal-fueled power plants, and regional coal-related jobs at the national level. The estimates include coal and lignite production capacity.
1/ Coal-related employment includes direct jobs in coal mines and coal-fueled power plants and estimated indirect jobs linked to the coal sector.
2/ For India, coal employment is expressed as a share of industrial (mining and factory workers) employment because of data limitations. For China, total employment in the region refers to total urban employment. n.a. = not available.

Online Annex Figure 1.6.1. Coal-Related Employment to Total Regional Employment in Coal-Intensive Regions (2015–17)
(Percent)

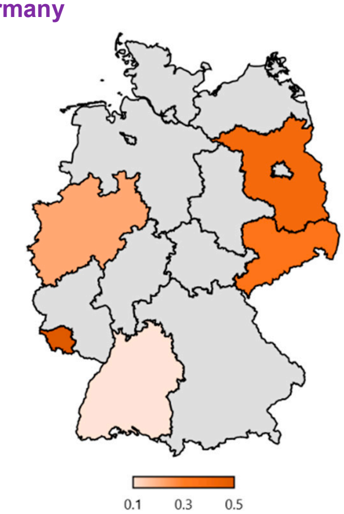
1. China

2. United States



3. India

4. Germany



Sources: Alves Dias and others (2018); CEIC; India's statistics office, US Department of Energy; and IMF staff estimates.
Note: Coal-related employment includes direct jobs in coal mines and coal-fueled power plants and estimated indirect jobs linked to the coal sector. For China, total employment in the region refers to total urban employment. In India, coal employment is expressed as a share of industrial (mining and factory workers) employment because of data limitations. Coal-intensive regions are selected based on the shares of (1) regional capacity of coal mines and coal-fueled power plants and (2) the regional coal-related jobs at the national level.

Online Annex 1.7. Prior Experiences with Carbon Taxation

More than 20 national and subnational governments have introduced carbon taxes (WBG 2019). The table below summarizes recent experiences in Colombia, France, and Singapore and long-standing experience in Sweden. The World Bank publishes an annual report (for example, WBG 2019) with details on carbon pricng systems worldwide.

Online Annex Table 1.7.1. Experiences to date in Colombia, France, Singapore, and Sweden

Country	Year of Reform	Carbon Tax Reform [1]	Success of Reform	Speed of Phase in	Stakeholder/Communications Program	Low-Income Households	Vulnerable Firms	Revenue Use
Colombia	2017	Tax of $5 per ton on oil and natural gas products with planned gradual increase to $11 per ton.	Successfully introduced	Gradual	Tax was adopted as part of a structural tax reform.	No information available	Exemptions for natural gas consumers that are not in the petrochemical and refinery sectors and fossil fuel consumers that are certified carbon-neutral.	Revenues earmarked for the Colombia Peace Fund, which supports activities like watershed conservation, ecosystem protection, and coastal erosion management.
France	2014	Tax on emissions not covered by the EU ETS. Rates were initally set at $8 per ton and were on a trajectory to reach $97 per ton in 2022.	Ramping up of tax suspended at $50 per ton in 2018	Rapid	Lack of public communication, especially on the use of carbon tax revenues.	Compensation system introduced in 2015 providing financial assistance to low-income households for their energy bills.	Agriculture, taxis, and trucks exempt to protect their competitiveness.	While France does not generally earmark revenues, the reform was accompanied by some support for the energy transition, financial assistance to low-income households, and broad tax reductions.
Singapore	2019	Tax, applying downstream to large emitters is set at $4 per ton from 2019 to 2023, with plans to increase it to $8-$11 by 2030.	Successfully introduced	Gradual	Public consultations carried out by various government agencies with stakeholders.	No information available	Tax rate starts low to account for potential competitiveness impacts.	Support climate initiatives (e.g., energy efficiency improvements for industry).
Sweden	1991	Tax on motor and heating fuels starting at $28 per ton (industries covered by the EU ETS emissions are excluded) and increased to $127 per ton by 2019. Lower rate for industry (at $7 per ton in 1991) was phased out by 2018.	Successfully implented as planned	Gradual	Tax was part of a broader fiscal reform including the reductions in taxes on energy, labor and capital, elimination of various tax shelters, and base broadening of the value-added tax. Business and other stakeholders were involved in the decision making process through general public consultation of the reform proposal.	Social transfers and reductions in the basic rate of income tax helped low and middle-income households.	Much lower initial rate for industry, which was phased out gradually.	Revenues go to the general budget but may be used for specific purposes linked to the carbon tax (e.g., addressing distributional consequences through cuts in income and labor taxes, financing other climate-related measures and public transportation investment).

Sources: WBG (2018, 2019); NCCS (2019); and www.government.se/government-policy/taxes-and-tariffs/swedens-carbon-tax.
Note: EU ETS = European Union Emissions Trading System.
[1] Tax rates are in 2017 US dollars.

Online Annex 1.8. Incidence Analysis

Input-output tables are used to estimate the impact of carbon pricing on industry costs. These costs are assumed to be passed into consumer prices, which are matched with household expenditure surveys to infer burdens across household groups, defined by per capita consumption. Incidence impacts are projected for 2030.[1]

The burden on household consumption groups from carbon pricing is measured by changes in "consumer surplus." Consumer surplus is defined as the benefit from consumption of a product minus what consumers pay for that product. In Figure 1.3.1, for example, the consumer surplus from the initial level of gasoline consumption is measured by the area between the demand curve and supply curve with height P_G^*, integrated between the origin and fuel consumption G^*. And with the new tax, consumer surplus falls to the area between the demand curve and supply curve with height P_G^0, integrated between the origin and fuel consumption G^0. That is, the reduction in consumer surplus, or the burden of the tax, is equivalent to $(P_G^0 - P_G^*) \cdot G^*$, the extra spending required to maintain the initial level of consumption, minus $(P_G^0 - P_G^*) \cdot (G^* - G^0)/2$, which is equivalent to the savings over spending at the higher price, minus the loss of consumer benefits, from the reduction in consumption. Dividing by total household consumption, and a little manipulation, gives

$$\rho^G \cdot \pi^G (1 - \alpha^G/2). \qquad (1.8.1)$$

In this expression, ρ^G is the proportionate increase in the price of gasoline from the tax, π^G is the share of the budget for the household group that is initially spent on gasoline, and α^G is the proportionate reduction in gasoline consumption caused by the tax. If the budget share for gasoline is, say, 10 percent, this formula implies that a 20 percent increase in its price, causing a 10 percent reduction in consumption, will cause a burden of 1.9 percent of income. The same approach, used for calculating the burden from the increase in prices for other consumer products and aggregating over products, gives the total household burden from the tax.

Budget shares are from the Survey of Household Spending[2] for Canada, the China Family Panel Studies[3] for China, the 68th Round of the National Sample Survey[4] for India, the 2015–16 Living Costs and Food Survey[5] for the United Kingdom, and the Consumer Expenditure Survey[6] for the United States. Households are first separated into quintiles by their total consumption expenditure, and budget shares are calculated by dividing spending on individual goods and services by total expenditure.

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[1] For other recent studies on the burden of carbon pricing see, for example, Vogt-Schilb and others (2019) and Dorband and others (2019).

[2] The survey, provided by Statistics Canada, distinguishes 20 aggregated categories of goods and interviewed 16,758 households in 2009.

[3] This includes data on household expenditures for 25 aggregated categories of goods and services. The latest year available for the survey is 2012 and includes information from a nationally representative sample of more than 13,000 households across 25 provinces in China. See www.isss.edu.cn/cfps/EN.

[4] The survey, which distinguishes 39 categories of goods, interviewed 101,724 households (59,700 rural and 42,024 urban) between July 2011 and June 2012.

[5] This survey contains 13 aggregated categories of expenditures, based on the Classification of Individual Consumption by Purpose (COICOP) standard, with an initial sample of 11,484 households (see https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/methodologies/livingcostsandfoodsurvey).

[6] The 2015 survey was used based on a nationally representative sample of 24,617 households (see www.bls.gov/cex/home.htm).

The spreadsheet tool mentioned in Annex 1.1 is used to calculate the impacts of carbon pricing on fuel and electricity prices and reductions in household demand for energy products. Indirect price increases for other consumer goods are calculated, assuming full pass-through of the burden from producers to consumers, using input-output tables (demand responses for these products are ignored but are likely of minor significance for overall incidence impacts). For Canada, the national input-output table is for 2013, for China 2012, for India 2007–08, for the United Kingdom 2015, and for the United States 2007.[7] Industries are mapped to the relevant product classification in the household data, and within that classification are weighted by their contribution to total household spending on that product.

In projecting to 2030, the shares of different industries in total output are assumed to be the same as in the years of the input-output data, while the energy intensity of the economy is assumed to decline based on estimates from Annex 1.1. The household budget shares for electricity and direct fuel consumption are scaled by the corresponding 2030 energy prices relative to prices in the year of the household survey. In addition, the weights of the household surveys are adjusted to reflect population projections in 2030, and household burdens are adjusted to fully reflect the impacts of fuel price increases on private consumption and investments.

When simulating the impact of various options on the use of carbon tax revenue, it is assumed that carbon tax revenue is first used to offset the impact on government consumption and investment (estimated from the input-output table) and to provide support for trade-affected firms and sectoral and place-based assistance. For the rest of carbon tax revenue, (1) under the universal lump-sum option, an equal amount is distributed among the entire population; (2) under the public investment option, the incidence is assumed to be the same as that of consumption; and (3) under the tax cut option, the incidence is assumed to be the same as that of existing payroll or income tax.

There are several caveats for the incidence analysis methodology:

(1) Not all the burden of carbon pricing may be passed forward in higher prices for households—some (likely a minor fraction) may be passed backward in lower prices for firms. As a result, some of the burden may be borne by owners of capital or workers in these firms, though it can be difficult to apportion these impacts to different household consumption groups.

(2) Not all the economic efficiency impacts of the carbon tax and the use of the carbon tax revenue are captured by the analysis—for example, the economic efficiency loss from the carbon tax on sectors beyond the energy sector and the economic efficiency gain from public investment and tax cuts of carbon tax revenue.

(3) The distributional incidence of the domestic environmental co-benefits of carbon pricing—principally the air pollution benefits—is not considered. If the valuation of health risks is roughly proportional to

[7] For Canada, the table is the latest version published by Statistics Canada and disaggregates 230 industries. For China, the table is the latest version published by the National Bureau of Statistics, covering 139 industries. For India, the table is from the Central Statistics Office, Ministry of Statistics and Programme Implementation of India, covering 130 industries. See http://mospi.nic.in/publication/input-output-transactions-table-2007–08. For the United Kingdom, the 2015 table (which includes 129 industries) was obtained from the Office for National Statistics: https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesdetailed. For the United States, the table is from the US Bureau of Economic Analysis (see www.bea.gov/industry/io_annual.htm) and covers 389 industries. Although more recent input-output tables are available from other sources (for example, www.wiod.org/home), they cover only a (standardized) set of (56) industries, which does not provide the necessary level of disaggregation (that is, separate categories for energy products, such as coal, oil, natural gas, electricity, and road fuels) needed to analyze the direct and indirect effects of carbon taxation. In any case, for comparable categories, budget shares have not changed much in more recent tables.

income,[8] then these benefits may be skewed toward lower-income households if these households are more likely to reside in severely polluted areas. Again, the effects become complex, however, if for example property values increase in areas with improving air quality (which would hurt low-income renters).

[8] See for example Coady and others (2019), 12–13.

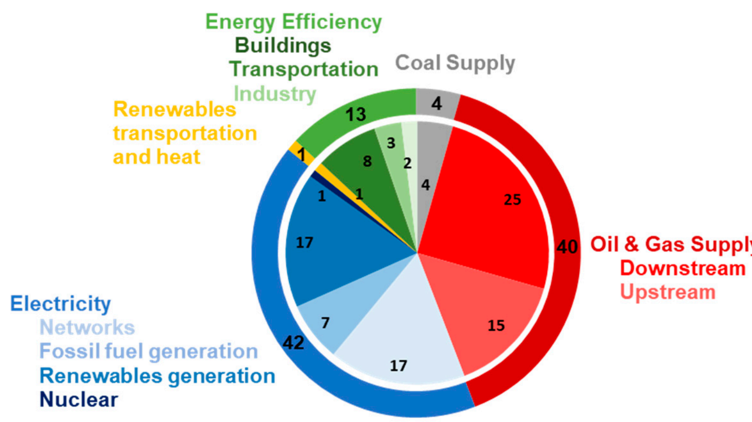
Online Annex 1.9. Energy Investment Needs, Methodology, and Case Studies

This annex takes a closer look at energy investment needs for climate change mitigation, discusses the methodology used to extrapolate model-based energy investment needs at the global level (obtained from existing studies[1]) to individual G20 countries, and provides examples of how supporting policies could improve investment incentives in China, India, and the United States.

Investment Needs for Mitigation

As of 2017, total investment in the global energy system was $1.8 trillion, or 1.9 percent of global GDP. Forty-two percent of the investment was in power generation (17 percent in new renewables capacity, 7 percent in fossil fuel generation, 17 percent in network upgrades, and a small fraction of a percent in nuclear); 40 percent was in oil and gas supply and distribution infrastructure; 13 percent was in energy efficiency in buildings, vehicles, and industry; and 4 percent was in new coal supply (Figure 1.9.1). Investment is more substantial in developing and emerging market economies, where energy use is expanding rapidly, averaging 3.5 percent of GDP compared with 1.3 percent of GDP in advanced economies. Much of the energy infrastructure (for example, power plants, refineries, power grids, buildings) has an expected lifetime of 30–60 years, underscoring the difficulty of rapidly transforming energy supply systems, but also the prolonged impact of investment choices made today.

Online Annex Figure 1.9.1. Global Energy Investment in 2017
(Percent)



Source: IEA (2018).

Achieving emission reduction targets under the 2°C scenario requires higher investment in China and India (by a third and a quarter, respectively),[2] though not necessarily in other G20 countries (Figure 1.9.2, estimated based on the methodology discussed below[3]). More important, model results from existing studies show that transforming the global energy system toward the 2°C scenario requires a significant reallocation of supply-side investment portfolios (Figure 1.9.3, panel 1). Investment must be shifted away

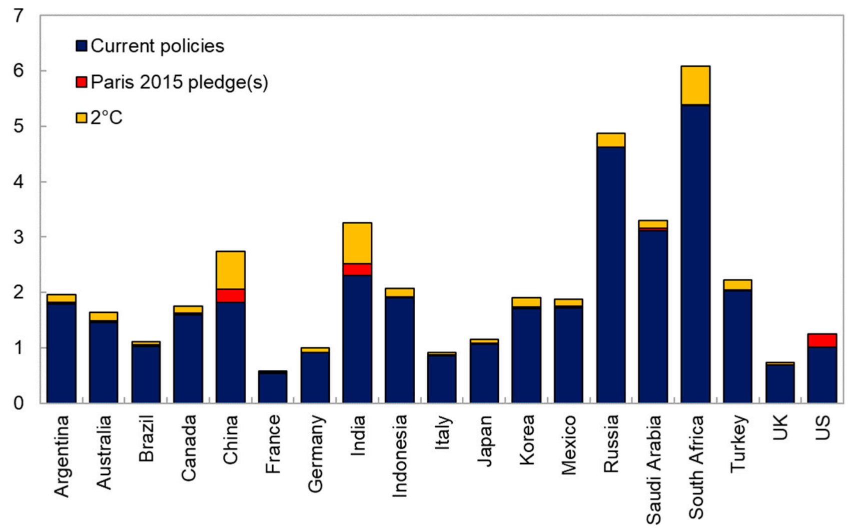
[1] McCollum and others (2018) and IEA/IRENA (2017).

[2] This is mainly because of China's and India's greater reliance on coal and the significantly higher investment costs of alternative technologies (for example, renewables).

[3] Numbers for China, India, and the United States are obtained directly from the multimodel averages of McCollum and others (2018). Investment needs for other G20 countries are those of the IMF staff based on estimates at the global level from existing studies. Note that these numbers are subject to significant variation across models. Moreover, future technological breakthroughs and costs and the speed and strategy of countries' adoption to achieve climate goals affect the size of investments.

from fossil fuel supply and conventional power generation to low-carbon sources, including renewables, nuclear, improved transmission and distribution networks, and carbon capture and storage.[4]

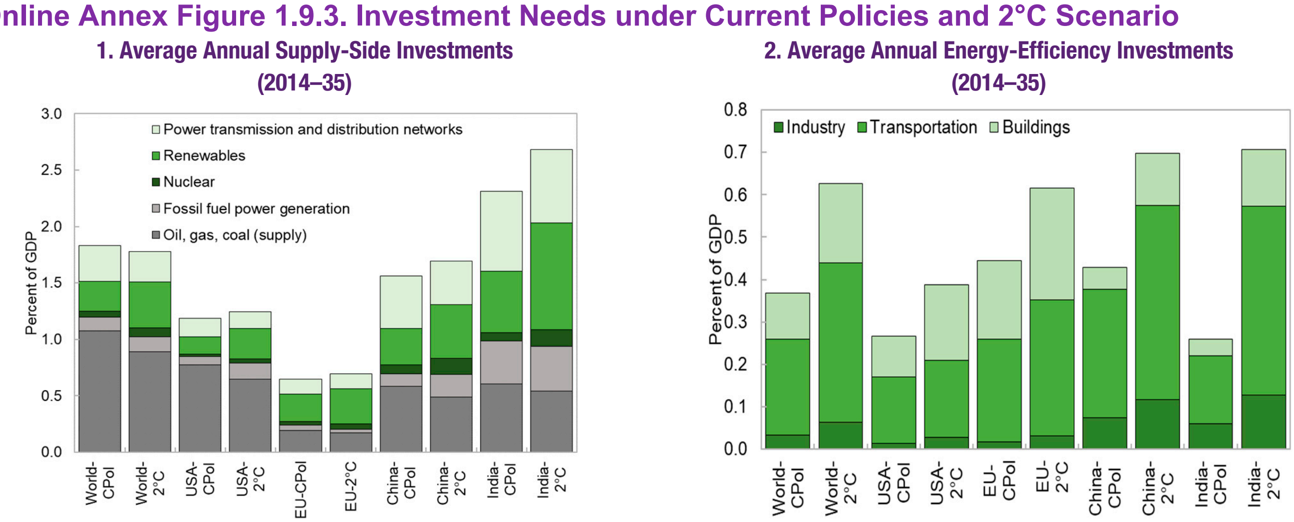
Online Annex Figure 1.9.2. Investment Needs (2030)
(Percent of GDP)



Source: IMF staff calculations based on IMF (2019) and McCollum and others (2018).
Note: NDC = Nationally Determined Contribution.

Moreover, sizable additional investment in energy efficiency is needed for buildings (for example, heating, cooling, appliances), transportation (for example, electric cars), and industry, amounting to 0.5 percent of global GDP (Figure 1.9.3, panel 2).[5] Such energy efficient investments can curb emissions more quickly because of their shorter life cycles compared with energy supply infrastructure.[6]

Online Annex Figure 1.9.3. Investment Needs under Current Policies and 2°C Scenario



Source: IMF staff calculations based on WEIO (2014).
Note: CPol: current policies; 2°C: 2 degree Celsius scenario.

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[4] Whether the costs associated with greater use of nuclear power outweigh the gains through lower carbon emissions is a hotly debated issue (for example, IPCC 2014). If nuclear is used, it would require adequate regulations and safeguards.

[5] IEA/IRENA (2017).

[6] IEA (2018).

Methodology for Extrapolating Investment Needs at the Country Level

Using the contribution of each G20 country to total CO_2 emission reduction at the global level under Nationally Determined Contributions (NDCs) and 2°C scenarios (obtained from IMF 2019 and model-based projections from the literature), we calculate the slope of the marginal abatement cost (MAC) curve for G20 countries individually and collectively (the MAC shows the marginal cost of reducing emissions). We follow previous studies[7] in postulating that the G20-wide total abatement cost (TAC) is a quadratic function of CO_2 emission reductions, or

$$\mathrm{TAC} = \theta(\Delta\mathrm{CO_2})^2 ,$$

in which ΔCO_2 is the reduction in total CO_2 emissions at the G20 level from the reference scenario and θ is a scaling parameter. The MAC can then be derived as follows:

$$\mathrm{MAC} = 2\theta(\Delta\mathrm{CO_2}).$$

The slope of the G20-wide MAC curve can be estimated from model-based energy investment cost projections as

$$\beta = \frac{MAC}{\Delta\mathrm{CO_2}} = 2\theta.$$

Given that the G20-wide MAC curve is the horizontal sum of the individual-country MAC curves,[8] we can use β to calculate the slope of the MAC curve of country *i*:

$$\beta_i = \frac{MAC}{(\Delta\mathrm{CO_2})_i} = \frac{\beta*(\Delta\mathrm{CO_2})}{(\Delta\mathrm{CO_2})_i} = \frac{\beta}{\alpha_i} = \frac{2\theta}{\alpha_i},$$

in which α_i is the contribution of country *i* to total emission reductions, ensuring that emission abatement is achieved in the most cost-effective way.

The contribution of individual countries to total CO_2 emission reductions is known from the IMF spreadsheet tool (Annex 1.1), so individual MAC curves can be estimated after solving for the scaling parameter θ. With a quadratic TAC function, the average abatement cost (AAC) is as follows:

$$\mathrm{AAC} = \theta(\Delta\mathrm{CO_2}),$$

implying that

$$\theta = \frac{AAC}{\Delta\mathrm{CO_2}}.$$

Hence, the individual MAC curve slope can be computed as

$$\beta_i = \frac{2\theta}{\alpha_i} = \frac{2}{\alpha_i} * \frac{AAC}{\Delta\mathrm{CO_2}}.$$

Given that the total G20 investment needs under the Nationally Determined Contributions and 2°C scenarios are known from the literature, the average abatement cost per ton of emission reduction can be calculated and used to compute the slope of the individual G20 MAC curves (see Figure 1.9.4 on MAC curves under the 2°C scenario).Once the slopes of the individual MAC curves are known, the total investment needs for an individual country *i* is computed as follows (Figure 1.9.2):

$$\mathrm{TAC}_i = \frac{\alpha_i\beta_i}{2}(\Delta\mathrm{CO_2})_i{}^2.$$

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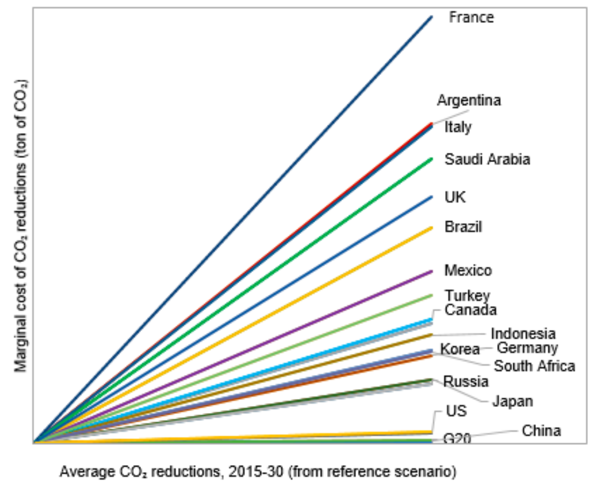
[7] See Cline (2011); Kesicki (2015); and Ibrahim and Kennedy (2016) for details.

[8] The analogy is the following: the market supply curve is the horizontal sum of individual firm supply curves.

Case Studies for Supportive Policies for Mitigation Investment (public and private)

Section V. (Supporting Policies for Clean Technology Investment) discusses how even with robust carbon pricing, investment in low-carbon technologies may be inadequate given various technology-related market failures and impediments. Here, case studies of China, India, and the United States highlight some of these impediments and how to address them.

Online Annex Figure 1.9.4. Marginal Abatement Cost Curves for G20 Countries under 2°C Scenario



Source: IMF staff calculations based on McCollum and others (2018).

China invested about $100 billion a year in clean energy during 2012–18. Progress was made to mitigate the curtailment rate—the loss of energy delivery from a generator to the electrical grid, typically because of transmission congestion or lack of transmission access—of wind and solar renewables, largely on par with other advanced countries. As some renewable technologies, such as solar photovoltaic cells, become more mature, fiscal incentives for their deployment are adjusted appropriately. For example, total subsidies for solar projects were targeted to be $0.4 billion in 2019, down from $18 billion in 2017. China also plans for subsidy-free solar and wind projects and aims to reach a grid parity target by 2020 so that electricity generated from solar and wind can be sold at the same price as coal-fired power (NDRC 2018). Tax exemptions on electronic vehicle purchases are extended in part to facilitate the adoption of tighter automobile emission standards (China VI) in key provinces ahead of schedule to contain pollution.

Nonetheless, changing the investment composition to meet emission reduction goals requires bolder action on market reforms of the energy sector. Specifically,

- *Less reliance on coal:* Coal accounts for two-thirds of the energy source in electricity generation capacity. The low cost of coal and a relatively stable grid purchasing price reinforce state-driven investment in fossil fuels (OECD 2017). A complex web of cross-subsidization of renewables and fossil fuels also tends to favor incumbent state-owned enterprises, hindering investment in renewables by new entrants. As a result, it is important to align fiscal incentives to avoid subsidizing both fossil fuels and renewables while enforcing restrictions on new coal investment to reduce reliance on coal. Greater investment in carbon capture and storage also mitigates emissions from the use of coal.
- *Reforming the electricity market:* Electricity generation from renewables is more volatile, and in many cases, costs more. For renewables to be competitive, electricity prices will need to be flexible to reflect supply and demand conditions. However, regulated electricity prices for power companies reduce incentives to switch to a more variable renewable energy supply and could contribute to the remaining curtailment (reduction of energy delivery from generation to electricity grid) of renewables generation

(OECD 2017).[9] Second, although state ownership of enterprises is found to increase renewables investment, it also raises market concentration that impedes new private entrants (Prag, Rottgers, and Scherrer 2018). At the same time, the recently proposed emission trading system contains multiple emission allowance benchmarks, which would likely not be cost-effective and would undermine the price signals for low-emission investment.[10] Finally, even the proposed system has the potential to take into account the disparity of regional development and economic cycles. Local governments may not be able to enforce compliance and distribute allowances effectively.

India has launched multiple policies and set up institutional mechanisms to support low-carbon investment (see India Economic Survey 2017–18 for details). The government is implementing the National Action Plan on Climate Change. Key measures include (1) expanding renewable energy capacity fivefold from 2014 to 2022, albeit from low levels; (2) introducing and increasing clean energy processes on coal; and (3) developing domestic carbon markets. In terms of instruments, India provides generation-based incentives, feed-in tariffs for power purchase agreements, capital and interest subsidies, grants, concessional finance, and priority lending. It introduced disclosure requirements for issuance and listing of green bonds. There are also regulations for mandatory installation of efficient appliances in all central government buildings. Nonetheless, implementation challenges and policy inconsistencies remain.

Despite tangible progress in expanding renewable energy capacity, market distortions may impede large-scale low-carbon investment in India. Specifically,

- *Reliance on coal:* About 60 percent of electricity is generated by burning coal, and there is substantial support for coal through subsidies (higher than for renewables; see Figure 1.9.5). The Goods and Services Tax (GST) rate on coal is 5 percent, and the clean energy excise (which later became the GST compensation cess on coal) is only 400 rupees (about $6) per ton of coal. Therefore, there is room for reconfiguration of subsidies, stricter environmental regulations on new coal plants, more efficient use of coal, and investment in carbon capture and storage technologies.

- *Financial weakness of power distribution companies:* Despite improvement in fuel supply and electricity generation, distribution remains problematic given the financial weaknesses of state-owned power distribution companies. These companies experience operational losses in part because electricity tariffs are low relative to the high cost of procuring power. The problem is worse for electricity generated from renewables given their higher production costs and low tariffs in power purchase agreements. Moreover, renewables in India are underused and have not reached economies of scale despite government subsidies (initially investment-based but more recently production-based, which is less distortionary). Building on past efforts, measures need to be implemented to improve the

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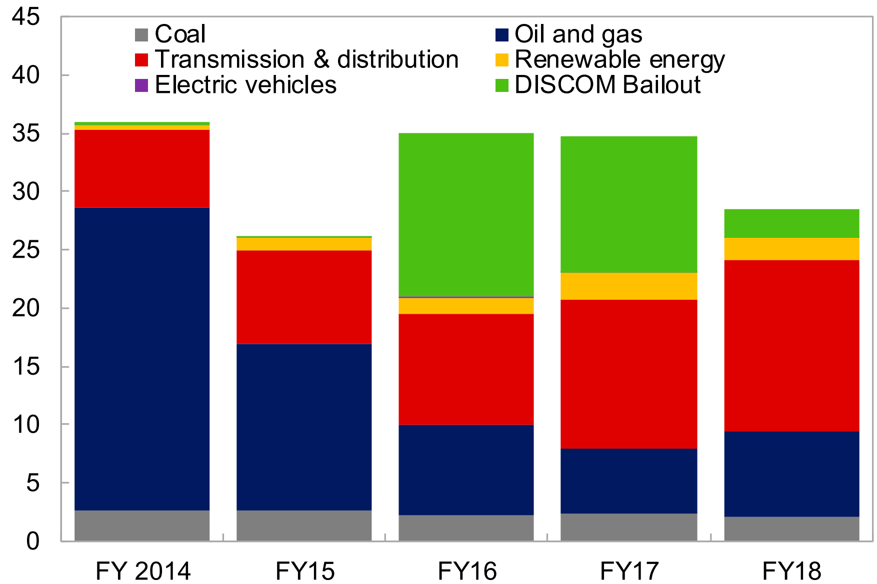
[9] Administered prices for electricity are generally set to cover average cost; public authorities require those generators to produce an annual quantity of electricity to equalize revenue and average cost. This reportedly led to heavy curtailment of renewables generation to maintain fossil fuel plants' hours of operation.

[10] China announced a rate-based emission trading system (ETS) in 2017 for carbon emissions from the fossil fuel power sector (with a plan to extend to six other industries later). The design of the ETS is a tradable performance standard, which includes an industry- and technology-specific allowance benchmark so that the size of allowances individual power plants receive depends on their end-of-period emission output ratios. This differs from a typical ETS in which the nationwide cap is not specified in advance by the regulatory authority. Detailed parameters have not been announced yet. The ETS in China can adapt to economic conditions to avoid high allowance prices and abatement costs during economic booms while mitigating the decline of allowance prices in downturns. It also allows for regional distribution disparity to accommodate the less-developed power plants in low-income areas under a carbon pricing system. However, the ETS is not expected to be fully cost-effective because differences in benchmarks imply sustained variation in power companies' marginal abatement costs if there are significant impediments to allowance trading. It also leads to higher output and emissions and lower electricity prices than under a typical cap-and-trade ETS (Goulder and Morgenstern 2018; Pizer and Zhang 2018).

operational efficiency of the state power distribution companies, including reducing transmission losses and raising power tariffs when needed.

- *Land acquisition challenges:* Streamlining and expediting land acquisition for renewables plants and simplification of procedures, at both the central and state levels, remains a priority. Recent initiatives include setting up special purpose vehicles to acquire land and obtain relevant permits and transferring procedural and administrative risks related to land acquisition to the government.

Figure 1.9.5. Subsidies for Fossil Fuels and Renewable Energy
(Billions of US dollars)



Source: Soman and others (2018).

In the United States, investments in low-CO_2 technologies have risen, particularly in the transportation and electricity sectors. Plug-in electric vehicles, including plug-in hybrids and all-electrics, first entered the US market in 2011. Sales have grown steadily, and by 2018 these vehicles accounted for 2 percent of new vehicle sales—roughly equaling sales of non-plug-in hybrids. However, the on-road vehicle fleet turns over gradually, and in 2018 plug-in vehicles accounted for less than 1 percent of total passenger vehicle travel.[11]

Likewise, in the electricity sector, wind and solar investments grew from negligible in the late 2000s to 11 gigawatts in 2018 (out of 31 gigawatts of utility-scale capacity additions during that year).[12] Because fossil-fuel-fired generators typically operate 40 years or more and the existing-generation stock includes roughly 1,000 gigawatts of capacity, the recent wind and solar investment levels will cause a gradual transition from fossil-fuel-fired to renewable sources of generation.[13]

Despite recent federal efforts to scale back national emission policies, such as carbon dioxide emission standards for electricity generators, several federal and state-level climate policies continue. Most supporting policies target the electricity and transportation sectors, which collectively account for roughly 60 percent of US greenhouse gas emissions.[14]

Research and development: Since 2009, Advanced Research Projects Agency–Energy (ARPA-E) has provided roughly $2 billion in grants to early-stage research projects. Collectively, the projects have a range of

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[11] The numbers on the share of mileage and average age were computed from the 2017 National Household Travel Survey, under the assumption that travel and age patterns during the 2017 survey year are similar to those in 2018.

[12] https://www.eia.gov/todayinenergy/detail.php?id=36092. The investment share excludes residential and commercial rooftop solar photovoltaic installations.

[13] https://www.eia.gov/todayinenergy/detail.php?id=1830.

[14] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

potential applications—such as grid-scale or vehicle electricity storage, low-carbon fuels, and energy efficiency—and have attracted more than $2 billion in follow-up private investment. ARPA-E is part of the U.S. Department of Energy, which also provides loan guarantees to reduce capital costs for commercial projects.

Renewables: The federal government supports renewables investment through tax credits equal to 30 percent of up-front investment costs. Historically, wind projects have received a production tax credit instead of the investment tax credit, but the production tax credit is being phased out. Many states provide additional investment subsidies for wind and solar, and some local governments provide feed-in tariffs. About 30 states have renewable portfolio standards, which require that renewables account for a specified share of total generation. For example, California has among the most aggressive policies, requiring that renewables account for 60 percent of generation in 2030.

Alternative fuel vehicles: Plug-in electric vehicle buyers are eligible for a federal tax credit of up to $7,500, depending on the vehicle's battery size. Currently, these tax credits are available for the first 200,000 vehicles sold by each manufacturer. California and 13 other states, which collectively account for 36 percent of the total passenger vehicle market, require manufacturers to sell a certain number of plug-ins and fuel cell vehicles each year.[15] Many states subsidize plug-in and fuel cell vehicles using policies such as tax credits for purchases, rebates for upgrading home charging systems, and access to high-occupancy-vehicle lanes.

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[15] https://ww2.arb.ca.gov/sites/default/files/2019-03/177-states.pdf.

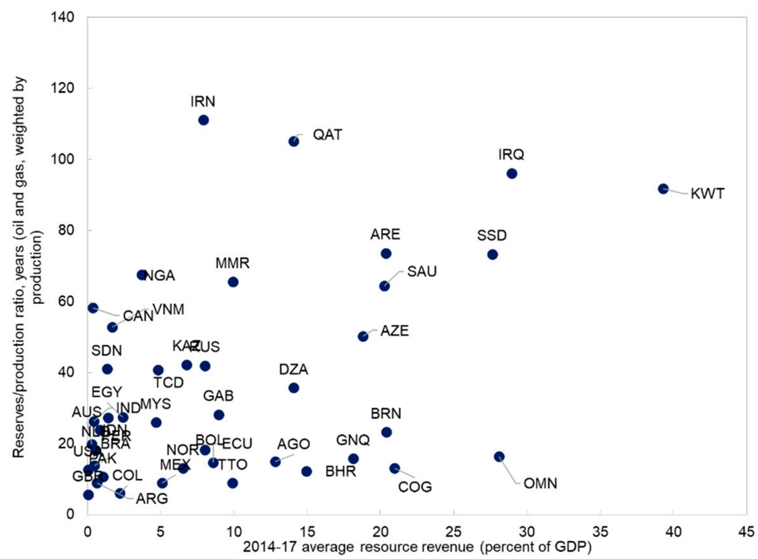
Online Annex 1.10. Fiscal Implications for Fossil-Fuel-Rich Countries

Considerable uncertainty surrounds the future baseline growth of fossil fuel use, the extent of future global mitigation, and the impacts of mitigation on fossil fuel production and prices. The general direction is clear; however, coal and oil production would fall the most, with the share of natural gas likely increasing in the energy mix given its somewhat lower carbon emissions, and carbon pricing would lead to a growing wedge between consumer and producer prices for all fossil fuels.

Revenue Risks for Producing Countries

Countries may be vulnerable if they are dependent on fossil fuel revenue or at risk of ending up with "stranded" fossil fuel assets that can no longer be extracted on a commercial basis. Figure 1.10.1 provides a snapshot of potentially vulnerable countries by reporting oil and gas revenues collected in recent years (as a share of GDP) and the remaining years of production from proven oil and gas reserves.[1] Several countries in the Middle East and Africa are dependent on fossil-fuel-based revenues and have large remaining reserves (for example, Iraq and Kuwait). Other large producers of fossil fuels are much less revenue-dependent, reflecting their more diversified economic structures (for example, China, India, United States). Some countries have large fossil fuel discoveries that have not yet been developed, which poses a risk of stranded assets (for example, Guyana, Mozambique, Timor-Leste).

Online Annex Figure 1.10.1. Revenue from Oil and Gas Compared with Remaining Years of Production



Sources: BP; IMF Fiscal Affairs Department Resource Revenue Database; and IMF, *World Economic Outlook*.
Note: Data labels in the figure use International Organization for Standardization (ISO) country codes.

The decline in fossil fuel demand will not impact producing countries uniformly, and countries with high extraction costs will likely face a greater proportional reduction in production with global climate change mitigation—as producer prices fall, production from fossil fuel assets with higher costs will be reduced or perhaps not developed at all. Fossil fuel producers may have an incentive to accelerate exploitation in the face of a credible climate mitigation scenario (especially small or emerging producers, whereas large producers may be more restrained to avoid further accelerating producer price declines). This is an example of the "green paradox," whereby announcement of future climate change mitigation measures leads to front-loading of fossil fuel production with a commensurate acceleration of CO_2 emissions.

Differences in countries' fiscal regimes (that is, tax and nontax instruments used to collect revenue from fossil fuel extraction) will also influence production decisions. Generally, a fiscal regime that depends

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[1] BP defines proven or 'proved reserves of a field as those that geologic and engineering data show have a better than 90 percent chance of being produced over the life of the field, under current economic and operating conditions.

more on production-based taxes (for example, a royalty) will impose a heavier tax burden on less profitable projects, which will discourage production. In contrast, the tax burden associated with more-profit-based instruments is more responsive to changes in profitability.

Countries therefore face a trade-off between production and revenue objectives in the transition to a future with lower fossil fuel production and prices. A fiscal regime that adapts more flexibly to a range of profitability outcomes (that is, more emphasis on profit-based fiscal instruments) would adjust better to declining economic rents. However, a production-based tax (such as a royalty) would provide more certainty about revenue during the transition period.

Estimating the Impact on Fossil Fuel Revenues

A simple modeling framework is used to estimate the impact of production and price declines on annual fossil fuel revenue by 2040 based on International Energy Agency (IEA) forecasts, capturing the combined impact of country-level differences in extraction costs and fiscal regime design.[2]

The framework uses the IMF Fiscal Analysis for Resource Industries (FARI) methodology to estimate the revenue impact of the production and price projections associated with various climate mitigation scenarios on a representative oil, gas, and coal project, for a sample of resource-rich countries.

FARI is a project-level modeling methodology to estimate the government's share of a resource project's total pretax net cash flows. It is an Excel-based, discounted cash flow model set up to reflect tax accounting rules and specific tax payments to the government. The FARI methodology starts with the calculation of projected net cash flows before any fiscal impositions. It then calculates each fiscal payment according to fiscal regime parameters. These individual payments are added up to calculate the total government revenue from the project. The model captures the effect of interactions among the parameters constituting the entire fiscal regime.

For each country in the sample, using a tailored project example and country-specific fiscal regime, the model calculates the relative change in government revenue under the price and production assumptions associated with each climate mitigation scenario, compared with a baseline scenario at 2017 price levels. This relative change is then applied to 2017 fossil fuel revenue figures from the IMF Resource Revenue Database to generate an estimate of revenue in 2040 under different price and production scenarios. GDP projections to 2024 are drawn from the World Economic Outlook database; real GDP growth thereafter is based on growth in the working-age population (sourced from the United Nations) and projected productivity growth. As a simplifying assumption, GDP projections are kept constant across all scenarios.

In applying country fiscal regimes to a tailored project example, this methodology seeks to quantify the revenue impact on producing countries, taking into account differences in fiscal regimes and production costs. Country selection was based on current fossil fuel production levels, remaining reserves, and current dependence on fossil fuel revenues. The sample comprises 57 countries (Figure 1.10.2), accounting for 95 percent of current global petroleum production and 95 percent of coal production. Prospective fossil fuel producers with recent discoveries, such as Guyana and Mozambique, are not included in the analysis.

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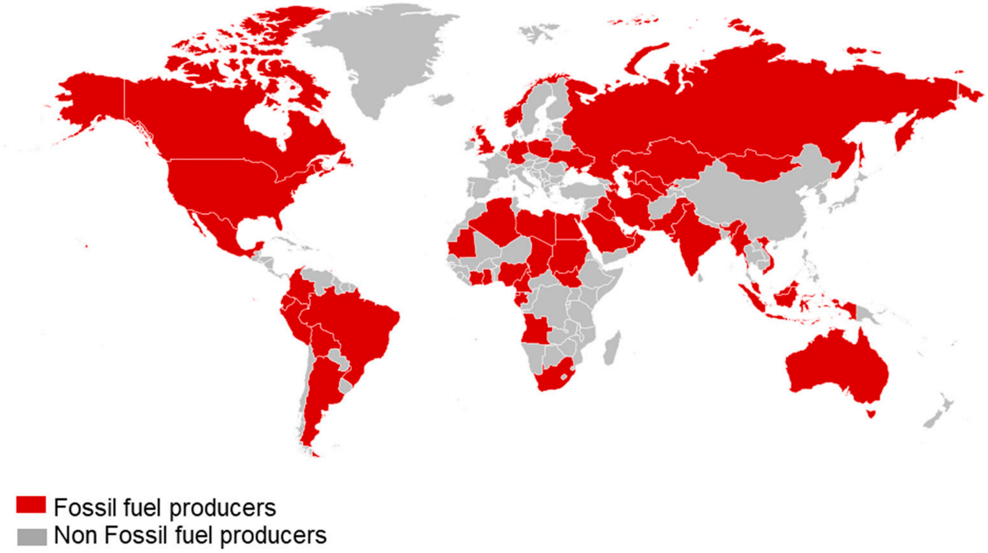
[2] The estimates focus on 2040 to assess the longer-term impact on fossil fuel production, prices, and government revenues over the next two decades.

Online Annex Figure 1.10.2. Fossil Fuel Producers

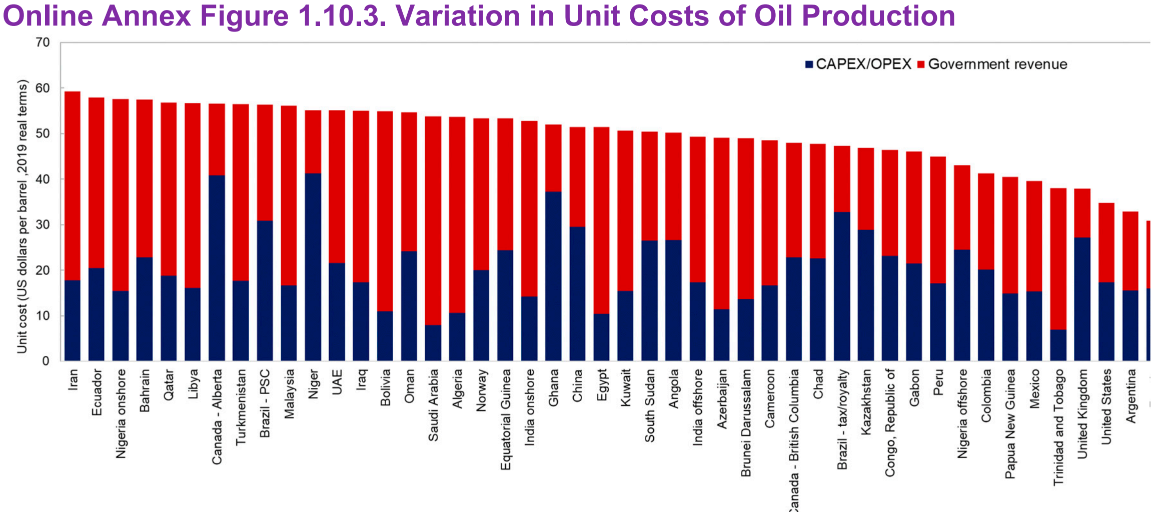


Source: IMF staff.

Model Inputs

- **Project Costs:** The framework uses stylized oil, gas, and coal project examples with country-specific adjustments. In modeling the impact on each resource producer, a country-specific adjustment is made to the assumed cost parameters to reflect the variation in unit capital and operating costs across countries (Figure 1.10.3).

Online Annex Figure 1.10.3. Variation in Unit Costs of Oil Production

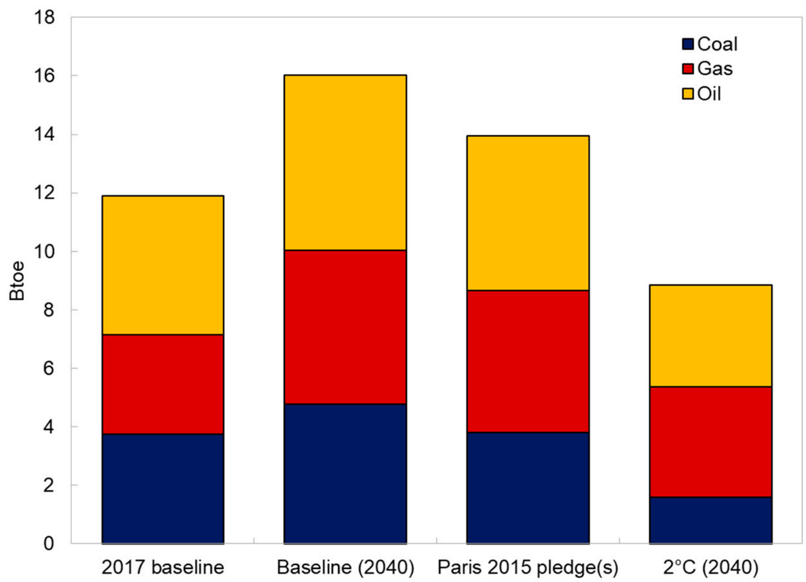


Sources: Rystad Energy; and IMF staff estimates.
Note: CAPEX = capital expenditure; OPEX = operational expenditure; PSC = production sharing contract; UAE = United Arab Emirates.

- **Fiscal Regime Parameters:** For each country, a representative fiscal regime was applied to the pretax cash flow of the stylized project example. The fiscal regime modeled constitutes the core tax and nontax charges on profit and production (for example, royalties, corporate income tax, additional rent taxes, payments to government under production sharing agreements, revenues from state participation in resource projects). In some countries (for example, Norway, United Kingdom), this reflects the statutory regime applicable to all projects operating in the country. In countries where the regime differs by type of operation (for example, onshore or offshore), both types of operations were modeled. In cases where fiscal regimes vary by contract, a representative regime was selected.

- **Production:** Oil, gas, and coal production forecasts under different climate change mitigation scenarios provide the basis for assessing the impact on fossil-fuel-producing countries (IEA 2018; Figure 1.10.4).[1] Under the business as usual (BAU) forecast, continued high demand for fossil fuels is expected to lead to increased production of coal and oil by 2040, together with a marked expansion of gas production. In an alternative scenario assuming implementation of the Paris pledges, fossil fuel production is lower than in the BAU forecast but still higher than today's production levels. A more ambitious climate change mitigation scenario, sufficient to keep global temperature increases below 2°C, envisages a reduction in oil and coal production in 2040 by 30 percent and 60 percent, respectively, relative to current levels.

Online Annex Figure 1.10.4. Global Fossil Fuel Production by Climate Mitigation Policy Scenario, 2017 and 2040
(Billions of tons of oil equivalent)



Source: IEA 2018 *World Energy Outlook*.
Note: BAU = business as usual.

Under the modeling framework, any change in global production associated with different climate mitigation scenarios is assumed to be distributed across countries weighted according to relative unit costs as well as current levels of production in each country. This reflects the premise that in a scenario of reduced fossil fuel demand and production, more costly operations will be curtailed, and if demand were to increase, the least costly production would increase, subject to production capacity and resource availability. The fiscal regime is assumed to remain constant; in practice, countries may adjust their fiscal regime as part of their adaptation strategy. Under the modeling framework, this country-specific relative

[1] (1) The BAU (IEA "current policies") scenario assumes no change in demand, which is expected to increase with GDP growth; (2) the Paris pledges (IEA "new policies") scenario assumes the implementation of all pledges; and (3) the (below) 2°C (IEA "sustainable development") scenario assumes a carbon price of $75/ton CO_2 by 2030 and $140/ton CO_2 in 2040. This scenario assumes technological innovation in both carbon capture and overall energy efficiency.

production increase or decrease associated with each climate scenario was applied to the stylized project example.

Prices: A constant oil, gas, or coal price from the IEA forecasts corresponding to the relevant climate change mitigation scenario is applied to the stylized project example. The IEA 2018 *World Energy Outlook* assumes an increase in real crude oil prices to $137/barrel by 2040 in the BAU scenario, with relatively lower prices of $112/barrel under the Paris pledges scenario and $64/barrel in the 2˚C scenario. Gas and coal prices follow a similar trajectory (Table 1.10.1). Given the uncertainty around these price paths, the analysis incorporates an alternative sensitivity scenario with lower commodity prices for the 2˚C scenario. The oil prices in the IEA scenario reflect a requirement that new fossil fuel investment compensate for declines in output from existing fields. The alternative price scenario is derived from a general equilibrium model developed by the IMF Research Department (Annex 1.11).

Results

The analysis shows that the revenue impact of the Paris pledges scenario is relatively benign for fossil fuel producer revenues, given the increase in prices and production relative to the current baseline. [2] However, under a 2˚C climate change scenario, revenues could decline between 7 and 9 percent of GDP by 2040, albeit with considerable variation between countries (Figure 1.10.5).

Online Annex Table 1.10.1. Mitigation Scenarios: Producer Price Assumptions

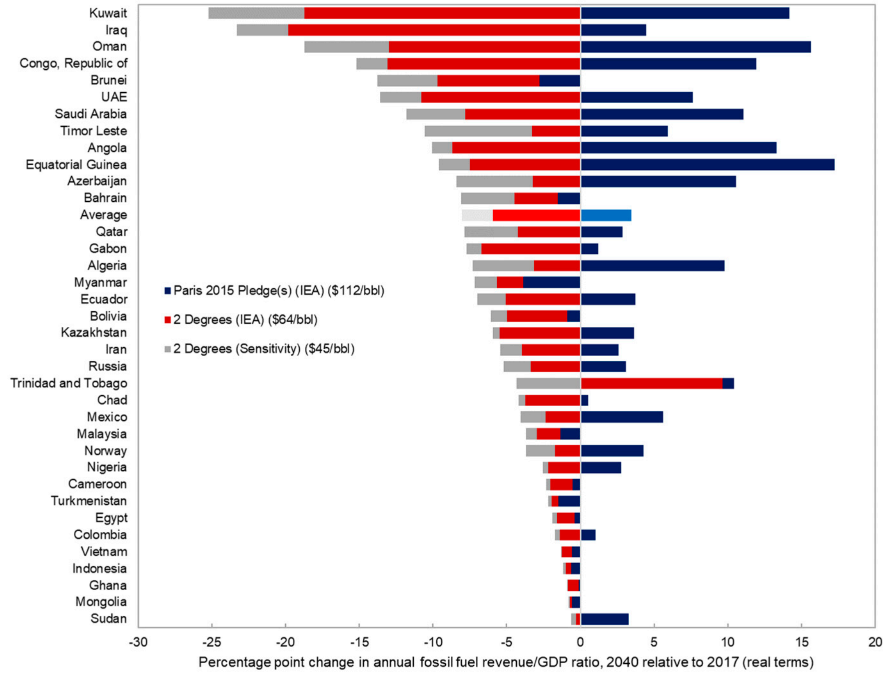
		2017	2040			
		Current	Baseline	NDC	2DC	2DC (sensitivity)
Crude Oil	*$/barrel*	52.05	137.00	112.00	64.40	45.00
Natural Gas						
United States	*$/MBTU*	2.99	5.30	4.90	3.60	2.52
European Union	*$/MBTU*	5.83	9.40	9.00	7.70	5.38
China	*$/MBTU*	6.48	10.20	9.80	8.50	5.94
Japan	*$/MBTU*	8.15	10.50	10.10	8.80	6.15
Steam coal ($/ton)						
United States	*$/ton*	60.40	68.83	63.72	56.43	39.43
European Union	*$/ton*	84.50	98.41	84.88	66.24	46.29
Japan	*$/ton*	94.76	104.54	90.22	70.40	49.19
Coastal China	*$/ton*	101.84	105.93	94.40	78.72	55.01

Source: IMF staff estimates.
Note: BAU = business as usual; MBTU = thousands of British thermal units.

The biggest economic impact will be felt in countries most dependent on fossil fuel revenue (for example, Kuwait, Saudi Arabia, Timor-Leste). Kuwait, for example, which currently collects about 40 percent of GDP in revenues from petroleum, would collect between 11 and 18 percent of GDP in 2040. The results are driven largely by movements in oil prices and production (Figure 1.10.6). While the impact of reduced coal production in affected regions may be significant, in macro-fiscal terms, coal revenues represent a small proportion of GDP in producing countries. The effect of changes in gas revenues is also modest under the IEA 2˚C price assumptions, generating significant effects only in a few predominantly gas producing countries. Other countries, while experiencing a large revenue decline relative to current levels, appear less vulnerable due to the relative diversification of their economies (for example, Colombia, Malaysia; Figures 1.10.7 and 1.10.8).

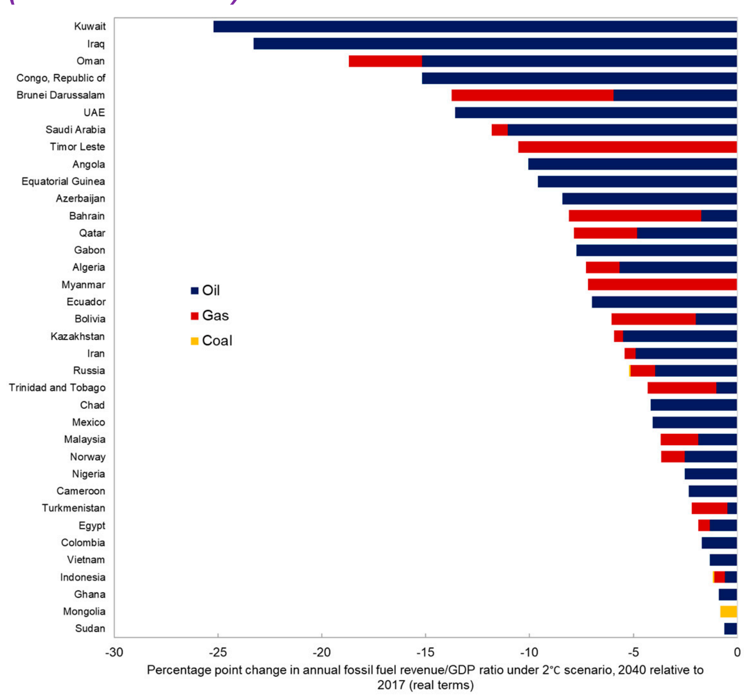
[2] Some countries (for example, Libya and South Sudan) see a decline in fossil fuel revenue relative to GDP even in the Paris pledges scenario (Figure 1.10.5). This is driven by GDP growth that is higher than the increase in fossil fuel revenues.

Online Annex Figure 1.10.5. Change in Fossil Fuel Revenue by Scenario
(Percent of GDP)



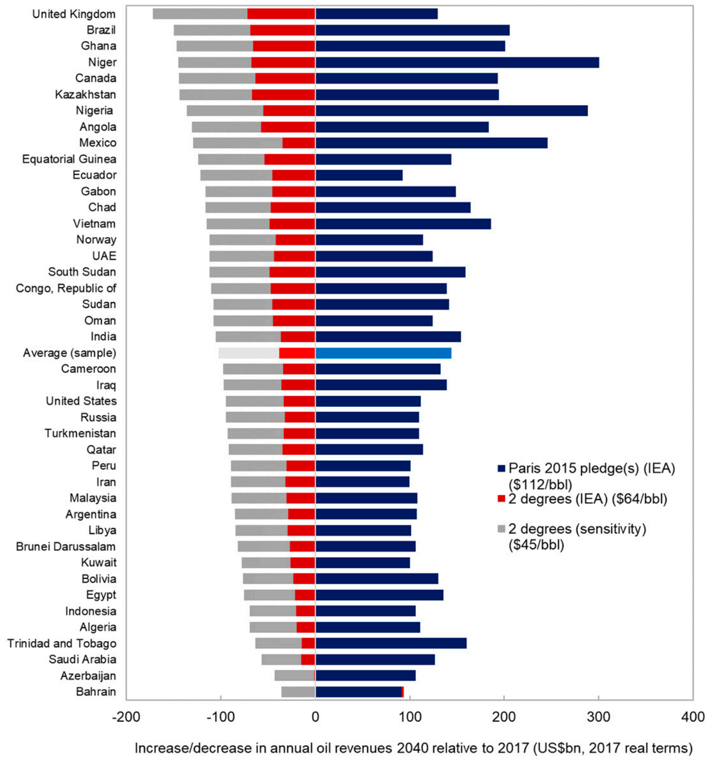
Source: IMF staff calculations.
Note: UAE = United Arab Emirates.

Online Annex Figure 1.10.6. Impact on Fossil Fuel Revenues by Commodity—2°C Scenario (Sensitivity)
(Percent of GDP)



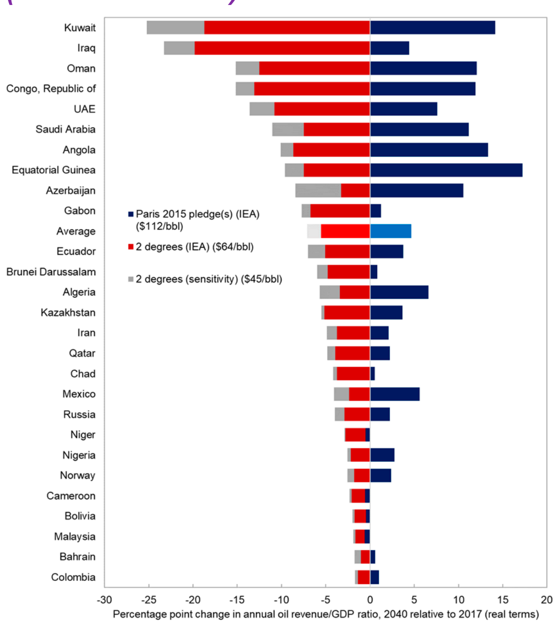
Source: IMF staff calculations.

Online Annex Figure 1.10.7. Percentage Change in Oil Revenues by Scenario



Source: IMF staff estimates.
Note: bbl = barrel; bn = billion; UAE = United Arab Emirates.

Figure 1.10.8. Change in Oil Revenues by Scenario *(Percent of GDP)*



Source: IMF staff estimates.
Note: bbl = barrel; bn = billion; UAE = United Arab Emirates.

For countries that depend on fossil fuel revenue, this potential revenue decline will require a significant fiscal adjustment. Beyond diversifying their economies, fiscal reforms that these countries should consider include scaling up financial savings from current hydrocarbon revenue and establishing a sound domestic revenue base outside the fossil fuel sector. The fiscal adjustment would also be supported by removing remaining fossil fuel subsidies.

A Carbon Royalty on Fossil Fuel Production

In the context of an internationally coordinated approach on a minimum carbon tax floor, one challenge in reaching consensus on a consumption-based carbon tax is the varied impact across countries—net importers of fossil fuel, which collect revenues on fuel consumption, and net exporters, which face revenue losses from reduced production and lower producer prices. In view of this adverse impact on revenues and economic activity for fossil-fuel-rich countries, it is important to explore innovative ways of making carbon taxation more acceptable for them.

In principle, a carbon tax could be imposed at any point in the fossil fuel production chain to achieve a particular production outcome. While a carbon tax imposed on consumption directly impacts consumer demand with a resulting effect on production and prices, a carbon tax on production would have a more direct impact on production decisions. Could a carbon tax imposed on production (combined with consumption-based measures) provide incentives for petroleum producing countries to support a carbon tax agreement and ease the transition to a low-carbon future?

Designing a Carbon Royalty

A royalty is commonly imposed as an ad valorem charge on fossil fuel production,[1] providing revenue to the government from the start of production.[2] Royalties are typically collected either by the tax authorities or a sector ministry or regulator. A carbon royalty could therefore be added to existing royalties in the petroleum fiscal regime,[3] and tax collection could utilize the existing institutional setup for administering production-based royalties. In some cases, it may also be politically preferable to collect a carbon tax directly on production rather than on final consumption.

However, the design of a carbon royalty would differ in some respects. A carbon royalty should be imposed as a specific levy based on the carbon content of fossil fuels (that is, per ton of CO_2). As an illustration, a carbon tax of $35 per ton of CO_2 would equal a production tax of $15 per barrel of oil and $11 per barrel of oil equivalent of gas, based on CO_2 emissions of 0.43 and 0.32 metric tons per barrel of oil equivalent, respectively. The taxes should be applied to all fossil fuels—oil, gas, and coal and to any refined fuel products derived from these commodities.

International Coordination

A carbon royalty could play an important role in reaching consensus for an internationally coordinated approach on a carbon price floor. A carefully calibrated combination of both a carbon royalty on fossil fuel production and a carbon tax on consumption would allow for a more even distribution of tax

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[1] Imposing a limit on cost oil recovery under a production sharing agreement also has a similar effect to a royalty.

[2] However, it also increases the risk of the production being shut down earlier as marginal costs increase.

[3] The "normal" royalty could alternatively be interpreted as a rent payment to the resource owner, an option price on extracting the resource, or a minimum tax payment to the government from the start of production.

revenue between net importers and exporters of fossil fuels while still achieving the same price and production outcomes.[4]

If a royalty were introduced among countries with sufficient collective market power, consumer and producer prices would indeed be unaffected by whether the carbon tax is imposed on consumption or production.

The carbon royalty could be part of a coordinated agreement on an international carbon price floor, with importing countries adjusting the carbon tax imposed on fossil fuel imports to provide a rebate for any carbon royalty paid on fossil fuel extraction in the exporting country.[5] The border adjustment is an important mechanism to ensure that the arrangement is not undermined in the event that a country reneges on the agreement. For example, if a producing country decided to reduce its carbon production tax, there would be an offsetting increase in the tax on consumption in the importing country to maintain the overall carbon tax burden. [6]

However, such international coordination would require careful design and consideration. Some countries may be driven to offset the introduction of a carbon royalty by reducing other royalty rates (or through other offsetting changes to the fiscal regime).[7] This is especially likely if their objective is to encourage continued investment and production of fossil fuels in a low-carbon environment. The issue may also be particularly pertinent for fossil fuel production by a national oil company in which case a higher royalty can be offset by lower transfers of after-tax profits to the national treasury. The scope for countries to impose additional taxes on fossil fuel extraction activities may also be limited by contractual stability clauses for existing projects.

The carbon royalty could also be introduced effectively by a group of countries (or a large producer) in the absence of a global agreement on carbon taxes. In this case, while other oil producers may have an incentive to increase production to meet the resulting unmet demand, doing so would still have an impact on final consumer prices, since the oil supply curve in individual countries is upward sloping, implying higher costs for any additional production.

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[4] While in theory, this would involve equalizing the posttax producer price by setting project-specific carbon royalties reflecting inter- and intracountry variations in cost and fiscal regime, this would be administratively complex, and therefore a more practical proposal involving a single specific carbon royalty rate is described here.

[5] In situations with more integrated supply chains—for example, crude oil refined in another country—this would require a monitoring system to track the origin of fuel products.

[6] An alternative revenue collection mechanism could collect the tax on final consumption but agree on a revenue sharing arrangement between net-importing and net-exporting countries (consumers and producers). However, this is likely to be less practical and politically more difficult as it would require continued revenue transfers from fossil fuel net importers to net exporters.

[7] This is not a unique problem but may also arise in the case of a domestic carbon tax and possibly offsetting adjustments to excise duties on fuel products.

Online Annex 1.11. The Oil Market Effect of a Carbon Tax Consistent with 2°C (Alternative Price Scenario)

A stylized oil market model is used to study the effect of a carbon tax consistent with a reduction in CO_2 emissions that would limit the rise in global temperature to 2 degrees Celsius—the upper limit proposed in the Paris 2015 agreement.

The Model

The model has two oil sectors, shale and conventional oil, oil-specific investment, and a demand side driven by population and income growth for a given oil price. A carbon tax is introduced as a wedge between the producer and consumer (that is, end-user) prices. Two price elasticities govern the demand substitution from petroleum products and oil-sector investment decisions. There is a substantial lag for conventional oil investment before oil production can come onstream, but this is much shorter for the tight oil sector. On the demand side, the price elasticity of demand is nonconstant and increases from zero, as the oil price deviates from its baseline value.[1] Both consumer and producer prices will be determined to clear the oil market and equilibrate demand and supply of oil.

The model is cast in deviations from a baseline assumed to be consistent with the approximate adoption of the Nationally Determined Contributions, in which oil consumption and emissions increase as in the International Energy Agency (IEA) "new policies" scenario. In contrast to the IEA's scenario, however, the model's baseline assumes a $60 (in 2018 US dollars) oil price prevailing over the long term as this is near its 1974–2018 historical average and the average of the five-year-ahead futures prices since the oil price collapse in 2015.[2]

The carbon tax required to meet the 2°C target is assumed to be $150 per ton of carbon, slightly higher than in the IEA sustainable development scenario (which, however, includes additional mitigation policies). We assume that the carbon tax is fully anticipated and introduced smoothly, rising from $0 to $150 by $6 a year with a five-year implementation lag.

Results

At the announcement, the carbon tax has a positive effect on energy prices as conventional oil producers cut investment in anticipation of reduced demand for petroleum products as a result of the future introduction of the carbon tax. Hence, initially, oil production declines, but only modestly since shale oil partially offsets that decline, gaining market share, attracted by short-term profits (see Figure 1.11.1). As the carbon tax wedge increases, however, both shale and conventional oil production decline since consumers become more sensitive to the higher prices of petroleum products and more willing to switch away from products with high carbon content. Under our reference scenario, the producer price of oil declines by 43 percent while global oil production declines by more than 30 percent. This means that the value of production has declined by more than 60 percent. The value of global oil production as a share

[1] The time-varying nature of the price elasticity captures the possibility of switching to alternative technologies with nonnegligible adoption costs. The stronger the change in the prospective oil prices the higher the price elasticity of demand. We calibrate the price elasticity of demand such that it is zero in a neighborhood of the baseline oil price, but it increases to –0.2 as the price increase reaches 20 percent and higher as the price increases further.

[2] An oil price at [$110] (2018 US dollars), as in the IEA new policy scenario, is the top 5th (3rd) percentile of the oil price distribution between 1974 and 2018 (1861 and 2018).

of global GDP initially increases slightly to 2.6 percent from 2.5 percent in the baseline and subsequently declines to 0.8 percent by 2040.[3]

Online Annex Table 1.11.1.

Assumptions		2016	2020	2025	2030	2035	2040	2045	2050-
Base Price (real)	(assumption)	$45	$60	$60	$60	$60	$60	$60	$60
Carbon Tax (wedge log difference)	(assumption)		0%	20%	40%	60%	80%	100%	100%
Carbon Tax (per barrel)			$0	$12	$24	$36	$48	$60	$60
Implied Carbon Tax per ton of CO_2			$0	$30	$60	$90	$120	$150	$150
Oil Production Base (MB/D)	(assumption)	96	101	105	108	109	111		
Energy Use (MB/D)		82	85	86	86	85	85		
Combustion (MTOE)		3,719	3,881	3,908	3,917	3,870	3,864		
TPED (MTOE)		4,364	4,559	4,754	4,830	4,842	4,894		
Petrochemical Use (MB/D)		9	9	10	11	12	13		
Global Oil Production over GDP	%	1.9%	2.5%	2.2%	1.9%	1.6%	1.4%		
Simulation Results									
Oil Production (MB/D)			101	103	99	91	83		
Producer Prices	USD (2018)		$62.3	$64.1	$59.5	$52.9	$44.9	$35.5	$36.5
Consumer Prices	USD (2018)		$62.3	$76.1	$83.5	$88.9	$92.9	$95.5	$96.5
Global Oil Carbon Tax Revenue	Billion USD (2018)		$0.0	$368.4	$693.3	$934.5	$1,113.7		
Global Oil Carbon Tax Revenue/GDP	%		0.0%	0.3%	0.6%	0.6%	0.6%		
Global oil production value/GDP	%		2.6%	2.3%	1.7%	1.2%	0.8%		

Source: International Energy Agency and IMF staff calculation.

Notes: Base oil production and global GDP projections are based on the International Energy Agency's, World Economic Outlook new policy scenario. MB/D = millions of barrels a day. USD = US dollars.

The burden of the carbon tax is initially borne by consumers who have difficulty switching to alternative oil sources in the initial transition phase after the tax is implemented. By 2030, indeed, almost 100 percent of the $60 carbon tax is borne by consumers. As the model converges to the new steady state the share of the carbon tax is rebalanced, with consumers paying 55 percent of the $150 carbon tax.

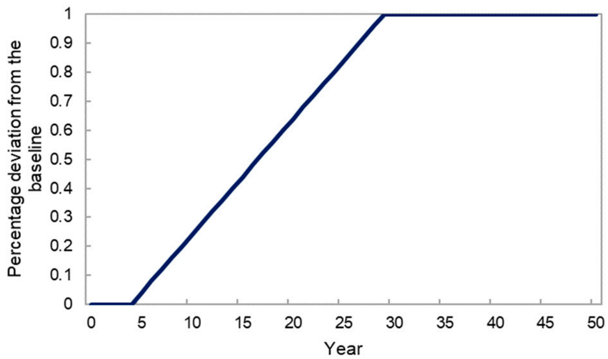
The carbon tax also raises fiscal revenues, which initially increase as the tax level rises but later stabilize thanks to the offsetting effect of lower oil production value.[4] The overall carbon tax revenues from oil rise to more than $1 trillion by 2035, representing 0.7 percent of global GDP.

[3] As in the IEA scenario we assume that global GDP grows 3.4 percent a year in 2018 US dollars, on average, between 2017 and 2040 (IEA 2018).

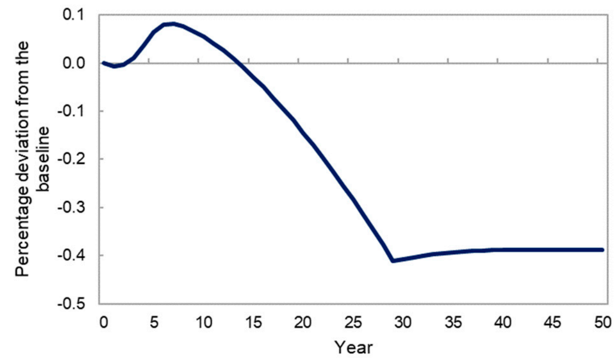
[4] For simplicity, in the model we posit that the use of fiscal revenues has no effect on demand for petroleum products or on CO_2 emissions.

Online Annex Figure 1.11.1. Model Simulations—Transition to a $150 Carbon Tax

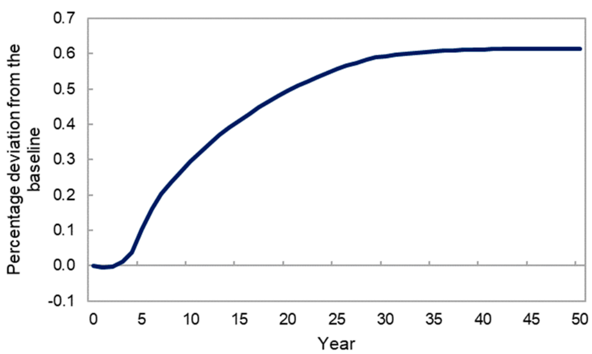
1. Tax Wedge (tax rate, percent)



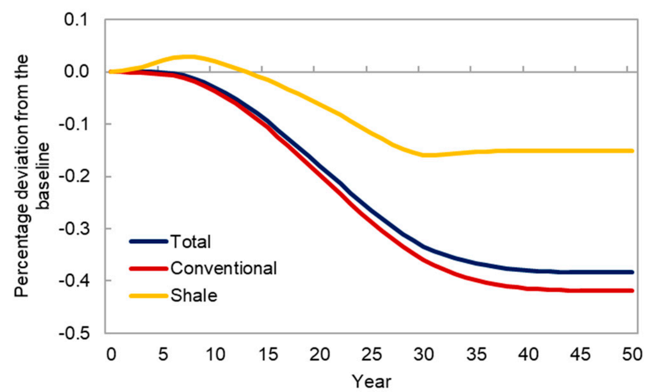
2. Producer Price of Oil



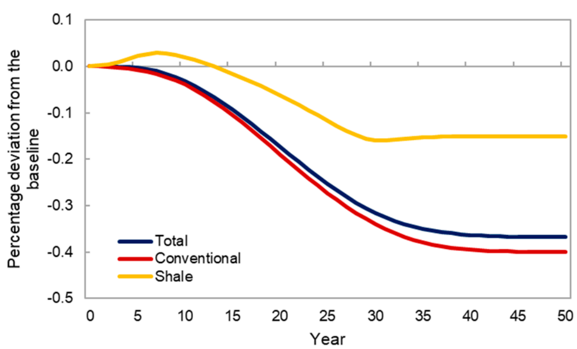
3. Consumer Price of Oil



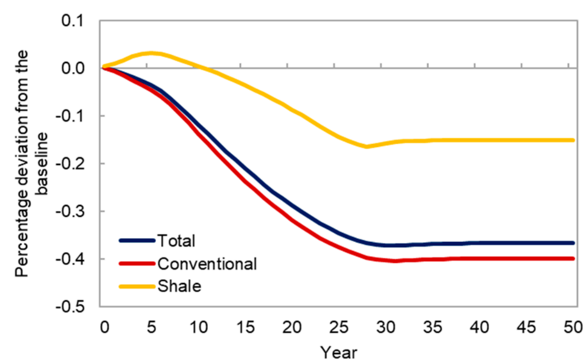
4. Oil Production



5. Oil Sector Capital Stock



6. Oil Sector Investment



Source: IMF staff estimates.
Note: See Table 1.11.1 for the evolution of the carbon tax shock and underlying assumptions.

Online Annex 1.12. Literature Review of Possible Financial Policies to Reinforce Mitigation Incentives

Financial policies could play an important role in mitigating climate change, but a consensus has yet to emerge on an appropriate set of policies. This annex provides an overview of recent proposals on how financial policies could support climate change mitigation.

Financial policies can complement fiscal policies to foster switching investment toward less-carbon-intensive sources. At present, investment in low-carbon technologies is too low because the payoff would be reaped many years—possibly decades—from now and profitability is very uncertain (see, for example, Carney 2015). Two major sources of risk differentiate these investments from other long-term investments: uncertainty about their ability to deliver carbon abatement and uncertainty about the future profitability of avoiding emissions. Financial policies could play a useful role by creating incentives for financial actors to divest from carbon-intensive activities and invest more in low-carbon projects (including renewable energy; energy efficiency; land use; and urban, transportation, infrastructure, and industrial systems), thereby helping decarbonize the productive structure of the economy, while maintaining macro-financial stability. While some of these ideas are unorthodox, the urgency of climate change mitigation suggests that they need to be considered.

Studies in this area can be divided into four broad categories (Krogstrup and Oman, forthcoming):

1. *Financial policies to correct underpricing and lack of transparency regarding climate risks in financial markets and prudential frameworks:* Prudential frameworks could give more favorable treatment to financial assets associated with low-carbon activities (Schmidt 2014). To mobilize capital for green investments, policymakers could engage with stakeholders to develop a taxonomy on economic activities that contribute to the low-carbon transition and those that are more exposed to climate-related risks (NGFS 2019). Prudential and collateral frameworks could also be adapted to incorporate climate-related financial risks, conditional on a thorough assessment of the financially systemic nature of climate risks (Monnin 2018, Schoenmaker and Tilburg 2016). One proposal is to introduce a "green supporting factor" in prudential rules to increase banks' demand for financing green investments (EU High-Level Expert Group on Sustainable Finance 2018).

2. *Policies to help reduce the short-term bias and improve governance frameworks of financial institutions:* Policies targeting corporate governance and the financial sector's interactions with regulation and accounting standards could correct the bias against the financing of long-term uncertain investments that are typical of mitigation investments. Biases are related to corporate governance that is heavily biased in favor of short-term financial returns, with managers' compensation typically dependent on financial targets (Admati 2017). Moreover, environmental, social, and governance (ESG) criteria could be given a greater role in the composition of equity indices used by institutional investors, with passive investment strategies based on the notion that the optimal allocation strategy is to diversify financial portfolios by tracking benchmark stock market indices. Likewise, central banks could incorporate ESG aspects into their portfolio management (NGFS 2019). ESG factors could also be progressively incorporated into corporate accounting standards (Investment Leaders Group 2014).

3. *Policies to support the development of markets for green financial markets and instruments:* Issues of sustainable finance, notably ESG criteria, are covered in the *Global Financial Stability Report* (IMF 2019), with an emphasis on the need to further develop transparent standards and disclosures.

4. *Using central bank asset purchases and funding and collateral policies to favor climate-friendly activities:* These proposals are among the most controversial because they add new goals to central bank policies. One

proposal is to use central bank asset purchases to reallocate financial resources toward green economic activities and steer the allocation of assets and collateral toward low-carbon sectors (De Grauwe 2019). Another is for central banks to ensure better access to funding systems for commercial banks that invest in low-carbon projects or to amend forward guidance policies to raise market expectations regarding green investments (Campiglio 2016). Public guarantees have also been proposed to boost the financing of the investments needed to gear national production structures toward the low-carbon economy (Dasgupta and others 2019). To enable financial actors to lock in returns to mitigation investments that are commensurate with their social value—and hence facilitate their financing—Aglietta and others (2015) propose so-called carbon remediation assets at a politically accepted predetermined return (corresponding to the social value of mitigation action) per ton of emissions avoided. The rationale behind this proposal is that it could help prevent the fragmentation of climate finance initiatives by fostering a new class of long-term, low-carbon assets, thus mobilizing large savings for low-carbon investments.