Office Memorandum

To: Members of the Executive Board — February 27, 2014

From: The Secretary

Subject: **Getting Energy Prices Right—from Principle to Practice**

Attached for the **information** of Executive Directors is a report on Getting Energy Prices Right—from Principle to Practice.

It is intended that this paper will be published in July 2014.

Questions may be referred to Mr. Keen (ext. 34442), Ms. Perry (ext. 36392), and Mr. Parry (ext. 39724) in FAD.

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Getting Energy Prices Right: From Principle to Practice

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Table of Contents Page

Boxes

Appendix Tables

EXECUTIVE SUMMARY

Many energy prices, in many countries, are wrong. They are set at levels that do not reflect environmental damages, notably global warming (projected to reach about 3-4°C by the end of the century, with serious tail risks), air pollution (killing 3.2 million annually), traffic congestion, and traffic accidents (killing 1.2 million). In doing so, they forego a way to more efficiently meet revenue needs that are acute in many countries.

This report is about getting the prices right. The principle that fiscal instruments must be center-stage in 'correcting' the major environmental side effects of energy use is well-established. This report aims to help put this principle into practice, by setting out a practicable methodology and associated tools for assessing what the right price is. Underpinning the policy recommendations is the notion that fiscal instruments, like taxation, can influence behavior—much the same way that taxes on cigarettes discourage their overuse, appropriate taxes should promote the responsible use of energy by reflecting negative environmental side effects. The report provides estimates (data permitting) for 156 countries of the taxes on coal, natural gas, gasoline, and diesel needed to reflect environmental costs (for year 2010 in US$). The main policy messages include:

- **Coal use is pervasively undercharged, not only for carbon emissions but also—indeed often more importantly—for the health costs of local air pollution, though appropriate charges for the latter differ considerably across countries.** Illustrative charges ($35/ton) for carbon dioxide (CO_2) amount to about $3.3/gigajoule (GJ) of energy from coal combustion, a substantial amount when set against average world coal prices of about $5/GJ in 2010, and what are at best minimal taxes on coal at present. But the size of the corrective tax for local air pollution, and the differences among countries (in part due to differences in population exposure to emissions), is striking. The corrective tax is over $5/GJ in nine of the countries shown in Figure 1(a), and over $10/GJ in China, Israel, Poland and the United Kingdom. Moreover, these corrective tax rates are based on net emissions, that is, after crediting for emissions control technologies currently in use at some coal plants in the country—corrective taxes can be dramatically higher for coal plants with no emissions controls (though crediting would provide especially strong incentives for all plants to adopt control technologies).

- **For natural gas, air pollution damages are modest relative to those from coal, but significant tax increases are still needed to reflect carbon emissions**. Charges for local air pollution from natural gas are around $1/GJ or less for most countries shown in Figure 1(b), as natural gas produces only very minimal amounts of the most damaging pollutants caused by coal combustion. The carbon component is also smaller, as natural gas produces about 40 percent less CO_2 per GJ than coal, though

charges needed to cover carbon emissions, about $2/GJ (40 percent of average world gas prices), are well above current tax levels.

- **Heavier taxes on motor fuels are warranted in many countries, though more to reflect the costs of traffic congestion and accidents than carbon emissions and (local) pollution.** Corrective gasoline taxes are 40 cents/liter (about $1.50/gallon) or more in 16 of the 20 countries illustrated in Figure 1(c) and they exceed current excise taxes in 15 cases, with the response to problems of congestion and accidents together accounting for about 70-90 percent of the correction needed. CO_2 emissions contribute 8 cents/liter in all cases and local pollution typically less than this. As for diesel fuel (primarily used by trucks but also some cars), corrective taxes are often somewhat higher than for gasoline (Figure 1(d)), so there appears to be little systematic basis for the common practice of taxing motor diesel less than gasoline. Ideally (and this should be feasible in the longer term) countries should partially shift from vehicle and fuel taxes to kilometer-based charging, for example, charges should focus on busy roads and vary with time of day, to more effectively reduce congestion.

- **Tax reforms can yield dramatic reductions in pollution-related deaths (especially from coal taxes), significant reductions in CO_2 emissions, and large revenue gains**. More precisely:

✓ ***Fuel tax reform can save nearly 2 million lives worldwide***. Pollution-related mortality is reduced upwards of about 60 percent in ten of the countries shown in Figure 2(a), with the vast majority of avoided deaths due to coal taxes.

✓ ***Tax reforms could reduce CO_2 emissions by roughly 30 percent globally***. Nationwide CO_2 emissions reductions exceed 20 percent (relative to 2010 levels) in most cases shown in Figure 2(b), and about 40 percent for China. For all but four countries coal (due to its high carbon intensity and high corrective taxes) accounts for over 50 percent of the CO_2 reductions, and more than 85 percent in five cases.

✓ ***Potential revenue from implementing corrective taxes average about 3 percent of GDP globally***. Corrective coal taxes could be a very significant revenue source for many countries shown in Figure 2(c), especially coal-intensive ones such as China (though revenue projections are necessarily very approximate). In other cases, like Brazil, Egypt, Indonesia, Nigeria, United States, higher motor fuel taxes are the dominant source of potential revenue gains (including subsidy elimination in some cases). It is important to recognize, however, that getting energy prices right is not inherently about increasing overall tax burdens. Revenues arising from the taxes used to correct energy pricing could be used to improve the overall structure of the tax system by, for example, reducing taxes on labor, capital, consumption, and (where they are poorly targeted from an environmental perspective) energy, and onto fuels.

- ✓ ***In short, the case for substantially higher energy taxes does not rest on climate change alone***. Decisive action need not wait on global coordination.

While the corrective energy taxes presented in this report provide a valuable starting point for policy reform, they should be treated with a good deal of caution, given gaps in data and remaining uncertainties and controversies over, for example, the valuation of climate damages, health risk, and the link between air quality and mortality.

Figure 1. Fuel Taxes to Correct Environmental Costs, Selected Countries, 2010

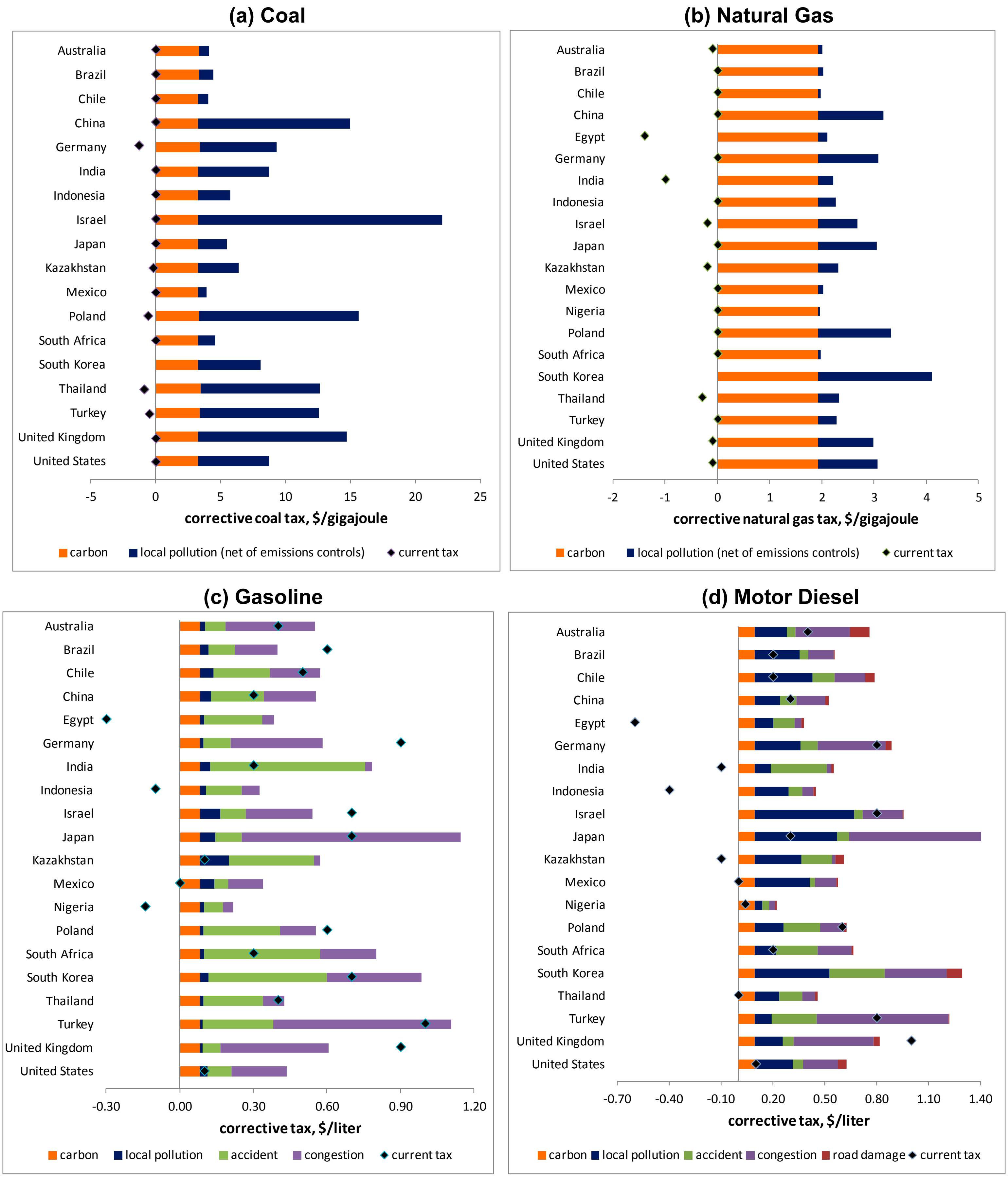
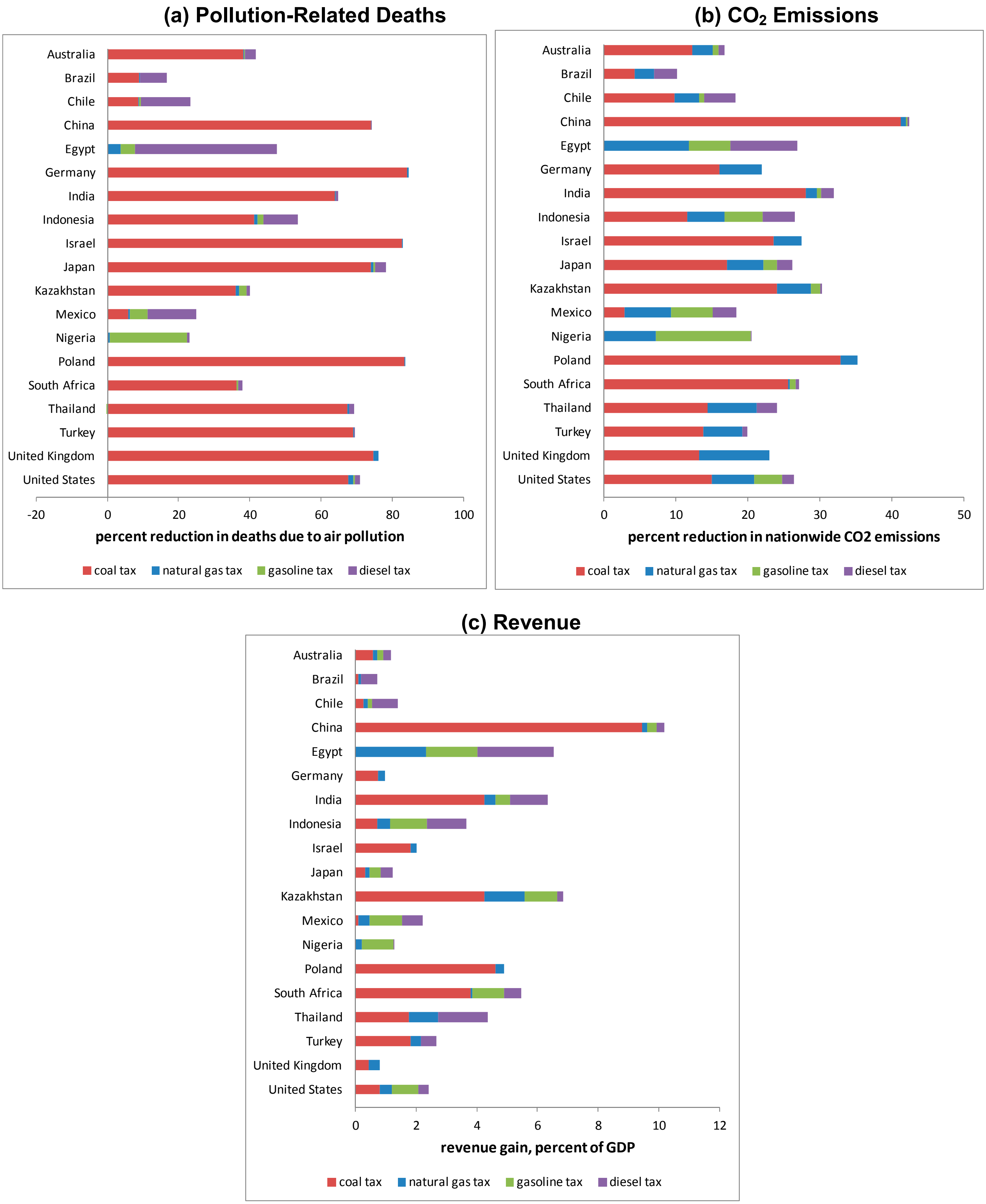


Figure 2. Impacts of Fuel Tax Reform, Selected Countries, 2010



INTRODUCTION

A. Background

While energy use is a critical ingredient to industrial and commercial production, and to final consumption, in the absence of proper pricing policies it can also result in excessive environmental and other side effects, with potentially sizeable costs to the economy. For example:

- If left unchecked, atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) are expected to double their pre-industrial levels by around mid-century, and continue rising after that. Such a doubling of GHG concentrations is projected to eventually warm the planet by about 3°C over pre-industrial levels.[1] Temperature changes of this magnitude are large by historical standards and pose considerable risks.

- Estimated damages from local (outdoor) air pollution, primarily risks to human health, can be substantial. Worldwide, local air pollution causes an estimated 3.2 million premature deaths a year, costing about 1 percent of GDP for the United States, and almost 4 percent for China.[2]

- And motor vehicle use leads to crowded roads, accidental death, injuries, and so on. Drivers in the London rush hour, for example, impose estimated costs on others equivalent to about US$10 per liter ($38 per gallon) of the fuel they use, through their contribution to traffic congestion, while traffic accidents cause an estimated 1.2 million deaths worldwide.[3]

The need for fiscal policies

Given the seriousness of these problems, addressing them with carefully-designed policy instruments is critical. Ideally, these policies should:

- Be *effective* in terms of exploiting all opportunities for reducing environmental harm and mobilizing private investment in clean technologies;

- Be *cost-effective* in terms of achieving environmental objectives at lowest cost to the economy; and

- Strike the right balance between the *benefits* of environmental improvements for the economy and the *costs*, thereby maximizing the net benefits.

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[1] IPCC (2013).

[2] Burnett and others (2013), NRC (2009), and SEPA/WB (2007).

[3] Parry and Small (2009) and WHO (2013a).

All three features are important for ameliorating trade-offs between environmental protection and economic growth and enhancing prospects for sustaining (and scaling up) efficient policy over time. *Fiscal instruments*—environmental taxes or tax-like instruments (primarily emissions trading systems with allowance auctions)—can fully meet these criteria (in conjunction with complementary measures, like R&D policies, public investments, and transportation safety regulations).

If fiscal instruments are targeted directly at the source of environmental harm, they promote the entire range of possibilities for reducing that harm. They can also produce a substantial revenue gain and, so long as this revenue is used productively—for example, to reduce other taxes that distort economic activity—environmental protection is achieved at lowest overall costs to the economy. And, not least, if these instruments are scaled to reflect environmental damages, they avoid either excessively burdening the economy or, conversely, foregoing (socially worthwhile) environmental improvements. In contrast regulatory alternatives (like requirements to achieve particular levels of energy efficiency, make some use of renewable energies, and to use emission control technologies to some standard) are less effective (for example, they do not promote sufficient reductions in polluting fuels and often do not apply to older plants), are not cost effective (unless they allow extensive credit trading across firms, programs, and time), and do not raise revenue.

Getting prices right

'Getting prices right' is convenient shorthand for this idea of using fiscal instruments to ensure that the prices that firms and consumers pay reflect the full cost to society of their energy use, which requires adjusting market prices by an appropriate set of 'corrective' taxes. This volume focuses on how developed and developing countries alike can get energy prices right, by pricing fossil fuels for CO_2 damages, local air pollution and, in the case of motor fuels, traffic congestion, accidents, and (less importantly) road damage.

In practice, many countries, far from charging for environmental damages, actually subsidize the use of fossil fuels. For many others energy taxes—if currently implemented at all—are often not well targeted at sources of environmental harm, nor set at levels appropriate to reflect environmental damages. Clearly there is much scope for policy reform in this area, but there are also huge challenges, both practical and analytical.

From a practical perspective, higher energy prices burden households and firms and, even with well-intentioned compensation schemes, can be fiercely resisted. These challenges—while not to understate them—are largely beyond the scope here, however, as a complementary volume (IMF, 2013) distills lessons to be drawn from case studies of energy price reforms. Moreover, getting energy prices right is not generally about increasing overall tax burdens but rather (partially) substituting direct taxes on work effort and capital accumulation (or environmentally blunt taxes on energy) with taxes on fossil fuels. And where new revenue sources might be needed, corrective energy taxes are an especially attractive option, as (unlike most other options) they improve economic efficiency by addressing a market failure. Moreover, the average taxpayer is likely better off when health, congestion, and other reform benefits are considered.

The main focus here is on assessing the prices that need to be put into practice. For the vast majority of countries, there has previously been no attempt to measure the *magnitude* of environmental damages across fossil fuel products—yet these measures are critical if actionable guidance is to be given on how countries can get (energy) prices right.

The corrective energy tax estimates presented in this report should be treated with a good deal of caution, given remaining uncertainties and controversies (e.g., over the valuation of climate damages and mortality risk, the link between air quality and mortality risk, the average delay one extra driver imposes on other road users), data gaps, and so on.

Nonetheless the estimates provide a valuable starting point for policy reform, scrutiny of the key uncertainties, and cross-country comparisons (estimated on a consistent basis).[4] Moreover, the impact of alternative assumptions on corrective tax estimates can be inferred from accompanying spreadsheets.[5] And, while tax assessments may change significantly as evidence evolves, data improves, and conditions (e.g., related to road congestion and vehicle safety) change, the basic findings—most notably the strong case for substantially higher taxes on coal and motor fuels in many countries—will likely remain robust.

Defining an efficient set of energy taxes

From the perspective of effectively reducing (energy-related) CO_2 emissions, local air pollution, and broader side effects from vehicle use, energy tax systems should comprise three basic components:

- a charge on fossil fuels in proportion to their CO_2 emissions multiplied by the global damages from those emissions (alternatively, the charge could be levied directly on emissions), though there are reasons why some governments (e.g., in low-income, low-emitting countries) may not wish to impose such charges;

- additional charges for fuels used in power generation, heating, and by other stationary sources, in proportion to the local air pollution emissions from these fuels but with crediting for demonstrated emissions capture during fuel combustion, as net emissions releases are what determine environmental damages (another possibility again is to charge emissions directly); and

- additional charges for the local pollution, congestion, accidents, and pavement damage attributed to motor vehicles. Ideally, some of these charges would be levied on kilometers driven (e.g., at peak period on busy roads for congestion) and this should become increasingly feasible as the technology needed for such schemes

[4] The estimates take into account extensive feedback from leading specialists, and participants at an expert workshop held at the IMF in April 2013.

[5] See www.imf.org/external/np/fad/environ/index.htm .

> matures. Until then however, reflecting all of these costs in motor fuel taxes is entirely appropriate and is the approach taken here.

In practice, there are complex political reasons why the bases and rates of energy taxes may diverge from the ideal and why regulatory instruments are frequently preferred.

But a necessary first step for understanding the trade-offs involved between all the policy choices, and how political constraints might be met with minimal compromise to environmental, fiscal, or other objectives, is to provide some *quantitative* sense of the corrective energy tax system for different countries, which provides a benchmark against which alternative policies should be evaluated. This volume provides corrective tax estimates for coal, natural gas, gasoline and motor diesel (wherever feasible) for 144 countries. All figures are for year 2010 (often the latest common year for which data was available) and (to facilitate cross-country comparisons) expressed in year US$2010.[6]

Methodology

The techniques used for assessing various types of environmental damages are straightforward conceptually though require extensive data compilation, aside from CO_2 damages which are taken to be the same regardless of where emissions are released. The main contribution here is to develop, and implement (wherever the data allow) cross-country estimates of air pollution damages and broader side effects associated with use of motor fuels.

Climate damage

The volume does not add to the (contentious) debate on climate damages, but simply uses an illustrative damage value of $35 per metric ton of CO_2 (from a recent, widely cited study by US IAWG 2013), combined with data on the carbon content of fuels, to infer carbon charges for all countries (the implications of different damage assumptions, including zero damages for low-income, low-emitting countries, are easily inferred).

Air pollution

As regards local air pollution, the major problem is elevated mortality risks to exposed populations. In the case of coal plant emissions, damages are assessed by first estimating how much pollution is inhaled by people in different countries, based on matching data on power plant location to data indicating how many people live at different distance classifications from each plant (smokestack emissions can be transported over considerable distances). This pollution intake is then combined with baseline mortality rates for pollution-related illness and the latest evidence on the relationship between exposure and elevated risks (though substantial uncertainties surround this relationship). Although contentious, health effects must then be monetized, and for illustration this is done using evidence on how people in

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[6] Purchasing Power Parity (PPP) exchange rates should be used to express these figures in local currency. Those used here are available at: www.imf.org/external/pubs/ft/weo/2013/01/weodata/index.aspx.

different countries value money/risk tradeoffs from numerous studies analyzed by OECD (2012). Governments may have different views on health risk valuation, but the implications of alternative assumptions are easily inferred from the spreadsheet. Finally, damages are expressed per unit of energy content using country-level data on emissions rates. The same approach is used to measure air pollution damages from natural gas plants. And damages from vehicle and other ground-level sources (which tend to remain locally concentrated) are extrapolated from a city-level database on pollution intake rates.

Air pollution damages from coal are much higher than for natural gas and motor fuels, as coal combustion causes large amounts of pollutants that are especially damaging to human health. However, it will be seen that there is substantial cross-country variation in the appropriate corrective fuel charges, reflecting differences in population exposure, emissions rates, and health risk valuation. On the latter, if the same values for mortality risks are used for all countries, based on the evidence for advanced countries, corrective charges for air pollution for relatively low-income countries are scaled up accordingly (though large cross-country differences in corrective taxes remain from other factors). Emissions rates are reduced considerably when coal plants apply control technologies, underscoring the need for appropriate crediting for these technologies (that is, charging for net emissions).

Congestion and accidents

Traffic congestion costs are estimated here by using a city level database to estimate relationships between travel delays and various transportation indicators and extrapolating the results using country-level measures of those same indicators. Average travel delays (that motorists themselves take into account) are then converted into delays that one motorist imposes on other road users using standard specifications from the literature. The resulting delays are monetized using evidence on the relationship between wages and how people value travel time. Accident costs are estimated based on country-level fatality data and assumptions about which types of risks drivers themselves might take into account versus those they do not, and extrapolations on the magnitude of various other (medical, property damage, non-fatal injury) costs.

Although these congestion and accident cost estimates are very approximate, a consistent finding is that they are much larger than the CO_2 and local air pollution damages from motor fuel combustion, and they are the main reason why current gasoline and diesel fuel taxes are less than corrective tax estimates for most countries. Accident costs tend to be relatively more important in developing countries with high traffic fatality rates, while congestion costs are often more important for advanced countries where travel time values are relatively high. At the same time, these estimates underscore the importance of considering other, more effective instruments (e.g., peak period congestion pricing).

Applications to other (non-tax) instruments

Even if energy tax reforms are not presently feasible (for political or other reasons), the environmental damage assessments presented here can still provide valuable guidance on the design of other policies, like energy efficiency, renewable, and emissions rate standards, which might be used in lieu of taxes (perhaps to avoid large increases in energy prices). The incremental cost of reducing emissions under these policies could be assessed and then compared with the environmental damages presented here, to gauge whether these other policies are appropriately scaled (in the sense that incremental abatement costs and environmental damages are equated).

Summing up

Getting energy prices right involves a fairly straightforward extension of (widely accepted and easily administered) motor fuel taxes—better aligning their rates with environmental damages and extending similar charges to other fossil fuel products (or their emissions). There are complications (e.g., charges should be based on emissions net of any application of emissions control technologies) but the issues should be manageable. The findings here suggest large and pervasive disparities between efficient fuel taxes and current practice in developed and developing countries alike, with much (in fact a huge amount in many cases) at stake in terms of fiscal, environmental, and health outcomes.

The challenges are how to get it done—how to build support for energy price reform. International organizations and others have an important role to play here, first in promoting dialogue about best practice, and second in providing solid analytical contributions quantifying the benefits of pricing policies relative to alternative approaches, and assessing distributional implications to inform the design of compensating measures.

Outline of the volume

The main findings of the report—the corrective tax estimates by fuel and by country and (rough estimates of) the fiscal, environmental, and health benefits from tax reform—are presented in Chapter 2, which can be read without going through Chapter 1 and the supplementary materials—some readers may prefer to skip straight to these results. The other chapters here and in the supplementary materials are organized as follows.

The next chapter discusses the case for and design of fiscal instruments to address environmental side effects. Chapter 3 offers brief concluding remarks.

In the supplement, the first chapter provides a quick overview of energy systems, the nature of environmental side effects and major fiscal policies affecting energy. Chapter 2 of the supplement discusses the measurement of global and, in particular, local air pollution damages from fossil fuel use. The measurement of congestion, accident, and road damage costs associated with vehicle use are discussed in Chapter 3 of the supplement. The supplement also contains the references.

CHAPTER 1. RATIONALE FOR, AND DESIGN OF, FISCAL POLICY TO 'GET ENERGY PRICES RIGHT'

The first part of this chapter discusses why environmental taxes or the equivalent emissions trading systems (ETSs) should be front and center in getting energy prices right, though design details (targeting the right base, exploiting the fiscal dividend, establishing stable prices aligned to environmental damages) are critical. The second part discusses a variety of further design issues (e.g., specifics for power generation and transportation fuels, the role of other instruments, overcoming challenges to price reform, issues for low-income countries).

Policies that emerge in practice from political processes may deviate in all sorts of ways from the economically ideal design principles outlined here. Nonetheless, having a clear sense of what constitutes sound policy design helps to discipline the policy debate, provides a sense of where policy should be heading, and provides a benchmark against which other (perhaps more politically palatable) policies should be evaluated to illuminate the trade offs. And as discussed, some of the design principles carry over if regulatory approaches are chosen in favor of fiscal approaches.

Although other (complementary) policies are needed—investments in transportation and energy distribution systems, safety regulations governing the extraction and production of energy (including shale gas and nuclear) and use of roads, etc.—these are largely beyond the scope here, which is about pricing for residual environmental damages.[7]

A. Policy Instrument Choice for Environmental Protection

There are three basic reasons for using fiscal instruments to address the environmental side effects of energy:

- *they are environmentally effective*—so long as they target the right base (e.g., emissions).
- *they can achieve environmental objectives at lowest economic cost*—so long as the fiscal dividend is exploited (e.g., revenues substitute for other burdensome taxes).
- *they strike the right balance between the environment and the economy*—so long as they reflect environmental damages.

These criteria are important, not just for their own sake, but also for credibility and sustainability. Subsections (i) to (iii) elaborate on these principles. Environmental taxes in a broader fiscal context, and taxes versus trading systems, are discussed in subsections (iv)

[7] The appropriate design of these broader policies can depend on fuel pricing policies. For example, taxing coal may increase the need for grid extensions to wind and solar generation sites.

and (v).[8]

(i) The Effectiveness of Alternative Environmental Policies

There are two basic points here.

First, if environmental taxes or similar pricing instruments are applied to the right base (a critical 'if') they will exploit all opportunities for reducing a particular environmental harm.

Second, in contrast regulatory policies by themselves are typically far less effective because they are focused on a (much) narrower range of these opportunities—though a fairer comparison might be between pricing instruments versus various combinations of regulations.

The case of energy-related carbon dioxide (CO_2) emissions is taken to illustrate these points. The discussion goes into some detail, given the importance of choosing the right instrument, and that relatively ineffective instruments are often used in practice. Box 1.1 illustrates similar points about the effectiveness of well-targeted fiscal instruments in other policy contexts.

Opportunities for reducing energy-related CO_2 emissions

Opportunities for mitigating energy-related CO_2 emissions can be principally classified as follows:

- *Increasing use of renewable generation fuels*—that is, shifting the power generation mix from fossil fuels to (carbon-free) renewables like wind, solar, and hydro.

- *Other options for reducing the emissions intensity of power generation*—including shifting from (high-carbon-intensive) coal to (intermediate-carbon-intensive) natural gas and from these fuels to (carbon-free) nuclear. Emissions intensity might also be reduced through adoption of carbon capture and storage (CCS) technologies if these prove viable in future.

- *Reducing electricity demand*—through the adoption of energy-saving technologies (e.g., more energy-efficient lighting, air conditioners, or appliances) and reducing the use of electricity-consuming products.

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[8] For more discussion of some of the issues covered below see, for example, Goulder and Parry (2008), Hepburn (2006), IMF (2008), Krupnick and others (2010), OECD (2010), and Prust and Simard (2004).

Box 1.1. Environmental Effectiveness of Alternative Instruments: Further Examples

SO_2 emissions. As discussed in Chapter 2 of the supplement, sulfur dioxide (SO_2) emissions from coal-fired power plants are a major cause of premature death. Options for reducing these emissions include:

- installing filter technologies in smokestacks to capture or 'scrub' SO_2 (turning it into sludge and solid waste for impoundment in landfills or recycling)—some scrubbing technologies can capture 90 percent or more of emissions
- shifting to coal with a lower sulfur content
- washing of coal at processing plants, which lowers sulfur content (and other impurities)
- shifting from coal to other generation fuels (natural gas, renewables, etc.) through retiring coal plants
- reducing the demand for electricity

Charging for SO_2 emissions released from smokestacks promotes all these possibilities—the first four of them lower generators' tax liabilities, while the pass through of emissions taxes and abatement costs promotes the last response through higher electricity prices. Alternatively (and perhaps administratively easier), all these responses could be promoted by a tax levied on coal use in proportion to its emissions rate, with appropriate crediting for use of emissions control technologies.

In contrast, mandating SO_2 control technologies promotes the first response, but not others. Limiting average SO_2 emissions per kWh over generators' portfolio of plants is more effective, in that it promotes the first three responses, but provides only weak incentives for the last two because generators do not pay for the full social cost of coal plants. A coal tax unrelated to pollution, on the other hand, will promote the last two opportunities but miss the first three.

Road traffic congestion. There are a various possibilities for reducing urban road congestion (taking transportation infrastructure as given), including encouraging people to:

- car pool
- use alternative transport modes (bus, rail, bike, walking)
- reduce trip frequency (e.g., by telecommuting, combining several trips, or simply reducing travel)
- set off later or earlier to avoid the peak within the rush hour
- avoid the rush hour altogether by driving at off-peak

Charging motorists per km driven on busy roads, where the charge rises and falls progressively as congestion rises and falls during the course of the rush hour promotes all these responses (as each would reduce motorists' tax liabilities).

A simple toll per km driven that does not vary with time of day is less effective, as it does not encourage the last two responses. And a transit fare subsidy is far less effective still, as it exploits only the second response (and even then it does not encourage shifting to other non-transit alternatives).

- *Reducing transportation fuel demand*—through raising the average fuel efficiency (kms per liter) of vehicle fleets (e.g., adopting technologies to improve engine efficiency or reduce vehicle weight, shifting to smaller vehicles or various classes of electric vehicles) and reducing vehicle kms driven (i.e., reducing vehicle ownership and the intensity with which vehicles are used).

- *Reducing direct fuel usage in homes and industry (mainly for heating)*—again, this can be achieved through adoption of energy-saving technologies (e.g., insulation upgrades), or reduced product use (e.g., turning down the heating).

Effect of carbon pricing

Pricing all fossil fuel CO_2 emissions through a carbon tax (or ETS), exploits all of the above mitigation opportunities, as the emissions price is reflected in higher prices for fuels and electricity.

For illustration, suppose that 25 percent of the CO_2 reduction comes from shifting to renewable generation fuels, 25 percent from other measures to reduce CO_2 per kWh in power generation, 20 percent from reductions in electricity demand, 15 percent from reductions in transportation fuels, and 15 percent from reductions in direct fuel consumption in homes and industry—with reductions split equally, in the last three cases, between energy efficiency improvements and reductions in product demand.[9] These illustrated reductions are summarized in the first row of Figure 1.1, where the length of the (green) bars are scaled to the emissions reductions forthcoming from different sources.

Effectiveness of regulatory policies relative to carbon pricing

Other rows in Figure 1.1 illustrate the relative effectiveness of various alternative policies where each is scaled such that the emissions reductions for the particular source targeted by the policy are the same as those under carbon pricing.[10] Green bars indicate a source of emissions reduction and brown bars where policies actually *increase* emissions (though lowering energy costs). Other policies typically have limited effectiveness because—by definition—they fail to exploit many of the mitigation opportunities exploited under carbon pricing.

For example, a subsidy for renewable generation fuels misses 75 percent of the emissions reductions exploited by carbon pricing. And a vehicle fuel efficiency standard misses

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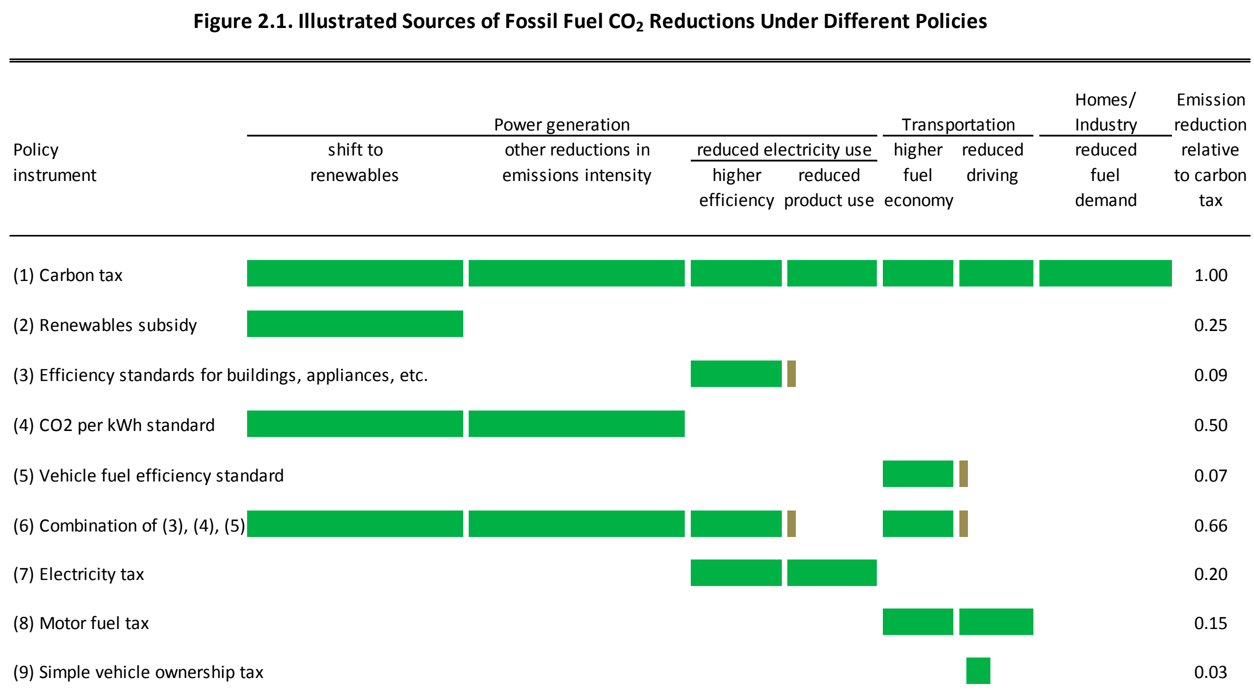
[9] These assumptions are based (approximately) on carbon price analyses for the United States in Krupnick and others (2010) and Parry, Oates, and Evans (2014). Most of the low-cost mitigation options are related to fuel switching in power generation, given the array of alternatives to (high-carbon) coal. In transportation, options for switching from fossil fuels to cleaner fuels remain limited and vehicle fuel efficiency is already high in many cases due to high fuel taxes and fuel efficiency regulations.
One complication (not considered here) is the possibility that future pledges to penalize carbon emissions might, by lowering the future returns to fossil fuel production, accelerate incentives for fuel production in the nearer term (thereby undermining some of the emissions benefits). For alternative perspectives on this see for example Sinn (2012) and Cairns (2012).

[10] For example, an electricity tax is taken to reduce electricity demand by the same amount as under a carbon tax and a renewables subsidy is taken to cause the same emissions reduction (from shifting from fossil generation fuels to renewables) as under the carbon tax.

93 percent of those reductions. In fact, these regulations cause a partially offsetting increase in emissions, through lowering fuel costs per km and increasing driving, though this 'rebound effect' appears to be relatively modest in size.[11]

However a 'smart' *package* of regulations can be a lot more effective. For example, a CO_2 per kilowatt hour (kWh) standard will promote all opportunities to lower CO_2 emissions per kWh in power generation (50 percent of the emissions reductions under the carbon tax). If combined with comprehensive policies to improve the energy efficiency of vehicles and electricity-using equipment, this package could exploit up to around two-thirds of the emission reductions under the carbon tax. But some mitigation opportunities are missed (e.g., encouraging people to drive less). Moreover, regulatory packages can be excessively costly without extensive credit trading (see below) and they do not raise revenue.

Figure 1.1. Illustrated Sources of Fossil Fuel CO_2 Reductions under Different Policies



Sources: Based approximately on analyses for the United States in Krupnick and others (2010) and Parry, Evans and Oates (2014).
Notes: Green bars indicate emissions reductions exploited by different policies where policies are scaled (when applicable) to have the same effect (e.g., on fuel efficiency, electricity demand) as a carbon tax. Brown bars indicate a source of increased emissions, as lower per unit energy costs increase demand for energy-using products (the rebound effect).

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[11] The illustration here assumes this effect offsets 10 percent of fuel savings from improved fuel efficiency based on Small and Van Dender (2006).

Targeting the right base

Other 'proxy' taxes are usually less effective, by far, than carbon pricing (again see Figure 1.1). For example, excise taxes on electricity consumption miss 80 percent of mitigation opportunities exploited by carbon pricing. Also prevalent are vehicle ownership taxes (sales excises as well as registration fees and annual road charges) but these taxes miss around 97 percent of the mitigation opportunities exploited by carbon pricing.[12]

(ii) Cost Effectiveness: A First Look

Besides their effectiveness, the second main rationale for fiscal instruments is that they achieve a given environmental improvement at lowest overall cost to the economy.

The focus here is on 'economic costs'—as defined in Box 1.2—rather than other metrics like GDP and employment. For now, policies are compared based on a limited definition of cost that ignores (important) linkages with the broader fiscal system (see below).

Environmental taxes (and ETSs) are cost-effective in that they promote equalization of incremental mitigation costs across different behavioral responses. For example, with the same price on all CO_2 emissions, firms and households alike face the same incentives to alter their behavior in ways to reduce emissions up to where the cost of the last ton reduced equals the emissions tax. ETSs are also cost-effective in this regard (so long as credit trading markets are fluid) as they also establish a uniform price on emissions across different sources.

Traditional regulatory policies, in contrast, may not perform well on cost-effectiveness grounds if they require that all firms meet the same standard and there is significant variation in pollution intensity among firms (implying it is a lot more costly for some to meet the standard than others). Credit trading (in fluid markets) is required to make these policies cost effective, including provisions allowing:[13]

- firms (e.g., generators with relatively emissions intensive plants) to fall short of th standard (e.g., a limit on average emissions per kWh produced), by purchasing credits from other firms (with relatively clean plants) that exceed the standard;

- firms to trade credits across different regulatory programs, thereby establishing a uniform emissions price across all sectors.

[12] This assumes (based on Fischer, Parry, and Harrington, 2007) that one-third of the reduction in driving in response to higher fuel prices comes from reduced vehicle ownership and two-thirds from reductions in kms driven per vehicle (a vehicle excise tax only promotes the first response).

[13] Empirical studies (see, e.g., Newell and Stavins, 2003, and the references contained in their footnote 2) have documented cases of substantial cost savings from these types of flexibility provisions.

Box 1.2. Defining Economic Costs

The economic costs of environmental policies refer to the costs (or benefits) of the various ways households and firms respond to the policy, both directly (e.g., through responses to higher fuel prices) and indirectly (e.g., through the responses to broader taxes which might be reduced with recycling of environmental tax revenues).

Staying with the carbon pricing example, the costs of the direct behavioral responses include, for example:

- higher production costs to power generators from using cleaner, but more expensive fuels
- costs to households from driving less than they would otherwise prefer (the value of trips forgone, less savings in time and fuel costs)
- costs to firms and households from switching to more energy-efficient vehicles, appliances, machinery and so on—that is, the upfront purchase costs less the lifecycle savings in fuel costs.

More generally higher energy and transportation costs tend to slightly contract the overall level of economic activity, which in turn may slightly reduce economy-wide employment and investment. As discussed below, employment and investment levels are already distorted due to taxes on work effort and capital accumulation—environmental policies cause economic costs if they worsen these distortions. On the other hand, there are offsetting benefits if environmental tax revenues are used to lower these taxes.

Economic costs do not include pure dollar transfers between the private sector and the government—whatever dollar amount the private sector pays in tax liabilities is offset by a revenue benefit to the government. Economic costs are also quite different from job losses in industries burdened by environmental policies (some of which at least are made up by other sectors after a, perhaps lengthy, adjustment period)—employment effects do matter for costs, as just noted, but the issue is entwined with the employment effects of the broader tax system. Economic costs need not be closely related to changes in GDP either (e.g., Krupnick and others, 2010, p. 23).

The concept of economic costs has been endorsed by governments around the world for purposes of evaluating government spending, tax, and regulatory policies. In the United States, for example, a series of executive orders since the 1970s has required government agencies to conduct hundreds of cost/benefit assessments a year, based on the notion of economic costs, to determine whether major policy initiatives are warranted from society's perspective.

As regards the broader macroeconomic impacts of environmental taxes, these are likely to be modest, at least if revenues are used to lower burdensome taxes on work effort and capital accumulation. The (short-term) macroeconomic impacts could be larger if revenues are used to reduce budget deficits, though that would be true of any fiscal consolidation measure. The fiscal crisis should not detract from efforts to price environmental damages, not least because they can ease the need for other consolidation measures (e.g., Jones and Keen, 2011).

(iii) Balancing Benefit and Costs

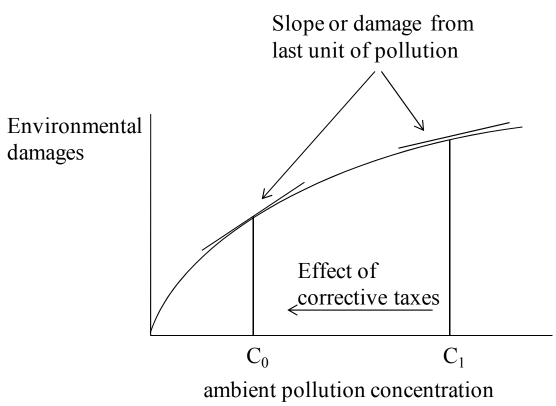
The third attraction of tax/pricing policies—that they can strike the right balance between environmental benefits and costs to the economy (though, as noted below, other policies are needed)—requires that prices are set equal to their 'corrective' levels, that is, (incremental) environmental damages. If prices are less than environmental damages, some socially desirable environmental improvements will be foregone; while if prices exceed environmental damages, some environmental improvements will be made that are not justified by their cost.[14]

The corrective tax calculations in Chapter 2 assume that environmental damages per unit are given (e.g., damages per ton of emissions, or congestion costs per vehicle km travelled). This seems reasonable, for example, for CO_2 damages, as one country's emissions in one year add very little to the atmospheric accumulation of greenhouse gases. The assumption might appear more questionable for local air pollution—as it implies the corrective tax should be independent of local ambient air pollution—though some justification is provided in Box 1.3.

Box 1.3. Are Local Air Pollution Damages Constant?

As discussed in Chapter 2 of the supplement, some evidence suggests that the relationship between environmental damages and ambient air pollution concentrations begins to flatten out at higher levels of pollution concentrations (due to people's ability to intake more pollution becoming saturated). This means that the slope of the environmental damage function is flatter at the high pollution concentration C_1 in Figure 1.2, compared with the slope at the lower concentration level C_0. In turn, this means that additional pollution emissions do less harm at concentration C_1 than at C_0.

Figure 1.2. Shape of the Air Pollution Damage Function



This might suggest that (given other factors) the corrective tax on fuel or emissions is lower (paradoxically) in high-pollution countries. This possibility is ignored in this study, however. The reason is that if corrective taxes of the scale typically estimated here were to be introduced, emissions would fall dramatically, most likely lowering pollution concentrations below levels at which the damage curve flattens out.

Constant environmental damages per unit also favor the use of instruments that price emissions (but allow the quantity to vary with changes in energy demand, fuel prices, and so on) versus instruments that fix the quantity of emissions (but allow prices to vary). The latter are more appropriate when there are known thresholds beyond which environmental damages rise sharply (e.g., Weitzman, 1974), though these cases do not seem especially relevant for this study.

[14] Corrective taxes are sometimes called 'Pigouvian' taxes after the economist, Arthur Pigou, who first recommended them.

Damages per unit also vary across regions within a country; for example, the human health effects of air pollution depend on local population exposure. In principle, charges could be differentiated according to the location of the emissions source, though this complicates administration—not least because pollution (from tall smokestacks) can be transported great distances (Chapter 2 of the supplement). Moreover, studies (e.g., Muller and Mendelsohn, 2009) suggest that imposing an appropriately scaled (uniform) emissions charge produces the biggest net benefit—differentiating the charge according to region produces further, but smaller, benefits.

(iv) Environmental Taxes in a Broader Fiscal Context

This subsection discusses the distortions to economic activity created by the broader fiscal system and how environmental taxes impact these distortions. The appropriate treatment of energy products under value-added (VAT) or similar sales tax systems is discussed in Box 1.4, but (assuming normal procedures are applied) is not really relevant for corrective tax design.

Box 1.4. Coverage of Energy Products under the Value-Added Tax (VAT)

Leaving aside environmental considerations, basic tax principles suggest that all consumption goods should be included under any VAT (or other general sales tax) system, to raise revenues without distorting choices among consumer goods. Intermediate inputs should be excluded from VAT, to avoid distorting firms' choices over the mix of labor, capital, energy and material inputs. These principles apply automatically under normal VAT systems, so long as intermediate goods are sold to entities paying VAT—any taxes paid under the VAT for power generation fuels, and electricity used by industry are (appropriately) reimbursed.

In contrast, any tax rate applying to consumer goods in general should also be applied to household purchases of electricity, vehicles, and fuels. Ideally any VAT should apply to fuel prices including corrective taxes, to avoid distorting the choice amongst consumption goods, taking account of their full social costs of production. Corrective fuel tax estimates reported in Chapter 5 are prior to any application of VAT.

Taxes on labor income (e.g., personal income and payroll taxes) can cause large differences between wages that workers take home and compensation paid by firms. As a result, these taxes tend to depress work effort by discouraging labor force participation, overtime, effort on the job, investments in human capital, etc. VAT (and other consumption taxes) has similar effects, as it reduces the amount of goods that can be purchased from a given amount of work effort.

Similarly, taxes on corporate income and individual income from savings tend to burden the economy by reducing capital accumulation below the level that would otherwise occur.

Environmental taxes (or similar instruments) interact with these sorts of distortions in two opposing ways (e.g., Goulder, 2002; Parry and Oates, 1999).[15]

First, as environmental taxes are passed forward into the prices for fuels, electricity, transportation and so on, they tend to contract (albeit very slightly) the overall level of economic activity, which in turn reduces employment and investment. In effect, energy taxes act like implicit taxes on labor and capital, and they compound the adverse effects of those taxes. Studies find that the costs of environmental taxes (or ETS) are considerably higher—possibly several times higher[16]—when their adverse effects in (tax-distorted) factor markets are taken into account.

Second, however, if environmental tax revenues fund broader tax reductions, this produces relatively large economic benefits (by increasing incentives for work effort and capital accumulation) offsetting most of (and perhaps more than offsetting) the adverse effects on factor markets from higher energy prices, implying moderate costs overall for the economy (and perhaps negative costs if revenues are used to reduce a particularly distortive tax). While environmental tax revenues are more often earmarked than other taxes, there are notable examples of environmental tax revenues substituting for other taxes (see Box 1.5). Of course there are alternative revenue uses that might yield comparable economic benefits, including reducing budget deficits (which in turn lowers future tax burdens), and funding socially desirable spending.

Despite the fiscal dividend, economic analysis suggests that (with some nuances) this is not a reason to set higher tax levels—roughly speaking, environmental taxes should be set on environmental grounds, with further revenue requirements met through broader fiscal instruments (personal income taxes, VAT etc.).[17]

However (insofar as possible) exploiting the fiscal dividend is critical, given the large amount of revenues at stake (Chapter 5). If revenues from environmental taxes are not used productively, the overall costs of environmental taxes can be substantially higher.[18]

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[15] The discussion here abstracts from the possibility of other (non-tax) distortions in labor markets like wage rigidity (e.g., from union power) and chronically deficient demand.

[16] See, again, Goulder (2002) and Parry and Oates (1999).

[17] See, for example, Goulder (2002). Once environmental damages are reflected in fuel (and other energy) prices, raising further revenues from these taxes generally involves higher economic costs than raising the same amount of extra revenue from broader taxes. Both taxes tend to have harmful effects on employment and investment. In addition, excessive fuel taxes will over-burden the energy sector relative to other sectors.

[18] In fact, environmental taxes can lose their cost-effectiveness advantage over regulatory alternatives (e.g., Goulder and others, 1999; Parry and Williams, 2012). Environmental taxes can cause larger increases in energy prices (as they involve the pass through of tax revenues in higher prices) than regulatory policies (which do not raise revenues): the larger the increase in energy prices, the larger the adverse effects on (tax-distorted) factor markets—and hence the need to offset these higher costs with productive use of revenues.

Box 1.5. Environmental Tax Shifting in Practice

Several countries have recently introduced, or increased, environmentally-related taxes while simultaneously cutting other taxes. For example:

- In the early 1990s, Sweden introduced taxes on oil and natural gas to charge for CO_2 and (for oil) SO_2 and on coal-related SO_2 and industrial NO_x emissions. These reforms were part of a broader tax-shifting operation that also strengthened the VAT while reducing taxes on labor and traditional energy taxes (on motor fuels and other oil products).
- Between 1999 and 2003, Germany increased taxes on transport fuels and introduced new taxes on natural gas, heating fuels, heavy fuel oil, and (primarily) residential electricity consumption. About 85 percent of revenue was used to fund reductions in employer and employee payroll taxes—about 14 percent was used for budget consolidation and 1 percent for renewable energy programs.
- In Australia's carbon pricing scheme, which covers about 60 percent of CO_2 emissions, around three quarters of the allowances are auctioned with half of this revenue used to fund a tripling of in personal income tax thresholds. This scheme was implemented in 2012, but now looks likely to be scrapped.
- From 2008 to 2012, British Columbia progressively introduced a carbon tax covering 70 percent of fossil fuel emissions, with over 90 percent of the revenues used to fund reductions in personal and corporate taxes.

Sources: DCCEE (2011), GBC (2012), pp. 66.

This last point has some notable policy implications:

- *Be wary of earmarking* environmental tax revenues (e.g., for clean energy programs, climate adaptation). Ideally, any earmarked spending should generate comparable economic benefits from alternative revenue uses (e.g., lowering other tax burdens).[19]

- *Compensate appropriately*. Compensation payments (e.g., for groups especially vulnerable to higher energy prices) may have a high equity and political value, but can significantly reduce the overall cost effectiveness of environmental taxes by reducing revenues for other (perhaps more economically efficient) purposes like cutting other burdensome taxes. Policymakers need to carefully evaluate the trade offs.

- *If possible, use compensation schemes that improve economic efficiency*. Tensions between compensation and cost effectiveness might be ameliorated if the compensation scheme produces economic benefits. For example, providing relief to low-income households through tax reductions (e.g., lowering the basic rate of tax, raising personal income tax thresholds, providing earned income tax credits)

[19] Another problem with earmarking is that there is no relation between the economically appropriate amount of spending on clean energy or related programs and the amount of revenues raised by a corrective environmental tax. With earmarked revenues there has been a tendency to set tax levels to meet spending requirements, implying tax rates frequently well below levels needed to correct for environmental damages (e.g., Opschoor and Vos, 1989).

improves incentives for work effort (while transfer payments made regardless of work effort do not).

(v) Taxes vs. ETS: A Quick Look

In principle, the choice between emissions taxes and ETS is less important than implementing one of them, but getting the design details right, most importantly:

- comprehensively covering the sources of environmental harm;
- prudent use of the fiscal dividend;
- scaling program stringency to environmental damages;
- establishing stable and predictable prices.

The importance of the first three design features was discussed above.

The fourth helps to avoid inflating program costs over time. In pure ETS systems there is a danger that either the cap will be set too low (e.g., because energy demand turns out to be lower than expected) in which case emissions prices are depressed and low-cost mitigation opportunities foregone, or the cap will be too tight (e.g., in periods of high energy demand) in which case emissions prices and mitigation costs are excessive. A stable (and rising) emissions price also fosters expectations that policy will be sustained over time, which is important for clean technology development and deployment (especially technologies with high upfront costs and long-range returns). Stable prices also enhance revenue stability. Price volatility has been a problem in some trading systems, for example in the European Union where futures prices reached €30/ton of CO_2 in 2006 and 2008, but fell below €5/ton in 2007 and again in 2013 (Figure 1.3).

Promoting price stability implies a (political) trade-off however, as emissions vary from year to year—to date, climate policy goals have usually been expressed in terms of annual emissions rather than price targets.[20]

[20] 'Carbon budgets' are a possible compromise between emissions and price targets. These budgets would specify allowable emissions cumulated over a long period (say 10 years), but allow year-to-year variability in emissions. They could be implemented through a carbon tax whose rate might be adjusted later on in the budget period if cumulative emissions would not otherwise be on track to stay within budget.

Figure 1.3. Price Experience in the EU Emissions Trading System

Source: Bloomberg (2013).

Appropriately designed environmental taxes naturally meet the above four design features. The same applies for ETS if allowances are auctioned and price stability provisions like price floors and ceilings are included.[21]

In practice, a carbon tax seems the more likely instrument to fully exploit the fiscal dividend as, presumably, it would be administered by a finance ministry (e.g., as an extension of existing motor fuel excises to other petroleum products, coal, and natural gas). An environmental agency administering an ETS might be reluctant (or might be legally unable) to remit all revenues from allowance auctions to the finance ministry.

Tax and pure ETS systems can also interact differently with other climate-related policies. For example, policies to promote renewables and energy efficiency will not affect emissions if these are held fixed by a cap—instead they lower emissions prices (if there is no price floor) and the potential fiscal dividend from an ETS.[22] In the presence of carbon taxes however, other policies reduce emissions (rather than the emissions price, which is fixed by

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[21] Studies for the United States (e.g., Fell, MacKenzie, and Pizer, 2008) suggest that an ETS scaled to achieve the same cumulative emissions reduction as a carbon tax would be moderately more (about 15 percent) costly over time if the ETS lacked any price stability provisions.

[22] In practice, however, policymakers may be more willing to tighten an emissions cap if emissions prices are reduced through other policies.

the tax) and therefore tend to have a (much) weaker impact on reducing revenues.

Sometimes it is suggested that an ETS is the more natural instrument for channeling climate finance to developing countries through offset programs. These provisions could be included under a tax however—tax credits could be awarded to domestic fuel suppliers for funding climate mitigation projects in developing countries. Again, offset provisions (assuming these promote genuine emissions reductions as opposed to reductions that would have occurred anyway) improve environmental effectiveness under a tax, without substantially reduced revenues. But under an ETS with no price floor, they lower the emissions price and carbon pricing revenues, with no effect on total emissions.

B. Further Design Issues

Several complicating factors are now considered, relating to overlapping environmental problems, the interactions with and role of other policies, measures to improve the acceptability of policy reform, and relevance for low-income countries. Some further issues are touched on in Box 1.6.

(i) Multiple Environmental Problems

As discussed in Chapter 1 of the supplement, energy and transportation systems cause more than one source of environmental harm—fuel combustion leads to both carbon emissions and local air pollutants, while broader adverse side effects of vehicle use include, for example, road congestion. The implications for fiscal policy design are discussed below, taking in turn power generation, heating, and transportation fuels.

Power generation fuels

Fossil fuel combustion at power plants causes carbon emissions and local air pollutants, the most important of which is fine particulates. These particulates are emitted directly (e.g., during coal combustion) and are formed indirectly from chemical transformations of sulfur dioxide (SO_2) in the atmosphere, and to a lesser extent (because it is less reactive), nitrogen oxides (NO_x). SO_2 is primarily caused by coal combustion while NO_x is produced from all fossil fuels.

Damages from these emissions are generally additive (with some caveats—see Chapter 2 of the supplement) and can be addressed either through taxes imposed on fuel supply in proportion to emissions factors (with appropriate crediting for any emissions capture at the point of fuel combustion) or taxes imposed directly on emissions.

Box 1.6. Unintended Consequences and Market Price Distortions

This box discusses examples of unintended consequences from tax reform and the implications of market price distortions.

An illustration of unintended consequences is when environmental taxes cause increased use of substitute fuels with environmentally-harmful effects and that cannot themselves be priced.

For example, fossil fuel taxes can lead to excessive reliance on nuclear power, with its consequent risks of meltdowns and unsafe waste disposal. In the absence of effective regulatory and liability frameworks to adequately minimize these risks (they are difficult to address through taxes on nuclear power, not least due to uncertainty over the probability and scale of disasters), taxes on fossil generation fuels should be phased in more cautiously. Similar issues arise if heavy taxation of coal use leads to extraction of domestic shale gas reserves, which (without safeguards) could pose significant environmental risks (e.g., from groundwater pollution or escape of methane—a potent greenhouse gas).

To take another, this time very specific, example, fine particulate concentrations are especially high in Ulaanbaatar, Mongolia—not least due to coal use for winter home heating (e.g., in shanty towns). However, if residential coal prices were significantly increased through taxation, this could induce households to instead burn highly toxic plastics, rubber, or other difficult-to-price garbage, with possibly even worse consequences for human health (World Bank, 2011). The problem is the lack of viable (cleaner) alternative fuels—until such alternatives (perhaps imports of oil or liquefied natural gas) are provided, high residential coal taxes may not make sense (though this should not preclude taxation of coal for power generation). In principle, the corrective fuel tax here would be adjusted downwards by the increase in use of other fuels per unit decrease in the taxed fuel, times the per unit environmental damage from the other fuel.

Another example is related to tax competition. For example, higher diesel fuel taxes in one European country could induce truckers to re-fuel in neighboring countries (with lower tax rates), offsetting some of the domestic pollution and congestion benefits. One response is for countries to coordinate over minimum fuel tax rates (e.g., T&E, 2011). Another is to partially transition to km-based tolls which truckers must pay, regardless of where their fuel is purchased.

Environmental taxes can also interact with market price distortions. If (e.g., due to limited competition) product prices exceed per-unit production costs, consumption of the product will be too low from an economic perspective. In principle, this may call for a lower environmental tax affecting this industry, though in practice any adjustments may be very modest (e.g., Oates and Strassmann, 1984). In other cases (e.g., at state-owned enterprises) product prices may fall short of per-unit production costs, though whether this justifies tax levels significantly higher than environmental damages is an open question (not least due to lack of transparency over the extent of price distortions). In either of these cases, however, the ideal policy would be to remove the market price distortion and set the environmental tax on environmental grounds.

As regards coal, the appropriate set of charges on fuel input at power plants includes four charges equal to:

- tons of CO_2 per unit of energy, times damages per ton of CO_2;
- tons of $PM_{2.5}$ per unit of energy, times damages per ton of $PM_{2.5}$;
- tons of SO_2 per unit of energy, times damages per ton of SO_2;
- tons of NO_x per unit of energy, times damages per ton of NO_x;

Emission rates here are defined with respect to energy rather than tons of coal, given variation in the energy content across different coal types (Chapter 2 of the supplement). Default charges could reflect emission rates prior to any application of emissions control technologies—for which reasonable data is generally available by country from independent sources (Chapter 2 of the supplement)—with the onus on the plant operator to demonstrate, through use of continuous emissions monitoring technologies, any reduction in emission rates due to application of control technologies to receive an appropriate tax credit.

Alternatively, if charges are levied on emissions rather than fuel input the appropriate rate per ton of emissions would simply reflect environmental damages per ton, with separate charges applicable to each of the four pollutants. This approach might be more complex to monitor and enforce as governments need to assemble local air emissions data themselves by ensuring that all plants install, and correctly operate, continuous emissions monitoring technologies.

The same design principles apply to natural gas plants, though emission damages in this case are a lot lower, and charges for direct particulates and SO_2 may not be needed, given the emissions rates for these pollutants are, at most, very small.

Heating fuels

A fuel charge is likely the preferred regime for heating fuels like natural gas, given the large numbers of small-scale emissions sources in the household sector. Again, the same principles for aggregating over emissions sources (though perhaps for just CO_2 and NO_x) as just discussed would apply.

Transportation

Fuel taxes are discussed first (the focus of this volume) followed by km-based taxes (a possibility for the longer term).

Motor fuel taxes. Consider first gasoline taxes for passenger vehicles, where there are four main environmental side effects: CO_2, local air pollution, traffic congestion, and traffic accidents.[23]

If fuel taxes are the only fiscal instrument available, the corrective tax (expressed, following normal practice, in fuel units) is given by (Parry and Small, 2005):

(1.1) [CO_2 damages per liter]

+

[(congestion, accident, and local pollution costs imposed on others per extra km of driving)

×

(km per liter)

×

(fraction of the fuel reduction due to reduced driving rather than higher fuel efficiency)]

The first component in this formula charges for CO_2 emissions and is calculated by CO_2 emissions per liter—essentially the same for gasoline across all countries[24]—times CO_2 damages per ton.

The second component reflects effects varying with vehicle km—congestion, accidents, and (see further explanations below) local pollution—rather than fuel use. Multiplying their combined (economy-wide average) costs per km by fuel efficiency (km per liter) expresses them in costs per liter.[25]

Distance-related costs are also multiplied by the fraction of the tax-induced reduction in gasoline use due to reduced driving, as opposed to the other fraction due to fuel efficiency improvements (as a rough rule of thumb this fraction is 0.5). The smaller is this first fraction, the smaller the congestion, accident, and local pollution benefits per liter of fuel reduced, implying a smaller corrective fuel tax.

Note that in the second component in (1.1) costs could alternatively be expressed per unit of fuel use, rather than per km, skipping the need to measure fuel efficiency (accurate data on this is often lacking)—so long as these costs are scaled by the driving fraction of the fuel response.

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[23] For further discussion of these side effects, see de Borger and Proost (2001); CE Delft and others (2011); Delucchi (2000); Maibach and others (2008); Quinet (2004); Santos and others (2010); US FHWA (1997).

[24] The discussion here focuses on the taxation of pure gasoline and leaves aside the taxation of ethanol (which is sometimes blended with gasoline) and compressed natural gas, both of which are relevant for specific country cases only.

[25] Ideally, account should be taken of how fuel efficiency responds to changes in fuel taxes, though for simplicity the calculations below omit this complication.

For gasoline (like for natural gas) the major local air pollutant is NO_x. The above formula assumes that reductions in kms driven reduce these emissions, while fuel efficiency improvements do not. This is reasonable in countries (like the United States) where the same emissions-per-km (or mile) standards are imposed on all vehicles (irrespective of their fuel efficiency) and emissions rates are maintained (at least to some extent) throughout the vehicle life by inspections programs (e.g., Fischer, Parry, and Harrington, 2007). In countries lacking these regulations, local emissions would instead be proportional to fuel use (and would therefore enter the first component in (1.1)).

As for motor diesel used by commercial trucks, the formula in (1.1) applies, with some modifications (aside from different input values). Local air emissions from trucks have not traditionally been regulated on an emissions per km basis and are therefore proportional to fuel use (i.e., they should not be multiplied by the driving portion of the fuel demand response). In addition, trucks are (almost entirely) responsible for vehicle-induced wear and tear on roads given that road damage is a rapidly escalating function of a vehicle's axle weight (e.g., Evans, Winston, and Small, 1989), and this damage should enter the second component of the corrective fuel tax.[26]

In practice motor diesel is used by both cars and trucks. Given administrative complications in differentiating the price at the pump paid by these different vehicles, the main corrective tax estimates presented here average over car and truck fuel use, though it turns out not much differentiation would be warranted anyway. On the other hand, a (much) lower tax rate would be appropriate for off-road uses of diesel (e.g., in farm and construction vehicles), though differentiation in this case is more feasible (e.g., through dying fuels).

Distance-based taxes. Ideally over the longer term, countries should be partially shifting away from fuel taxes toward km-based taxes to more effectively address side effects that vary directly with distance travelled (e.g., Johnson, Leicester, and Stoye, 2012).

For congestion, per-km tolls on busy roads, progressively rising and falling during the course of the rush hour, exploit all possibilities (given existing transportation infrastructure) for behavioral changes to alleviate congestion (see Box 1.1).

For accidents, per-km charges might be scaled according to driver risks (e.g., higher for those with higher insurance company rating factors based on age, prior crash record, etc.) and perhaps higher for larger vehicles posing greater crash risk to others.[27]

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[26] Noise is sometimes discussed as another adverse side effect from trucks, though is ignored here as the damage cost appears modest relative to other effects (e.g., US FHWA, 2000).

[27] Distance-based charges for congestion and accidents should apply equally to similar size vehicles, regardless of their fuel type or fuel efficiency (i.e., besides traditional fuel vehicles they should also cover hybrid, electric, and natural gas vehicles).

Even for local air emissions, a better corrective tax might be a per km toll whose rate depends on the emissions characteristics of the vehicle and on local population exposure to those emissions.

And road damage is most efficiently addressed through per-km tolls on heavy trucks, scaled by their axle weight, which would encourage truckers to seek vehicle fleets that carry goods efficiently over more axles.

In principle then, the ideal fiscal system for motor vehicle transport would involve charging motorists for each km driven, where the charge is scaled according to factors affecting the congestion, accident, local pollution and possible road damage costs imposed on others by that km, with a fuel tax component retained to address carbon emissions. Developments in metering technologies like Global Positioning Systems (GPS) imply that km-based tax systems are now feasible (see Box 1.7). The trade-offs between policy effectiveness and administration costs need careful study however—for example, extra administration required to fine tune local km charges to emission rates and population exposure may not be worthwhile, if emissions are being controlled effectively through direct regulations.

In any case, given that widespread applications of km-based taxes appear to be a long way off,[28] in the interim it is still appropriate (i.e., it produces significant net economic benefits), to reflect all adverse side effects of vehicle use in fuel taxes.

(ii) Implications of Other Policies for Environmental Tax Design

The discussion now turns to a variety of other commonly implemented (mostly regulatory) policies aimed at reducing fossil fuel emissions and that may have implications for the impact and/or design of environmental taxes.[29]

Renewable and energy efficiency mandates. Renewables and energy efficiency mandates (for the power sector) do not affect environmental damages per unit of coal or natural gas and therefore do not change corrective taxes for these fuels. Their effect is to reduce environmental benefits from tax reform, as some of the potential behavioral responses (shifting from fossil fuels to renewables, adoption of electricity-saving technologies) will already have been induced by the mandate.

ETS. Taking the example of a carbon tax, if this is targeted on the same base to which an ETS (without price floors) already applies, the tax will reduce allowance prices, rather than affecting emissions (which are fixed by the cap). On net, government revenues (from the

[28] For example, recent proposals for nationwide distance-based taxes in the Netherlands and the United Kingdom have been put on hold.

[29] Subsidies for fossil fuel consumption are not considered here, as they act like negative fuel taxes (though existing subsidies are factored into estimates of the impacts of policy reform in Chapter 2).

Box 1.7. Distance-Based Charging for Vehicles: Some Initial Examples

This box describes some examples of per-km charging systems, though only the last is a nationwide scheme.

Singapore introduced an area license (or day-pass) scheme in 1975, which dramatically raised travel speeds within the restricted zone, though also initially increased congestion outside of the zone (e.g., Santos, 2005). In 1998 area licensing was replaced with a toll debited electronically on certain links, with the objective of maintaining average speeds of 30-40 miles per hour on expressways and 12–18 miles per hour on major roads. Charges rise and fall in 30-minute steps during peak periods, based on congestion levels observed in the previous quarter.

Norway experimented with cordon tolling, though with little effect on congestion given the objective was to raise (a modest amount of) transportation revenue rather than deter congestion.

London introduced an area licensing scheme in 2003 with a daily congestion charge (on weekdays) of GBP £8. Collection is by video cameras at checkpoints into and within the priced area recording each vehicle's license plate (penalties are mailed to drivers who have not prepaid). In the first two years, congestion fell 30 percent within the priced zone, though by 2008 average speeds had fallen back to pre-charging levels due to more traffic from exempt vehicles and reserving some roads for the exclusive use of buses, pedestrians, and cyclists (TfL, 2008). A similar scheme now operates in Milan, with a fixed daily charge of €5.

Stockholm implemented a cordon toll in 2007 covering an area of about 36 square km (again enforcement is based on number plate recognition). Fees for passing the cordon vary between SEK 10 and 20 with time of day, though some vehicles are exempted (e.g., emergency vehicles, buses, motorcycles, alternative fuel vehicles). Congestion initially dropped by 50 percent on the main routes approaching the city center, and 20 percent within the city center, though there has recently been some deterioration (Eliasson, 2009).

Congestion pricing is gaining limited momentum in the United States, with federal funding for pilot schemes under the Value Pricing Program and the reduction of regulatory obstacles to freeway pricing. Some schemes open up links previously reserved for high-occupancy vehicles to single-occupant vehicles in exchange for a fee (e.g., I-15 in San Diego) while others use tolls to fund new infrastructure (e.g., lanes added to SR-91 in Orange County, California in 1995).

Germany introduced a nationwide tolling system (metered by GPS) for highway use by trucks (weighing 12 tons or more) in 2005. Charges vary between €0.14 and €0.20 per km according to vehicle type, number of axles, and emission rates—eventually, the tolls will also vary with time of day and region.

tax and the ETS) should be unaffected (if allowances are auctioned) or increased (if allowances are freely allocated)—in the latter case, the tax appropriates rents that would otherwise have accrued to allowance holders.[30]

Air emissions mandates. Mandates in this context may include requirements that (new) plants incorporate control technologies (e.g., flue gas de-sulfurization technologies), or maximum allowable rates for emissions per kWh averaged across generators' plants (see Box 1.1). Again, these policies do not affect the appropriate charge per ton for the remaining emissions, though they do affect the appropriate tax credit to reflect differences between uncontrolled and controlled emission rates in a fuel charge system. They also shave off some of the effectiveness of emissions charges.

Vehicle fuel efficiency and emissions standards. Fuel efficiency standards also dampen some of the environmental effectiveness of fuel taxes. In addition, they can raise corrective motor fuel taxes by increasing the fraction of a given (tax-induced) reduction in fuel use that comes from reduced driving thereby (see formula (1.1)) multiplying the contribution of km-related costs to the corrective fuel tax. Emissions per km standards (applied to new vehicles) have the opposite effect—by reducing average emission rates they lower the local pollution component of the corrective fuel tax.

(iii) Other Policies to Address the Limits of Environmental Taxes

Regulatory policies have a potential role to complement environmental taxes, for example if there are practical constraints on pricing reforms, or if they promote responses beyond the reach of fuel taxes (e.g., emissions regulations encourage vehicle manufacturers to reduce emissions per liter, while fuel taxes do not). This sub-section briefly discusses how the environmental damage estimates presented later can be used to guide the design of these policies, focusing firstly on traditional regulations and then more novel policies.

Traditional regulatory approaches

Desirable features of regulatory policies include:

- broad coverage to promote the widest possible range of opportunities for reducing environmental harm. As mentioned earlier, for example, a CO_2 per kWh standard for power generation is much more effective than a renewables policy, because the former promotes all fuel switching possibilities to reduce emissions rather than just shifting to renewables.

- credit trading provisions to contain costs by allowing some firms to fall short of the standard by purchasing credits from other firms going beyond the standard.

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[30] This occurs in the EU ETS as the UK government collects revenue from its carbon tax floor essentially at the expense of allowance holders elsewhere in the EU.

- price ceilings and floors (though these reduce the urgency of credit trading provisions). The ceiling allows firms to pay fees instead of fully meeting the standard (which they might do in periods when compliance costs are relatively high), while the floor allows firms to receive subsidies to go beyond the standard (in periods when compliance costs are relatively low). Ideally, these price ceilings and floors would be harmonized across different regulations *and*, most importantly, they would be set so implicit prices on emissions are in line with estimated environmental damages.

These price stability features would make regulations look more like corrective environmental taxes. However, regulations would still differ in that they do not exploit all emissions mitigation opportunities and they do not (on average) raise revenue. They might be more politically acceptable however, as they have smaller impacts on energy prices (as they do not involve the pass through of tax revenue in higher prices).

Novel alternatives to environmental taxes

Here some more novel options for mimicking the effects of environmental taxes, again without a large (politically difficult) increase in energy or product prices, are considered.

One possibility is a combination of fees and rebates, known as 'feebates'. These policies have mainly been discussed as an alternative to new vehicle CO_2 emissions per km (or equivalently fuel per km) standards (e.g., Small, 2010). In this context, they would involve a fee on new vehicles with above average CO_2 per km and a rebate to vehicles with below average CO_2 per km, where fees/rebates are levied in proportion to the difference between the vehicle's CO_2 per km and some 'pivot point' level. If the pivot point is the average CO_2 per km of, say, last year's new vehicle fleet (and updated accordingly over time), the policy would be approximately revenue neutral. If (due to constraints on broader fiscal instruments) revenue from vehicles is a priority, feebates can be combined with vehicle excise taxes—see Box 1.8.

Feebates might also be applied to reduce the emissions intensity of power generation. In this case, generators with high emissions intensity would pay fees in proportion to the difference between their emissions per kWh (averaged over their portfolio of plants) and a pivot point emissions per kWh, while generators with low emissions intensity would receive corresponding rebates.

Feebates have several attractive features (though regulations can have similar merits if accompanied by design features, like price ceilings and floors).

First, feebates are cost effective as all firms face the same rewards for reducing emissions. Second, feebates automatically provide ongoing incentives to continually reduce emissions (traditional regulations do not, as once firms have met the standard they have no incentives to go beyond it). Third, fees and rebates can be set (approximately) such that the implicit reward for reducing emissions reflects environmental damages. Fourth, they create some winners (i.e., those receiving subsidies) from the affected industry which could help with acceptability.

Box 1.8. Reconciling Fiscal and Environmental Objectives in Vehicle Taxation

Vehicle excise taxes are often related to CO_2 per km, with vehicles classified into different brackets and more favorable taxes applied to the lower emission rate brackets. This represents an improvement over tax systems related to engine capacity as the former promote some emissions-saving opportunities (e.g., reducing vehicle weight or improving rolling resistance) that the latter do not.

But one problem with these schemes is that they set up a tension between revenue and environmental objectives—the more successful the policy in shifting people to lower emission vehicles, the lower the tax receipts. Moreover, tax brackets do not provide ongoing incentives for manufacturers to reduce the emission rate of the vehicle, once it has (just) fallen into the next (lower) tax bracket.

Both problems are avoided by combining an ad valorem tax on vehicle sales with a feebate. The tax provides a stable source of revenue that does not decline as emissions rates fall (and it does not distort the choice among vehicles, as all vehicle prices rise in the same proportion). In addition, the feebate provides ongoing rewards for all opportunities to reduce emission rates for all vehicles.

Another novel policy—one that encourages people to drive less (a response that is difficult to regulate) and without a (politically difficult) increase in tax burden for the average motorist—is to change automobile insurance from lump-sum payments into payments proportional to kms driven. This possibility is discussed in Box 1.9.

Box 1.9. Pay-As-you-Drive Auto Insurance

One promising way to reduce vehicle kms travelled in countries with well-established automobile insurance systems—but systems where premiums take the form of lump-sum annual payments—is to transition to pay-as-you-drive (PAYD) insurance, where premiums vary in proportion with the policyholder's annual km.[1] Existing rating factors (determined by insurance companies) would be used to set per km charges for different drivers: inexperienced drivers, or those with prior crash records, for example, would pay higher per-km charges. This would maximize the road safety benefits, as those with the greatest crash risks would have the greatest incentives to drive less.

The transition to PAYD could occur on a voluntary basis, with the government kick-starting the process through tax incentives.[2] Drivers with below-average annual km would have the strongest incentives to take up PAYD (under the current system low-km drivers subsidize high-km drivers) and as they switched, premiums would rise (to maintain insurance company profits) for the remaining pool of drivers with lump-sum insurance, encouraging further shifting to PAYD. GPS and nearly tamperproof odometers (with appropriate safeguards) now provide a reliable and accurate way to collect information on kms driven.

[1] Under existing systems, there is often a modest discount for drivers with annual driving below a certain threshold. However, if motorists are below, or well above, this threshold they have no incentive to reduce driving.

[2] Government incentives may be needed to overcome obstacles to the private development of PAYD. When an insurer charges by the km, its costs are reduced to the extent that its own customers reduce their accident risk by driving less. However, the costs to other insurance companies also are lowered, by reducing the risk of two-car accidents for their own customers—the other cost savings cannot be captured by the company offering the km-based insurance.

(iv) Policies to Address Obstacles to Clean Technologies

Even if corrective environmental taxes are feasible, most likely they are not enough, due to various obstacles preventing sufficient investments in clean technologies. However, while complementary policies are likely needed, they are largely tangential to the focus here on environmental tax design.

For one thing, usually the most important policy, meaning the one yielding the biggest net benefits, is getting the prices right through corrective fiscal instruments, not least because this provides across the board incentives for clean technology development and deployment. Further innovation incentives can yield significant, additional benefits, though studies suggest they are on a smaller scale.[31]

And given that barriers vary in severity across different technologies this calls for targeted measures, rather than setting environmental taxes in excess of environmental damages (the latter would encourage all technologies equally).[32]

The remainder of this sub-section discusses the nature of technology barriers and possible responses (to complement environmental taxes) in the context of private sector research and development (R&D) and technology deployment.[33]

The focus here is on altering private sector investment behavior rather than public investment (in transportation systems, fuel distribution infrastructure, smart grids, etc.). Generally, the latter investments should be warranted in their own right (based on cost-benefit criteria), taking into account their potential role in enhancing the effectiveness of environmental taxes, for example, by providing commuters with public transit alternatives (e.g., World Bank, 2012).

[31] See, for example, Goulder and Mathai (2000), Nordhaus (2002), Parry, Evans, and Oates (2014), and Parry, Pizer, and Fischer (2003). A caveat here is that there are costs to delaying clean technology transitions—costs that grow over time if economies become more locked into emissions intensive capital and infrastructure (e.g., Acemoglu, Aghion, Bursztyn, and Hemous, 2012).

[32] Studies indicate that it is much less costly to promote emissions reductions and cleaner technologies by combining environmental taxes with technology incentives, rather than relying exclusively on taxes (e.g., Goulder and Schneider 1999; Fischer and Newell 2008).

[33] Governments also conduct basic research into new technologies, the fruits of which are then used by the private sector. For example, the US federal government spends about $4 billion a year on energy-related technologies, though a number of analysts believe that significantly more spending is warranted (e.g., Newell, 2008).

R&D

Private R&D into cleaner technologies is inadequate (even with corrective environmental taxes) when innovators are unable to capture spillover benefits of new technologies to other firms who might copy them or use them to further their own research programs. Uncertainty about future policy also makes firms hesitant to invest in new technologies. Although similar barriers might apply to technology development in other sectors, they seem especially severe for cleaner energy technologies (e.g., renewables plants) where upfront costs are often large and emissions reductions may persist for several decades—even with adequate corrective taxes now, tax rates in the far future are inherently uncertain.

One technology instrument is R&D subsidies (like tax credits), though these policies do not distinguish among the more promising, and not so promising, research possibilities. Intellectual property rights are better in this respect, as the value of the patent depends on the commercial viability of the technology. But patents set up a tension between R&D incentives and diffusion—if it is easy for other firms to 'imitate around' the patented technology this helps diffuse new technologies, but undermines returns to the original innovator. Prizes for new technologies may be a useful supplement, as they avoid this tension. Awards for critical new technologies might be based on objective analytical work (estimating, for example, how much they help to lower the costs of meeting climate objectives) or (smaller) rewards might be paid to the innovator each time the technology is adopted by another firm based on potential emissions reductions.

Technology deployment

Deployment of (clean) technologies may also be insufficient, despite emissions pricing and R&D incentives, for several reasons beyond future policy uncertainty. For example, individual firms may be reluctant to pioneer use of an immature technology, as they incur costs associated with learning about how to reliably and efficiently use it, while benefits from this learning partially accrue to other firms that subsequently adopt the technology. And there could be a variety of problems at the household level, though the basis for policy intervention remains contentious (see Box 1.10).

Although additional instruments to promote technology deployment are likely needed, their appropriate form, scale and phasing out can be tricky to judge. Interventions might take the form, for example, of supplementary measures (e.g., feebates, regulations) to improve vehicle fuel efficiency or promote the penetration of renewable or other technologies. In the latter case, adoption subsidies might be better than mandates that force in the technology in regardless of economic conditions—consistent with the previous discussion, subsidies allow firms the flexibility to deploy the technology on a more limited basis, should its costs turn out to be greater (relative to other options) than initially expected.

Box 1.10. The Energy Paradox Controversy

The 'energy paradox' refers to the observation that seemingly cost effective energy-saving technologies (i.e., whose lifetime fuel savings discounted at market rates exceed their upfront purchase and installation costs) are not always adopted in the market place.

Numerous explanations have been proposed for this phenomenon, many of which may justify policy action. For example, consumers may have limited information, limited ability to calculate future energy costs from the information they have, or may have more product characteristics to consider than they can process, and so omit energy savings. They may also be mistrustful of claimed energy cost savings, doubtful about future fuel prices, or short-sighted in their assessment of the future. Informational gaps in used product markets could perpetuate such short-sightedness by not allowing people to reap the full advantage of more energy-efficient products. Consumers may also be subject to borrowing constraints causing them to under-invest in energy-saving technologies relative to what would be desirable from society's perspective. Landlords may also be reluctant to upgrade energy efficiency if they pay the costs and tenants gain the benefits in terms of lower electricity bills (e.g., IEA 2007).

Other explanations, however, do not warrant policy intervention. For example, the observed reluctance of consumers to pay for more energy efficient products may reflect their awareness of possible undesirable side effects, such as reduced acceleration for cars, inferior quality of lighting for fluorescent bulbs compared with incandescent, or greater likelihood of these products needing repairs.

However, evidence on the extent to which energy efficiency is undervalued, and if so, how much policy intervention this warrants, remains inconclusive, making it difficult to draw solid recommendations about the appropriate role of additional policies to address the energy paradox (e.g., Allcott and Wozny, 2012; Busse, Knittel, and Zettelmeyer, 2012; Gillingham, Newell, and Palmer, 2009; Helfand and Wolverton, 2011; Huntington, 2011; Parry, Evans, and Oates, 2014; Sallee 2013).

(v) Overcoming Obstacles to Environmental Tax Reform

Implementing environmental tax reform is very challenging, not least because of opposition to higher energy prices. As noted in Chapter 1 of the supplement, rather than tax fossil fuel energy, many countries subsidize it, to the tune of $490 billion in 2011. Moreover, even in countries that tax energy heavily, often this takes the form of taxes that are relatively blunt from an environmental perspective. And, due to overlapping programs, and lower rates for favored groups, different fuel users can be charged at quite different rates for the same emissions sources.[34]

Opposition to higher energy prices comes from households (and a particular concern is low-income households) and from (energy-intensive) firms (especially in trade sensitive sectors). Each is discussed below but only briefly as the issues are extensively covered elsewhere (e.g., Clements and others, 2013; Dinan, 2013). Clements and others (2013) also discuss

[34] In the United Kingdom, for example, Johnson, Leicester, and Levell (2010), Table 4.1., estimate implicit CO_2 taxes in 2009 were GBP £26 and £41/ton for natural gas used in domestic and business power generation respectively, and £0 and £9/ton for natural gas used in homes and industry, respectively.

(based on case studies) broader possibilities for enhancing the prospects for energy price reform (e.g., improving transparency, phasing reforms, informational campaigns).

Compensating households

For some countries, one possibility for reducing household opposition to environmental tax reform is to scale back pre-existing taxes affecting energy that are (at least on environmental grounds) made redundant by the environmental tax. For example, in most OECD countries, most if not all of the burden of carbon pricing on residential electricity consumers and motorists could be offset by reducing current excise taxes on electricity consumption and vehicle sales (IMF, 2011). Another possibility might be to provide (transitory) subsidies for the adoption of cleaner energy alternatives (e.g., heat insulation, florescent lighting, solar water heaters).

In developed countries, poorer households tend to spend a relatively large portion of their income on electricity and fuels for transportation, heating, and cooking. Consequently, relative to their income the burden of higher energy prices tends to be greater for lower income households than for wealthier households, which runs counter to broader efforts to moderate income inequality. For developing countries, the burden of higher energy prices (relative to income) might be smaller for lower-income groups, due to limited vehicle ownership or grid access among these groups. But any policy that potentially reduces living standards for the poor may require some offsetting compensation.

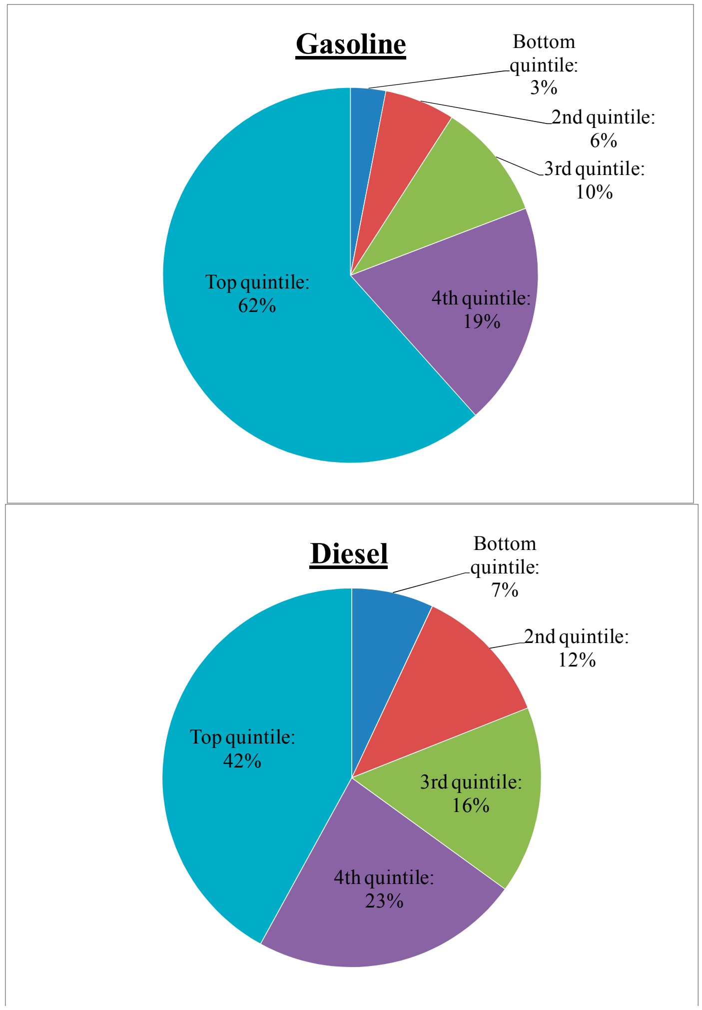
A basic point here is that holding down energy prices below levels warranted by production costs and environmental damages is usually a highly inefficient way to help them. According to estimates summarized in Figure 1.4, only 3 percent and 7 percent of the benefits from lower gasoline and diesel prices respectively, in countries that subsidize these fuels, accrue to the bottom income quintile.

In other words, there are much more efficient (i.e., more targeted) ways to help these groups, such as:

- targeted tax cuts (e.g., payroll tax rebates, earned income tax credits, higher personal income tax thresholds) for countries where large numbers of low income (energy-dependent) households are covered by such taxes;
- transfer payments, wage subsidies for low-paid jobs, etc. in countries where these compensation schemes are (or could be) administratively feasible; or
- increased government spending (e.g., on schools, education, housing, jobs programs) that disproportionately benefit low-income households.

Recall, however, the above caveats about overcompensation, and the preference for schemes also promoting economically desirable behavior.

Figure 1.4. Distributional Incidence of Energy Subsidies



Sources: Clements and others (2013).
Notes: These figures summarize, aggregated across all countries that subsidize gasoline and diesel fuels, the portion of benefits accruing to different income groups.

Compensating firms

Higher energy costs for trade-exposed industries (e.g., steel, aluminum, cement producers)—a particular concern for carbon pricing—can lead to a dual problem: a loss of competitiveness, reflected in firms relocating to other countries (where carbon pricing is not applied) and 'emissions leakage' (increased emissions in these countries partly offsetting domestic reductions).[35] Possible responses, in the context of carbon pricing, include (e.g.,

[35] Studies (e.g., Böhringer, Carbone, and Rutherford, 2012) suggest that leakage offsets around 5 to 20 percent of the emissions reductions from carbon pricing, depending on the size of the coalition of countries taking action. This leakage reflects not only the international migration of economic activity, but also increases in fossil fuel use in other countries as world fuel prices fall in response to reduced demand in countries with carbon pricing. The latter type of leakage is not easily addressed through policy.

Fischer, Morgenstern, and Richardson, 2013):

- Using some of the carbon pricing revenues to fund a general reduction in corporate income taxes provides offsetting gains in competitiveness for the economy as a whole, though these reductions are not well targeted at the most vulnerable (energy-intensive) firms and therefore do little to limit emissions leakage.

- Protecting energy-intensive, trade-sensitive firms through production subsidies, to roughly offset their higher energy costs. These subsidies preserve incentives for reducing emissions per unit of output (though not for reducing their overall level of output). However, they use up some of the carbon tax revenues and complicate administration.

- Border adjustments which might impose a charge on embodied carbon in products imported to a country (or bloc of countries) with carbon pricing. A key attraction of these adjustments is that they encourage other (trading) countries to price carbon to avoid bearing some of the burden of tax accruals to other countries. The legality of such charges (under free trade agreements) is uncertain, however. Moreover, import fees may be tricky to implement (especially if applied to a large number of products, from many different countries) if embodied carbon, and the extent to which other countries are mitigating carbon, are difficult to measure.

- Yet another possibility is simply to exempt trade-sensitive firms—for example, by providing them a rebate for purchases of electricity and fuels to neutralize the effect of carbon pricing on their input costs. These exemptions also forgo revenue and, to a greater extent than for other measures, undermine environmental effectiveness.

In short, all the above options have their drawbacks. Ideally, countries would coordinate over carbon pricing policies, lessening the pressure for the above types of measures (and in any case, firms that cannot compete when domestic energy is appropriately priced should eventually be allowed to go out of business).

(vi) Applicability to Low-Income Countries

How applicable is the above discussion to low-income countries, where the primary concern of policymakers may be to lift people out of abject poverty (rather than raise the costs of energy and transportation)?

As regards climate change, low-income countries contribute very little to global emissions and for practical purposes the case for them undertaking costly mitigation policies is correspondingly weak (Gillingham and Keen, 2012). But pricing for local environmental problems—air pollution, congestion, accidents—is in these countries' own interests as this provides net economic benefits. There are some nuances, however.

One is that the potential fiscal and environmental benefits are less important in relative terms, for countries with a relatively low energy intensity of GDP and that (as common in Africa) do not use coal. Another is that, even with corrective taxes, and leaving aside the technology barriers already mentioned, private sector investment in green technologies may still be insufficient in low-income countries because of capital shortages. This is the basic rationale for donor contributions supporting other investments (e.g., infrastructure projects) and similar external funding has a complementary role to play in the environmental area. And more generally, technology transfers to low-income countries can be promoted through dissemination of know-how acquired in advanced and emerging economies.

C. Summary

Although this chapter provides a broad overview of instrument choice and policy design issues, for the purposes of the following chapters (which mainly focus on assessing efficient tax levels) the main points are:

- For power generation, either (i) taxes should be levied on fuel supply (coal or natural gas) in proportion to emissions factors weighted by environmental damages per unit of emissions, with appropriate crediting for any emissions captured during fuel combustion or (ii) charges should be directly levied on emissions released from smokestacks reflecting environmental damages per ton of emissions. The choice between these charging schemes largely hinges on administrative considerations (though the former could be the easier).

- For heating fuels, charges should be levied on fuel supply to reflect emissions rates and environmental damages (pricing emissions is not practical given large numbers of fuel users).

- For transportation fuels, corrective taxes accounting for a wider range of side effects should be calculated according to formula (2.1) above.

CHAPTER 2. THE RIGHT ENERGY TAXES AND THEIR IMPACTS

This chapter summarizes the corrective tax estimates for coal, natural gas, and motor fuels based on the methodology outlined in the supplementary materials, both for selected countries and (using ranges of values in heat maps) for all countries, and then discusses the fiscal, health, and environmental impacts of tax reform. Various tables in the Appendix provide full details of this information, country by country, including estimates of current fuel taxes or subsidies.

A. Corrective Tax Estimates

(i) Coal

Figure 2.1 shows the corrective taxes (i.e., taxes to reflect environmental damages) on coal use (by power plants) from a representative sample of countries with different income levels, geographical locations, and energy mixes, these taxes being expressed (given that energy content per ton varies significantly across different types of coal) in (year 2010) US $/gigajoule (GJ) of energy.

In this figure, the orange bar indicates the tax on coal to correct only for carbon emissions (based on the illustrative damage value of $35/ton of CO_2). The other bars indicate the additional taxation needed to reflect local pollution damages, depending on whether coal plants are using emissions control technologies (e.g., to filter emissions in the smokestack). Specifically, the dark blue bar is the corrective tax for representative plants in different countries with control technologies and the light blue bars indicate the additional corrective coal charges for plants without emissions control technologies. Current taxes, taken from estimates in Clements et al. (2013)[36] and shown by the diamonds, are zero or thereabouts. To put the corrective tax estimates in perspective, the world average coal price in 2010 was approximately $5/GJ.[37] There are a number of noteworthy points from this figure.

The carbon component of the corrective tax is substantial, equivalent to about $3.3/GJ, or about 66 percent of the average world coal price in 2010. The corrective tax varies very little across countries, as there is little variation in carbon emissions/GJ of coal, and the illustrated CO_2 damage value ($35 per ton) is applied to all countries.

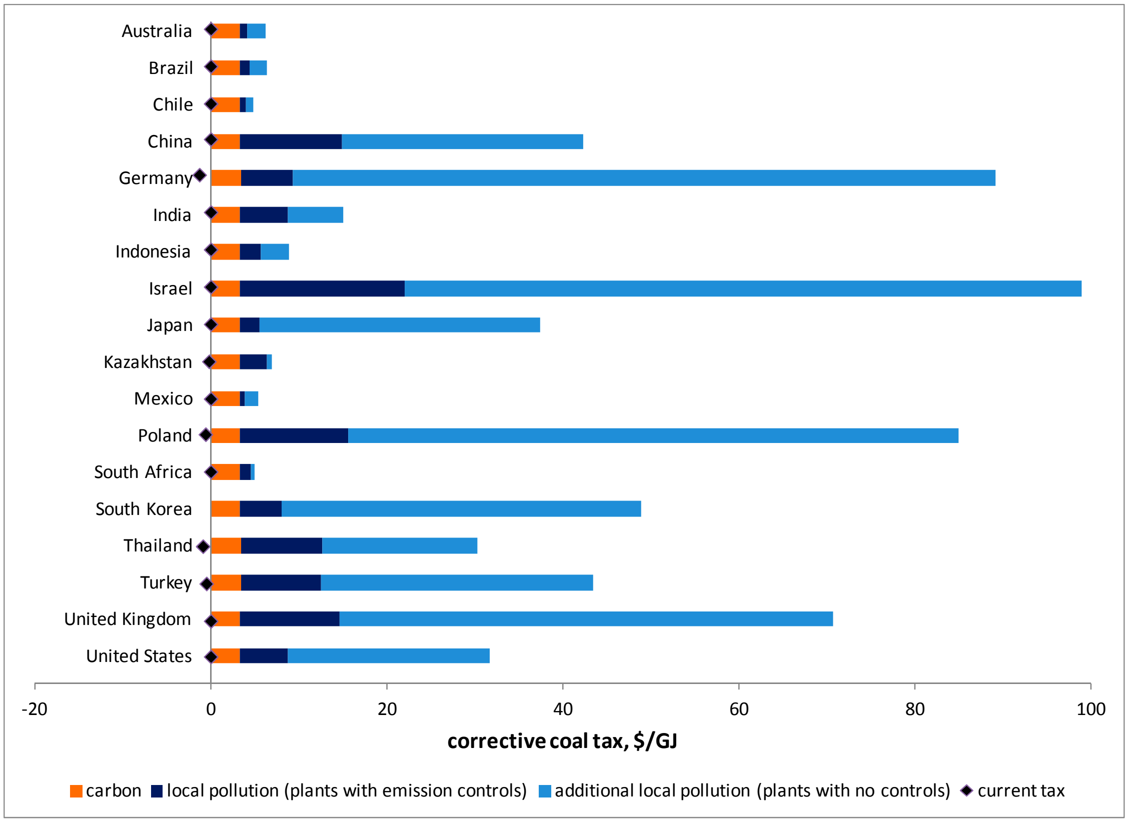
Far more striking however is that for most countries the local pollution charge for plants without emissions controls is larger than the carbon charge—in fact it often swamps the carbon charge. For example, in the United States local pollution damages contribute about

[36] These estimates are calculated on a consistent basis across countries, mostly based on a comparison of domestic fuel prices with international prices, though they will differ somewhat from authorities' own data on fuel tax rates.

[37] This and other global average fuel prices mentioned below are inferred from Clements et al. (2013).

$28/GJ to the corrective tax, or 90 percent of the total corrective coal tax of $32/GJ. For China, premature deaths per ton of coal burned are several times those for the United States, though the corrective coal tax for local pollution is only moderately higher at about $39/GJ, given the assumption that lower income causes lower health values (see below).

Figure 2.1. Corrective Coal Tax Estimates, Selected Countries, 2010



Sources: See Chapter 2 of the supplement.
Notes: The sum of the dark and light blue bars is the appropriate coal tax for local air emissions for plants with no emissions controls. The dark blue bar is the tax that would be paid for a representative plant with control technologies receiving an appropriate credit for the emissions mitigation. Data on South Korea's current coal tax was not available from the sources used here.

Some countries have even higher corrective taxes for local air pollution from (uncontrolled) coal use—they exceed $65/GJ in Germany, Israel, Poland, and the United Kingdom, or over 13 times the world price. These corrective taxes are high for largely the same reason (discussed in Chapter 2 of the supplement) that damages/ton from sulfur dioxide emissions are high for these countries, namely the higher average population exposure to their emissions (in addition for Israel, the average sulfur content of coal is substantially higher than in most other countries).

The corrective local air pollution charge for (uncontrolled) coal use in Australia, on the other hand, is about $2/GJ—less than the carbon component (though still 40 percent of the world coal price). This reflects relatively low population exposure to its pollution (much of which disperses over the ocean) and low average sulfur content. Premature deaths/GJ of coal burned in Australia are 11 and 5 percent respectively of those for coal burned in the United States and the United Kingdom. South Africa also has a relatively low corrective tax—about $2/GJ. This reflects a combination of a relatively low sulfur content, assumed mortality value, and premature mortalities/ton of emissions.

Another key point from Figure 2.1 is the substantial reduction in corrective taxes for local air pollution when power plants incorporate emissions control technologies and are credited accordingly—corrective taxes fall by two-thirds or more for 12 of the countries in this figure. Generally speaking, these control technologies are common for newer coal plants in advanced countries but are less common in developing countries: for example, only one plant in India has a technology for capturing sulfur dioxide (Cropper and others, 2012). The large tax difference would create very strong incentives for the adoption of control technologies across new and old plants alike, with potentially dramatic health benefits (see below). Even if the control technologies currently used by some plants in a country were applied to all plants, corrective taxes for air pollution could still be significant however—more than the carbon charge for ten of the countries shown in Figure 2.1.

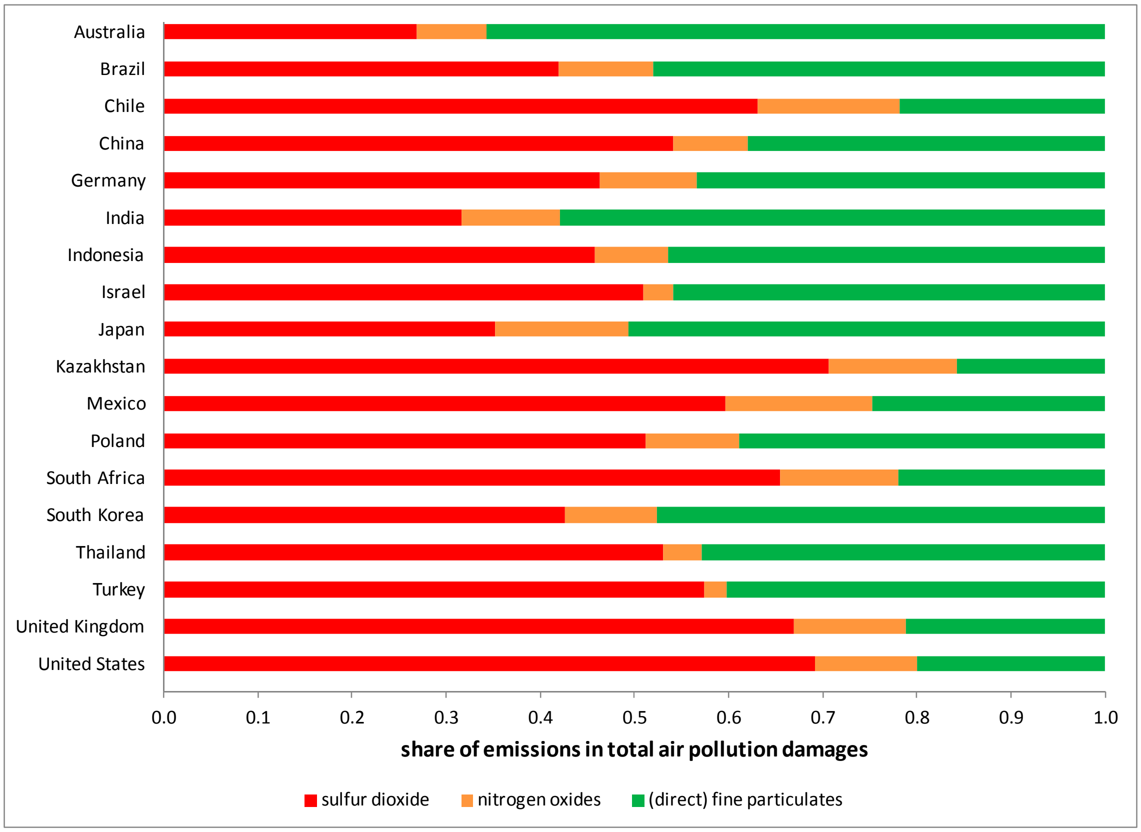
There is no obvious relation between the corrective taxes on coal use (shown in Figure 2.1) and the countrywide average level of outdoor air pollution (shown in Figure 1.9 in Chapter 1 of the supplement). For example, Germany and Israel have intermediate ambient pollution concentrations but very high corrective taxes for coal, and vice versa for China. As noted earlier (see Box 1.3 of Chapter 1) the health damages from an extra ton of emissions are taken, based on evidence, to be independent of the level of pollution concentration.

Figure 2.2 shows the breakdown of air pollution damages from uncontrolled coal plants by type of emissions. For most countries, sulfur dioxide is the most damaging pollutant (its share in total pollution damages varies across countries from 27 to 71 percent), followed by (direct) fine particulate emissions, though in some cases (Australia, Brazil, India, Japan and Korea) direct particulates cause the most damage (their share in total pollution damages varies from 16 to 66 percent). Nitrogen oxide emissions are responsible for a relatively minor share of damages (2 to 16 percent), as their emission rate are smaller than for sulfur dioxide, and they are less prone to reacting in the atmosphere to form the fine particulates that give rise to major health risks.

Figure 2.3 shows a heat map of corrective coal tax estimates, based on uncontrolled emissions, for all countries that use coal. No color represents a country that does not consume coal, while brown indicates a country where data constraints prevent a corrective tax estimate.

The relative cross-country pattern of corrective taxes looks broadly similar to that for sulfur damages presented in Chapter 2 of the supplement (though Figure 2.3 also reflects other local pollutants, carbon damages, and the emissions intensity of locally used coal). Corrective taxes are highest in Europe (where population exposure and per capita income are relatively high) and lowest in the limited number of African countries (that use coal and where data is available), with North and South America, Asia, and Oceania generally intermediate cases.

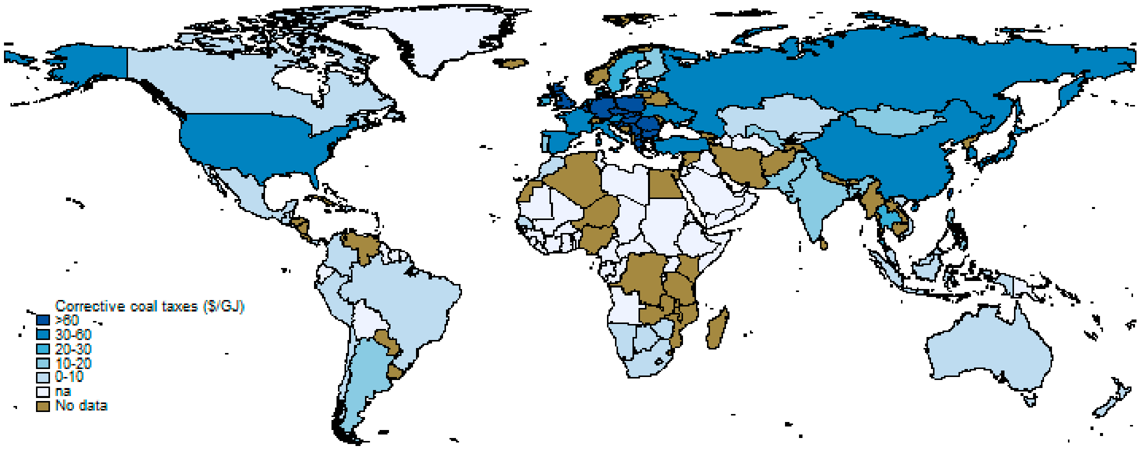
Figure 2.2. Breakdown of Air Pollution Damages from Coal by Emissions, Selected Countries, 2010



Sources: See Chapter 2 of the supplement.

Figure 2.4 reproduces the corrective coal tax estimates for selected countries from Figure 2.1, but this time using the same mortality value, namely that for the average OECD country, in all cases (given the controversy over applying different values across different countries). Not surprisingly, the main effect is to substantially scale up the corrective tax estimates for countries with per capita incomes well below the OECD average. For example, China's corrective tax (for uncontrolled coal plants) rises from $42/GJ to $133/GJ, while that for India rises from $15/GJ to $77/GJ. Dramatic differences in corrective taxes across countries still remain however, reflecting large differences in population exposure and (to a lesser degree) emission rates.

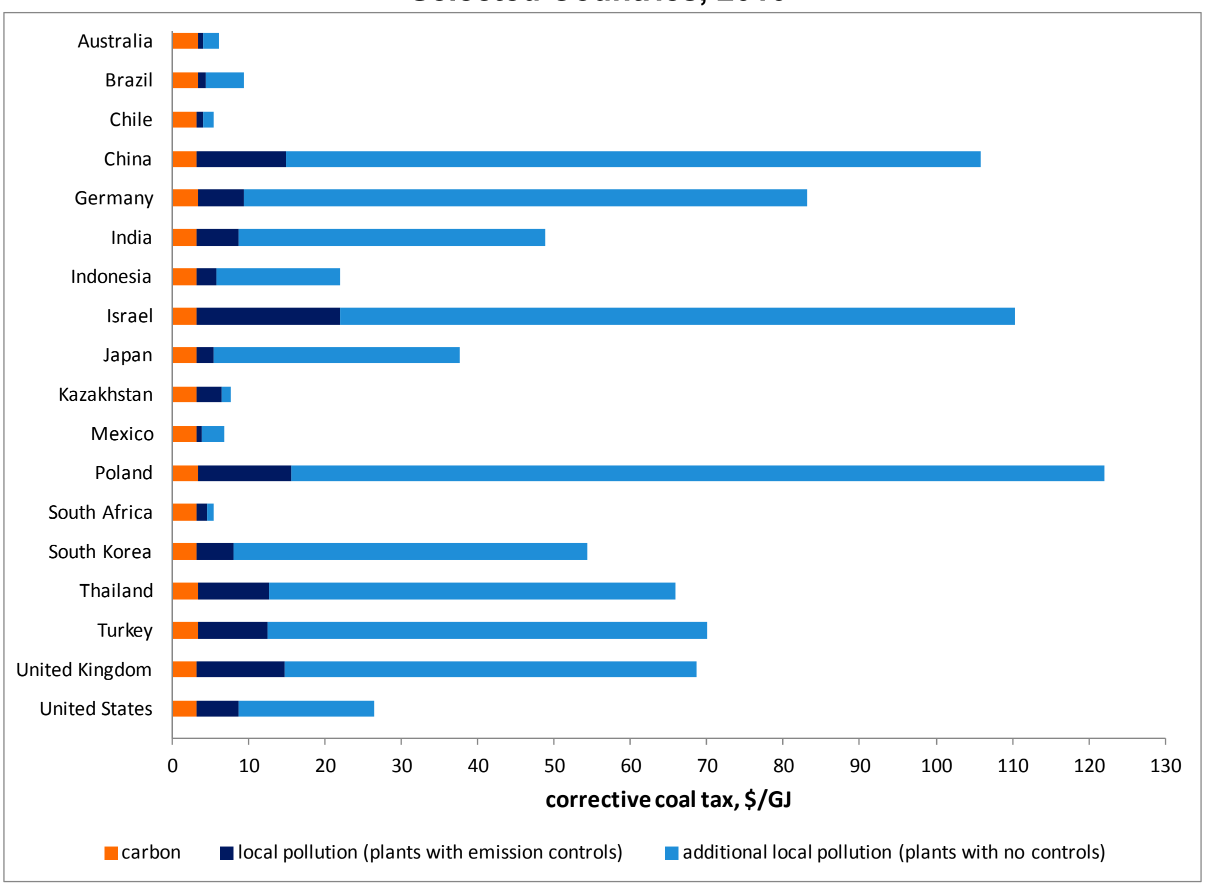
Figure 2.3. Corrective Coal Tax Estimates, All Countries, 2010



Sources: See Chapter 2 of the supplement.

Notes. na refers to no coal use in a particular country.

Figure 2.4. Corrective Coal Tax Estimates with Uniform Mortality Values, Selected Countries, 2010

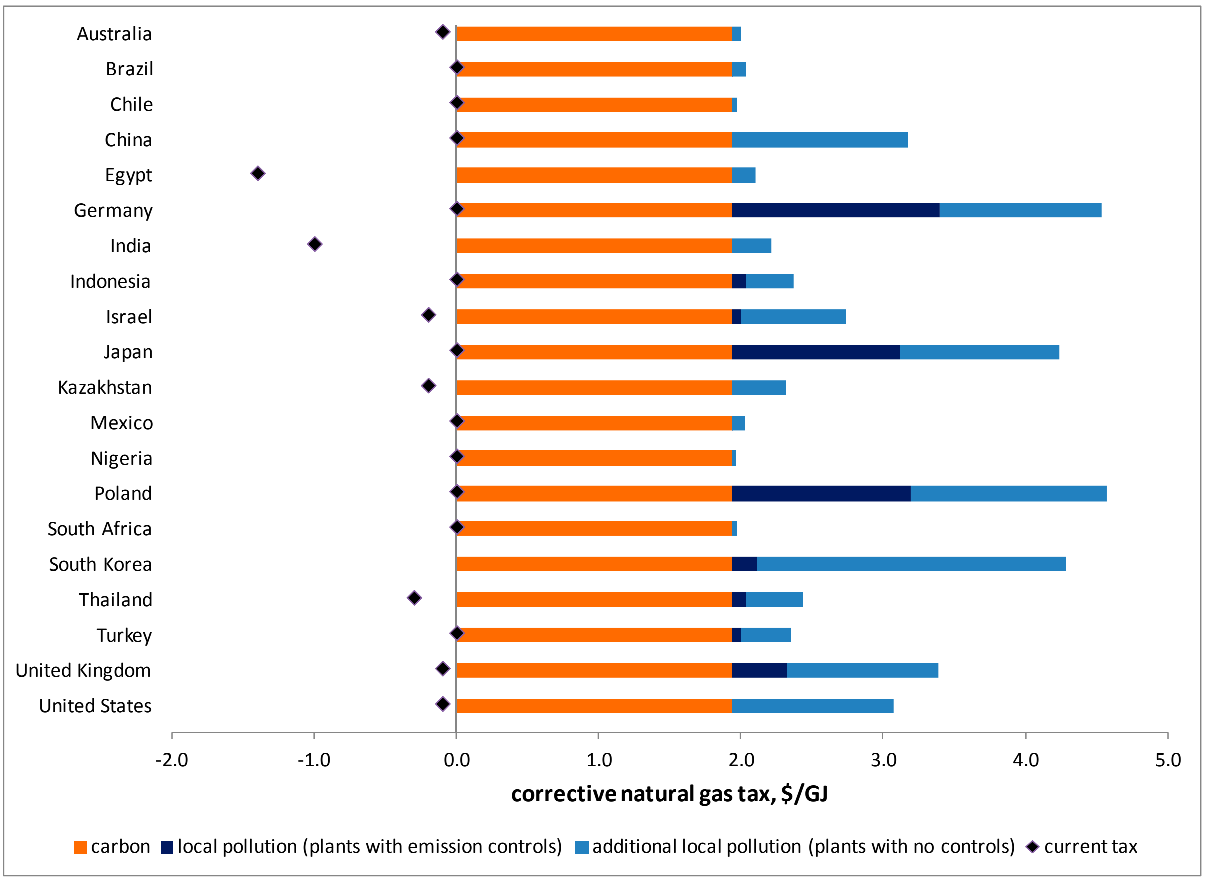


Sources: See Chapter 2 of the supplement.
Notes: This figure adjusts the corrective tax estimates from Figure 2.1 by setting mortality values for all countries equal to the average value for OECD countries.

(ii) Natural Gas

Figure 2.5 shows corrective taxes for natural gas, based on estimated carbon and air pollution damages from power plants. Again taxes are expressed in $/GJ with the same color coding as before. Current taxes are about zero in many cases, though natural gas is subsidized in some cases, especially Egypt ($1.4/GJ) and India ($1.0/GJ). For perspective, the world average price for (pipeline) natural gas in 2010 was around $5/GJ.

Figure 2.5. Corrective Natural Gas Tax Estimates (for Power Plants), Selected Countries, 2010



Sources: See Chapter 2 of the supplement.

Note: The explanation for this figure follows that in the note to Figure 2.1.

The corrective taxes in this figure look quite different than those for coal in Figure 2.1.

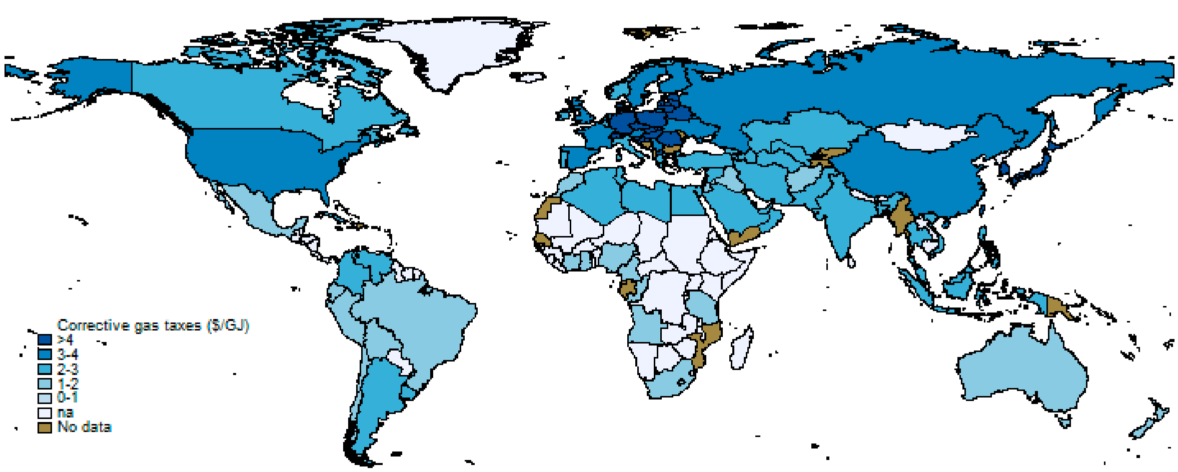
First, the carbon charge is a lot lower, $1.9/GJ or about 55 percent of that for coal. This reflects the lower carbon emissions rate (per GJ of energy) for natural gas.

Second, the local pollution damages are also dramatically lower. For most countries (except those with especially high population exposure to their emissions) the corrective taxes (for uncontrolled plants) are smaller than the carbon component, and often very much smaller: in seven of the twenty countries shown the corrective tax for local pollution is less than 10 percent of that for carbon. The main reason is that gas combustion generates minimal amounts of sulfur dioxide and (direct) fine particulates—the two big sources of air pollution damages for coal. Moreover, the nitrogen oxide emissions rates/GJ for natural gas are less than half of those for coal. Again, corrective taxes (net of appropriate credits) are considerably lower for plants with control technologies (though these technologies are less common at gas plants than coal plants).

Although far less severe than for coal there is, nonetheless, significant undercharging for natural gas, with currently estimated taxes for the countries shown in Figure 2.5 either about zero or negative, compared with corrective charges of about 40 percent or more of the world price.

Figure 2.6 shows corrective tax estimates for natural gas (used at power plants with no emissions controls) across all countries. The differences across countries are far less pronounced than for coal given that local pollution damages are a lot smaller (relative to carbon) for natural gas.

Figure 2.6. Corrective Natural Gas Tax Estimates (for Power Plants), All Countries, 2010



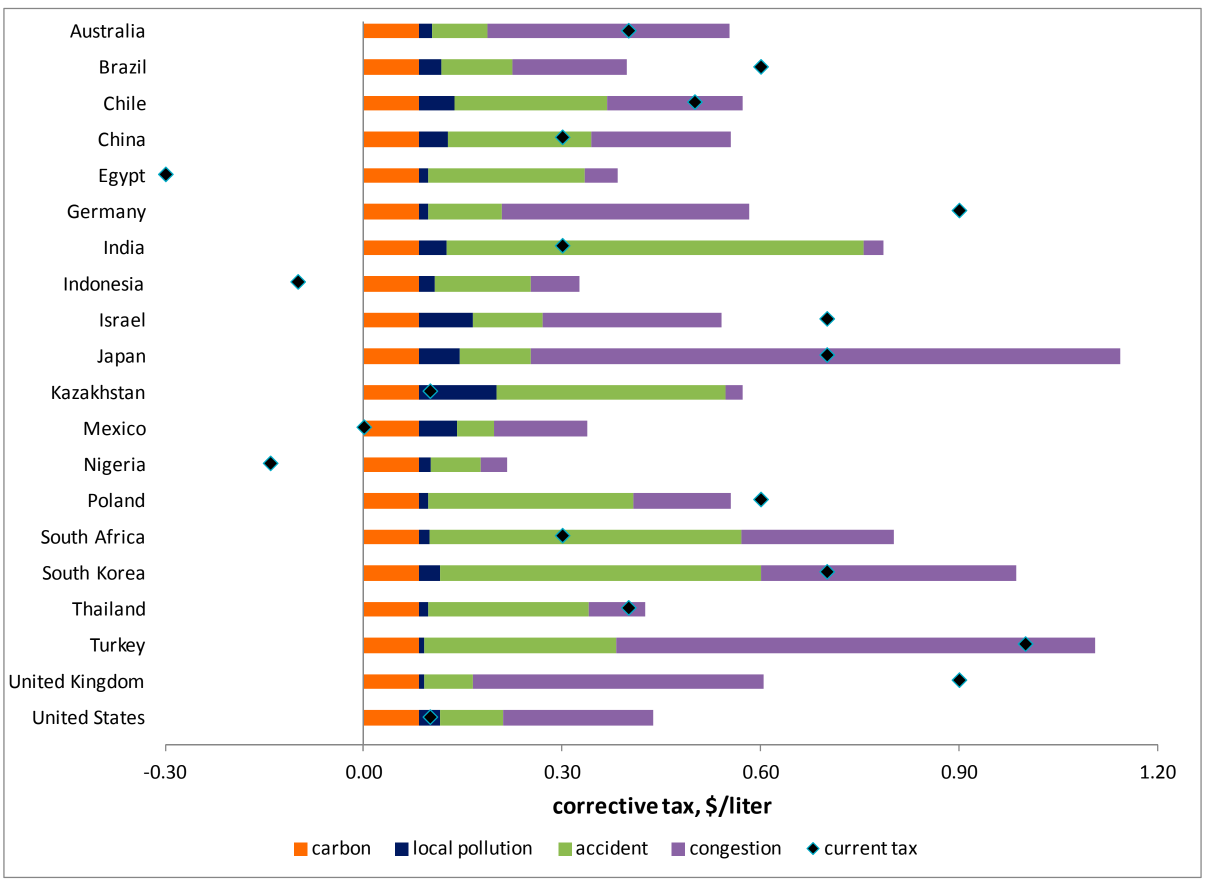
Sources: See Chapter 2 of the supplement.
Notes. na refers to no coal use in a particular country.

As regards corrective taxes for natural gas combusted at ground level (e.g., for home heating), the carbon charge is the same as for power plant use of natural gas and, again, the charge for local air pollution is less important (see the Appendix). Given the dominance of the carbon charge in each case, there does not appear to be a strong case (on pollution grounds) for differentiating natural gas taxes according to end user.

(iii) Motor Fuels

Figure 2.7 shows estimates of corrective gasoline taxes for selected countries, expressed in year 2010 US $/liter (to convert to $/gallon multiply by 3.8), and the contribution of carbon, local pollution, traffic accidents, and congestion, to the corrective tax (the corrective tax refers to the excise tax, prior to application of any VAT or sales tax). Current (estimated) excise taxes vary considerably, from subsidies of 30 cents/liter in Egypt to taxes of 60 cents/liter or more in Brazil, Germany, Israel, Japan, Poland, South Korea, Turkey and the United Kingdom. For perspective, the world (pre-tax) price of gasoline averaged about 80 cents/liter in 2010, equivalent to $23/GJ.

Figure 2.7. Corrective Gasoline Tax Estimates, Selected Countries, 2010



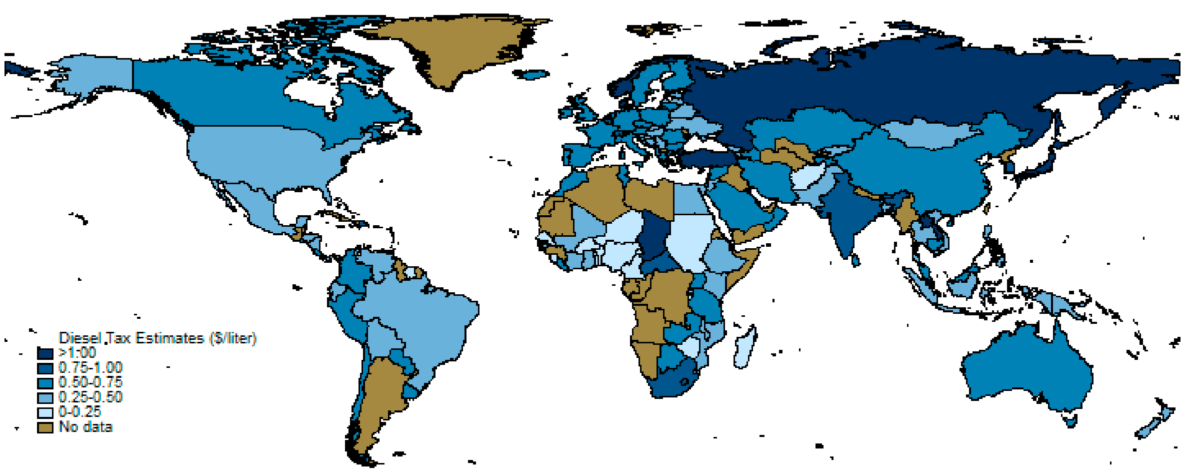
Sources: See Chapter 3 of the supplement.
Notes. To express taxes in $ per gallon, multiply by 3.8.

The carbon component of the corrective gasoline tax (based on the $35/ton damage assumption) is 8 cents/liter across all countries. This amounts to $2.4/GJ, a little higher than for natural gas, although for gasoline the carbon charge is a smaller portion (about 10 percent) of the world price.

Again, the local pollution component is usually smaller than the carbon charge, and mainly for the same reason—gasoline produces only very small amounts of the most damaging pollutants, sulfur dioxide and (direct) fine particulates. Carbon and local pollution point to corrective gasoline taxes of, at most, 20 cents/liter for the illustrated countries.

But much heavier taxation of gasoline is warranted by other factors, and heavier taxes than currently imposed in most cases, due to the combination of traffic congestion and traffic accidents. The former tends to be a largest component of the corrective tax in developed countries (in part due to higher values from lost time) and often the latter in developing countries (where, for example, pedestrians are more prone to injury risk). These additional costs raise corrective gasoline taxes in Figure 2.7 to between 40 and 60 cents/liter in Australia, Brazil, Chile, China, Germany, Israel, Kazakhstan, Poland, Thailand, and the United States and about 80 cents/liter or more in (or 100 percent of the pre-tax world price) in India, Japan, South Africa, South Korea, and Turkey. The corrective tax estimates exceed current taxes for 15 of the countries in Figure 2.7, and fall short of them in five cases.[38]

Figure 2.8. Corrective Gasoline Tax Estimates, All Countries, 2010



Sources: See Chapter 3 of the supplement.

Figure 2.8 underscores the heavy taxation of gasoline warranted worldwide. For the majority of countries (for which data are available), corrective taxes are at least 40 cents/liter (50 percent of the pre-tax world price) and frequently much higher. Broadly speaking, the

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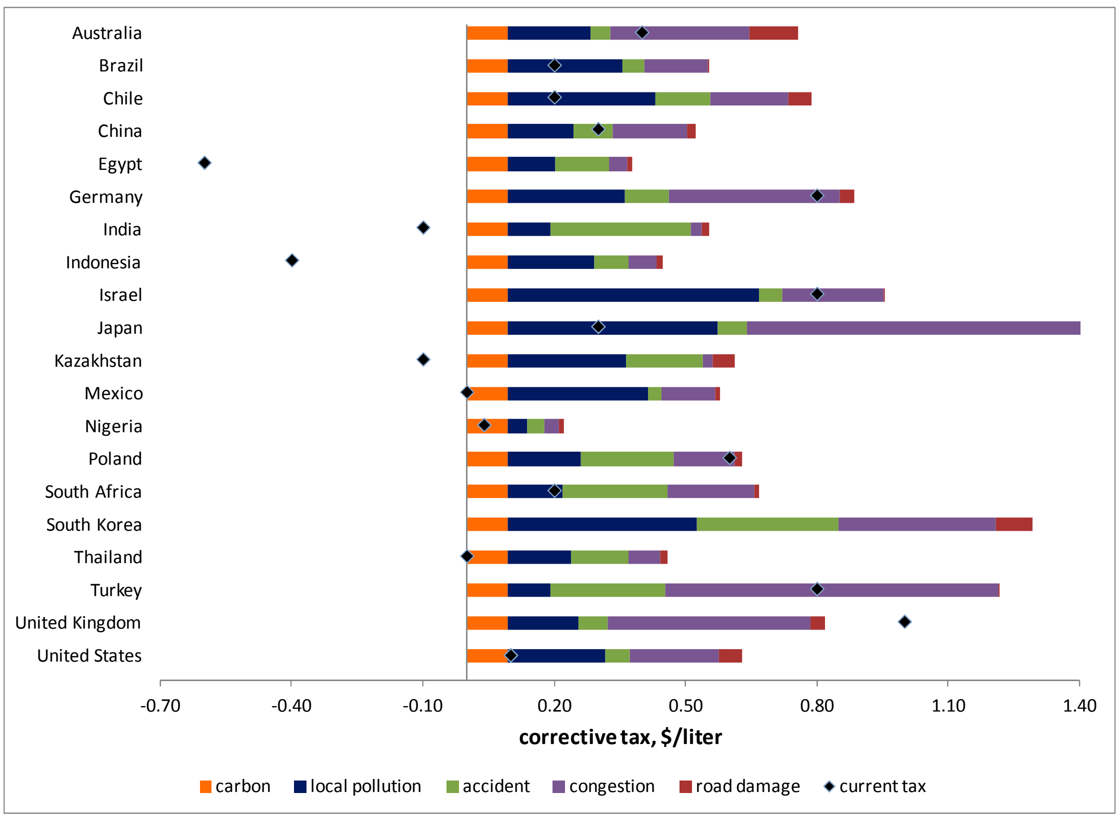
[38] Even in these cases (e.g., Germany, United Kingdom) reductions in gasoline taxes may not be efficient in practice as there are a variety of reasons (discussed in Chapter 3 of the supplement and its Appendix) why the corrective taxes may be understated.

rates of gasoline tax currently applying in most OECD countries, around 40 cents to $1/liter, appear to be in the right ballpark for countries worldwide (at least until distance-based charging becomes widespread).

Turning to diesel fuel, the corrective (excise) tax estimates for selected countries (averaging over diesel use by cars and trucks) in Figure 2.9 follow a broadly similar pattern to those for gasoline taxes in Figure 2.7. Most estimates are between about 40 to 80 cents per liter, though corrective taxes for Japan, South Korea, and Turkey are much higher. For 15 countries, corrective diesel fuel taxes are somewhat higher than corrective gasoline taxes, suggesting that, if anything, diesel should be taxed more heavily than gasoline. In contrast, many governments tax diesel at a lower rate than gasoline (10 of the countries shown in Figure 2.9 and 28 out of 34 OECD countries shown in Figure 1.14 from Chapter 1 of the supplement). Corrective taxes exceed current taxes in all but one case (United Kingdom) in Figure 2.9.

Figure 2.9. Corrective Diesel Tax Estimates, Selected Countries, 2010



Sources: See Chapter 3 of the supplement.
Notes. To express taxes in $ per gallon multiply by 3.8. Data on South Korea's diesel tax were not available from the sources used here.

The generally higher corrective taxes for diesel fuel (compared with gasoline) reflect its higher emission rates (both for carbon and, especially, local pollution), that most diesel is used by trucks which add more to congestion per vehicle km than cars, and also that trucks cause more road damage. However, road damage is relatively modest—less than the local pollution component in all cases. And a partially offsetting factor is that trucks have much lower fuel efficiency than cars. This means that a liter reduction in diesel fuel consumption results in a much smaller reduction in vehicle km driven (implying smaller congestion and accident benefits) compared with a liter reduction in car km driven.

In fact, if it were administratively feasible to do so, in principle a case could be made for taxing diesel fuel used by cars at higher rate than that for trucks—the corrective tax for car diesel is higher than for truck diesel (these results are not shown in the figures), though the differences tend to be fairly modest.

B. Impacts

The above findings provide a useful marker for policymakers interested in heading towards the efficient system of fuel taxes needed to balance environmental and economic concerns. But obviously the fiscal, health, and environmental impacts of tax reforms are of great interest in themselves—most importantly for helping policymakers to prioritize among different reform options. These impacts will vary considerably across countries depending, for example, on their prevailing fuel mix and fiscal (and other) policies currently affecting their energy and transportation systems.[39]

Tax reform options are here compared based on 'back-of-the-envelope' calculations described in the Appendix. This involves estimating the change in fuel prices that would result from implementing corrective taxes (relative to current taxes, which are often zero, and sometimes negative, and assuming full pass through into consumer prices), using the dataset complied by Clements and others (2013) that estimates fuel prices (with and without current taxes) by product and country. The price changes are combined with an assumption (based loosely on the limited evidence available) that each one percent increase in a fuel price eventually reduces use of that fuel by half of a percent (through, for example, adoption of fuel-saving technologies and reduced use of energy-consuming products). The fiscal, health, and CO_2 impacts of these fuel and tax changes are then inferred. Additionally for coal, it is assumed—based on a comparison indicating the fiscal incentives provided by corrective taxes for adopting emission control technologies are large relative to the costs of technology adoption—that implementing the corrective tax with appropriate crediting for mitigation during fuel combustion would lead to the adoption of such control technologies at all coal plants (remaining operational).

[39] For example just because, for a particular fuel, there might be a wide gap between the current and corrective tax, this does not necessarily mean the fiscal and environmental benefits from reforming this fuel tax are larger than for other reform options, as these benefits also depend on fuel usage.

These calculations leave aside a wide range of country-specific details (e.g., factors that might affect the price responsiveness of carbon-intensive fuels and the environmental/fiscal implications of switching between coal and natural gas), but they are still useful in giving an, albeit very rudimentary, sense of potential effects. Fiscal impacts are, however, overstated to the extent that compensation schemes (e.g., for low-income households) need to accompany tax reform.[40]

(i) Fiscal Impacts

Despite the (large) uncertainties surrounding these projections, there is clearly a potentially large fiscal dividend from reforming fuel taxes, which is the flip side of large environmental damages. The estimated dividend in Figure 2.10 is more than 2 percent of GDP in 12 countries, more than 4 percent in 7 countries, and about 10 percent in China (which has a coal intensive energy sector).[41] And even in Germany and the United Kingdom, where motor fuel taxes are relatively high, implementing corrective taxes on coal and natural gas raise estimated revenues of close to 1 percent of GDP. At a global level, revenue gains amount to about 3 percent of world GDP.[42] These calculations do not take into account changes in VAT (or similar) taxes paid at the household level, though this additional revenue is relatively minor.

The composition of potential revenue also differs markedly across countries. For example, coal is by far the dominant source of potential revenue in China, Germany, India, Israel, Kazakhstan, Poland, South Africa, and Turkey, while higher motor fuel taxes are the dominant source of potential revenue in Brazil, Chile, Egypt, Indonesia, Japan, Mexico, Nigeria, and the United States. Corrective taxes for natural gas also produce significant revenues in some cases (about 0.3 percent or more of GDP in ten of the countries).

As indicated from the earlier graphs, the bulk of the revenue opportunities tend to come from charges that are in countries' own national interests rather than carbon charges.

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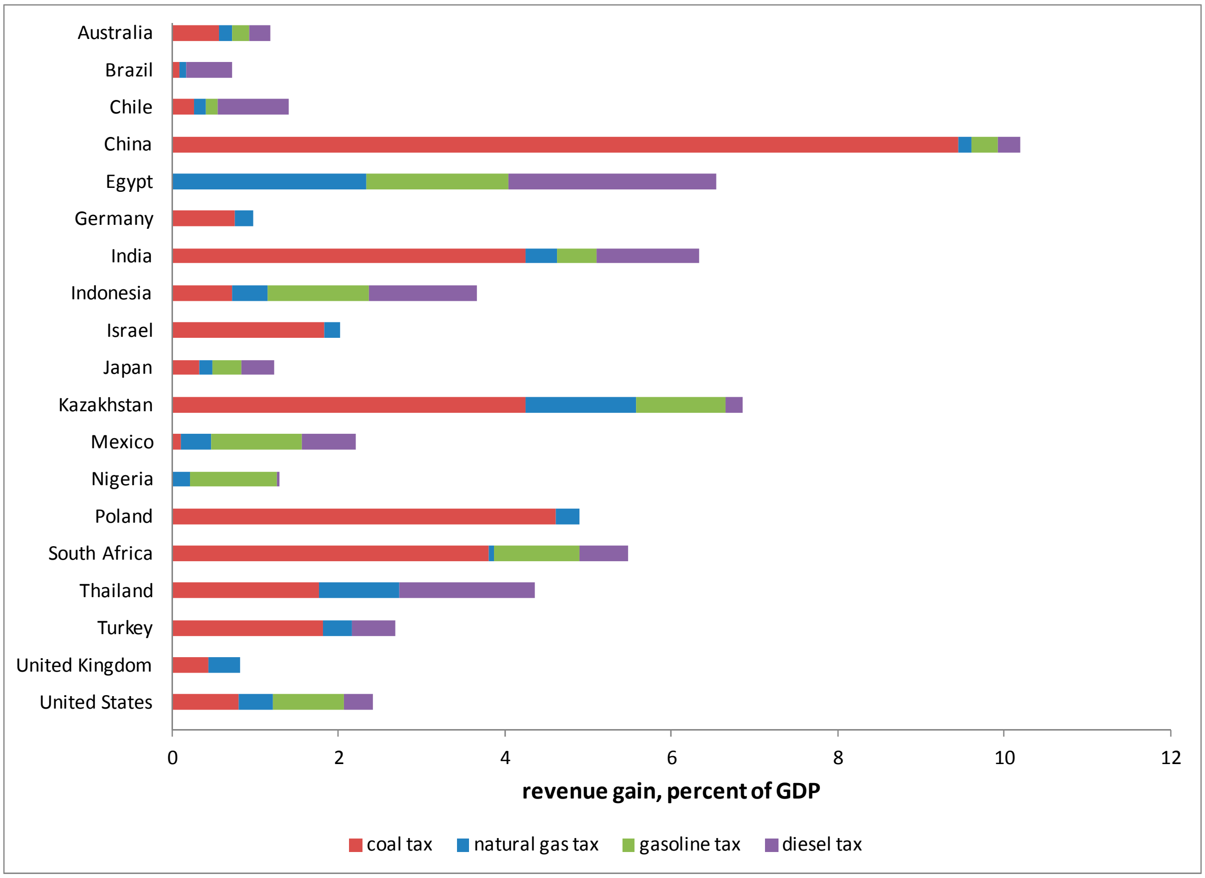
[40] Dinan (2013), for example, estimates that for the United States full compensation for the bottom income quintile for a carbon tax would offset 12 percent of the revenue.

[41] The fiscal dividend from the corrective coal tax in China, 9.5 percent of GDP, is evidently very large, but is based on the following assumptions. The corrective tax for local air pollution, at controlled emission rates, is \$11.7/GJ which, along with the carbon charge of \$3.3/GJ, increases the baseline coal price (\$6.4/GJ) by about 230 percent. In turn, this reduces coal use by 45 percent to about 37,500,000,000 GJ. Multiplying this amount by the corrective tax (\$15/GJ) gives revenue of about \$560 billion, and dividing by 2010 GDP (\$5,930 billion) gives the above figure.

[42] Clements et al. (2013) estimate fossil fuel subsidies worldwide, including the implicit subsidy from the failure to charge for environmental side effects, at almost 3 percent of global GDP. This estimate is based on a cruder assessment of external costs (using a simple extrapolation from several country case studies to the global level) and does not account for the impact of higher fuel prices from policy reform on fuel use.

Figure 2.10. Potential Revenue from Corrective Fuel Taxes, Selected Countries, 2010

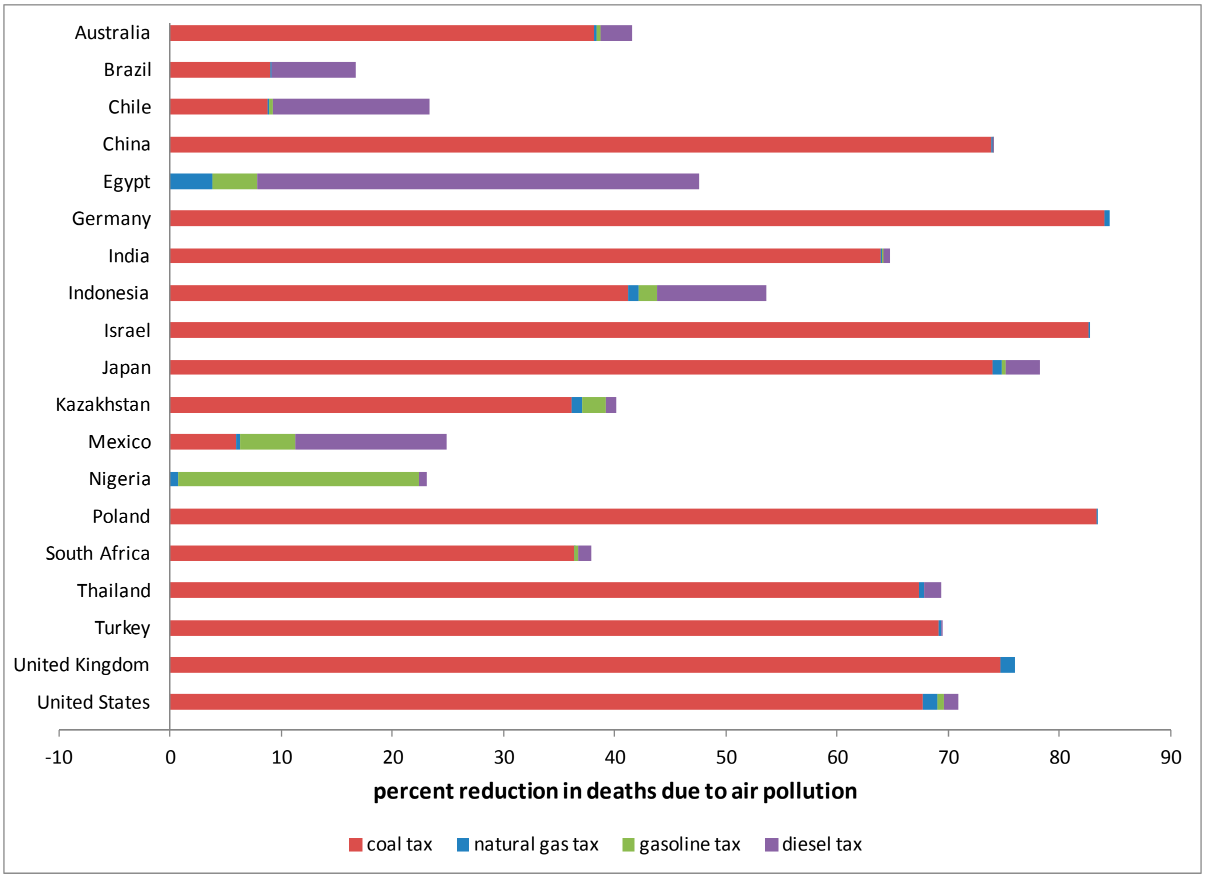


Sources: See Appendix.
Notes: Figure shows (expressed as a percent of GDP) revenue from corrective fuel taxes (allowing for behavioral responses to the tax and changes in VAT receipts) relative to current fuel tax revenues (which are often zero, and negative in cases where fuels are currently subsidized). In the few cases where corrective taxes fall short of current taxes the revenue potential is taken as zero. These figures will overstate the actual net revenue gain to the extent that compensation schemes (e.g., for low-income households) accompany tax reform.

(ii) Health Impacts

Fuel tax reform can also reduce—quite dramatically—premature deaths from local air pollution, especially in countries using a lot of coal. Pollution-related deaths are reduced by about 60 percent or more in ten of the countries shown in Figure 2.11 and, at a global level, tax reform could save about 1.8 million lives (across countries where data permits this calculation). Reductions in emissions from coal combustion (due to adoption of control technologies and reduced use of coal) are by far and away the main source of mortality reductions in almost all cases.

Figure 2.11. Reduction in Pollution-Related Deaths from Corrective Fuel Taxes, Selected Countries, 2010



Sources: See Chapter 2 of the supplement.

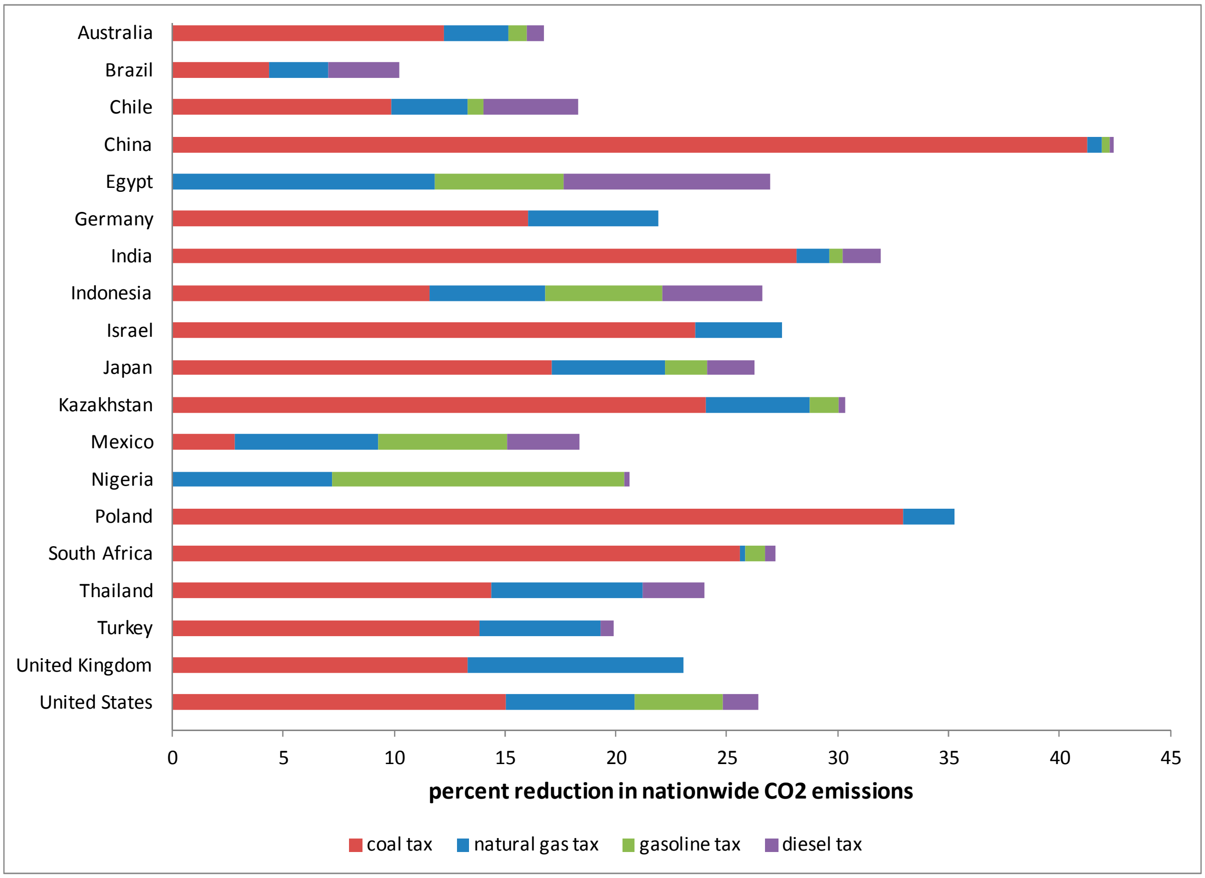
Notes: Figure shows percent reduction in premature deaths attributed to air pollution from increasing current fuel taxes to their corrective levels on all fuels. In the few cases where corrective taxes fall short of current taxes the tax is held fixed (so there are no reductions in deaths).

(iii) Climate Impacts

Figure 2.12 indicates another important benefit of fuel tax reform (distinct from the health benefits of better local air quality)—potentially large reductions in (energy-related) CO_2 emissions, expressed as annual percent reductions in nationwide emissions for year 2010. These reductions exceed 15 percent in all but one case—the greatest emissions reductions are 42 percent in China (these estimated reductions reflect, implicitly, some combination of the main behavioral responses summarized in Figure 2.1 of Chapter 2). At a global level, CO_2 reductions would amount to something in the order of 30 percent.

For all but four countries shown in this figure, coal (due to its high carbon intensity and the especially large increase in coal prices) accounts for more than 50 percent of the calculated total emissions reductions, and more than 85 percent of the reductions in China, India, Israel, Poland, and South Africa. But in most cases there are also significant carbon reductions from implementing corrective taxes on natural gas and motor fuels.

Figure 2.12. Reduction in (Energy-Related) CO_2 Emissions from Corrective Fuel Taxes, Selected Countries, 2010



Sources: See text.
Notes: Figure shows reduction in nationwide energy-related CO_2 emissions (relative to 2010 levels) from increasing current fuel taxes (which are negative in the case of subsidies) to their corrective levels on all fuels. In the few cases where corrective taxes fall short of current taxes the tax is held fixed (so there are no emission reductions).

C. Summary

Tax reforms can yield large fiscal dividends (even in countries with high motor fuel taxes)—3 percent of GDP worldwide; significant reductions in global CO_2 emissions—about 30 percent; and (especially from coal taxes) dramatic reductions in pollution-related deaths—nearly 2 million per year.

Coal use in particular is highly, and pervasively, undercharged, not only for carbon emissions but also—in fact often more importantly—for the health costs of air pollution, though appropriate charges for the latter differ considerably across countries. Heavy taxes on motor fuels are warranted in most developed and developing countries alike, but more to reflect the costs of traffic congestion and accidents rather than carbon emissions and pollution (for countries where motor fuel taxes are already high, the main opportunity for reform is to begin a progressive transition to km-based charges to better manage, in particular, congestion). As for natural gas, although corrective charges are small relative to those from coal (due to limited air pollution benefits), these charges can still generate significant revenue and CO_2 reductions. In short, much of the gains from energy price reform are in countries' own national interests.

CHAPTER 3. CONCLUDING THOUGHTS

Promoting environmentally sustainable growth is an inherent problem faced by all countries. The beauty of fiscal instruments (environmental taxes or tax-like instruments) is that (albeit with some important caveats about base targeting, exploiting fiscal opportunities, and use of complementary instruments) they can achieve the efficient balance between environmental and economic concerns—*if* they are set to reflect environmental damages.

The goal of this volume has been to show how environmental damages can be measured for different countries—focusing on damages related to the use of fossil fuels—and how this information can be used to put into practice the principle of 'getting prices right'.

There are plenty of caveats to this exercise. From an analytical perspective, there are legitimate questions about data reliability and methods used to quantify environmental damages. However, the accuracy of environmental damage assessment has been improving dramatically in recent years, and will continue to do so, not least because of modeling efforts elsewhere.[43] And although legitimate disagreements will remain, for example over appropriate values for carbon emissions and (pollution- and accident-related) premature deaths, spreadsheets accompanying this report can help to discipline this debate by clarifying how alternative assumptions affect the efficient system of energy taxes.

Implementing efficient energy tax systems is highly challenging, not least because of resistance to higher energy prices. But having some sense of where policy should be headed from an economic perspective is very useful. It provides a benchmark against which other (perhaps politically easier) options can be compared, giving policymakers a better sense of the tradeoffs they face, for example in terms of environmental effectiveness and revenue from well-designed tax reforms versus the weaker environmental effectiveness and lack of revenue from regulatory approaches. Moreover, the economically efficient stringency of other, non-fiscal instruments (e.g., standards for energy efficiency and renewables) can be evaluated by comparing the implicit charges on fuel use or emissions they impose with the type of environmental damage estimates laid out here.

In short, our hope is that this report will help countries move forward with policy reforms, as well as promoting further analytical work and data collection needed to improve the accuracy of country-by-country damage assessments, all of which promote more informed policy decisions. The findings here suggest large and pervasive disparities between efficient fuel taxes and current practice in developed and developing countries alike—with much at stake in terms of health, environmental, and fiscal outcomes. The aim here has been to provide the tools and evidence to help put sound energy pricing principles into practice.

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[43] For example, the Intergovernmental Panel on Climate Change on climate impacts and the Global Burden of Disease project, the International Institute for Applied Systems Analysis, and the Climate and Clean Air Coalition on air pollution damages.

Appendix for Chapter 2

This appendix first discusses additional data and assumptions used to estimate the impacts of fuel tax reform. It then summarizes all of the available information related to corrective fuel taxes, their impacts, and current taxes, country by country.

(i) Additional Data and Assumptions Used to Estimate the Impacts of Fuel Tax Reform

Several additional pieces of information are needed to provide first-pass calculations of the impacts of fuel tax reform.

First is fuel prices faced by fuel users (primarily households or power plants) by country, which are taken for year 2010 from an IMF database compiled from multiple sources (see Clements and others, 2013, pp. 143–44).[44] This price data implicitly includes any excise tax (or subsidy) and value added tax (which applies to fuels used by households but not, under normal tax producers, to fuels used by firms).

Second is the baseline quantity of the four fuels used in each country in 2010. Again this is mostly taken from the database in Clements and others (2013), which was compiled from OECD and International Energy Agency (IEA) data. Diesel used by road vehicles was taken directly from IEA data.[45] Fuel use reflects consumption by both households and firms combined—diesel fuel corresponds to that used by motor vehicles and natural gas to that used by power plants and other industrial sources as well as residential uses.[46]

Third the following, commonly used functional form was used to compute changes in fuel demand in response to changes in fuel prices:

(A.1) $$Q_1 = \left(\frac{p_1}{p_2}\right)^{\eta} Q_0$$

Here Q and p denote quantities and prices of a particular fuel respectively, and subscripts 0 and 1 denote initial (current) values and values after adjusting the fuel tax rate to its

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[44] For petroleum products domestic prices to fuel users are taken from publicly available sources for OECD countries and for other countries they were provided by country authorities to the IMF, supplemented by survey data from Ebert and others (2009). Where fuel prices were unavailable they were imputed based on the observed pass-through of international fuel prices for that country. For coal and natural gas, where data is more sparse, Clements and others (2013) infer domestic prices from international prices, making an adjustment for transportation and distribution costs, and subtracting any fuel subsidies which have been quantified (for countries where they are significant) by the OECD and IEA.

[45] See www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances/extended-world-energy-balances_data-00513-en (the 'product' category is gas/diesel oil and the 'flow' category is road).

[46] In principle, given that corrective taxes differ for natural gas depending on whether the emissions are released from smokestacks or at ground level, different natural gas uses should be distinguished and the different corrective taxes applied. However, this will make little difference to the calculations given the relatively small differences in corrective taxes across end users.

corrective level. η denotes the fuel price elasticity, or the percent change in fuel use per one percent increase in fuel price. Changes in fuel taxes are assumed to be fully reflected in the price paid by fuel users.[47]

The calculations here simply assume that η = -0.5 for all fuels in all countries (i.e., each 1 percent increase in fuel price reduces fuel use by 0.5 percent). Numerous studies have estimated gasoline price elasticities for different countries and the value assumed here reflects, roughly speaking, a central value from the literature.[48] This assumption may, on average, overstate the price responsiveness of coal and natural gas somewhat (e.g., US EIA, 2012). If so, in this regard the fiscal impacts of the fuel tax reforms will be (moderately) understated, while the CO_2 and health impacts will be (moderately) overstated. It is difficult to make generalizations however—for example, in countries with a lot of potential for renewables and nuclear, coal and natural gas may have relatively large responsiveness and vice versa in countries with little potential for these fuels. Also notable is that, to keep the calculations manageable, the fuel demand function in (A5.1) is independent of other fuel prices. This will tend to overstate somewhat the impacts of full tax reform on fuel demand where fuels are substitutes (e.g., coal and natural gas in power generation, gasoline and diesel in passenger vehicles). In this regard, there is some understatement of revenue effects and overstatement of CO_2/health effects.

The fourth piece of information is current excise tax (or subsidy) rates. Again these are obtained from the IMF (2013) database which also includes an estimate of fuel supply prices, based on a reference international fuel price (adjusted for transportation and distribution costs) applying to different regions. The excise tax (or subsidy) is the difference between the user price and the producer price, after netting out any applicable value added taxes.

Changes in fuel use are calculated using equation (A5.1), where the difference between the new and initial fuel price is the difference between the corrective tax level and any existing excise tax (which is often zero, and sometimes negative, in which case the price increase exceeds the corrective tax).[49] Revenue from the corrective tax is simply the product of the excise tax and fuel use with this tax (Q_1). And the change in revenue is this amount less the product of the initial tax and initial fuel use (Q_2). The revenue change exceeds revenue from the corrective tax if fuel is initially subsidized.

To calculate health effects it is assumed that the corrective tax would provide incentives for all coal and natural gas plants to adopt emissions control technologies, in which case the

[47] In reality some portion might be passed backwards into lower prices for fuel suppliers depending on the relative slope of fuel demand and supply curves, though this portion appears to be relatively modest (e.g., Bovenberg and Goulder, 2001).

[48] Roughly speaking, this seems to be a plausible central case estimate from the large empirical literature on motor fuel price elasticities (see e.g., various reviews cited in Parry, Walls, and Harrington, 2007 and Sterner, 2007).

[49] The price increase is understated somewhat in the case of coal and natural gas as it ignores additional costs at plants that apply control technologies in response to the corrective tax.

relevant emissions factor is the one for representative plants in each country that already apply such technologies. This seems plausible, based on a quick comparison of the costs of installing and operating emissions control technologies, and the resulting tax credit that would (ideally) be provided if taxes were set at their corrective levels.[50] Mortality reductions are calculated by fuel use at the corrective tax times the weighted sum of SO_2, (direct) $PM_{2.5}$, and NO_x, where the weights are deaths per ton for these emissions, less initial fuel use times the corresponding weighted sum of emissions. For the first product, controlled emission factors are used. For the second, a weighted average of controlled and uncontrolled emissions factors is used.[51]

Finally CO_2 emissions reductions are easily computed based on the tax-induced fuel reductions and the (fixed) carbon emissions factors for the fuels.[52]

(ii) Corrective Estimates, their Impacts, and Current Taxes, by Country

The following tables summarize, country by country, all of the results related to corrective fuel taxes presented in Chapter 2 of the main report. In particular Tables A7, A8, A9, and A10 provide, respectively, the estimated corrective taxes on coal, natural gas, gasoline, and (motor) diesel; the fiscal impacts of tax reform (revenue gains as a percent of GDP); the percent reduction in premature deaths and percent reductions in CO_2 emissions from tax reform; and current excise taxes on fuel products.

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[50] For example (using data supplied by Dallas Burtraw) the capital costs and discounted operating costs over a 10-year period for installing and using an SO_2 scrubber at a 500 mega-watt coal plant in the United States would amount to about $300 million. And assuming the scrubber cuts emissions (that would otherwise be 42,000 tons a year) by 98 percent, the discounted tax savings (assuming a corrective tax of $17,000 per ton of SO_2) amount to about $5,500 million, or over 18 times the technology cost.

[51] Country-level data is not available on the fraction of plants that have control technologies. These fractions were imputed for developed and developing countries such that baseline mortality rates implied by the mortality damage estimates are roughly in line with those in Burnett and others (2013), making an assumption that controls for direct $PM_{2.5}$ are more prevalent than those for SO_2 and NO_x. This led to assumed application rates for control technologies of 40 percent and 60 percent for SO_2 and direct $PM_{2.5}$ in developed countries, and 10 and 20 percent respectively in developing countries. These assumptions are very approximate, but they only affect the calculation of health benefits. For NO_x, there is relatively little difference between controlled and uncontrolled emissions rates, and a simple average is taken.

[52] CO_2 emissions reductions are expressed against a baseline equal to emissions from the four fuels (which is a little less than total energy-related emissions as it excludes emissions from fuel products not considered here, principally petroleum products other than motor fuels).

Table A1. Corrective Fuel Tax Estimates All Countries, $/unit, 2010

Country	sulfur dioxide			nitrogen oxides			(direct) fine particulates		
	$ per ton			$ per ton			$ per ton		
	coal	natural gas	ground level	coal	natural gas	ground level	coal	natural gas	ground level
North America									
Canada	3,908	8,994	13,284	2,757	5,917	2,712	4,887	11,480	349,161
Mexico	2,240	3,599	7,704	1,797	2,179	1,575	2,700	4,416	203,680
United States	17,132	18,978	17,005	12,472	12,092	3,468	21,402	23,294	445,484
Central & South America									
Argentina	8,328	4,928	7,553	3,475	2,375	1,532	10,420	6,167	193,736
Barbados	#na	26,387	#na	#na	12,166	#na	#na	33,014	#na
Bolivia	#na	343	355	#na	237	73	#na	410	9,624
Brazil	2,004	4,293	5,013	1,492	2,401	1,021	2,626	5,258	130,726
Chile	1,409	1,989	7,057	1,029	1,185	1,434	1,730	2,482	182,276
Colombia	1,867	1,648	6,180	1,162	1,084	1,265	2,307	2,047	164,342
Costa Rica	#na	#na	2,316	#na	#na	477	#na	#na	63,036
Cuba	#na	4,447	3,627	#na	3,033	743	#na	5,293	96,420
Dominican Republic	3,007	#na	3,475	1,694	#na	714	3,713	#na	93,597
Ecuador	#na	748	721	#na	454	148	#na	915	19,505
El Salvador	#na	#na	696	#na	#na	143	#na	#na	18,949
Guatemala	882	#na	417	501	#na	87	1,076	#na	11,721
Honduras	#na	#na	936	#na	#na	194	#na	#na	26,190
Jamaica	#na	#na	1,617	#na	#na	336	#na	#na	45,210
Nicaragua	#na	560	265	#na	374	55	#na	665	7,338
Panama	1,560	#na	1,581	1,079	#na	324	2,031	#na	42,080
Paraguay	#na	#na	825	#na	#na	170	#na	#na	22,594
Peru	359	1,415	2,435	290	593	498	447	1,767	64,499
Saint Vincent/Grenadin	#na	#na	#na	#na	#na	#na	#na	#na	#na
Suriname	#na	#na	649	#na	#na	133	#na	#na	17,461
Trinidad and Tobago	#na	2,883	#na	#na	1,977	#na	#na	3,553	#na
Uruguay	#na	3,151	2,184	#na	2,164	443	#na	3,773	55,994
Venezuela	#na	2,027	4,000	#na	1,203	811	#na	2,575	102,381
Europe									
Albania	#na	#na	4,927	#na	#na	1,023	#na	#na	137,666
Austria	41,004	41,889	12,951	31,812	31,666	2,664	51,736	53,150	350,052
Belgium	53,017	51,863	10,883	34,613	34,243	2,201	64,698	63,189	276,234
Bosnia and Herzegovina	#na	#na	5,556	#na	#na	1,157	#na	#na	156,869
Bulgaria	23,980	#na	7,536	19,472	#na	1,545	28,991	#na	201,479
Croatia	35,046	35,676	10,533	28,197	27,410	2,179	44,610	45,720	290,953
Cyprus	#na	#na	2,232	#na	#na	458	#na	#na	59,950
Czech Republic	56,034	55,308	9,670	40,836	41,184	1,982	69,818	68,676	258,025
Denmark	26,136	26,025	6,276	20,048	19,993	1,277	34,589	34,627	162,816
Finland	14,814	16,035	10,786	12,152	12,711	2,198	17,739	19,320	281,719
France	33,555	37,779	15,908	24,511	27,670	3,239	41,725	46,003	414,075
Germany	53,192	56,125	20,082	35,624	36,603	4,115	65,936	69,514	535,454

Table A1. Corrective Fuel Tax Estimates All Countries, $/unit, 2010 (continued)

Country	sulfur dioxide			nitrogen oxides			(direct) fine particulates		
	$ per ton			$ per ton			$ per ton		
	coal	natural gas	ground level	coal	natural gas	ground level	coal	natural gas	ground level
Greece	20,699	20,734	8,028	16,843	16,213	1,657	25,562	25,570	219,970
Hungary	41,057	40,925	11,070	30,712	30,608	2,275	51,744	51,840	298,250
Iceland	#na	#na	3,855	#na	#na	781	#na	#na	98,626
Ireland	12,897	18,828	4,991	10,468	14,585	1,030	16,217	22,833	136,535
Italy	26,627	31,596	13,346	20,905	22,958	2,744	33,654	40,278	360,129
Luxembourg	#na	86,775	#na	#na	65,283	#na	#na	105,443	#na
Macedonia	16,736	17,560	5,832	13,541	14,096	1,206	20,686	21,656	160,515
Malta	#na	#na	#na	#na	#na	#na	#na	#na	#na
Montenegro	21,031	#na	4,205	17,103	#na	867	26,405	#na	114,743
Netherlands	53,065	50,535	13,357	35,421	34,581	2,723	65,304	62,168	349,477
Norway	#na	17,667	35,210	#na	14,920	7,194	#na	23,495	928,330
Poland	38,887	35,828	9,468	28,429	27,749	1,955	49,082	45,043	259,582
Portugal	12,221	12,533	6,383	9,265	9,355	1,318	14,755	15,177	175,156
Romania	26,813	27,895	7,995	21,377	21,041	1,659	33,293	34,439	223,169
Serbia	24,142	24,194	6,728	18,319	18,274	1,393	30,381	30,841	186,463
Slovakia	42,444	46,050	7,275	32,616	33,770	1,508	53,469	58,463	202,158
Slovenia	52,466	52,388	10,936	39,744	39,419	2,273	67,044	66,807	307,217
Spain	16,871	19,270	19,055	13,364	14,498	3,897	20,852	23,980	504,326
Sweden	17,058	19,702	16,370	13,005	15,757	3,333	21,281	25,956	426,238
Switzerland	#na	46,015	11,919	#na	34,809	2,443	#na	57,827	317,909
Turkey	7,341	9,611	5,264	5,746	6,507	1,081	9,146	11,858	141,362
United Kingdom	36,577	40,069	12,325	22,857	27,378	2,518	45,415	48,658	324,687
Eurasia									
Armenia	#na	7,411	3,020	#na	5,584	622	#na	9,156	82,228
Azerbaijan	#na	8,462	3,498	#na	6,417	726	#na	10,520	97,516
Belarus	#na	26,576	15,038	#na	21,381	3,080	#na	33,671	400,285
Estonia	#na	28,605	8,435	#na	22,914	1,733	#na	34,958	226,999
Georgia	#na	6,049	2,762	#na	4,613	573	#na	7,525	77,102
Kazakhstan	2,668	6,107	3,104	2,225	5,306	644	3,184	7,588	86,461
Kyrgyzstan	1,934	#na	654	1,518	#na	137	2,328	#na	19,010
Latvia	23,252	28,935	10,572	19,784	23,459	2,174	29,743	36,413	285,607
Lithuania	#na	34,985	13,522	#na	27,769	2,782	#na	44,700	365,862
Russia	17,562	22,105	32,383	12,508	14,317	6,637	21,525	27,714	863,732
Tajikistan	#na	#na	418	#na	#na	88	#na	#na	12,393
Turkmenistan	#na	5,775	1,632	#na	4,770	340	#na	6,978	46,015
Ukraine	17,851	16,728	6,377	13,593	12,690	1,311	22,086	20,497	171,913
Uzbekistan	3,451	2,797	659	2,552	2,162	138	4,175	3,359	19,116
Middle East									
Bahrain	#na	7,161	2,451	#na	5,303	498	#na	8,563	63,360
Iran	#na	5,066	3,956	#na	3,694	813	#na	6,171	106,587
Iraq	#na	1,171	857	#na	877	176	#na	1,482	23,197

Table A1. Corrective Fuel Tax Estimates All Countries, $/unit, 2010 (continued)

Country	sulfur dioxide			nitrogen oxides			(direct) fine particulates		
	$ per ton			$ per ton			$ per ton		
	coal	natural gas	ground level	coal	natural gas	ground level	coal	natural gas	ground level
Israel	24,369	24,926	11,652	15,717	15,759	2,364	29,482	30,226	299,185
Jordan	#na	2,429	1,113	#na	1,643	227	#na	2,975	29,144
Kuwait	#na	#na	9,771	#na	#na	1,976	#na	#na	247,625
Lebanon	#na	7,253	2,080	#na	4,753	423	#na	9,202	53,922
Oman	#na	7,088	3,095	#na	6,022	634	#na	8,028	82,631
Qatar	#na	16,731	7,246	#na	13,738	1,465	#na	19,600	183,468
Saudi Arabia	#na	4,895	4,651	#na	3,641	949	#na	6,018	121,849
Syria	#na	2,829	1,404	#na	1,864	291	#na	3,612	38,929
United Arab Emirates	#na	6,431	3,019	#na	4,845	615	#na	7,578	78,782
Africa									
Algeria	#na	3,442	1,834	#na	2,381	376	#na	4,242	49,099
Angola	#na	465	1,320	#na	312	273	#na	567	36,392
Benin	#na	#na	75	#na	#na	16	#na	#na	2,122
Botswana	1,007	656	680	798	556	140	1,238	879	18,629
Burkina Faso	#na	#na	68	#na	#na	14	#na	#na	2,027
Burundi	#na	#na	16	#na	#na	3	#na	#na	494
Cameroon	#na	312	419	#na	254	87	#na	391	11,732
Cape Verde	#na	#na	#na	#na	#na	#na	#na	#na	#na
Central African Republic	#na	#na	130	#na	#na	27	#na	#na	3,745
Comoros	#na	#na	#na	#na	#na	#na	#na	#na	#na
Congo (Brazzaville)	#na	66	87	#na	52	18	#na	77	2,378
Cote dIvoire (IvoryCoast	#na	312	289	#na	197	60	#na	391	8,096
Egypt	#na	5,288	1,912	#na	2,764	399	#na	6,460	54,506
Ethiopia	#na	#na	70	#na	#na	15	#na	#na	2,114
Gambia, The	#na	#na	73	#na	#na	15	#na	#na	2,017
Ghana	#na	270	117	#na	197	24	#na	344	3,273
Guinea-Bissau	#na	#na	81	#na	#na	17	#na	#na	2,315
Kenya	#na	234	90	#na	173	19	#na	289	2,683
Liberia	#na	#na	171	#na	#na	35	#na	#na	4,814
Libya	#na	2,470	1,296	#na	1,942	265	#na	2,952	34,272
Madagascar	#na	#na	81	#na	#na	17	#na	#na	2,371
Malawi	#na	148	38	#na	91	8	#na	#na	1,164
Mali	#na	#na	56	#na	#na	12	#N/A	#na	1,621
Mauritius	438	#na	#na	206	#na	#na	545	#na	#na
Morocco	1,540	1,762	1,563	930	1,085	324	1,901	2,167	43,251
Mozambique	#na	#na	44	#na	#na	9	#na	#na	1,303
Namibia	202	#na	281	167	#na	59	233	#na	8,111
Niger	#na	#na	28	#na	#na	6	#na	#na	844
Nigeria	#na	714	535	#na	425	111	#na	887	15,051
Rwanda	#na	#na	51	#na	#na	11	#na	#na	1,545

Table A1. Corrective Fuel Tax Estimates All Countries, $/unit, 2010 (concluded)

Country	sulfur dioxide			nitrogen oxides			(direct) fine particulates		
	$ per ton			$ per ton			$ per ton		
	coal	natural gas	ground level	coal	natural gas	ground level	coal	natural gas	ground level
Sao Tome and Principe	#na	#na	#na	#na	#na	#na	#na	#na	#na
Senegal	134	#na	112	71	#na	23	164	#na	3,188
Seychelles	#na	#na	#na	#na	#na	#na	#na	#na	#na
Sierra Leone	#na	#na	68	#na	#na	14	#na	#na	1,959
South Africa	1,602	2,550	1,690	1,031	1,219	349	1,905	3,154	46,284
Sudan and South Suda	#na	207	100	#na	171	21	#na	239	2,934
Swaziland	#na	#na	#na	#na	#na	#na	#na	#na	#na
Tanzania	#na	175	116	#na	115	24	#na	221	3,429
Togo	#na	272	44	#na	187	9	#na	345	1,261
Tunisia	#na	3,925	1,834	#na	2,952	378	#na	4,758	49,730
Uganda	#na	#na	44	#na	#na	9	#na	#na	1,340
Zambia	#na	#na	84	#na	#na	18	#na	#na	2,430
Zimbabwe	51	#na	50	41	#na	10	65	#na	1,435
Asia & Oceania									
Afghanistan	#na	866	186	#na	642	39	#na	1,077	5,545
Australia	2,098	2,136	9,220	1,129	900	1,873	2,632	2,698	238,099
Bangladesh	6,057	6,131	1,757	4,082	3,757	371	7,181	7,430	51,932
Bhutan	#na	#na	#na	#na	#na	#na	#na	#na	#na
Brunei	#na	10,797	#na	#na	9,274	#na	#na	12,225	#na
Cambodia	#na	#na	486	#na	#na	103	#na	#na	14,655
China	22,045	25,577	4,422	15,530	16,605	920	27,609	32,238	124,441
Fiji	#na	#na	#na	#na	#na	#na	#na	#na	#na
Hong Kong	82,580	72,288	#na	53,207	49,085	#na	103,759	91,246	#na
India	7,833	6,837	1,093	5,683	4,762	230	9,773	8,549	32,075
Indonesia	4,617	5,627	2,159	2,492	2,699	449	5,636	6,936	60,669
Japan	36,786	47,176	31,548	24,230	24,772	6,405	44,381	57,309	812,178
Kiribati	#na	#na	#na	#na	#na	#na	#na	#na	#na
Korea, South	35,228	34,688	20,862	25,439	25,375	4,253	46,054	45,507	545,623
Malaysia	6,525	6,104	4,028	4,360	4,273	826	7,891	7,406	107,824
Maldives	#na	#na	#na	#na	#na	#na	#na	#na	#na
Mongolia	3,138	#na	2,253	2,736	#na	463	3,498	#na	60,870
New Zealand	1,568	1,296	2,508	479	396	510	1,981	1,637	65,153
Pakistan	2,254	2,902	630	1,698	2,075	132	2,942	3,663	18,290
Papua New Guinea	#na	#na	91	#na	#na	19	#na	#na	2,777
Philippines	3,372	4,426	1,393	1,969	2,246	290	4,053	5,377	39,237
Samoa	#na	#na	#na	#na	#na	#na	#na	#na	#na
Singapore	#na	21,698	42,652	#na	13,439	8,617	#na	27,223	1,077,044
Sri Lanka	4,262	#na	410	3,258	#na	87	5,068	#na	12,500
Taiwan	46,892	49,692	#na	35,615	36,445	#na	59,253	63,012	#na
Thailand	9,036	9,067	2,013	6,941	6,087	423	10,886	11,105	58,683
Vietnam	5,823	3,274	1,416	4,060	2,028	298	7,243	3,989	41,622

Sources: See Chapter 3.
Notes: The table shows estimates of corrective taxes for coal and natural gas, reflecting combined damages from carbon and local pollution emissions, and motor fuels, reflecting combined damages from carbon and local pollution emissions, congestion, accidents, and, for diesel, road damage (from trucks). For coal and natural gas used in power plants, taxes are shown for representative plants with and without emissions controls (in the latter case, the tax is net of the appropriate rebate for the emissions reductions). Corrective motor fuel taxes are not reported when two or more components of the corrective tax cannot be estimated. The color coding for #N/A is as follows: red and black indicate respectively cases where data is not available and the fuel is not used.

Table A2. Fiscal Impacts of Tax Reform, All Countries, percent of GDP, 2010

Country	coal tax		natural gas tax		gasoline tax		diesel tax	
	revenue from		revenue from		revenue from		revenue from	
	corrective tax	tax change	corrective tax	tax change	corrective tax	tax change	corrective tax	tax change
North America								
Canada	0.2	0.2	0.4	0.4	1.4	0.5	0.7	0.3
Mexico	0.1	0.1	0.4	0.4	1.2	1.1	0.7	0.7
United States	0.8	0.8	0.4	0.4	1.3	0.9	0.5	0.3
Central & South America								
Argentina	0.1	0.1	0.8	1.3	#na	#na	#na	#na
Barbados	#na	#na	0.0	0.0	#na	#na	#na	#na
Bolivia	#na	#na	0.9	0.9	1.4	1.3	1.5	2.6
Brazil	0.1	0.1	0.1	0.1	0.9	0.0	0.8	0.5
Chile	0.3	0.3	0.1	0.1	1.0	0.1	1.2	0.9
Colombia	0.2	0.2	0.2	0.2	1.0	0.1	1.0	0.7
Costa Rica	#na	#na	#na	#na	1.2	0.6	1.1	1.0
Cuba	#na	#na	#na	#na	#na	#na	#na	#na
Dominican Republic	0.2	0.2	#na	#na	1.7	1.0	0.8	0.7
Ecuador	#na	#na	0.1	0.1	1.0	2.7	0.5	2.1
El Salvador	#na	#na	#na	#na	1.2	1.2	0.8	0.9
Guatemala	0.1	0.1	#na	#na	#na	#na	#na	#na
Honduras	#na	#na	#na	#na	1.5	1.0	#na	#na
Jamaica	#na	#na	#na	#na	1.5	1.2	1.4	1.2
Nicaragua	#na	#na	0.0	0.0	1.2	0.7	#na	#na
Panama	0.0	0.0	#na	#na	1.1	1.3	1.0	1.4
Paraguay	#na	#na	#na	#na	1.3	0.5	2.6	2.2
Peru	0.1	0.1	0.3	0.3	0.6	0.1	1.3	0.9
Saint Vincent/Grenadin	#na	#na	#na	#na	#na	#na	#na	#na
Suriname	#na	#na	#na	#na	#na	0.0	#na	0.9
Trinidad and Tobago	#na	#na	7.1	7.1	#na	#na	#na	#N/A
Uruguay	#na	#na	0.0	0.0	0.9	0.1	1.0	0.2
Venezuela	#na	#na	0.5	0.8	0.3	2.8	0.1	0.7
Europe								
Albania	#na	#na	#na	#na	0.7	0.0	3.3	0.8
Austria	0.2	0.2	0.2	0.2	0.4	0.0	1.3	0.3
Belgium	0.3	0.3	0.4	0.4	0.3	0.0	1.5	0.4
Bosnia and Herzegovina	#na	#na	#na	#na	0.8	0.0	2.9	0.5
Bulgaria	14.7	14.7	#na	#na	0.9	0.0	2.3	0.4
Croatia	0.7	0.7	0.6	0.6	0.8	0.0	1.6	0.2
Cyprus	#na	#na	#na	#na	1.0	0.0	0.9	0.0
Czech Republic	4.1	4.1	0.4	0.4	0.7	0.0	1.5	0.1
Denmark	0.2	0.2	0.1	0.1	0.8	0.3	1.2	0.5
Finland	0.4	0.4	0.1	0.1	0.7	0.0	1.0	0.3
France	0.1	0.1	0.2	0.2	0.3	0.0	1.4	0.4
Germany	0.6	0.7	0.2	0.2	0.5	0.0	0.9	0.1

Table A2. Fiscal Impacts of Tax Reform, All Countries, percent of GDP, 2010 (continued)

Country	coal tax		natural gas tax		gasoline tax		diesel tax	
	revenue from		revenue from		revenue from		revenue from	
	corrective tax	tax change	corrective tax	tax change	corrective tax	tax change	corrective tax	tax change
Greece	1.6	1.6	0.1	0.1	1.1	0.0	0.8	0.1
Hungary	1.3	1.4	0.9	0.9	0.7	0.0	1.4	0.0
Iceland	#na	#na	#na	#na	0.9	0.0	0.8	0.0
Ireland	0.1	0.2	0.2	0.2	0.6	0.0	1.0	0.0
Italy	0.1	0.1	0.3	0.3	0.4	0.0	1.0	0.1
Luxembourg	#na	#na	0.3	0.3	0.7	0.2	3.3	1.4
Macedonia	#na	#na	#na	#na	#na	#na	#na	#na
Malta	#na	#na	#na	#na	0.6	0.0	0.9	0.0
Montenegro	#na	#na	#na	#na	#na	#na	#na	#na
Netherlands	0.2	0.2	0.5	0.5	0.5	0.0	0.9	0.2
Norway	#na	#na	0.1	0.1	0.4	0.0	0.9	0.4
Poland	4.3	4.6	0.3	0.3	0.7	0.0	1.6	0.2
Portugal	0.1	0.1	0.2	0.2	0.5	0.0	1.5	0.1
Romania	3.8	3.8	0.8	0.8	0.7	0.0	1.4	0.2
Serbia	15.6	15.6	0.6	0.6	0.8	0.0	1.9	0.3
Slovakia	#na	#na	#na	#na	#na	#na	#na	#na
Slovenia	1.4	1.5	0.2	0.2	0.7	0.0	1.6	0.0
Spain	0.2	0.2	0.2	0.2	0.4	0.0	1.7	0.6
Sweden	0.1	0.1	0.0	0.0	0.7	0.0	0.9	0.1
Switzerland	#na	#na	0.1	0.1	0.7	0.2	0.6	0.2
Turkey	1.7	1.8	0.3	0.3	0.4	0.0	1.6	0.5
United Kingdom	0.4	0.4	0.4	0.4	0.6	0.0	1.0	0.0
Eurasia								
Armenia	#na	#na	1.1	1.1	0.8	0.2	0.3	0.2
Azerbaijan	#na	#na	1.3	1.8	1.2	1.0	0.5	0.6
Belarus	#na	#na	4.1	4.1	1.2	0.3	2.5	2.1
Estonia	#na	#na	0.3	0.3	0.6	0.0	1.5	0.0
Georgia	#na	#na	0.7	0.7	1.7	0.7	1.3	0.9
Kazakhstan	4.0	4.2	1.2	1.3	1.4	1.1	0.2	0.2
Kyrgyzstan	#na	#na	#na	#na	#na	#na	#na	#na
Latvia	0.1	0.1	0.7	0.7	0.8	0.0	2.9	1.0
Lithuania	#na	#na	0.6	0.6	0.7	0.0	2.7	1.2
Russia	2.7	2.7	3.0	3.9	2.1	2.0	1.2	1.2
Tajikistan	#na	#na	#na	#na	1.0	0.8	#na	#na
Turkmenistan	#na	#na	6.1	20.5	#na	#na	#na	#na
Ukraine	15.4	15.4	4.6	7.9	1.5	0.9	0.9	0.9
Uzbekistan	0.6	0.6	7.1	28.7	#na	#na	#na	#na
Middle East								
Bahrain	#na	#na	2.9	2.9	0.8	1.8	0.5	1.5
Iran	#na	#na	2.2	8.0	1.4	3.0	0.3	3.1
Iraq	#na	#na	0.2	0.4	#na	#na	#na	#na

Table A2. Fiscal Impacts of Tax Reform, All Countries, percent of GDP, 2010 (continued)

Country	coal tax		natural gas tax		gasoline tax		diesel tax	
	revenue from		revenue from		revenue from		revenue from	
	corrective tax	tax change	corrective tax	tax change	corrective tax	tax change	corrective tax	tax change
Israel	1.8	1.8	0.2	0.2	0.9	0.0	0.7	0.1
Jordan	#na	#na	0.6	0.6	1.6	1.0	0.7	1.2
Kuwait	#na	#na	#na	#na	0.9	1.6	0.5	1.0
Lebanon	#na	#na	0.0	0.0	#na	#na	#na	#na
Oman	#na	#na	1.8	4.0	1.3	2.0	0.1	0.2
Qatar	#na	#na	2.0	3.5	#na	#na	#na	#na
Saudi Arabia	#na	#na	0.9	0.9	1.0	2.3	0.5	2.3
Syria	#na	#na	0.9	0.9	2.4	1.6	1.5	3.1
United Arab Emirates	#na	#na	1.4	4.8	#na	#na	#na	#na
Africa								
Algeria	#na	#na	1.0	6.2	#na	#na	#na	#na
Angola	#na	#na	0.0	0.0	#na	#na	#na	#na
Benin	#na	#na	#na	#na	2.1	0.2	1.3	0.4
Botswana	0.5	0.5	0.0	0.0	1.5	1.3	0.8	0.7
Burkina Faso	#na	#na	#na	#na	0.3	0.0	0.6	0.0
Burundi	#na	#na	#na	#na	0.3	0.0	0.7	0.0
Cameroon	#na	#na	0.1	0.1	0.3	0.0	0.5	0.1
Cape Verde	#na	#na	#na	#na	1.7	0.2	1.9	0.7
Central African Republic	#na	#na	#na	#na	1.7	0.4	2.4	0.0
Comoros	#na	#na	#na	#na	#na	#na	#na	#na
Congo (Brazzaville)	#na	#na	#na	#na	#na	#na	#na	#na
Cote dIvoire (IvoryCoast	#na	#na	#na	#na	#na	#na	#na	#na
Egypt	#na	#na	1.3	2.3	0.7	1.7	0.5	2.5
Ethiopia	#na	#na	#na	#na	0.3	0.1	0.7	0.9
Gambia, The	#na	#na	#na	#na	0.4	0.0	0.7	0.0
Ghana	#na	#na	0.0	0.0	0.8	0.5	0.6	0.7
Guinea-Bissau	#na	#na	#na	#na	1.0	0.2	1.4	0.5
Kenya	#na	#na	0.0	0.0	1.1	0.4	1.0	1.0
Liberia	#na	#na	#na	#na	1.2	1.0	1.7	1.5
Libya	#na	#na	0.6	0.9	#na	#na	#na	#na
Madagascar	#na	#na	#na	#na	0.5	0.0	0.8	0.0
Malawi	#na	#na	#na	#na	1.1	0.0	1.6	0.0
Mali	#na	#na	#na	#na	0.9	0.0	1.2	0.3
Mauritius	0.5	0.5	#na	#na	1.4	0.2	1.2	0.6
Morocco	0.4	0.4	0.0	0.0	0.5	0.1	1.6	1.4
Mozambique	#na	#na	#na	#na	0.9	0.3	1.2	0.6
Namibia	0.1	0.1	#na	#na	#na	#na	#na	#na
Niger	#na	#na	#na	#na	0.5	0.1	0.9	0.0
Nigeria	#na	#na	0.2	0.2	0.6	1.0	0.0	0.0
Rwanda	#na	#na	#na	#na	0.8	0.0	1.4	0.0

Table A2. Fiscal Impacts of Tax Reform, All Countries, percent of GDP, 2010 (concluded)

Country	coal tax revenue from corrective tax	coal tax revenue from tax change	natural gas tax revenue from corrective tax	natural gas tax revenue from tax change	gasoline tax revenue from corrective tax	gasoline tax revenue from tax change	diesel tax revenue from corrective tax	diesel tax revenue from tax change
Sao Tome and Principe	#na	#na	#na	#na	#na	#na	#na	#na
Senegal	0.1	0.1	#na	#na	0.2	0.0	0.9	0.0
Seychelles	#na	#na	#na	#na	#na	#na	1.2	0.0
Sierra Leone	#na	#na	#na	#na	0.4	0.1	0.6	0.6
South Africa	3.8	3.8	0.1	0.1	1.7	1.0	1.0	0.6
Sudan and South Suda	#na	#na	#na	#na	#na	#na	#na	#na
Swaziland	#na	#na	#na	#na	0.9	0.5	1.2	0.6
Tanzania	#na	#na	0.2	0.2	0.7	0.2	1.3	0.2
Togo	#na	#na	0.0	0.0	1.6	0.0	0.7	0.1
Tunisia	#na	#na	0.7	0.7	0.8	0.5	1.6	1.3
Uganda	#na	#na	#na	#na	1.2	0.0	1.5	0.3
Zambia	#na	#na	#na	#na	0.9	0.1	0.9	0.0
Zimbabwe	2.7	2.7	#na	#na	0.7	0.0	0.7	0.1
Asia & Oceania								
Afghanistan	#na	#na	0.1	0.1	0.6	0.1	0.8	0.4
Australia	0.6	0.6	0.1	0.2	0.8	0.2	0.6	0.3
Bangladesh	0.1	0.1	1.2	2.9	0.2	0.1	0.4	0.7
Bhutan	#na	#na	#na	#na	1.4	1.0	1.8	2.3
Brunei	#na	#na	#na	#na	#na	#na	#na	#na
Cambodia	#na	#na	#na	#na	1.2	0.7	1.7	1.5
China	9.5	9.5	0.2	0.2	0.8	0.3	0.6	0.3
Fiji	#na	#na	#na	#na	#na	#na	#na	#na
Hong Kong	#na	#na	#na	#na	#na	#na	#na	#na
India	4.2	4.2	0.3	0.4	0.8	0.5	1.0	1.2
Indonesia	0.7	0.7	0.4	0.4	0.9	1.2	0.5	1.3
Japan	0.3	0.3	0.2	0.2	1.1	0.3	0.6	0.4
Kiribati	#na	#na	#na	#na	#na	#na	#na	#na
Korea, South	#na	#na	#na	#na	#na	#na	#na	#na
Malaysia	0.9	0.9	0.9	1.3	2.0	2.1	1.0	1.3
Maldives	#na	#na	#na	#na	#na	#na	#na	#na
Mongolia	8.9	8.9	#na	#na	2.7	1.3	0.2	0.2
New Zealand	0.1	0.1	0.2	0.2	1.0	0.0	0.6	0.6
Pakistan	0.6	0.6	1.2	3.8	0.5	0.3	1.0	1.4
Papua New Guinea	#na	#na	#na	#na	0.5	#na	#na	#na
Philippines	0.7	0.7	0.1	0.1	0.5	0.2	0.7	0.9
Samoa	#na	#na	#na	#na	0.4	0.1	0.8	0.3
Singapore	#na	#na	0.3	0.3	0.5	0.3	1.2	1.0
Sri Lanka	0.0	0.0	#na	#na	0.9	0.6	1.1	2.0
Taiwan	#na	#na	#na	#na	#na	#na	#na	#na
Thailand	1.6	1.8	0.8	1.0	1.0	0.0	1.6	1.6
Vietnam	2.3	2.3	0.6	0.8	2.4	1.2	2.3	2.0

Sources: See Chapters 3 and 4.
Notes: The table shows estimates of the revenue effect, as a percent of GDP, from imposing corrective taxes on different fuels, one column indicating the revenue from these taxes and the other the change in revenue from implementing the corrective tax compared with any revenue (or revenue losses) from existing taxes (or subsidies). Where current taxes exceed corrective taxes, revenue gains from tax reform are taken to be zero (for reasons discussed in Chapter 4, corrective motor fuel taxes may be understated, so lowering tax rates in these cases may not be warranted).To keep them manageable, the calcuations do not account for the impact of taxes on one fuel affecting revenues from substitute fuels. The color coding for #N/A is as follows: red and black indicate respectively cases where data is not available and the fuel is not used.

Table A3. Health and Environmental Impacts of Tax Reform, All Countries, 2010

Country	percent reduction in pollution deaths from				percent reduction in nationwide (energy-related) CO2 emissions			
	coal tax	natural gas tax	gasoline tax	diesel tax	coal tax	natural gas tax	gasoline tax	diesel tax
North America								
Canada	23.9	1.9	1.5	3.8	5.0	7.5	2.5	1.2
Mexico	5.9	0.4	5.0	13.6	2.8	6.5	5.8	3.3
United States	67.7	1.3	0.6	1.4	15.1	5.8	4.0	1.6
Central & South America								
Argentina	#na	#na	#na	#na	1.3	11.6	#na	#na
Barbados	#na	#na	#na	#na	#na	0.7	#na	#na
Bolivia	#na	1.2	1.5	20.6	#na	7.9	3.3	7.3
Brazil	9.0	0.1	0.0	7.5	4.3	2.7	0.0	3.2
Chile	8.8	0.1	0.4	14.0	9.9	3.4	0.7	4.3
Colombia	4.9	0.3	0.0	14.9	7.0	5.9	0.4	4.3
Costa Rica	#na	#na	1.4	14.2	#na	#na	5.0	8.0
Cuba	#na	#na	#na	#na	#na	1.4	#na	#na
Dominican Republic	12.3	#na	2.8	12.4	8.0	#na	6.5	4.5
Ecuador	#na	0.1	7.9	45.0	#na	1.2	23.6	21.4
El Salvador	#na	#na	3.1	14.1	#na	#na	10.8	7.9
Guatemala	#na	#na	#na	#na	4.3	#na	#na	#na
Honduras	#na	#na	#na	#na	#na	#na	5.0	#na
Jamaica	#na	#na	1.7	9.4	#na	#na	6.0	5.1
Nicaragua	#na	0.0	0.9	#na	#na	0.0	3.3	#na
Panama	2.5	#na	2.8	20.1	2.0	#na	10.1	11.4
Paraguay	#na	#na	0.4	12.7	#na	#na	2.0	9.8
Peru	0.7	0.3	0.3	10.1	2.5	6.5	0.6	4.1
Saint Vincent/Grenadin	#na	#na	#na	#na	#na	#na	#na	#na
Suriname	#na	#na	0.0	4.6	#na	#na	0.1	1.3
Trinidad and Tobago	#na	#na	#na	#na	#na	15.8	#na	#na
Uruguay	#na	0.1	0.0	0.0	#na	0.8	1.5	0.0
Venezuela	#na	1.4	29.3	52.0	#na	8.9	30.5	8.7
Europe								
Albania	#na	#na	0.0	0.0	#na	#na	0.1	0.3
Austria	64.8	1.3	0.0	0.0	8.6	7.3	0.0	0.2
Belgium	58.2	2.2	0.0	0.6	9.0	10.9	0.0	0.9
Bosnia and Herzegovina	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Bulgaria	79.2	#na	0.0	0.0	40.4	#na	0.0	0.0
Croatia	49.7	4.1	0.0	0.0	11.5	12.0	0.0	0.0
Cyprus	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Czech Republic	85.6	0.2	0.0	0.0	29.6	3.6	0.0	0.0
Denmark	74.0	1.2	0.0	1.6	12.0	5.4	1.4	2.9
Finland	55.9	1.0	0.0	0.6	13.0	4.4	0.0	0.5
France	45.2	1.7	0.0	1.8	7.2	7.8	0.0	1.8
Germany	84.1	0.5	0.0	0.0	16.1	5.9	0.0	0.0

Table A3. Health and Environmental Impacts of Tax Reform, All Countries, 2010 (continued)

Country	percent reduction in pollution deaths from				percent reduction in nationwide (energy-related) CO2 emissions			
	coal tax	natural gas tax	gasoline tax	diesel tax	coal tax	natural gas tax	gasoline tax	diesel tax
Greece	64.3	0.1	0.0	0.0	13.1	2.3	0.0	0.0
Hungary	84.8	1.0	0.0	0.0	9.8	12.3	0.0	0.0
Iceland	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Ireland	49.3	1.3	0.0	0.0	5.6	6.8	0.0	0.0
Italy	48.9	2.1	0.0	0.0	5.9	9.8	0.0	0.0
Luxembourg	#na	#na	#na	#na	#na	5.7	0.6	4.4
Macedonia	#na	#na	#na	#na	36.4	0.7	#na	#na
Malta	#na	#na	#na	#na	#na	#na	0.0	0.0
Montenegro	#na	#na	#na	#na	40.6	#na	#na	#na
Netherlands	65.4	3.2	0.0	0.4	7.0	12.7	0.0	0.4
Norway	#na	1.2	0.0	10.1	#na	9.0	0.2	2.8
Poland	83.3	0.2	0.0	0.0	32.9	2.3	0.0	0.0
Portugal	33.9	0.9	0.0	0.0	6.4	5.2	0.0	0.0
Romania	76.4	0.8	0.0	0.0	19.2	9.5	0.0	0.0
Serbia	66.0	0.2	0.0	0.0	42.1	2.6	0.0	0.0
Slovakia	87.9	0.5	#na	#na	17.4	7.9	#na	#na
Slovenia	90.1	0.2	0.0	0.0	16.5	3.8	0.0	0.0
Spain	42.0	0.7	0.0	3.4	6.2	6.9	0.1	2.9
Sweden	44.3	0.3	0.0	0.0	6.5	1.8	0.0	0.0
Switzerland	#na	6.5	0.4	4.3	#na	4.0	1.9	1.2
Turkey	69.1	0.2	0.0	0.2	13.8	5.4	0.1	0.6
United Kingdom	74.7	1.3	0.0	0.0	13.3	9.7	0.0	0.0
Eurasia								
Armenia	#na	#na	#na	#na	#na	5.1	0.2	0.1
Azerbaijan	#na	6.4	9.6	11.1	#na	11.7	3.1	1.8
Belarus	#na	13.2	0.2	14.0	#na	21.9	0.4	2.9
Estonia	#na	1.6	0.0	0.0	#na	1.3	0.0	0.0
Georgia	#na	1.6	2.9	5.8	#na	8.8	2.2	2.1
Kazakhstan	36.1	1.0	2.1	0.9	24.1	4.7	1.3	0.3
Kyrgyzstan	#na	#na	#na	#na	8.3	#na	#na	#na
Latvia	21.9	3.3	0.0	0.0	2.7	12.1	0.0	2.3
Lithuania	#na	2.4	0.0	10.5	#na	11.5	0.0	3.4
Russia	47.3	3.3	4.7	7.3	13.3	15.0	2.9	1.5
Tajikistan	#na	#na	#na	#na	#na	#na	2.8	#na
Turkmenistan	#na	#na	#na	#na	#na	15.4	#na	#na
Ukraine	63.5	1.5	0.0	0.2	28.4	10.7	0.5	0.5
Uzbekistan	#na	#na	#na	#na	1.1	14.8	#na	#na
Middle East								
Bahrain	#na	9.6	3.9	20.5	#na	14.7	4.4	3.9
Iran	#na	3.1	7.0	61.8	#na	12.0	8.4	12.3
Iraq	#na	#na	#na	#na	#na	3.8	#na	#na

Table A3. Health and Environmental Impacts of Tax Reform, All Countries, 2010 (continued)

Country	percent reduction in pollution deaths from				percent reduction in nationwide (energy-related) CO2 emissions			
	coal tax	natural gas tax	gasoline tax	diesel tax	coal tax	natural gas tax	gasoline tax	diesel tax
Israel	82.6	0.1	0.0	0.0	23.6	3.9	0.0	0.0
Jordan	#na	2.4	2.0	14.1	#na	8.0	3.5	4.0
Kuwait	#na	#na	14.1	49.0	#na	#na	11.5	6.8
Lebanon	#na	#na	#na	#na	#na	1.3	#na	#na
Oman	#na	12.3	9.1	4.6	#na	14.8	7.2	0.6
Qatar	#na	#na	#na	#na	#na	17.8	#na	#na
Saudi Arabia	#na	1.7	8.6	57.4	#na	10.0	13.1	14.7
Syria	#na	2.3	2.0	33.7	#na	9.6	3.6	10.0
United Arab Emirates	#na	#na	#na	#na	#na	13.9	#na	#na
Africa								
Algeria	#na	#na	#na	#na	#na	10.4	#na	#na
Angola	#na	#na	#na	#na	#na	2.4	#na	#na
Benin	#na	#na	0.0	0.0	#na	#na	0.6	0.0
Botswana	18.7	0.0	3.8	4.0	14.3	0.0	5.0	2.5
Burkina Faso	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Burundi	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Cameroon	#na	0.1	0.0	0.0	#na	2.9	0.0	0.0
Cape Verde	#na	#na	#na	#na	#na	#na	0.6	1.2
Central African Republic	#na	#na	1.0	0.0	#na	#na	1.9	0.0
Comoros	#na	#na	#na	#na	#na	#na	#na	#na
Congo (Brazzaville)	#na	#na	#na	#na	#na	4.5	#na	#na
Cote dIvoire (IvoryCoast	#na	1.3	#na	#na	#na	7.4	#na	#na
Egypt	#na	3.8	4.0	39.8	#na	11.8	5.8	9.3
Ethiopia	#na	#na	0.9	11.6	#na	#na	1.7	10.5
Gambia, The	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Ghana	#na	0.0	3.1	6.7	#na	0.0	4.9	5.0
Guinea-Bissau	#na	#na	0.0	0.0	#na	#na	0.3	0.2
Kenya	#na	0.0	1.5	8.6	#na	0.0	2.3	6.3
Liberia	#na	#na	3.5	9.7	#na	#na	2.6	3.5
Libya	#na	#na	#na	#na	#na	8.3	#na	#na
Madagascar	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Malawi	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Mali	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Mauritius	#na	#na	#na	#na	9.0	#na	0.4	0.7
Morocco	12.8	0.0	0.4	9.6	13.2	0.9	0.5	6.2
Mozambique	#na	#na	#na	#na	#na	#na	1.5	1.0
Namibia	#na	#na	#na	#na	3.4	#na	#na	#na
Niger	#na	#na	0.0	0.0	#na	#na	0.7	0.0
Nigeria	#na	0.7	21.7	0.8	#na	7.2	13.2	0.2
Rwanda	#na	#na	0.0	0.0	#na	#na	0.0	0.0

Table A3. Health and Environmental Impacts of Tax Reform, All Countries, 2010 (concluded)

Country	percent reduction in pollution deaths from				percent reduction in nationwide (energy-related) CO2 emissions			
	coal tax	natural gas tax	gasoline tax	diesel tax	coal tax	natural gas tax	gasoline tax	diesel tax
Sao Tome and Principe	#na	#na	#na	#na	#na	#na	#na	#na
Senegal	4.5	#na	0.0	0.0	5.4	#na	0.0	0.0
Seychelles	#na	#na	#na	#na	#na	#na	#na	0.0
Sierra Leone	#na	#na	0.0	1.7	#na	#na	0.3	0.5
South Africa	36.3	0.0	0.3	1.2	25.6	0.2	0.9	0.5
Sudan and South Suda	#na	#na	#na	#na	#na	#na	#na	#na
Swaziland	#na	#na	#na	#na	#na	#na	2.2	1.3
Tanzania	#na	0.3	0.7	0.0	#na	4.7	0.9	0.0
Togo	#na	0.0	0.0	0.0	#na	0.0	0.0	0.0
Tunisia	#na	2.0	2.3	10.2	#na	10.4	1.7	3.9
Uganda	#na	#na	0.0	0.0	#na	#na	0.0	0.0
Zambia	#na	#na	0.0	0.0	#na	#na	1.4	0.0
Zimbabwe	27.4	#na	0.0	0.0	19.9	#na	0.0	0.0
Asia & Oceania								
Afghanistan	#na	0.1	0.0	0.0	#na	0.7	0.2	0.0
Australia	38.1	0.2	0.4	2.9	12.3	2.9	0.8	0.7
Bangladesh	16.1	6.3	0.6	9.5	2.1	15.0	0.3	2.2
Bhutan	#na	#na	#na	#na	#na	#na	4.7	12.4
Brunei	#na	#na	#na	#na	#na	20.4	#na	#na
Cambodia	#na	#na	2.6	13.3	#na	#na	2.0	4.5
China	73.9	0.1	0.0	0.0	41.3	0.7	0.3	0.2
Fiji	#na	#na	#na	#na	#na	#na	#na	#na
Hong Kong	#na	#na	#na	#na	14.5	#na	#na	#na
India	63.9	0.1	0.1	0.6	28.1	1.5	0.6	1.7
Indonesia	41.2	0.9	1.6	9.8	11.6	5.2	5.3	4.5
Japan	73.9	0.8	0.4	3.0	17.1	5.1	1.9	2.1
Kiribati	#na	#na	#na	#na	#na	#na	#na	#na
Korea, South	76.8	1.1	0.0	#na	23.3	5.3	0.5	#na
Malaysia	41.8	1.5	2.0	9.7	10.0	7.0	5.1	3.2
Maldives	#na	#na	#na	#na	#na	#na	#na	#na
Mongolia	64.3	#na	0.1	0.1	19.2	#na	0.9	0.1
New Zealand	17.8	0.4	#na	9.9	5.3	5.1	0.0	3.3
Pakistan	43.9	2.6	0.3	2.9	3.2	10.3	0.6	3.1
Papua New Guinea	#na	#na	#na	#na	#na	#na	#na	#na
Philippines	58.5	0.1	0.1	3.1	16.3	1.9	0.6	3.5
Samoa	#na	#na	#na	#na	#na	#na	#na	#na
Singapore	#na	2.3	1.0	36.3	#na	1.6	0.3	1.1
Sri Lanka	6.2	#na	2.4	21.4	#na	#na	2.9	11.8
Taiwan	#na	#na	#na	#na	19.6	3.4	#na	#na
Thailand	67.4	0.5	0.0	1.5	14.4	6.9	0.0	2.8
Vietnam	48.1	0.2	1.0	3.4	15.8	2.9	1.7	2.8

Sources: See Chapters 3 and 4.
Notes: The table shows the percent reduction in countries' nationwide deaths from air pollution and the percent reduction in nationwide CO_2 emissions due to implementing corrective taxes on each of the fuels (ignoring impacts on use of other fuels). The reduction in CO_2 emissions comes from the sorts of behavioral responses summarized in Figure 3.1 while the reduction in premature deaths comes from similar responses and the adoption of emissions control equipment at power plants. In cases where current taxes exceed corrective taxes, potential health and CO_2 reductions from tax reform are indicated by 0. The color coding for #N/A is as follows: red and black indicate respectively cases where data is not available and the fuel is not used.

Table A4. Estimates of Current Fuel Excise Taxes, All Countries, 2010

Country	current excise taxes			
	$ per GJ	$ per GJ	$ per liter	$ per liter
	coal	natural gas	gasoline	diesel
North America				
Canada	0.0	-0.2	0.36	0.42
Mexico	0.0	0.0	0.10	0.10
United States	0.0	-0.1	0.13	0.14
Central & South America				
Argentina	0.0	-1.3	0.33	0.39
Barbados	0.0	0.0	0.42	0.28
Bolivia	0.0	0.0	0.07	-0.12
Brazil	0.0	0.0	0.75	0.28
Chile	0.0	0.0	0.60	0.26
Colombia	0.0	0.0	0.78	0.29
Costa Rica	0.0	0.0	0.31	0.11
Cuba	#na	#na	#na	#na
Dominican Republic	0.0	0.0	0.40	0.17
Ecuador	0.0	0.0	-0.32	-0.45
El Salvador	0.0	0.0	0.09	0.03
Guatemala	0.0	0.0	0.13	0.04
Honduras	0.0	0.0	0.21	0.06
Jamaica	0.0	0.0	0.15	0.12
Nicaragua	0.0	0.0	0.26	0.00
Panama	0.0	0.0	0.02	-0.09
Paraguay	0.0	0.0	0.45	0.15
Peru	0.0	0.0	0.58	0.24
Saint Vincent/Grenadin	#na	#na	#na	#na
Suriname	0.0	0.0	0.31	0.26
Trinidad and Tobago	0.0	0.0	0.00	0.00
Uruguay	0.0	0.0	0.66	0.58
Venezuela	0.0	-1.3	-0.60	-0.65
Europe				
Albania	0.0	0.0	0.63	0.54
Austria	0.0	0.0	0.93	0.78
Belgium	0.0	0.0	1.18	0.83
Bosnia and Herzegovina	0.0	0.0	0.59	0.56
Bulgaria	0.0	0.0	0.71	0.65
Croatia	0.0	0.0	0.86	0.73
Cyprus	#na	0.0	0.69	0.66
Czech Republic	0.0	0.0	0.99	0.89
Denmark	0.0	0.0	1.16	0.87
Finland	0.0	0.0	1.22	0.80
France	0.0	0.0	1.13	0.84
Germany	-1.3	0.0	1.20	0.92

Table A4. Estimates of Current Fuel Excise Taxes, All Countries, 2010 (continued)

Country	current excise taxes			
	$ per GJ	$ per GJ	$ per liter	$ per liter
	coal	natural gas	gasoline	diesel
Greece	-0.1	0.0	1.29	0.89
Hungary	0.0	0.0	0.95	0.82
Iceland	#na	0.0	0.88	0.85
Ireland	-3.3	0.0	1.05	0.90
Italy	0.0	0.0	1.08	0.86
Luxembourg	#na	0.0	0.84	0.60
Macedonia	#na	#na	#na	#na
Malta	#na	0.0	0.87	0.73
Montenegro	#na	#na	#na	#na
Netherlands	0.0	0.0	1.31	0.84
Norway	0.0	-0.2	1.34	1.11
Poland	-0.6	0.0	0.85	0.71
Portugal	-0.1	0.0	1.12	0.77
Romania	0.0	0.0	0.76	0.69
Serbia	0.0	0.0	0.67	0.62
Slovakia	#na	#na	#na	#na
Slovenia	-0.4	0.0	0.96	0.86
Spain	-2.0	0.0	0.85	0.70
Sweden	0.0	0.0	1.19	1.01
Switzerland	#na	0.0	0.87	0.92
Turkey	-0.5	0.0	1.37	0.97
United Kingdom	0.0	-0.1	1.20	1.21
Eurasia				
Armenia	#na	0.0	0.28	0.14
Azerbaijan	#na	-0.9	0.09	-0.05
Belarus	0.0	0.0	0.45	0.20
Estonia	0.0	0.0	0.83	0.79
Georgia	0.0	0.0	0.30	0.23
Kazakhstan	-0.2	-0.2	0.12	-0.08
Kyrgyzstan	#na	#na	#na	#na
Latvia	0.0	0.0	0.76	0.71
Lithuania	0.0	0.0	0.87	0.62
Russia	0.0	-0.9	0.02	0.02
Tajikistan	0.0	0.0	0.13	0.10
Turkmenistan	0.0	-4.4	-0.34	-0.38
Ukraine	0.0	-1.9	0.18	0.06
Uzbekistan	0.0	-5.3	0.17	0.08
Middle East				
Bahrain	0.0	0.0	-0.30	-0.38
Iran	0.0	-4.8	-0.37	-0.55
Iraq	0.0	-1.6	-0.18	-0.23

Table A4. Estimates of Current Fuel Excise Taxes, All Countries, 2010 (continued)

Country	current excise taxes			
	$ per GJ	$ per GJ	$ per liter	$ per liter
	coal	natural gas	gasoline	diesel
Israel	0.0	-0.2	0.93	0.94
Jordan	0.0	0.0	0.14	-0.09
Kuwait	0.0	-1.7	-0.32	-0.38
Lebanon	0.0	0.0	0.36	-0.06
Oman	0.0	-2.2	-0.24	-0.19
Qatar	0.0	-1.6	-0.33	-0.38
Saudi Arabia	0.0	0.0	-0.38	-0.50
Syria	0.0	0.0	0.27	-0.34
United Arab Emirates	0.0	-4.6	-0.20	0.03
Africa				
Algeria	0.0	-8.6	-0.24	-0.39
Angola	0.0	0.0	-0.12	-0.31
Benin	0.0	0.0	0.20	0.22
Botswana	0.0	0.0	0.10	0.11
Burkina Faso	0.0	0.0	0.57	0.38
Burundi	0.0	0.0	0.63	0.60
Cameroon	0.0	0.0	0.37	0.24
Cape Verde	0.0	0.0	0.99	0.44
Central African Republic	0.0	0.0	0.81	0.76
Comoros	0.0	0.0	0.00	0.00
Congo (Brazzaville)	#na	#na	#na	#na
Cote dIvoire (IvoryCoast	#na	#na	#na	#na
Egypt	#na	-1.4	-0.42	-0.57
Ethiopia	0.0	0.0	0.23	0.00
Gambia, The	0.0	0.0	0.56	0.35
Ghana	0.0	0.0	0.11	0.05
Guinea-Bissau	0.0	0.0	0.52	0.29
Kenya	0.0	0.0	0.38	0.07
Liberia	0.0	0.0	0.17	0.14
Libya	0.0	-1.1	-0.41	-0.46
Madagascar	0.0	0.0	0.57	0.31
Malawi	0.0	0.0	0.88	0.68
Mali	0.0	0.0	0.51	0.30
Mauritius	0.0	0.0	0.62	0.29
Morocco	0.0	0.0	0.61	0.14
Mozambique	0.0	0.0	0.38	0.25
Namibia	0.0	0.0	0.23	0.23
Niger	0.0	0.0	0.24	0.30
Nigeria	0.0	0.0	-0.19	0.11
Rwanda	0.0	0.0	1.00	0.96

Table A4. Estimates of Current Fuel Excise Taxes, All Countries, 2010 (concluded)

Country	current excise taxes			
	$ per GJ	$ per GJ	$ per liter	$ per liter
	coal	natural gas	gasoline	diesel
Sao Tome and Principe	#na	#na	#na	#na
Senegal	0.0	0.0	0.59	0.32
Seychelles	0.0	0.0	0.00	0.55
Sierra Leone	0.0	0.0	0.14	0.10
South Africa	0.0	0.0	0.35	0.34
Sudan and South Suda	#na	#na	#na	#na
Swaziland	0.0	0.0	0.24	0.24
Tanzania	0.0	0.0	0.48	0.40
Togo	0.0	0.0	0.31	0.26
Tunisia	0.0	0.0	0.22	0.16
Uganda	0.0	0.0	0.73	0.39
Zambia	0.0	0.0	0.76	0.59
Zimbabwe	0.0	0.0	0.46	0.29
Asia & Oceania				
Afghanistan	#na	0.0	0.20	0.18
Australia	0.0	-0.1	0.49	0.49
Bangladesh	0.0	-2.6	0.26	-0.23
Bhutan	#na	0.0	0.25	-0.04
Brunei	#na	#na	#na	#na
Cambodia	#na	0.0	0.32	0.12
China	0.0	0.0	0.39	0.37
Fiji	#na	0.0	0.00	0.00
Hong Kong	#na	#na	#na	#na
India	0.0	-1.0	0.36	-0.04
Indonesia	0.0	0.0	-0.13	-0.35
Japan	0.0	0.0	0.75	0.46
Kiribati	#na	0.0	0.00	0.00
Korea, South	#na	#na	0.85	#na
Malaysia	0.0	-0.8	-0.04	-0.10
Maldives	#na	0.0	0.00	0.00
Mongolia	0.0	0.0	0.28	0.18
New Zealand	0.0	0.0	0.63	0.13
Pakistan	0.0	-4.1	0.17	-0.03
Papua New Guinea	#na	0.0	0.00	0.00
Philippines	0.0	0.0	0.22	-0.02
Samoa	#na	0.0	0.20	0.20
Singapore	#na	0.0	0.69	0.31
Sri Lanka	0.0	0.0	0.21	-0.20
Taiwan	#na	#na	#na	#na
Thailand	-0.9	-0.3	0.59	0.09
Vietnam	0.0	-0.7	0.25	0.11

Sources: See above.
Notes: The table shows estimates of the current excise tax (or subsidy) for each fuel as measured in Clements et al. (2013) using the price-gap approach (e.g., comparing differences between domestic and international fuel prices) consistently applied across countries. These estimates will differ from authorities' assessments of tax rates based on their own (country-specific) data. The color coding for #N/A is as follows: red and black indicate respectively cases where data is not available and the fuel is not used.

Glossary of Technical Terms and Abbreviations (Including those for the Supplement)

Air capture technologies. These involve bringing air into contact with a sorbent material that binds chemically with CO_2 and extracts the CO_2 from the sorbent for underground, or other, disposal. Conceivably, if these technologies could be scaled up globally (and funded publicly), they might be used to slow atmospheric GHG accumulations, though only in high-warming scenarios, given their high costs.

Air emissions mandates. Refers to mandates for the use of emissions control technologies or maximum allowable emission rates (e.g., per kWh averaged over a generator's plants).

Air quality model. Computational models that link emissions from different sources to ambient pollution concentrations in nearby and more distant regions, accounting for meteorological and other factors that influence pollution formation.

Ambient air pollution. Outdoor (as opposed to indoor) pollution due to emissions from fossil fuel consumption (and other sources) other than carbon emissions. The main damage component from air pollution is elevated mortality risks for exposed populations.

Area licensing scheme. A scheme charging motorists for driving in a restricted (downtown) area.

Biofuels. A fuel that containing energy from recent production of carbon in living organisms like plants and algae.

Border adjustments. Refer here to the use of charges on the embodied pollution of imported products to alleviate concerns about the impact of environmental taxes on the international competitiveness of domestic firms.

Breathing rate (BR). This refers to the rate at which a given amount of outdoor air pollution is inhaled by the average person.

British thermal unit (Btu). Measurement of energy based on heat content.

Bureau of Public Roads formula. The traditional equation used for predicting vehicle speed as a function of the ratio of traffic volume to road capacity.

Carbon budget. Specifies a maximum allowable amount of CO_2 emissions that a country can emit, cumulated over a long period (say 10 years).

Carbon capture and storage (CCS). These technologies involve the separation of CO_2 emissions during fuel combustion at, for example, coal plants, transporting it to a storage site, and depositing it in an underground geological formation (e.g., depleted gas fields) to prevent its release into the atmosphere. At present, they would require very high CO_2 prices to be commercially viable.

Carbon dioxide (CO_2). The pre-dominant GHG. To convert tons of CO_2 into tons of carbon, divide by 3.67. To convert a price per ton of CO_2 into a price per ton of carbon, multiply by 3.67.

Carbon dioxide (CO_2) equivalent. The warming potential of a GHG over its atmospheric lifespan (or over a long time period) expressed in terms of the amount of CO_2 that would yield the same amount of warming.

Carbon Monitoring for Action (CARMA). A database used for obtaining the geographical location of coal and natural gas power plants across different countries.

Carbon tax. A tax imposed on CO_2 releases emitted largely through the combustion of carbon-based fossil fuels. Administratively, the easiest way to implement the tax is through taxing the supply of coal, oil, and natural gas (e.g., at the refinery) in proportion to their carbon content.

Common but differentiated responsibilities. A principle of the UNFCCC calling for developing countries to bear a disproportionately larger burden of mitigation costs (e.g., by funding emissions reduction projects in developing countries), given that they are relatively wealthy and contributed most to historical atmospheric GHG accumulations.

Concentration response function. The relationship between ambient pollution concentrations and elevated risks of various fatal diseases for populations exposed to the pollution.

Contingent valuation. A common type of stated preference study where people are asked directly about their money risk trade-offs.

Cost effective environmental policy. A policy that achieves a given level of environmental protection at minimum economic costs. This requires (a) pricing policies to equate incremental mitigation costs across different sources of an environmental harm (b) the revenue potential from pricing policies is realized and revenues are used productively (e.g., to lower other taxes that distort economic activity).

Corrective tax. A charge levied on a source of environmental harm and set at a level to reflect, or correct, for environmental damages.

Credit trading. In cap-and-trade systems, credit trading allows firms with high pollution abatement costs to do less mitigation by purchasing allowances from relatively clean firms with low abatement costs. Similarly, in regulatory systems credit trading allows firms with high compliance costs to fall short of an emissions (or or other) standard by purchasing credits from other firms that exceed the standard.

Distance-based taxes. Taxes that vary directly in proportion to how much a vehicle is driven, for example, on busy roads at peak period.

Downstream policy. Here this refers to an emissions policy imposed at the point where CO_2 emissions are released from stationary sources (primarily from smokestacks at coal plants and other facilities).

Economic costs. Refers to the costs of the various ways households and firms respond to a policy (e.g., through conserving on energy or using cleaner but more costly fuels). Costs also encompass the impact of a new policy on distortions (e.g., to work effort and capital accumulation) created by the broader fiscal system (these costs can be partially offset through recycling of environmental tax revenues).

Efficiency standards. Requirements for the energy efficiency of products, usually electricity-using products like lighting, household appliances, space heating and cooling equipment. Similar policies are sometimes applied to vehicles though they are more commonly known as fuel efficiency standards.

Emissions control technology. Refers here to the use of technologies to capture emissions at the point of fuel combustion thereby preventing their release into the atmosphere. Available technologies can dramatically cut local air pollution emissions from power plants and vehicles with costs that are usually modest relative to environmental benefits. Technologies to capture carbon emissions (see CCS) are, however, far more costly.

Emissions factor (or coefficient). Defines the amount of a particular emissions source released per unit of fuel combustion. For coal and natural gas emissions factors are expressed in tons per unit of energy while for motor fuels they are expressed in tons per liter of fuel.

Emissions leakage. This refers to a possible increase in emissions in other regions in response to an emissions reduction in one country or region. Leakage could result from the re-location of economic activity, for example the migration of energy-intensive firms away from countries whose energy prices are increased by climate policy. Alternatively, it could result from price changes, for example, increased demand for fossil fuels in other countries as world fuel prices fall in response to reduced fuel demand in countries taking mitigation actions

Emissions pricing. Refers to policies that put a price on carbon or local air emissions

Emissions trading system or scheme (ETS). A market-based policy to reduce emissions. Covered sources are required to hold allowances for each ton of their emissions or (in an upstream program) embodied emissions content in fuels. The total quantity of allowances is fixed and market trading of allowances establishes a market price for emissions. Auctioning the allowances can provide a valuable source of government revenue.

Energy paradox. The observation that some energy-efficient technologies are not adopted by the market even though they appear to pay for themselves in terms of discounted lifetime energy savings exceeding the upfront investment costs.

Environmental tax shifting. Introducing (or increasing) an environmental tax and simultaneously lowering other taxes leaving government revenue (on net) unchanged.

Externality. A cost imposed by the actions of individuals or firms on other individuals or firms that the former do not take into account (e.g., when deciding how much fuel to burn or how much to drive).

Feebate. This policy imposes a fee on firms with emission rates (e.g., CO_2 per kWh) above a 'pivot point' level and provides a corresponding subsidy for firms with emission rates below the pivot point. Alternatively, the feebate might be applied to energy consumption rates (e.g., gasoline per km) rather than emission rates. Feebates are the pricing analog of an emissions (or energy) standard, but they circumvent the need for credit trading (across firms and across time periods) to contain policy costs.

Fiscal dividend. Refers here to the revenue gain from energy tax reform.

Flue-gas desulfurization units (scrubbers). Technologies used to remove SO_2 from exhaust flue gases of fossil-fuel power plants. The most common technology is wet scrubbing using a slurry of alkaline sorbent (usually limestone, lime, or seawater). Flue-gas desulfurization remove 90 percent or more of the SO_2 in the flue gases for coal-fired power plants.

Fuel efficiency (or fuel economy) standards. Policies that regulate the allowable fuel use per unit of distance (or distance per unit of fuel use) for new vehicles (often averaged over a manufacturer's vehicle fleet).

Getting (energy) prices right. This means reflecting both production costs and environmental damages in energy prices faced by energy users.

Gigajoule (GJ). A metric term used for measuring energy use. For example, 1 GJ is approximately equivalent to the energy available from 278 kWh of electricity, 26 cubic meters of natural gas, or 26 liters of heating oil. One gigajoule is equal to one billion joules.

Gigatonne (Gt). 1 billion (10^9) tonnes.

Global Burden of Disease (GBD). This project is an effort to describe the global distribution and causes of a wide array of major diseases, injuries, and health risk factors (including pollution-related illness).

Global warming. The rise in observed globally averaged temperature over pre-industrial levels that is largely attributed to rising atmospheric accumulations of GHGs (as opposed to other factors like changes in solar radiation).

Global Positioning System (GPS). A space-based satellite navigation system that (in the above context) can provide information on where and what time vehicles are driven.

Greenhouse gas (GHG). A gas in the atmosphere that is transparent to incoming solar radiation but traps and absorbs heat radiated from the earth. CO_2 is easily the most predominant GHG.

Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) Model. This model, developed by the International Institute for Applied Systems Analysis, was used to compute emissions factors (with and without emissions control technologies) for different fuel products in different countries.

Integrated Assessment Model. A model that combines a simplified representation of the climate system with a model of the global economy to project the impacts of mitigation policy on future atmospheric GHG concentrations and temperature.

Inter-agency working group on the Social Cost of Carbon (SCC). A group of representatives from US executive branch agencies and offices tasked with developing consistent estimates of the SCC for use in regulatory analysis.

Intergovernmental Panel on Climate Change (IPCC). The IPCC assesses the scientific, technical, and socio-economic information relevant for understanding climate change. Its Fifth Assessment Report (AR5) is to be published in 2014.

Intake fraction. It is defined as average pollution inhaled per unit of emissions released, and is usually expressed as grams of $PM_{2.5}$ inhaled per ton of primary emissions.

Kilowatt hour (kWh). A unit of energy equal to 1,000 watt hours or 3.6 million joules.

LandScan data. Provides population counts by grid cell across different countries.

Megawatt hours (MWh). A unit of energy equal to 1,000,000 watt hours or 3.6 billion joules

Meta analysis. Refers to an analysis of existing similar studies to infer relations (e.g., between income and people's risk preferences).

Metric tonne (or ton). A unit of mass equal to 1,000 kilograms, or 2,205 pounds. In the United States, the 'short' ton, equal to 907 kilograms or 2,000 pounds, is more commonly used.

Microgram (*µg*). Unit of mass equal to one millionth of a gram.

Micrometer (µm). A distance equal to one millionth of a meter.

Millennium Cities Database for Sustainable Transport. Database providing travel speeds and various transportation indicators for 100 cities across many different countries.

Mortality risk value. Value attached to a premature death (due to pollution exposure or a traffic accident) used to monetize health risks, which is needed to assess corrective energy taxes.

Nitrogen oxides (NO_x). These pollutants are generated from combustion of coal, petroleum products, and natural gas. They react in the atmosphere to form fine particulates which are harmful to human health (although NO_x is less reactive than SO_2).

Offset. A reduction in emissions in other countries (or unregulated sectors) that is made and credited in order to reduce the tax liability or permit requirements for emissions covered by a formal pricing program.

Ozone. A secondary pollutant formed at ground level from chemical reactions involving NO_x and VOCs which can have health effects (although these are on a much smaller scale to those caused by fine particulates).

Particulate matter (PM). These are classified into fine particulates $PM_{2.5}$ (with diameter up to 2.5 micrometers) and course particulates PM_{10} (with diameter up to 10 micrometers). Fine particulates are damaging to human health as they are small enough to penetrate the lungs and bloodstream, thereby raising the risk of heart, lung, and other diseases.

Parts per million (ppm). Units for measuring the concentration of GHG molecules in the atmosphere by volume.

Passenger car equivalent (PCE). The contribution to congestion from a vehicle km driven by another vehicle (e.g., a truck) relative to that from a km driven by a car.

Pavement damage. Wear and tear on the road network caused by vehicles, especially heavy trucks (because damage is a rapidly escalating function of a vehicle's axle weight).

Pay-as-you-drive (PAYD) auto insurance. A system of car insurance where motorists pay premiums in direct proportion to the amount they drive.

Petajoule (PJ). A metric term used for measuring energy use. A petajoule is equal to one quadrillion joules.

Primary (air) pollutant. A pollutant like SO_2 or NO_x that subsequently transforms through chemical reactions in the atmosphere into a 'secondary' pollutant, fine particulates, which in turn has harmful effects on human health.

Primary energy consumption. The energy content of fossil and other fuels prior to any transformation into secondary energy (e.g., electricity).

Proxy (environmental) tax. An environmentally-related tax that forgoes some environmental effectiveness as it is not directly targeted at the source of environmental harm (e.g., unlike a direct tax on emissions, a tax on electricity consumption does not promote use of cleaner power generation fuels).

Rebound effect. This refers to the increase in fuel use (or emissions) resulting from increased use of energy-consuming products following an improvement in energy efficiency, which lowers their operating costs. For vehicles in the United States, the rebound effect (increased driving) is thought to offset about 10 percent of the fuel savings in response to higher fuel efficiency.

Revealed preference. Refers to studies that use observed market behavior to estimate people's trade-offs. For example, estimates of how much people are willing to pay for reduced mortality risk have been inferred from studies that look at the lower wages paid for jobs with lower occupational risks.

Secondary energy. An energy source (primarily electricity) produced from combusting a primary fuel.

Secondary (air) pollutant. A pollutant (fine particulates) formed from atmospheric reactions involving primary pollutants (like SO_2 and NO_x).

Severity-adjusted injury risk. Refers to the extra injury risks that one extra driver imposes on other road users, accounting for the possibility that other drivers may drive slower or more carefully with more vehicles on the road.

Social cost. This refers to the sum of private cost and external cost. It is not always a useful concept for policy however, as policy should focus on external costs, which are sometimes less than social costs.

Social cost of carbon (SCC). The present discounted value of worldwide damages from the future global climate change associated with additional ton of GHG emissions.

Stated preference. Refers to studies that use (web-based or other) questionnaires to infer people's preferences (e.g., their willingness to pay for reducing fatality risk).

Sulfur dioxide (SO_2). A pollutant caused by fuel (primarily coal) combustion that reacts in the atmosphere to form fine particulates with potentially harmful effects on human health.

Targeting the right base. Refers to levying charges directly on the sources of an environmental harm to promote all opportunities for reducing that harm.

TM5-Fast Scenario Screening Tool (FASST). A simplified model linking pollution emissions from different sources and geographical sites to ambient pollution concentrations and health risks in different regions.

United Nations Framework Convention on Climate Change (UNFCCC). This is an international environmental treaty produced at the 1992 Earth Summit. The treaty's objective is to stabilize atmospheric GHG concentrations at a level that would prevent 'dangerous interference with the climate system'. The treaty itself sets no mandatory emissions limits for individual countries and contains no enforcement mechanisms. Instead, it provides for updates (called 'protocols') that would set mandatory emission limits.

Upstream policy. In the present context, this refers to an emissions pricing policy imposed approximately at the point where fossil fuels enter the economy (e.g., on refined petroleum products, or at the minemouth for coal).

Value of travel time (VOT). This is the monetary cost that people attach to the time used up per unit of travel.

Volatile organic compounds (VOCs). These primary pollutants are released during motor fuel combustion and react in the atmosphere to form ozone.