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Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates

by David Coady, Ian Parry, Nghia-Piotr Le, and Baoping Shang

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Abstract

This paper updates estimates of fossil fuel subsidies, defined as fuel consumption times the gap between existing and efficient prices (i.e., prices warranted by supply costs, environmental costs, and revenue considerations), for 191 countries. Globally, subsidies remained large at $4.7 trillion (6.3 percent of global GDP) in 2015 and are projected at $5.2 trillion (6.5 percent of GDP) in 2017. The largest subsidizers in 2015 were China ($1.4 trillion), United States ($649 billion), Russia ($551 billion), European Union ($289 billion), and India ($209 billion). About three quarters of global subsidies are due to domestic factors—energy pricing reform thus remains largely in countries' own national interest—while coal and petroleum together account for 85 percent of global subsidies. Efficient fossil fuel pricing in 2015 would have lowered global carbon emissions by 28 percent and fossil fuel air pollution deaths by 46 percent, and increased government revenue by 3.8 percent of GDP.

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I. INTRODUCTION

There is now unprecedented worldwide interest in the reform of fossil fuel pricing, reflecting several underlying factors.[1] First, reducing carbon dioxide (CO_2) emissions from fossil fuels is central to greenhouse gas (GHG) mitigation commitments submitted by 190 countries for the 2015 Paris Agreement. Second, many countries are concerned about dangerously high local air pollution concentrations that frequently exceed (often dramatically so) World Health Organization (WHO) guidelines, and much of this pollution comes from fossil fuel combustion. Third, in the aftermath of the financial crisis, many countries face growing fiscal pressures from rising debt levels, which are likely to be reinforced over the medium to longer term by spending pressures from ageing populations (especially in advanced economies) and financing needs for the Sustainable Development Goals (especially in developing economies). Increasing fossil fuel prices is administratively straightforward and could play the central role in addressing all three concerns.

Information on the gap between existing and efficient levels of fossil fuel prices is a key ingredient of an informed debate on the need for, and benefits of, fuel pricing reform. It provides a basis for understanding the environmental, fiscal, and economic welfare impacts of moving to more efficient pricing, the likely social and political challenges, and a benchmark against which alternative policies (e.g., less ambitious fuel pricing or the use of non-pricing instruments) can be evaluated. This helps policymakers understand trade-offs, prioritize reforms, understand differences across countries, and communicate the case for reform.

This paper provides an updated assessment of global and regional energy subsidies[2] based on comprehensive country-level estimates for 191 countries. Coady and others (2015) projected global energy subsidies for 2015 at a striking $5.3 trillion, or 6.5 percent of global GDP, with under-charging for domestic air pollution accounting for about half of the total subsidy and global warming about a quarter.[3] Updating these estimates is important for various reasons. For one thing, the policy landscape is continuously changing as some countries move to more liberalized energy prices, some introduce or scale up carbon taxes and emissions trading systems (ETSs), some adjust pre-existing energy tax systems, and some take additional measures (e.g., through air emission regulations) to reduce local environmental impacts.[4] For another, the impacts of domestic energy price reforms are constantly changing with changes in fuel consumption, international energy prices, numbers of people exposed to air pollution, road safety, people's valuation of environmental risks, and so on. In addition, new and often higher

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[1] Appendix 1 provides statistical background on these factors for selected countries.

[2] Henceforth, we use the terms fossil fuel pricing/subsidies and energy pricing/subsidies interchangeably.

[3] Coady and others (2015) estimated global energy subsidies using estimates of efficient taxes for fossil fuel products based on a methodology developed by Parry and others (2014), while also accounting for the additional taxation needed to contribute to revenue raising objectives using consumption taxation. This provided a basis for estimating the gap between existing fossil fuel consumer prices and efficient prices reflecting supply costs and efficient taxes for a range of energy products. Both analyses also provided practical online spreadsheet tools readily enabling cross-country comparisons and sensitivity analysis; see https://www.imf.org/external/np/fad/subsidies/ and https://www.imf.org/external/np/fad/environ/.

[4] Appendix 2 highlights some recent energy and carbon pricing developments.

quality data are constantly becoming available (e.g., on components of environmental costs or fuel-price responsiveness) and methodologies for using these data may evolve. The new estimates presented in this paper are based on a comprehensive updating of a diverse range of international databases on fuel consumption, prices, air pollution emission rates, health indicators, road statistics, and environmental valuations, in addition to refined methodologies.

The main findings of the paper can be summarized as follows:[5]

- *Underpricing of fossil fuels remains pervasive and substantial.* For example, country-level coal prices were typically well below half of their fully efficient levels in 2015. Undercharging for road fuels is also pervasive with prices frequently falling short of their efficient levels by over 20 percent.

- *At the global level, energy subsidies are estimated at $4.7 trillion[6] (6.3 percent of world GDP) in 2015 and $5.2 trillion (6.5 percent of GDP) in 2017.* At the aggregate level, the moderately smaller global figure for 2015 compared to previous estimates is mainly due to lower externality estimates (e.g., lower air pollution emission rates in China) and lower (than previously projected) fuel consumption, reflecting mostly updated data and regulatory policy changes. At the product and country level, there are numerous other, often offsetting, factors significantly changing energy subsidy estimates. The impact of recent energy (and carbon) pricing reform at the global level is limited.

- *In absolute terms, China was still, by far, the largest subsidizer in 2015 (at $1.4 trillion)*, followed by the United States ($649 billion), Russia ($551 billion), European Union ($289 billion), and India ($209 billion). By region, Emerging/Developing Asia accounts for nearly 40 percent of global energy subsidies, followed by Advanced Economies (27 percent), Commonwealth of Independent States (15 percent), Middle East, North Africa, Afghanistan, and Pakistan (9 percent), Latin America/Caribbean (5 percent), Emerging/Developing Europe (3 percent), and Sub-Sahara Africa (2 percent).

- *By component, underpricing for local air pollution is still the largest source (48 percent in 2015)*, while that for global warming is similar to earlier estimates (24 percent), followed by broader environmental costs of road fuels (15 percent), undercharging for general consumption taxes (7 percent) and for supply costs (7 percent). Energy pricing reform therefore remains largely in countries own interest, given that about three quarters of the benefits are local.

- *By fuel, coal remains the largest source of subsidies (44 percent)*, followed by petroleum (41 percent), natural gas (10 percent), and electricity output (4 percent).

- *If fuel prices had been set at fully efficient levels in 2015, estimated global CO_2 emissions would have been 28 percent lower*, fossil fuel air pollution deaths 46 percent lower, tax

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[5] The focus on 2015 when reporting on the composition of subsidies reflects the more complete data available for that year.

[6] All monetary figures below are expressed in nominal terms.

revenues higher by 3.8 percent of global GDP, and net economic benefits (environmental benefits less economic costs) would have amounted to 1.7 percent of global GDP.

The rest of paper is organized as follows. Section 2 recaps the definition of corrective fuel taxes and energy subsidies and discusses procedures for updating their estimates with a particular focus on local air pollution given its importance for the results. Section 3 distills some of the quantitative results—the complete set of results for 191 countries is provided in the online spreadsheet—and reconciles results with earlier estimates. Reflecting the uncertainty associated with the estimates, it also presents sensitivity analyses with respect to key parameter assumptions. Section 4 offers concluding remarks.

II. METHODOLOGY

A. Conceptual Issues: A Quick Recap

Components of Efficient Fuel Prices

Economically efficient fossil fuel prices have three basic components.

First, and most straightforward, is the economic (or opportunity) cost of supplying fuel to consumers. For products traded across regions, such as gasoline and diesel, this can be measured by the international reference price as reflected in the cost faced by importers or the revenue foregone by domestically consuming rather than exporting the product. For non-traded energy, such as electricity, the supply cost is the domestic production cost or 'cost-recovery' price, with fuel inputs evaluated at international reference prices.

Second, there are the environmental costs associated with fossil fuel consumption, the most quantitatively important of which includes local air pollution mortality, broader costs associated with the use of fuels in road vehicles, and global warming.[7] The valuation of environmental costs is, however, much more contentious than for supply costs.

For one thing, environmental costs are measured with considerable uncertainty—most obviously global climate change, but another example is local air pollution, where there are several sequential linkages between the burning of a fuel and changes in the mortality rates for exposed populations (see below), all of which involve plenty of data uncertainties. In addition, there are differing views on how to value the associated health risks. Nonetheless, environmental costs are just as real as supply costs, and undercharging for an unbiased (albeit uncertain) estimate of them is tantamount to undercharging for the true social costs of consumption. Moreover, the estimates presented here should be viewed as indicative—the implications of alternative views on underlying parameters should be largely transparent from the discussion and the spreadsheet tools available online.

[7] Other externalities associated with fossil fuel production and consumption are not considered because they are not well defined (e.g., energy security), a country-level database to quantify them is not available (e.g., methane and CO2 from petroleum and natural gas field operations), or their damages are relatively small. On the last point, combined estimates of morbidity, impaired visibility, crop damage, and building corrosion for local air pollution tend to be moderate relative to mortality impacts (e.g., NRC 2009, Ch. 2).

Another reason for contention is that pure fuel taxes are not always the single most efficient environmental instrument. For example, fees on coal plant emissions promote both reductions in emission rates (e.g., through use of filtering technologies in smokestacks) and in coal use (e.g., through reduced electricity demand or switching to cleaner generation fuels). However, our accompanying online spreadsheets can readily convert efficient coal taxes into efficient emissions fees, and combining an upfront coal tax with a rebate for downstream mitigation can have the same effects as an emissions fee and may be more administratively practical[8]. Factoring air pollution costs into coal taxes is therefore still appropriate. Care is needed, however, in interpreting the efficient energy prices and subsidies presented below as—for the most part—they exclude the possibility of accompanying measures like downstream rebates for mitigation that would lower the efficient energy price. Another example is traffic congestion where fees per vehicle mile driven on busy roads, rising and falling during the rush hour, would promote a wider range of congestion-reducing responses than higher road fuel prices.[9] Nonetheless, it will likely be a long time before any country comprehensively prices congestion across its entire road network and, in the interim, it is entirely appropriate to reflect unpriced (nationwide) congestion costs in road fuel prices.[10]

The third component of efficient fuel prices reflects general revenue-raising considerations, and here the general policy guidance is to apply the same consumption taxes to fuels as applied to other consumption goods in general. Under the (near ubiquitous) value-added tax (VAT) this would apply the standard VAT rate to final fuel consumption—*based on prices reflecting supply and environmental costs*—but not to intermediate purchases.[11]

Definitions of Fossil Fuel Subsidies

It is helpful to distinguish two different notions of fossil fuel subsidies. One is a narrow measure, termed *pre-tax subsidies*, reflecting differences between the amount consumers actually pay for fuel use and the corresponding opportunity cost of supplying the fuel. In contrast, a broader measure, termed *post-tax subsidies*, reflects differences between actual consumer fuel prices and

[8] Many countries presently lack the institutional capacity for continuously monitoring air emissions from all industrial smokestacks. Under a rebate system, the onus is on individual entities to demonstrate emissions reductions (e.g., through installing continuous emissions metering technologies) to administrators. Spatial differentiation to account for local population exposure might, however, be simpler to integrate into a downstream air fee system (e.g., as in Chile). Most common, however, is to regulate local pollution through emission rate or technology standards, which lower efficient charges on fuel use, though some charge is still needed to efficiently reduce fuel demand.

[9] Including flattening of the distribution of trip departure times within peak periods, shifting to off-peak travel, and shifting to less congested links in road networks.

[10] Not doing so implies potentially large losses in economic efficiency and perverse policy implications, for example, that European countries should lower road fuel taxes towards U.S. levels (see below). See Parry and Small (2005) for analytical derivations of (second-best) efficient road fuel taxes.

[11] See, for example, Diamond and Mirrlees (1971). In principle, extra taxation of individual products like fuels might be warranted on fiscal grounds when the full range of distortions from broader taxes (e.g., disincentives for work effort and investment, biases towards informal activity, untaxed fringe benefits, and other tax-favored spending) is considered (e.g., Parry and Bento 2000). This issue is not pursued further, however, partly due to lack of a cross-country database on the parameters needed for these calculations.

how much consumers would pay if prices fully reflected supply costs plus the taxes needed to reflect environmental costs and revenue requirements.[12] The post-tax measure therefore corresponds to the definition of subsidies used in this paper, although the international debate (e.g., at the 2009 G20 meeting in Pittsburg) typically focuses on the narrower notion of pre-tax subsidies. Where prices exceed supply costs or efficient prices, then pre-tax and post-tax subsidies respectively are counted here as zero (rather than negative), given our focus on underpricing.

The discussion is primarily about consumer price distortions, but producer subsidies also arise when firms receive direct or indirect support (e.g., prices above supply costs, preferential tax treatment, direct government budget transfers, or paying input prices below supply costs) that is not passed forward to lower consumer prices (OECD, 2018). Producer subsidies are included in pre-tax subsidies below, but they are relatively small. Subsidies for non-fossil fuels are excluded from our calculations.[13]

B. Environmental Costs—A Closer Look and Update

Climate Change

Global CO_2 emissions from fossil fuel and other industrial sources were 34 billion (metric) tons in 2016.[14] These heat-trapping gases accumulate in the atmosphere (with average residence times of around a century or longer) affecting the global climate system. Economic efficiency requires that individual fuel users are charged for the resulting costs. The most efficient instrument is a charge on fuel supply equal to the fuel's CO_2 emissions factor (i.e., emissions per unit of fuel combustion) times a CO_2 price—administratively, these charges would be a straightforward extension of (generally well established) fuel tax systems.[15]

There are different approaches to valuing CO_2 emissions in the economics literature. One involves estimating the 'social cost of carbon' (SCC)—the discounted value of worldwide damages from the future global climate change associated with an additional ton of current emissions—and some recent assessments suggest an SCC of around $35 per ton for

[12] The above terminology for subsidies was introduced by Clements and others (2013). See Coady and others (2015) for a graphical comparison of the different notions of subsidies.

[13] Renewables subsidies in power generation, for example, were $140 billion worldwide in 2016 according to IEA (2017). Note, however, that efficient fuel pricing would remove one of the key motivations for renewable energy subsidies.

[14] Coal, oil, and natural gas combustion accounted for 40, 34, and 20 percent of these emissions respectively and combustion of limestone in cement manufacturing 6 percent. Non-CO_2 GHGs (methane, nitrous oxide, and hydrofluorocarbons) contributed 12 billion tons to 2016 emissions and human-induced land use and deforestation 4.5 billion tons. In the absence of mitigating measures, fossil fuel emissions are projected to grow more rapidly than other GHGs. See Le Quéré and others (2018), Tollefson (2018), and UNEP (2017).

[15] Alternatively, emissions can be priced downstream at the point of fuel combustion for large stationary sources (e.g., power plants), as is common in ETSs, though this requires new capacity for monitoring emissions and trading markets and these systems need to be combined with upfront charges on fuel supply for small-scale sources (e.g., for use in buildings and vehicles).

2015 emissions (in U.S. $2015), though estimates are contentious.[16] Another approach is to estimate global emissions prices consistent with cost effectively meeting temperature stabilization goals; for example, a recent review suggests a global CO_2 emissions price of $40-80 per ton (in $2015) by 2020 would be consistent with the Paris goal of limiting mean projected warming to 2^{o}C (Stern and Stiglitz, 2017). A third approach is to assess carbon prices consistent with countries' mitigation pledges, and a recent assessment[17] puts this at around $35 per ton in 2030 (in 2015$) for G20 countries combined, though considerably higher for many advanced countries. Based on this summary, the estimates discussed below assume, common across all countries, an illustrative value of $40 per ton for 2015 emissions, rising at 3 percent a year in real terms (U.S. IAWG 2016).

Local Air Pollution

Air pollution mortality is caused by people inhaling or ingesting ambient $PM_{2.5}$ (particulate matter with diameter up to 2.5 micrometers), which is fine enough to penetrate the lungs and bloodstream.[18] $PM_{2.5}$ can be emitted directly from fuel combustion or formed indirectly from atmospheric reactions involving sulfur dioxide (SO_2) or nitrogen oxides (NO_x).[19] Coal and diesel combustion (at least per unit of energy) are the major causes of fossil fuel air pollution rather than natural gas and gasoline. Parry and others (2014) developed a methodology for estimating air pollution damages, by fuel product and country, and accounting for cross-border pollution[20]—their approach is used here and updated where practical. Damages depend on five factors—statistics on these factors are shown, for a selection of diverse countries, in Table 1.

First is the "intake fraction", that is, the fraction of pollution—direct $PM_{2.5}$, along with SO_2 and NO_x converted to $PM_{2.5}$ equivalents—emitted from a fuel product that, on average, is inhaled/ingested by exposed populations. We rely (without updating) on the intake fractions estimated by Parry and others (2014). For coal and natural gas plants, these fractions are from geographical data on plant location in countries[21] matched to granular data on population density at different distances from each plant (up to 2,000 km away, within and across borders), and regression coefficients (for China) indicating how intake fractions at different distances vary

[16] See Nordhaus (2017) and US IAWG (2016). The SCC is especially sensitive to alternative approaches to inter-generational discounting and modelling of tail risks.

[17] See Parry and others (2018) and, for further discussion, Aldy and others (2016).

[18] Indoor air pollution caused an estimated 2.9 million deaths in 2015, compared with 4.2 million deaths for outdoor air pollution (GBD 2016) but the former is not considered here as the nature of the externality is unclear when those producing pollution are largely the ones affected by it.

[19] Ozone is another local air pollutant caused by fuel combustion although it accounts for a fairly modest fraction of outdoor air pollution deaths (7 percent worldwide according to GBD 2016) and is not considered here.

[20] WHO (2017) reports outdoor, pollution-related deaths by country for 2015 but these are not broken down by the contribution from individual fuel products, some of the deaths are from non-fossil sources (e.g., dust, chemicals), and cross-border deaths from domestic fuel consumption are not distinguished.

[21] Data was available for 110 countries in 2009. Intake fractions for other countries were inferred here from comparable countries in the region.

with population density.[22] For vehicle and building emissions (which generally remain close to ground level rather than being transported through the atmosphere), intake fractions were extrapolated nationwide from a database of (ground-level) intake fractions for over 3,000 urban areas (ground-level intake fractions tend to be higher for direct $PM_{2.5}$ but lower for SO_2 and NO_x). Intake fractions (Table 1, second column) for the case of SO_2 from coal plants (generally the most important local air pollutant for coal) are relatively high in densely populated countries (e.g., China, Germany, India, Indonesia, Japan, Thailand, United Kingdom) and relatively low in countries with low population density (e.g., Australia, Canada) and perhaps also with coastal location of plants (implying some emissions disperse over oceans without harming human health).

The second factor is baseline mortality rates for exposed populations for four fatal illnesses—strokes, chronic obstructive pulmonary disease, ischemic heart disease, and lung cancer—whose prevalence is increased by inhaling/ingesting fine particulates. The mortality rates, for those over 25,[23] are taken from WHO (2017) and are more accurate than estimates used in Parry and others (2014) as the latter (due to data constraints at the time) were based on regional averages. Baseline mortality rates vary significantly across countries (Table 1, third column) and are relatively high in Russia and Ukraine (countries with relatively high prevalence of heart and lung disease from alcohol and cigarette consumption).

The third factor is 'concentration-response functions' for each of the four illnesses, that is, the proportionate increase in an individual's mortality risk as a function of the ambient $PM_{2.5}$ concentration. Based on Burnett and others (2013, 2014), these relationships are taken to be the same across countries and linear[24], with each 10 microgram/cubic meter increase in ambient $PM_{2.5}$ concentrations increasing the prevalence of strokes, chronic obstructive pulmonary disease, ischemic heart disease, and lung cancer by 15, 5, 8, and 7 percent respectively. Some new research suggests that mortality may be dramatically more responsive to $PM_{2.5}$ exposure than previously thought—hence our air pollution cost estimates might be quite conservative—though our preference is not to use this new information until it becomes the consensus estimate in the health literature.[25]

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[22] This approach ignores differences in atmospheric conditions (between China and other countries) that might affect intake fractions, though checks against a regional air quality model suggest this may not substantially and systematically bias the results (see Parry and others, 2014, pp. 83-87). For example, wind speeds and direction differ across countries, though this will only really matter when there are substantial differences between population density upwind and downwind of the representative power plant.

[23] Typically, around 90-100 percent of total deaths (WHO 2017).

[24] Burnett and others (2013), Figure 1.

[25] Burnett and others (2018) estimate that global outdoor air pollution deaths in 2015 were 8.9 million, up from 4.0 million in previous estimates (in part due to a wider range of diseases whose prevalence is increased from pollution exposure). A further caveat is that concentration response functions may flatten out at extreme levels, beyond about 100 micrograms/cubic meter, as people's channels for absorbing pollution may become saturated, paradoxically diminishing the incremental health benefits from cutting pollution. However, at least at the country average level, concentrations are well below this level (e.g., Appendix 1 third column) and fuel price reform would lower them further.

Combining the first three factors gives estimates of the mortality impacts per ton of direct $PM_{2.5}$, SO_2 and NO_x. The fourth factor is the emission rates for these pollutants, which are used to express deaths per unit of fuel use. These rates were obtained on a country-by-country basis, and by fuel, from the International Institute for Applied Systems Analysis and were updated from 2010 to 2015 for this paper using the most recent modelling.[26] There is extensive cross-country documentation of emission rates for the power and transport sector (where there are data gaps they are filled using comparable countries), but this is far less true of the industrial and household sectors. For the latter, the same emission rates as estimated for the power sector are used, which likely gives conservative pollution damages (e.g., because control technologies for these sectors are generally less common than for the power sector).

The emission rates (for power and transport) represent an average over sources in a sector with and without the most advanced emissions control technologies. Across our illustrated cases (Table 1, fourth column), average SO_2 emission rates from coal plants are relatively high in countries like Kazakhstan, Pakistan, Turkey, and Ukraine, but low, for example in EU countries, Japan, and the United States with more extensive use of control technologies. Estimated death rates, expressed per million gigajoules (GJ)[27] of coal used for power generation (Table 1, fifth column), are below 1 in eight countries (e.g., Australia, Canada, Costa Rica, Côte d'Ivoire, Japan, United States); between 1 and 3 in thirteen countries (e.g., Colombia, Ethiopia, Germany, Kazakhstan, Philippines), between 3 and 10 in China, India, Indonesia, Pakistan, Russia, Thailand, and Turkey and (strikingly) 43 in Ukraine.[28] In general, the emission rate estimates have not changed substantially since Parry and others (2014), but there are notable exceptions. For example, in China the emission rates for coal plants are about 60 percent lower[29] and on-road emission rates for diesel vehicles have been revised upwards (given recent evidence that on-road emission rates exceeded new vehicle standards).

[26] The estimates were compiled by Fabian Wagner using the Greenhouse Gas—Air Pollution Interactions and Synergies (GAINS) model.

[27] One GJ is equivalent to 0.034 tons of coal, 0.17 barrels of oil, or 278 kilowatt hours of electricity.

[28] Ukraine has, by far, the highest baseline mortality rate from pollution-related illness, the highest SO_2 emission rate, and a higher than average intake fraction.

[29] Reflecting recent efforts by the Chinese authorities to deploy control technologies and retire older plants as part of a broader rebalancing strategy to a greener and more service-based economy, not least in response to environmental concerns of the public (see, e.g., Zhang 2016).

Table 1. Local Air Pollution Statistics in Selected Countries, 2015

Country	Intake fraction, grams PM2.5 inhaled/ton of coal plant SO2	Mortality rate from pollution-related illness, deaths per 1000	SO2 emission rates at coal plants, kilo-tons/petajoule	Death rates from coal plants, per mn GJ	Mortality value, 2015$ million
Argentina	1.04	3.8	0.38	2.3	2.2
Australia	0.12	2.6	0.29	0.2	5.2
Canada	0.19	2.7	0.26	0.2	5.0
China	4.25	5.3	0.08	5.8	1.6
Colombia	0.52	2.2	0.69	1.2	1.5
Costa Rica	0.32	1.9	0.69	0.6	1.7
Côte d'Ivoire	0.20	3.5	0.68	0.9	0.4
Ethiopia	0.60	2.0	0.68	1.6	0.2
France	1.81	2.8	0.17	1.5	4.5
Germany	2.67	4.6	0.06	1.6	5.2
India	3.42	3.9	0.43	9.9	0.7
Indonesia	1.78	4.3	0.34	5.9	1.2
Iran	0.90	2.5	0.69	2.7	1.9
Jamaica	0.46	3.1	0.69	1.8	1.0
Japan	2.44	3.8	0.02	0.6	4.4
Kazakhstan	0.21	5.7	0.97	1.7	2.7
Mexico	0.45	1.9	0.10	0.3	2.0
Morocco	0.57	2.6	0.69	1.9	0.9
Pakistan	1.19	3.7	1.31	9.6	0.5
Philippines	1.39	4.0	0.07	1.3	0.8
Russia	0.54	10.0	0.43	5.0	2.9
Saudi Arabia	0.51	1.6	0.69	1.0	6.0
South Africa	0.48	3.0	0.78	1.9	1.4
Tanzania	0.50	2.6	0.68	1.5	0.3
Thailand	2.01	3.1	0.88	9.5	1.8
Turkey	1.04	3.1	1.13	5.7	2.6
UAE	0.37	1.1	0.69	0.4	7.3
Ukraine	1.31	16.0	1.42	43.1	0.9
United Kingdom	1.91	4.5	0.17	2.9	4.6
United States	0.70	4.9	0.17	0.9	6.1

Sources: Updated estimates from Parry and others (2014), available at www.imf.org/environment.
Note: In cases where there are data gaps on intake fractions and emission rates these are inferred from comparable countries.

The final step is converting health impacts into a monetary component, which is controversial, though necessary to infer the air pollution component of corrective fuel taxes. Again, the assumptions used here are indicative, and the implications of alternative assumptions are transparent (given the proportionality between damages and mortality values). The approach draws on the OECD (2012) meta-analysis of several hundred stated preference studies (mainly for advanced and emerging market economies) on how people are willing to trade-off income for mortality risks. The OECD figure is updated (for inflation and real per capita income growth) to $4.7 million for 2015[30] and then extrapolated to other countries in proportion to their per capita

[30] This implies that, for the average advanced country, the average individual is willing to give up $4,700 a year to avoid a 1 in 1000 risk of a fatal illness.

income in 2015 relative to the OECD average.[31] This implies a unitary elasticity of the mortality value with respect to income—in Parry and others (2014) this elasticity was 0.8, but more recent studies typically assume the elasticity is about 0.8-1.0 for advanced countries and 1.0-1.2, or perhaps as high as 1.5, for low and middle income countries.[32] Using a higher elasticity for low- and middle-income countries would reduce the valuation of health costs, though on the other hand the base mortality value from the OECD study (relative to per capita income) is around 40 percent lower than suggested by U.S. empirical literature.[33] Mortality values (Table 1 last column) vary widely from $0.2 million (Ethiopia) to $7.3 million (United Arab Emirates).

Broader Vehicle Externalities

A major side effect from the use of road fuels in vehicles (but not uses of petroleum beyond the transport sector) is traffic congestion, which is excessive because motorists do not consider their impact on adding to congestion and slowing speeds for other road users. Due to data limitations, nationwide average congestion costs can only be estimated in a highly rudimentary way for most countries. The approach here uses estimates from Parry and others (2014) who first estimated (from an international database with 100 cities) statistical relationships between average travel delays per vehicle mile and various transportation indicators, and then extrapolated average delays nationwide using country-level values for those indicators.[34] Average nationwide delays per vehicle mile are converted into marginal delays (i.e., the delay an additional vehicle mile imposes on others), based on statistical relationships in the literature suggesting marginal delay is around four times the average delay, and a downward adjustment to account for the relatively weaker responsiveness of driving on busy roads (which is dominated by commuting) to fuel prices. Further adjustments are made to account for the share of buses and trucks in the vehicle fleet which contribute more to congestion per vehicle mile. The result is monetized using the value of travel time in each country, which (based on empirical evidence) is taken to be 60 percent of the market wage. No attempt is made here to update travel delays per vehicle mile, but the value of travel time is updated with inflation and growth in real GDP per

[31] As in Robinson and others (2018), purchasing power parity income, which takes local price levels into account, is used as it more accurately reflects people's willingness to pay for risk reductions out of their own income.

[32] See Robinson and others (2018), Tables 3.1 and 3.3. and Viscusi and Masterman (2017). Above unitary elasticities imply people in lower income countries are willing to give up a smaller fraction of their income to reduce annualized fatality risk by a given amount, a possible rationale being that a higher fraction of their income is needed for subsistence consumption. Mortality valuations may also differ across countries with differences in life expectancy, health, religion, culture, economic and social support and so on, however the effects of these factors are poorly understood and there is little basis for accounting for them at present (Robinson and others 2018).

[33] U.S. literature makes more use of revealed preference studies, for example that look at wage premiums for occupations with higher fatality risk. These studies tend to yield higher mortality valuations than stated preferences studies though the reasons for this are not entirely clear.

[34] Checks against more reliable estimates from detailed data on travel delays by road class, available for the United States and United Kingdom, suggest the extrapolation approach yields reasonable congestion delay estimates in the former case though somewhat understates congestion delays in the latter case.

capita. Congestion costs are multiplied by fuel economy[35] to express them per liter of fuel use, and a downward adjustment (of 50 percent or thereabouts) is made to account for the portion of a price-induced fuel reduction that would come from reduced vehicle miles as opposed to long-run improvements in average on-road fuel economy.

The other major side effect of vehicle use is traffic accidents. Some accident costs are borne by individual drivers (e.g. injury risks to themselves in single-vehicle crashes), but some are imposed on others (e.g., injury risks to pedestrians, cyclists, and other vehicle occupants in multi-vehicle collisions, third-party medical and property damages). Parry and others (2014) apportioned country-level data on traffic fatalities into external versus internal risks, monetized them using the above approach for mortality valuation, extrapolated non-fatality costs to other countries from several country case studies, and expressed the result per unit of fuel use (making analogous adjustments for larger vehicles and the mileage-component of fuel price responses as for congestion). These costs were re-estimated here using 2015 traffic fatality data from IRF (2017) and updated injury valuations. Finally, road damage costs (applicable to high axle-weight vehicles) were also updated using more recent data on highway maintenance expenditures (also from IRF 2017 and attributing half the expenditures to vehicles as opposed to natural deterioration) though these costs are a relatively minor component of efficient diesel fuel taxes. Where data is unavailable for countries (e.g., for many African countries) congestion, accident, and road damage costs are taken from another comparable country in the region.[36]

C. Remaining Data and Estimation Procedures

Retail Prices and Supply Costs for Finished Fuel Products

Retail prices are available in various frequencies (monthly, quarterly, annual average, or mid- and end-of-year) and are converted to an annual average price.[37] For petroleum products, retail prices are taken (when available) from the International Energy Agency's (IEA's) quarterly fuel price and tax database, supplemented by fuel price data sets from IMF sources (retail pump prices compiled from national regulatory agencies, IMF staff, and news reports) and German Agency for International Cooperation (GIZ). Retail prices for coal and natural gas are inferred, for countries with pre-tax subsidies according to IEA, by the supply cost less the per-unit subsidy (i.e., subsidy outlays divided by fuel consumption); for OECD countries, excise tax data are available from the OECD Statistical Database; and for other countries, retail prices are assumed to

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[35] Assumed (based on judgment and typical assumptions in other studies, as on-road fuel economy is not directly observed) to vary between (the equivalent of) 20 and 40 miles per gallon for gasoline vehicles, depending on region, to be 16 percent greater for corresponding diesel cars, and to be two-thirds lower for trucks and buses than corresponding diesel cars.

[36] Underpricing for the congestion, accident, and road damage costs from electric vehicles is not counted in the subsidy estimates below. And to the extent that higher fuel prices for gasoline and diesel vehicles leads to switching towards electric vehicles the efficient taxes on road fuels would be lower than computed here.

[37] End-of-year prices are assumed to be equal to the beginning of the following year and are included in the calculation of average price for both years, weighted by one-half the weight of other observations for the year.

equal the supply cost.[38] For electricity, prices are taken from the IEA quarterly database on household prices when available, supplemented with data from the U.S. Energy Information Administration (EIA), IMF and World Bank staff, or from news reports.

For finished petroleum products, supply costs consist of the port (or hub) prices from IEA, with countries mapped (based on region) to either the United States, NW Europe, or Singapore. A shipping and distribution margin of $0.20 per liter—the average in OECD countries—is added for countries that are net oil importers. For natural gas, supply costs are based on port prices for either Henry Hub USA, the Russian export price to Germany, and Japan (again countries are mapped to ports based on region). For coal, the supply prices are based on an average of prices from South Africa and Australia and are converted from per ton to per GJ using an average conversion factor (consumption weighted). For electricity, supply costs are assumed to equal the electricity retail price plus any pre-tax subsidy per unit.[39] For natural gas, coal and electricity, the constructed supply costs may differ from the actual, but this is expected to have minimal impacts on the subsidy estimates as the gaps between supply costs and consumer prices are determined elsewhere as discussed above. The only channel that the supply costs matter for the post-tax subsidy estimates in this case is through the revenue components of the efficient prices (calculated as the consumption tax rate multiplied by the sum of supply costs and environmental externalities) and this effect tends to be small.

Energy Consumption

For fuel consumption (coal, natural gas, gasoline, diesel, kerosene, electricity, and their decomposition by sector and intermediate/final consumption), the primary source is IEA, supplemented by data from EIA and the United Nations. It is typically assumed that final consumption (for which VAT is applicable) consists of residential, commercial, and public services use. However, for gasoline, we assume that final consumption also includes gasoline used for transportation as most of this is by households. Where no fuel use data is available (generally small island developing states with miniscule shares of global consumption), fuel use is extrapolated from comparable countries in the region adjusting for real GDP.[40] For the most part, fuel consumption for 2016 and 2017 is based on projections.[41]

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[38] Unlike for road fuels, coal excises are rare. India, for example, has a coal tax, though in terms of CO_2 it is modest at $3 per tonne (Parry and others 2017).

[39] As noted in Appendix 2, carbon taxes are implicit in our subsidy calculations but not ETSs applied at the point of fuel combustion, though the quantitative importance of this is small given that the global average carbon price from ETS is only around $2 per ton (calculated from WBG 2018). Road congestion or mileage-related vehicle charges are also excluded from our estimates though again this likely makes very little difference.

[40] The calculations do not include international aviation and maritime fuels. These fuels are not subject to excises and their prices reflect supply costs but not environmental costs, the main cost being CO_2 emissions. Including these fuels (which account for about 4 percent of global CO_2 emissions—Keen and others 2013) would add about 1 percent to our post-tax subsidy estimate.

[41] For petroleum products in 2016, this is based on 2015 fuel use scaled by the ratio of total petroleum consumption across these two years from EIA. In other cases, fuel use is projected based on GDP and the same income elasticities (varying between 0.5 and 1) for energy products as used in Parry and others (2018).

Miscellaneous Data

The consumption tax component of efficient energy prices is computed by the standard VAT (or general sales tax) in each country (from IMF sources) and applied to the sum of supply and environmental cost and for final consumption only (not intermediate use). Additional data on income and inflation, used for projection purposes, are from IMF (2018). Estimates of producer subsidies for fossil fuels by country are from the OECD.

Calculating Subsidies and Reform Impacts

Subsidy estimates are based on the methodologies and steps outlined above and discussed in Coady and others (2015). With the availability of environmental cost estimates for 2010 and 2015 (from Parry and others 2014, and updated here, respectively), costs for 2011-2014 are interpolated from a linearization of 2010 and 2015 estimates in real terms and then adjusted for inflation. Projections for 2016-2017 are obtained using the 2015 estimates, adjusting for inflation and income.

Consistent, country-level models of how fossil fuel use responds to price reform are not yet available on a wide scale[42] and therefore, as in Coady and others (2015), a first-pass assessment is obtained by simply assuming constant elasticity fuel demand functions (leaving aside cross-price effects among fuels) and perfectly elastic supply functions. Price elasticities for electricity demand, gasoline and diesel, and fuels used in the industrial and household sectors are taken to be -0.5 (elasticities reflect substitution away from energy products and energy-intensive consumption and improvements in energy efficiency). In the power sector, the price elasticities for fossil generation fuels are taken to be -0.7 (moderately larger than in Coady and others 2015), given the generally greater possibilities for substituting to cleaner production technologies. The same elasticities are used for all countries in the absence of systematic evidence that could be used to differentiate elasticities across countries (Charap and others, 2013). Although crude, these assumptions are broadly in line with: (i) cross-country econometric studies on fuel and electricity price elasticities, and (ii) results from detailed energy models (e.g., that incorporate general equilibrium effects, or disaggregation by industry and technologies) on the underlying relationship between carbon pricing and CO_2 emissions.[43]

In computing the environmental, fiscal, and economic welfare impact of energy pricing reform, average emission rates are assumed to reflect those with advanced control technologies, on the assumption that reform would be accompanied by measures (e.g., rebates or regulations) to promote greater use of control technologies.

III. Results

This section discusses current and efficient fuel prices for selected countries; the global picture on energy subsidies and their underlying determinants; reform benefits; sensitivity analyses; and

[42] Parry and others (2018) have developed streamlined models for individual G20 members, and these models are currently under extension across the Fund membership.

[43] See Parry and others (2018, pp. 12, 17, and Appendix 2) for a summary of the relevant evidence, modelling results, and consistency of our approach with other studies.

reconciles results with prior estimates. The discussion mostly centers on 2015 estimates for which the data availability is most complete—for 2016 and 2017, data availability varies by product and country (Appendix 3).

A. Comparing Current and Efficient Prices for Selected Countries

Figure 1 compares, for a selected 30 countries, actual and efficient prices in 2015 for coal and natural gas use in power generation, gasoline, and (road) diesel.

Coal and Natural Gas

Global warming damages are a very substantial component of efficient coal prices—equivalent to about $4 per GJ of coal (using the illustrative $40 per ton for CO_2), with little cross-country variation in these costs.[44]

Local air pollution costs—based on current industry average emission rates—can also be large, but they vary dramatically across countries. Damages are relatively high in some densely populated Asian countries like China ($9 per GJ), India ($7), Indonesia ($7), Pakistan ($5), and Thailand ($17); European countries like Germany ($8), Turkey ($15) and United Kingdom ($13); and especially in Russia ($15), and Ukraine ($38). On the other hand, damages are relatively low in African countries like Ethiopia ($0.3), Côte d'Ivoire ($0.3), Morocco ($1.6), South Africa ($2.8), and Tanzania ($0.5); advanced countries with relatively low population density and emission rates like Australia ($0.8), Canada ($1.0), Japan ($2.5); and Latin American and Caribbean countries like Colombia ($1.8), Costa Rica ($1.1), and Jamaica ($1.7).

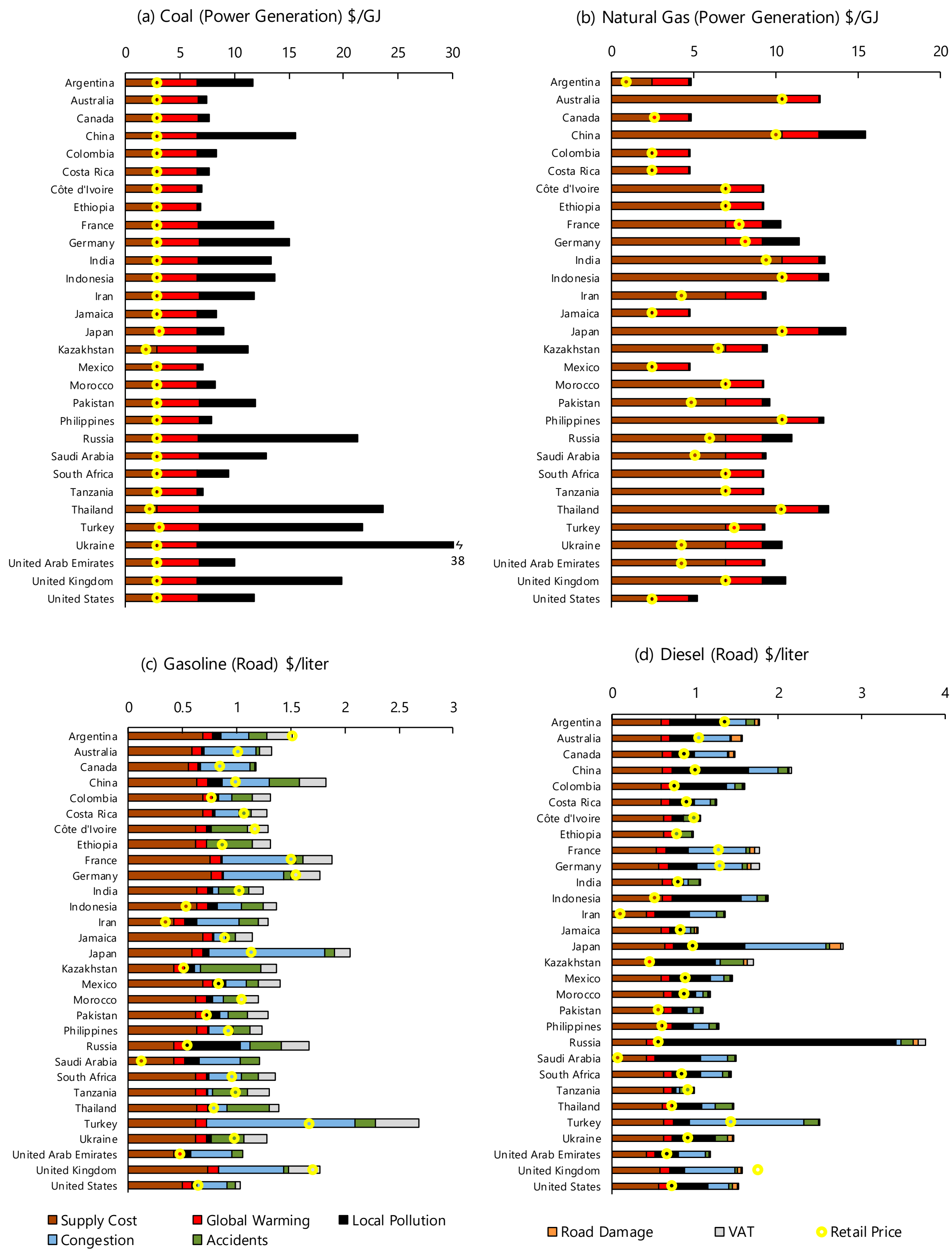
As noted above, efficient coal taxes may be lower in the presence of other mitigation measures like those to reduce air emission rates. If, for example, all coal plants had the same emission rates as representative plants in a country with currently the lowest rates then air pollution damages would be dramatically lower in Thailand ($5 per GJ) and Turkey ($3) and significantly lower in China ($6.6) and United States ($2.5).

Nonetheless, the bottom line—given our general assumption that current prices reflect supply costs—is that undercharging for coal use is substantial and pervasive with current prices typically a minor fraction of efficient prices for countries illustrated in Figure 1(a). Note that there is no VAT component for coal used as an intermediate product.

Natural gas prices do not reflect environmental costs either for the countries shown in Figure 1(b), though the degree of undercharging is less pronounced than for coal—gas prices are typically around 50-80 percent of the efficient price. This reflects three factors. First, supply prices for natural gas are around $2.5-10 per GJ, which are generally higher than for coal. Second, absolute carbon emission rates per GJ are about 40 percent lower for gas than for coal. Third, local air pollution damages are modest for natural gas, between $0-1.5 per GJ for countries in Figure 1(b).

[44] Carbon emission rates vary significantly across coal types (e.g., lignite, bituminous, sub-bituminous, anthracite) per unit of weight, but far less so per unit of energy content.

Figure 1. Current and Efficient Fuel Prices, 2015



Source: Authors' calculations.

Note: The selected countries account for 70-90 percent of global consumption of fuel products.

Petroleum Products

Supply costs for gasoline were 42-76 cents per liter in 2015 for the countries shown in Figure 1(c), and prices exceed these costs in all but three cases, principally because of fuel excises—prices were moderately below supply costs in Indonesia and Iran, and well below supply costs in Saudi Arabia. Nonetheless, even in countries where prices are above supply costs, they fall short of efficient prices in all cases, and more than 20 percent below efficient prices in 23 cases. Global warming costs are modest for gasoline at 10 cents per liter. And local air pollution costs are about the same as global warming costs, or smaller (except in Russia, due to an unusually large ground-level intake fraction for $PM_{2.5}$ suggested by our data). Traffic congestion costs are more substantial than global warming/local air pollution costs combined in 18 countries in Figure 1(c), especially high-wage, densely populated countries with high vehicle ownership rates (e.g., Europe). Accident costs can also be substantial, exceeding congestion costs in 11 cases, for example in countries where modal shares for pedestrians and cyclists are large, which increases the likelihood of their being hit by vehicular traffic. The VAT component of efficient gasoline prices (essentially all gasoline is taken to be a household product) is also substantial, varying between 10 and 30 cents per liter across most countries.

Undercharging for diesel—averaged across uses in transport, industry, households, and power generation—is also pervasive with prices falling short of their efficient levels by more than 20 percent in 22 countries (Figure 1(d)). Local air pollution costs for diesel are substantially larger than for gasoline due to higher air emission rates. On the other hand, congestion and accident costs per liter are generally smaller for diesel fuel, reflecting the share of heavy-duty vehicles in diesel consumption (which drive a shorter distance on a liter of fuel, implying smaller congestion and accident costs per liter of fuel). In addition, the VAT component for diesel fuel is smaller given the substantial share of intermediate use in fuel consumption.

B. Fossil Fuel Subsidies at the Global and Regional Level

The Global Picture

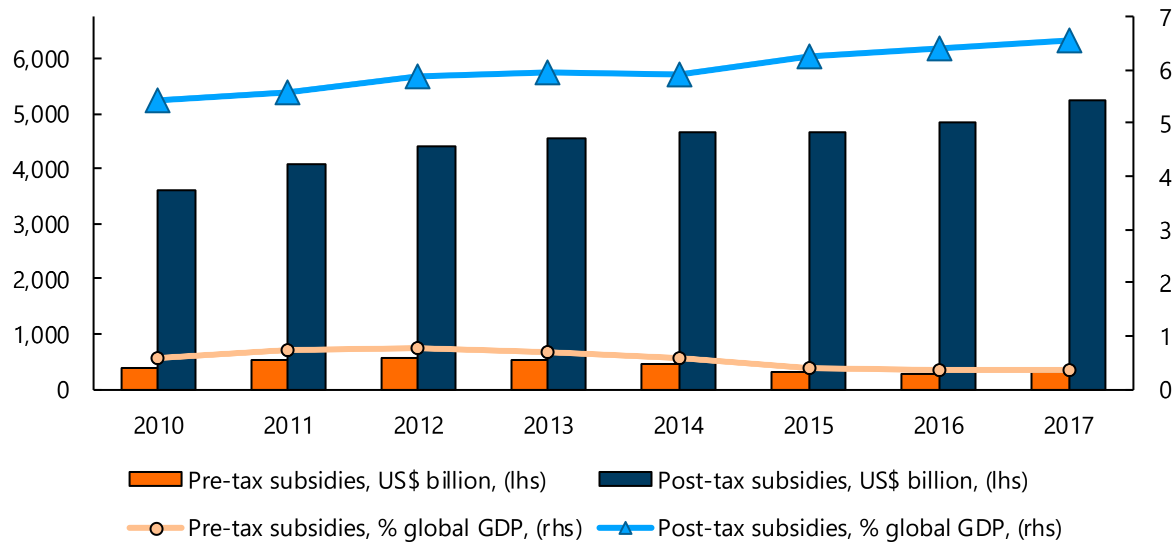
Figure 2 indicates trends in global pre-tax and post-tax fossil fuel subsidies. Global pre-tax subsidies, in both relative and absolute terms, declined substantially from 2012 (0.77 percent of global GDP or U.S. $572 billion) to 2016 (0.36 percent of global GDP or $269 billion).[45] This trend primarily reflects declining international fuel prices lowering the gap between them and domestic prices and efforts to reform fuel pricing in some, particularly oil-exporting, countries (Appendix 2). International prices rebounded in 2017, implying larger absolute price gaps in countries retaining price controls—the pre-tax subsidy rose slightly in absolute terms to $296 billion (0.37 percent of GDP).

But the far more important statistic for our purposes—not least because they are 15-20 times larger than pre-tax subsidies—is the post-tax fossil fuel subsidies. These subsidies have been reasonably stable, varying between 5.4 and 6.5 percent of global GDP between 2010 and 2017. In nominal terms, global subsidies were $4.7 and $5.2 trillion for 2015 and 2017 respectively—the

[45] For comparison, IEA (2017) put the corresponding, but slightly different measure of pre-tax subsides at $260 billion in 2016.

former figure is $0.6 trillion less than the corresponding estimate in Coady and others (2015) for reasons discussed below. The bottom line from Figure 2 is that there has not been a sharp increase in the pricing of environmental costs at the global level, despite some progress on fuel price reform and carbon pricing at the national level.

Figure 2. Global Energy Subsidies, 2010–2017



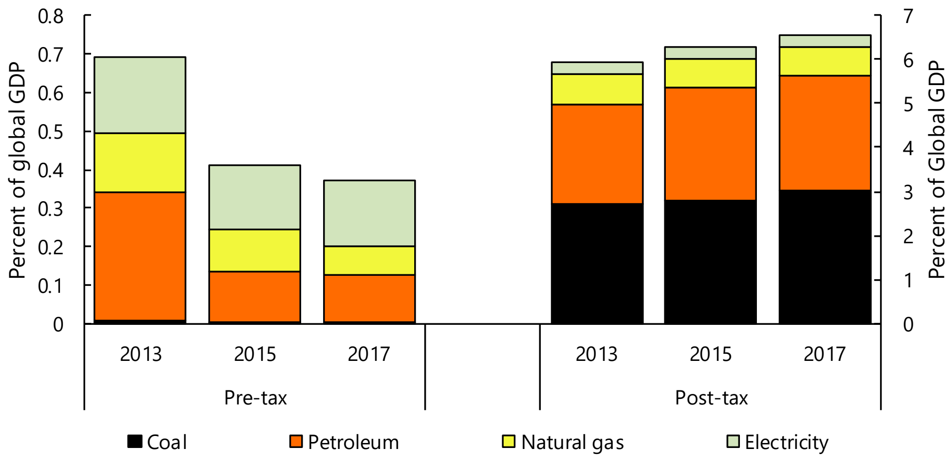
Source: Authors' calculations.

Subsidies by Fuel Product

Figure 3 shows the breakdown of subsidies by fuel product. In 2015, underpricing of supply costs for petroleum, natural gas, and electricity accounted for 32, 27, and 40 percent respectively of the global pre-tax subsidy (pre-tax subsidies for coal are negligible). In aggregate, 96 percent of the pre-tax subsidy in 2015 reflects consumer-side subsidies and 4 percent producer-side subsidies. For petroleum and natural gas, consumer subsidies primarily stem from the setting of domestic petroleum and gas prices below international prices in energy exporting countries, while the electricity subsidy largely reflects the failure to fully reflect generation costs in domestic tariffs. The decline in the global pre-tax subsidies reflects a decline in the component for petroleum products (down from 0.36 percent of global GDP in 2012 to 0.12 percent in 2017), for natural gas (down from 0.19 percent of global GDP in 2012 to 0.08 percent in 2017), and for electricity (down from 0.21 percent of global GDP in 2012 to 0.17 percent in 2017).

Of more interest, however, is the decomposition of post-tax subsidies and here coal is the most important fuel, accounting for 44 percent of the global subsidy in 2015, reflecting the underpricing of its large carbon and local air pollution costs. Petroleum is close behind, however, accounting for 41 percent of the global subsidy, largely reflecting the failure of excises on petroleum products to fully reflect environmental costs. Natural gas and electricity account for 10 and 4 percent respectively of the global post-tax subsidy—note that environmental costs in the power sector are attributed to the fuel inputs rather than the electricity output. The shares stay largely unchanged in 2017.

Figure 3. Global Energy Subsidies by Energy Product, 2013–2017

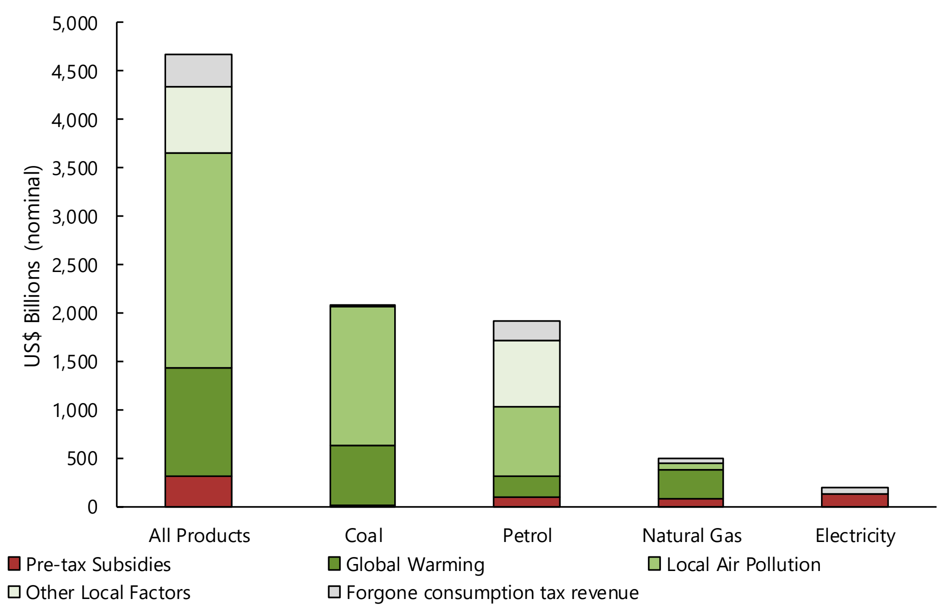


Source: Authors' calculations.

Post-tax Subsidies by Component

Figure 4 indicates the breakdown of global post-tax subsidies by component for 2015. Aggregated across all fuels, underpricing for air pollution accounts for 48 percent of post-tax subsidies, followed by undercharging for global warming (24 percent), broader environmental costs of road fuels (15 percent), undercharging for general consumer taxes (7 percent) and for supply costs (7 percent). For coal, global warming and air pollution account for 30 and 69 percent respectively of the post-tax subsidy, while for petroleum underpricing for local air pollution and congestion/accidents account for about 38 and 36 percent respectively of its post-tax subsidy.

Figure 4. Global Energy Subsidies by Energy Product and Subsidy Component, 2015



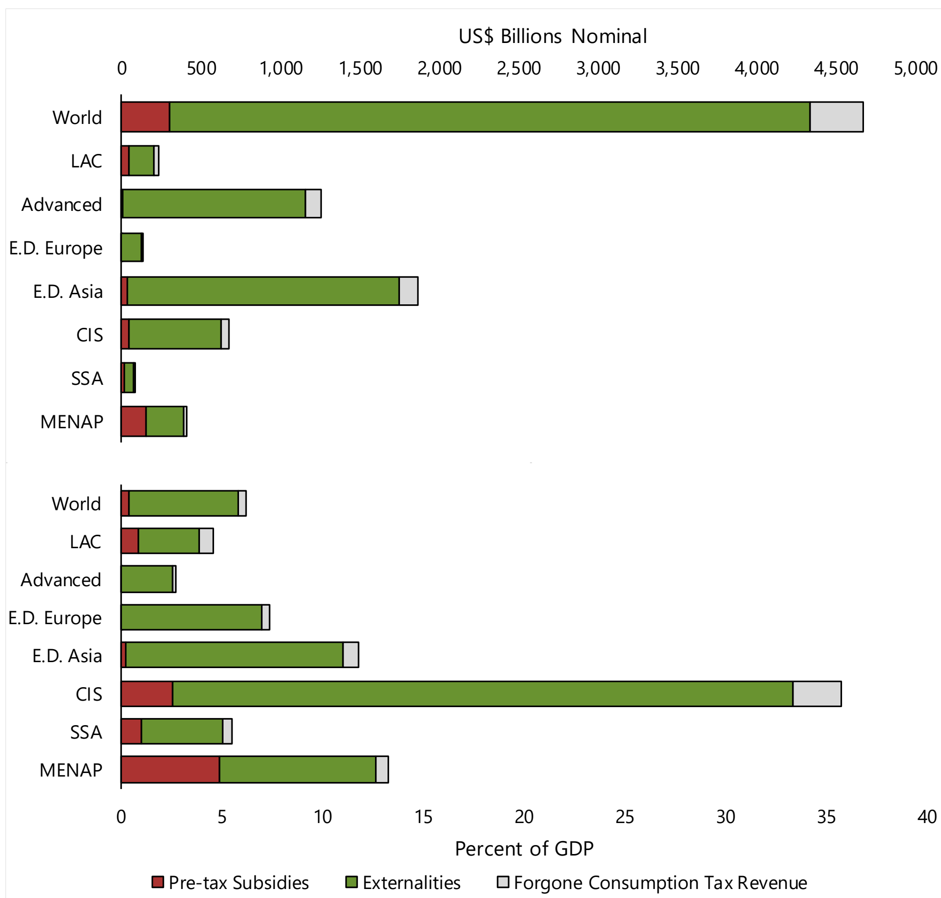
Source: Authors' calculations.

Subsidies by Region and Country

Figures 5 and 6 show energy subsidies in 2015 by region—see Appendix 4 for the countries covered by these regional classifications—broken down by component and energy product respectively, and both in absolute dollars and as a share of regional GDP.

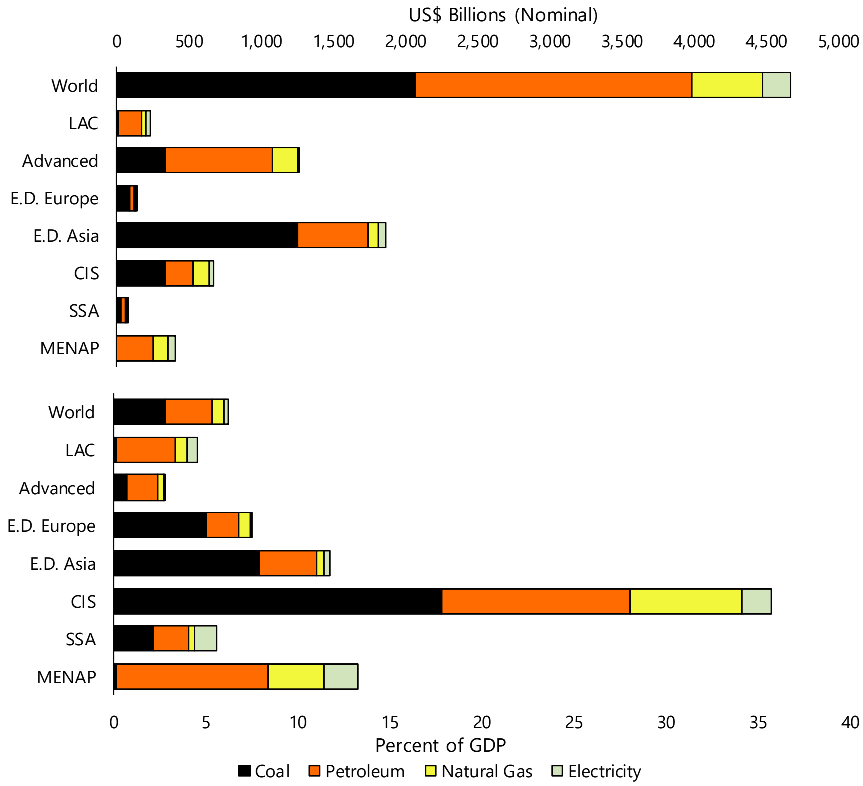
Pre-tax subsidies appear to be mostly a developing country issue, as the Middle East, North Africa, Afghanistan, and Pakistan (MENAP) region accounts for $152 billion of the global subsidy, followed by Commonwealth of Independent States (CIS) ($49 billion), Latin America and Caribbean (LAC) ($46 billion) and Emerging and Developing Asia (E.D. Asia) ($38 billion), compared with the small subsidy ($4 billion) from Advanced Economies. For post-tax subsidies, E.D. Asia accounts for the largest amount ($1.9 trillion), followed by advanced countries ($1.3 trillion), CIS ($0.7 trillion), MENAP ($0.4 trillion), LAC ($0.2 trillion), Emerging and Developing Europe (E.D. Europe) ($0.1 trillion), and Sub-Saharan Africa (SSA) ($0.09 trillion). As a percent of regional GDP, however, post-tax subsidies for advanced countries are still the smallest at about 3 percent. In contrast, post-tax subsidies are at a staggering 36 percent of regional GDP in CIS, and 13 and 12 percent respectively in MENAP and E.D. Asia.

Figure 5. Global Energy Subsidies by Region and Subsidy Component, 2015



Source: Authors' calculations.
Note: See text for regional definitions.

Figure 6. Global Energy Subsidies by Region and Energy Product, 2015



Source: Authors' calculations.
Note: See text for regional definitions.

The large subsidies primarily reflect, in CIS, high externality costs from coal, petroleum and natural gas use; in E.D. Asia, coal and natural gas use; and in MENAP, substantial undercharging for supply and environmental costs of petroleum.

By country[46] China remains, by far, the largest absolute subsidizer (at $1.4 trillion in 2015) and the next largest subsidizers are United States ($649 billion), Russia ($551 billion), European Union ($289 billion), and India ($209 billion). In per capita terms, subsidies are high in Russia ($3,832 per capita), Saudi Arabia ($3,709), UAE ($2,452), United States ($2,028), and Kazakhstan ($1,631).

C. Reform Benefits

Here we discuss estimates of the reform impacts had fuel prices fully reflected their efficient levels rather than their actual levels in 2015. While raising energy prices to efficient levels in one-go may not be realistic, the exercise provides a benchmark against which other more partial reforms might be evaluated.[47]

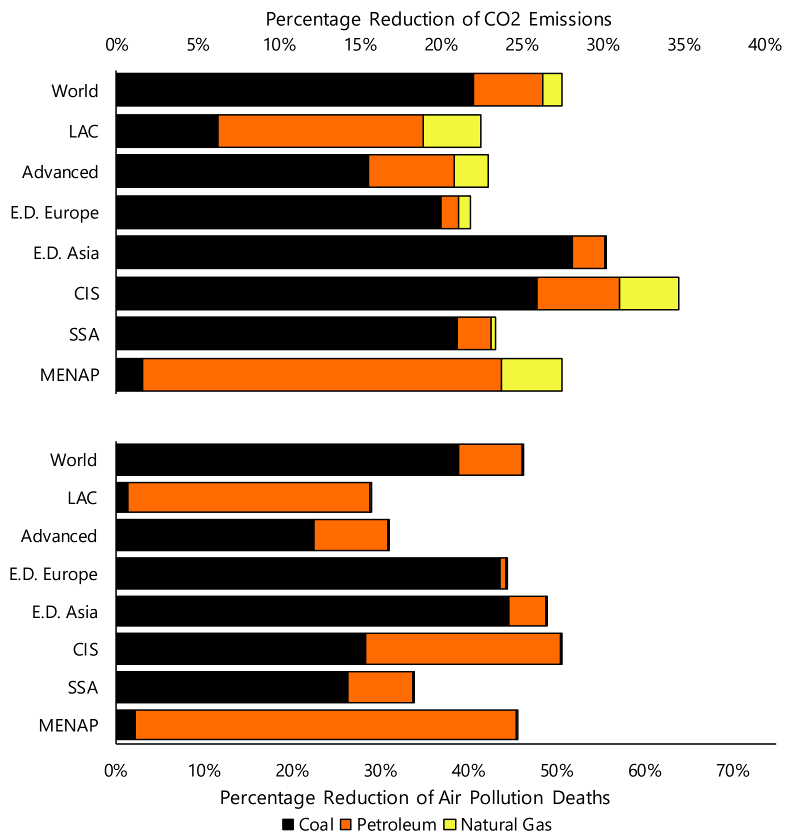
[46] See Appendix 5 for subsidy estimates for a list of selected countries. More detailed country-level subsidy estimates by fuel and by subsidy component can be found at https://www.imf.org/external/np/fad/subsidies/.

[47] See Clements and others (2013) and Coady and others (2018) for a discussion of reform challenges.

Environmental Benefits

Figure 7 shows the environmental benefits—the percent reductions in CO_2 emissions and premature air pollution deaths—broken down by region and fuel product. Globally, the CO_2 reduction is 28 percent, and varies regionally from 22 percent in E.D. Europe to 35 percent in CIS, and would represent a huge step towards meeting (or exceeding) countries' Paris mitigation pledges.[48] Around 80 percent of the CO_2 reduction is due to the reduction in coal use. The reduction in premature global air pollution deaths is about 46 percent, ranging from 29 percent in LAC to 51 percent in CIS. Again, the reduction is dominated by coal (at nearly 85 percent) because of both the reduction in coal consumption and the assumed accompanying reduction in air emission rates.

Figure 7. Environmental Gains from Removing Energy Subsidies, 2015



Source: Authors' calculations.
Note: See text for regional definitions.

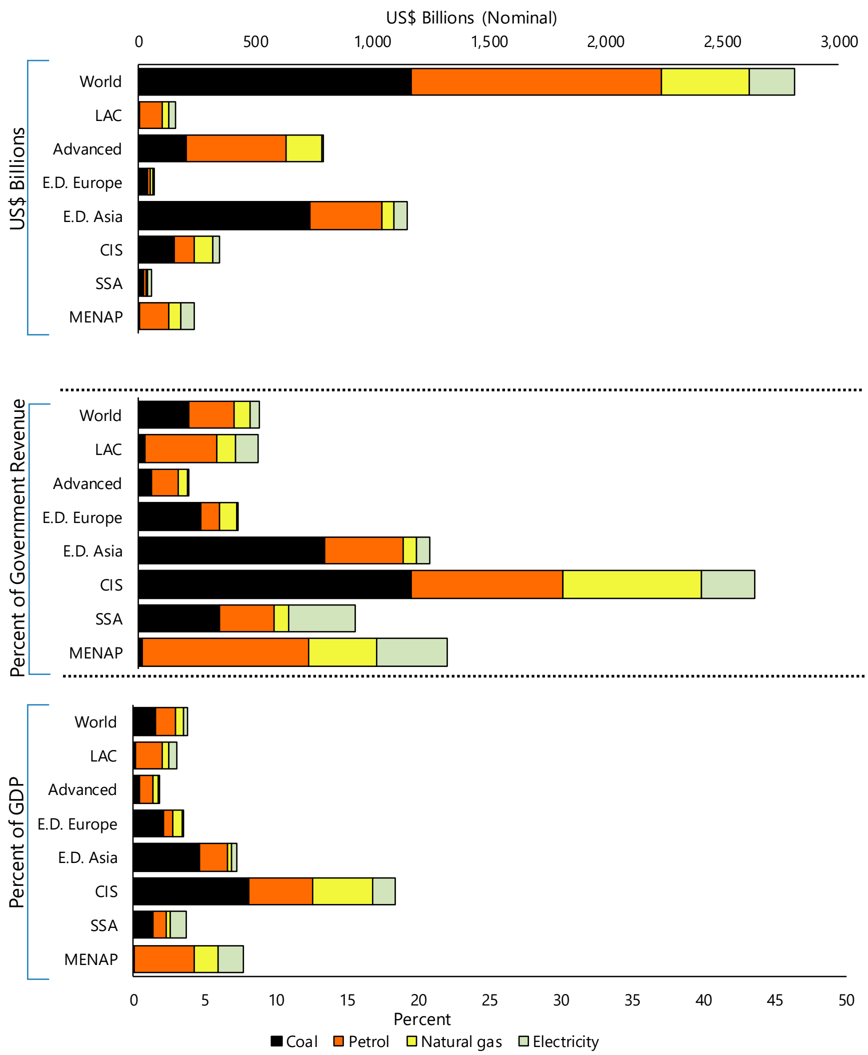
Fiscal Benefits

Figure 8 summarizes global and regional revenue gains for 2015. At a global level, the fiscal gain amounts to U.S. $2.8 trillion (3.8 percent of global GDP). The projected gain for 2017 (not shown

[48] In fact, according to Parry and others (2018), meeting these pledges would require a 21 percent reduction in CO_2 emissions below business as usual levels for G20 countries combined in 2030.

in the figure) is about $3.2 trillion (4 percent of global GDP). While the revenue gain is much lower than the post-tax energy subsidy, as expected due to demand responses, it is still substantial in the context of current revenue mobilization needs. Revenue gains vary substantially across regions, largely mirroring the distribution of post-tax energy subsidies.

Figure 8. Fiscal Gains from Removing Energy Subsidies, 2015

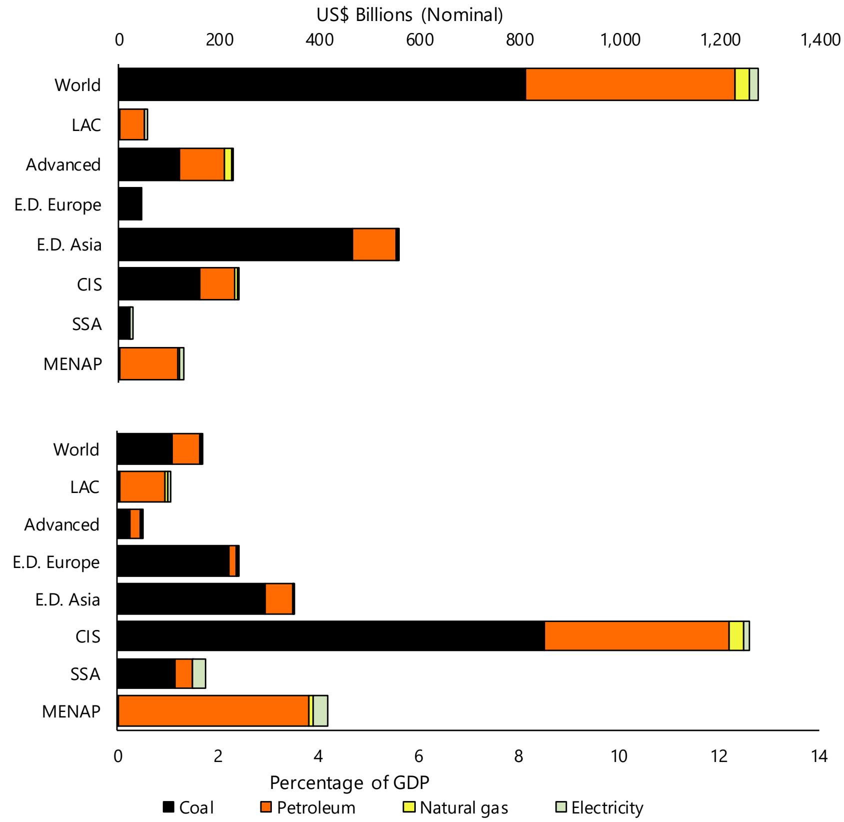


Source: Authors' calculations.
Note: See text for regional definitions.

Economic Welfare Benefits

Figure 9 summarizes the net economic welfare gains from eliminating post-tax subsidies, calculated as the benefits from reduced environmental damage and higher revenue minus the losses from consumers facing higher energy prices. At the global level, there is an annual welfare gain of more than $1.3 trillion, or 1.7 percent of global GDP, in 2015. Again, the distributions by region and by fuel products are similar to those for post-tax subsidies and fiscal gains.

Figure 9. Welfare Gains from Removing Energy Subsidies, 2015



Source: Authors' calculations.
Note: See text for regional definitions.

D. Sensitivity Analysis

Some of the estimation methodologies and assumptions underlying the above results may be subject to large uncertainties and controversies. This includes estimates of the pass-through of international price changes to domestic prices when projecting domestic prices when they are not available; price elasticities; transportation and distribution margins for fuel products; global warming, air pollution, and other vehicle externalities; and the income elasticity to extrapolate mortality valuation estimates from advanced to developing economies.

Table 3 summarizes various sensitivity analyses illustrating the importance of underlying assumptions for estimates of global energy subsidies and reform benefits for 2015 and 2017. In general, the results are only moderately sensitive to different assumptions, consistent with the findings in Coady and others (2015).

In terms of global post-tax subsidies as a share of global GDP, the lower-bound estimates for each sensitivity exercise ranges from 4.6-6.2 percent compared to the baseline 6.3 percent in 2015, while the upper-bound estimates range from 6.4-7.9 percent. For example, post-tax energy subsidies would still be a substantial 5.4 percent of global GDP even if global warming damages are 50 percent lower, and reach 7.1 percent of global GDP if they are 50 percent higher than in the baseline case. And subsidies are moderately sensitive to alternative assumptions about income elasticities for extrapolating mortality value estimates from advanced to developing countries—varying the income elasticity between 0.8 and 1.2 implies post-tax subsidies of 5.9 to 6.8 percent of global GDP.

CO_2, air pollution mortality, and economic welfare benefits are all sensitive to different assumptions for fuel price elasticities—for example, halving fuel price elasticities reduces CO_2 and air pollution benefits by about half and welfare gains by about a third.

E. Comparison with Earlier Estimates

Coady and others (2015) estimated global post-tax energy subsidies at $5.3 trillion (*earlier*) in 2015, which is $632 billion, or about 13.5 percent, larger than the updated estimate of U.S. $ 4.7 trillion (*current*). Pre-tax subsidies, however, are much closer, U.S. $333 billion in Coady and others (2015) compared to the updated estimates of U.S. $305 billion.

A simple decomposition (see Table 2 and Appendix 6 for details) suggest that most of the difference in post-tax subsidy estimates for 2015 is due to two main factors. First (and explaining $389 billion of the difference) is that actual fuel use for 2015 was significantly lower than projected in Coady and others (2015), partly justifying the revised methodology for fuel projections discussed above. Second (and explaining $382 billion) is that, on balance, environmental cost estimates are lower than previously projected. On the other hand, increases in country coverage, and changes in consumer prices and supply costs, moderately increase post-tax subsidies over earlier estimates. These aggregate figures mask considerable disparities in changes in estimated post-tax subsidies at the country level—for example, subsidies for China and Russia are $878 billion lower and $217 billion higher, respectively.

It should be noted that the differences between current and earlier estimates not only reflect data updates and changes in methodologies, but also pricing and regulatory reforms that countries have introduced to reduce pre-tax subsidies and address environmental externalities of energy consumption (Appendix 1). For example, coal consumption in China in 2015 was slightly lower than in 2012 while its economy experienced real annual growth of more than 7 percent on average during this period and as noted above, new data for China suggests a substantial decline in air emission rates between 2010 and 2015. This likely reflect recent efforts by the Chinese authorities to deploy control technologies and retire older plants as part of a broader rebalancing strategy to a greener and more service-based economy, as noted earlier.

Table 2. Decomposition of the Difference between Current and Earlier Estimates

Category	In US$ (billions)	In percent
Total difference in post-tax subsidy estimates for 2015 (new-old)	-632	100%
Differences in country coverage	105	-17%
Updates of OECD producer subsidies	-12	2%
Changes in consumption	-389	62%
Changes in prices (consumer prices and supply costs)	49	-8%
Changes in externality estimates	-382	60%

Source: Authors' calculations.

Table 3. Sensitivity Analysis

	Energy subsidies				Benefits from reform							
	Pre-tax, percent of GDP		Post-tax, percent of GDP		Revenue Gain		Percent Reduction in CO_2 emissions		Percent reduction in premature deaths		Net welfare gain, percent of GDP	
	2015	2017	2015	2017	2015	2017	2015	2017	2015	2017	2015	2017
Baseline	0.4	0.4	6.3	6.5	3.8	4.0	27.5	26.5	46.2	44.9	1.7	1.7
Fuel price elasticities												
Increased by 50%	NA	NA	NA	NA	3.1	3.3	37.8	36.6	55.1	53.5	2.2	2.2
Decreased by 50%	NA	NA	NA	NA	4.6	4.8	15.1	14.5	35.1	34.4	1.1	1.1
Coal and Natural Gas increased to 0.5	NA	NA	NA	NA	3.2	3.4	43.6	42.2	58.2	56.2	2.2	2.2
Transportation and distributive costs												
Increased by 50%	0.4	0.4	6.4	6.6	3.8	4.1	27.6	26.6	46.3	45.0	1.7	1.7
Decreased by 50%	0.4	0.4	6.2	6.5	3.7	3.9	27.4	26.3	46.0	44.7	1.7	1.7
Global warming damages												
Increased by 50%	0.4	0.4	7.1	7.5	4.3	4.6	29.9	28.8	47.7	46.5	1.9	2.0
Decreased by 50%	0.4	0.4	5.4	5.6	3.2	3.4	24.6	23.6	44.3	43.0	1.5	1.5
Air pollution damages												
Increased by 50%	0.4	0.4	7.9	8.3	4.5	4.8	30.5	29.7	49.4	48.1	2.5	2.6
Decreased by 50%	0.4	0.4	4.6	4.8	3.0	3.2	23.5	22.1	41.7	40.4	1.0	1.0
Other vehicle externalities												
Increased by 50%	0.4	0.4	7.1	7.4	4.2	4.4	28.3	27.4	46.8	45.5	1.9	1.9
Decreased by 50%	0.4	0.4	5.5	5.8	3.3	3.5	26.4	25.2	45.4	44.1	1.6	1.6
Income elasticity of mortality value of life												
Decreased to 0.8	0.4	0.4	6.8	7.0	4.0	4.2	28.5	27.5	47.6	46.2	1.9	1.9
Increased to 1.2	0.4	0.4	5.9	6.2	3.6	3.8	26.5	25.5	44.8	43.7	1.5	1.5

Source: Authors' calculations.

IV. Conclusion

Measures of post-tax fossil fuel subsidies provide a summary statistic of prevailing underpricing of fossil fuels. The above update confirms the earlier finding of substantial and pervasive underpricing of fossil fuels across countries, estimates subsidies that are of macroeconomic importance, and large economic welfare gains from energy price reform. Going forward, the composition of energy subsidies may change significantly. For example, the appropriate value on carbon emissions will likely rise as countries ramp up their Paris mitigation pledges, while underpricing for air pollution may decline with policies to reduce local air emission rates. However, we anticipate large overall fossil fuel subsidies will persist for the foreseeable future.

Not all countries are willing and able to raise fossil fuel prices, depending on national circumstances. Some, for example, may prefer policies that mimic many of the behavioral responses of higher fuel prices but without a first-order tax burden on energy users[49], while others may, for competitiveness concerns, be constrained by actions of comparator countries. The above analysis is still useful, however, in indicating the implicit prices that would be efficient for other policy instruments to target, and in informing international and regional debates on the possible coordination of energy price reform.

At an analytical level, the first-pass nature of the above estimates should be borne in mind. Given the broad country coverage, there are necessarily many simplifications in the approach and country authorities may have different perspectives on some of the assumptions and parameter values. We hope the above analysis, combined with the associated online analytical tools that facilitate country-level sensitivity analysis, will encourage efforts to further refine country-level assessments of the appropriate level of fossil fuel prices, the trade-offs with alternative policy instruments, and the benefits from policy reform.

[49] For example, combining a sliding scale of (i) taxes on emissions-intensive generators and subsidies for non-emissions-intensive generators with (ii) taxes on electricity-inefficient products and subsidies for electricity-efficient products could promote most of the behavioral responses from a power sector emissions tax, without a first-order burden on electricity prices.

Appendix 1. Climate, Air Pollution, and Fiscal Background in Selected Countries

Country	Climate	Air Pollution	Fiscal	
	Mitigation pledge for Paris Accord	Urban fine particualte concentration (micrograms/cubic meter), 2016	General government debt (% GDP)	
			2007	2017
Argentina	Reduce GHGs 30% below BAU in 2030	12	61	53
Australia	Reduce GHGs 26-28% below 2005 by 2030	7	10	42
Canada	Reduce GHGs 30% below 2005 by 2030	7	67	90
China	Reduce CO2/GDP 60-65% below 2005 by 2030	51	29	48
Colombia	Reduce GHGs 20% below BAU by 2030	17	32	49
Costa Rica	Reduce GHGs 44% below BAU by 2030	17	27	49
Côte d'Ivoire	Reduce GHGs 28% below BAU by 2030	24	74	46
Ethiopia	Reduce GHGs 64% below BAU by 2030*	34	47	56
France	Reduce GHGs 40% below 1990 by 2030	12	64	97
Germany	Reduce GHGs 40% below 1990 by 2030	12	64	64
India	Reduce GHG/GDP 33-35% below 2005 by 2030	68	74	70
Indonesia	Reduce GHGs 29% below BAU in 2030	16	32	29
Iran	Reduce GHGs 12% below BAU in 2030	34	11	41
Jamaica	Reduce GHGs 7.8% below BAU by 2030	14	114	104
Japan	Reduce GHGs 25% below 2005 by 2030	12	175	236
Kazakhstan	Reduce GHGs 15% below 1990 by 2020	15	6	21
Mexico	Reduce GHGs 25% below BAU in 2030	21	37	54
Morocco	Reduce GHGs 17% below BAU by 2030	31	52	64
Pakistan	No specific target	56	52	67
Philippines	Reduce GHGs 70% below BAU by 2030	19	52	38
Russia	Reduce GHGs 25-30% below 1990 by 2030	15	8	17
Saudi Arabia	Reduce GHGs 130 million tons below BAU by 2030	87	17	17
South Africa	Reduce GHGs 398-614 million tons in 2025 and 2030	24	27	53
Tanzania	Reduce GHGs 10-20% below BAU by 2030	25	22	38
Thailand	Reduce GHGs 20% below BAU by 2030	27	36	42
Turkey	Reduce GHGs up to 21% below BAU by 2030	41	38	28
UAE	Clean energy 24% by 2021	37	8	19
Ukraine	Reduce GHGs to 60 percent of 1990 levels by 2030	19	12	76
United Kingdom	Reduce GHGs 40% below 1990 by 2030	11	42	87
United States	Reduce GHGs 26-28% below 2005 by 2025	8	65	108

Sources: http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx. http://apps.who.int/gho/data/node.main.152?lang=en; and www.imf.org/external/pubs/ft/weo/2018/01/weodata/weoselgr.aspx.

Note: Mitigation pledges for the Paris Accord are detailed in countries 'Nationally Determined Contributions'—some pledges specify both conditional (contingent on external finance) and unconditional (not contingent) pledges, and in these cases the conditional pledges are included above; the United States announced its withdrawal from the Paris Agreement in May 2017 (to take effect in November 2020). For EU countries, the EU-wide target is shown (some member states like Germany have more ambitious targets). Air pollution statistics are a population-weighted average of annual concentrations of fine particulate matter—WHO (2018) recommends limiting these concentrations to below 10 micro grams per cubic meter. Debt statistics are gross debt (excluding any government assets).

Appendix 2. Some Recent Energy and Carbon Pricing Developments

Energy Pricing to Reflect Supply Costs[50]

Global pre-tax fossil fuel subsidies have declined substantially since 2014, reflecting both lower supply costs and efforts to reform pre-tax fossil fuel subsidies. While some countries only partially passed the reductions in international prices to domestic consumers, some others actively reformed their fuel prices.

Driven by a sharp decline in oil revenues because of lower oil prices, many oil exporting countries, particularly those in the Middle East, increased domestic prices for gasoline and diesel as well as electricity in some cases, including Bahrain, Egypt, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates. For example, in December 2015, Saudi Arabia increased the price of higher-grade gasoline by about 50 percent, regular gasoline by 67 percent (from a low-price level), and electricity tariffs for households by 35 percent on average (IMF, 2017). Some countries implemented automatic pricing mechanisms (China, Côte d'Ivoire, Jordan, Madagascar, Mexico, Oman, and United Arab Emirates) or liberalized energy prices (India, Indonesia, Thailand, and Tunisia) to prevent the return of energy subsidies.

However, as international oil prices started to rebound, some countries have implemented, announced or are considering reform reversals because of political pressures. Indonesia has frozen some domestic fuel prices; Brazil has lowered rather than increased its diesel prices; Malaysia has announced plans to restore fuel subsidies; Morocco is discussing introducing a cap on currently liberalized fuel prices; and Jordan and Madagascar temporarily suspended the implementation of their automatic pricing mechanisms.

Carbon Pricing[51]

At a national level, carbon taxes were introduced in the early 1990s in Denmark, Finland, Norway and Sweden, and since 2010 in Chile, Colombia, France, Iceland, Ireland, Japan, Mexico, Portugal, South Africa, Switzerland, and the United Kingdom. None of these taxes fully cover fossil fuel CO_2 emissions however—for example, in European countries taxes typically apply to emissions outside the EU ETS, though in contrast the UK carbon tax is imposed on top of the ETS charge for power sector emissions. Tax rates are relatively high in some cases, equivalent in 2017 to US $139, $101, $77, and $55 per ton of CO_2 in Sweden, Switzerland, Finland, and France respectively; between about $25 and $35 per ton in Denmark, Iceland, Ireland and the UK; and below $10 per ton in other cases.

Besides the EU, ETSs have been implemented at the national level in Kazakhstan, Korea, New Zealand, and (slated for 2020) China, and at the regional level in Canada, China, and the United States. These pricing systems typically cover emission from power generation and large industrial facilities, but not small-scale emissions (e.g., from vehicles, buildings, and small firms). Emissions prices have typically been between about $5 and $20 per ton. Canada is phasing in a carbon price floor arrangement (with a price equivalent to $40 per ton of CO_2 by 2022) which provinces

[50] The following discussion is based on information collected by IMF staff.

[51] The following discussion is based on WBG (2018).

and territories are required to meet through a carbon tax or equivalent ETS (for those out of compliance the federal government will impose carbon pricing).

At a global level, carbon pricing schemes currently cover only about 15 percent of GHGs (or 20 percent when China's national ETS comes into force) and the global average price is only about $2 per ton. If carbon pricing is applied to the supply of fossil fuels (as for most carbon taxes), it should be reflected in the consumer prices for those fuels and is therefore netted out from our estimates of fuel subsidies. If carbon pricing is applied at the point of fuel combustion (as for ETSs), it should be reflected in electricity prices, and is therefore not taken into account in our subsidy estimates.

Appendix 3. Tabular Summary of Data Sources

International Energy Agency	Countries Covered	Time period
Coal Consumption	138*	2010-2015
Diesel Consumption	138	2010-2015
Electricity Consumption	138	2010-2015
Gasoline Consumption	138	2010-2015
Kerosene Consumption	138	2010-2015
LPG Consumption	138	2010-2015
Natural Gas Consumption	138	2010-2016
Pre-tax subsidy estimates (coal, natural gas, electricity)	40	2010-2016
Organization of Economic Co-operation and Development		
Producer support estimates	33	2010-2016
USA Energy Information Agency		
Coal Consumption	124	2010-2016
Electricity Consumption	186	2010-2017
Gasoline Consumption	187	2010-2017
Kerosene Consumption	147	2010-2016
LPG Consumption	173	2010-2016
NG Consumption	111	2010-2014
United Nations		
Diesel Consumption	187	2010-2014
Electricity Consumption	173	2010-2014
Gas Consumption	189	2010-2016
Natural Gas/LPG Consumption	102	2010-2014
IMF		
VAT Database	152	2010-2017
Information from Country Desks	145	2010-2017
Oil international port price projections (US WTI; Brent; Dubai)	-	2010-2017
Natural gas international port price (US Henry Hub; Germany; Japan)	-	2010-2017
Coal international port price (Australia; South Africa)	-	2010-2017
Electricity subsidy estimates (including update of World Bank estimates)	27	2010-2017
Electricity subsidy estimates from Di Bella and others, 2015	32	2010-2017
Other macroeconomic data	-	2010-2017
Corrective tax estimates	150	2010
	182	2015
Other		
GIZ Gas and Diesel Price Database	165	2010, 2012, 2014, 2016
World Bank Doing Business Electricy Prices	2001	2014-2017
OECD		
Fossil Fuel VAT Database	34	2010-2017
Petroleum Product Supply Costs	-	2010-2017
Other press reports		
Electricity retail price	12	2010-2011

Note: * Coal consumption is available for 2016 for a limited number of countries.

Appendix 4. Regional Classification of Countries

Advanced Economies	Commonwealth of Independent States	Emerging and Developing Asia	Emerging and Developing Europe	Latin America and the Caribbean	Middle East, North Africa, Afghanistan, and Pakistan	Sub-Sahara Africa
Australia	Armenia	Bangladesh	Albania	Antigua and Barbuda	Afghanistan	Angola
Austria	Azerbaijan	Bhutan	Bosnia and Herzegovina	Argentina	United Arab Emirates	Burundi
Belgium	Belarus	Brunei Darussalam	Bulgaria	Bahamas, The	Bahrain	Benin
Canada	Georgia	Cambodia	Croatia	Barbados	Djibouti	Burkina Faso
Cyprus	Kazakhstan	China	FYR Macedonia	Belize	Algeria	Botswana
Czech Republic	Kyrgyz Republic	Fiji	Hungary	Bolivia	Egypt	Central African Republic
Denmark	Moldova	India	Kosovo	Brazil	Iran	Côte d'Ivoire
Estonia	Russia	Indonesia	Montenegro, Rep. of	Chile	Iraq	Cameroon
Finland	Tajikistan	Kiribati	Poland	Colombia	Jordan	Congo, Democratic Republic of the
France	Turkmenistan	Lao P.D.R.	Romania	Costa Rica	Kuwait	Congo, Republic of
Germany	Ukraine	Malaysia	Serbia	Dominica	Lebanon	Comoros
Greece	Uzbekistan	Maldives	Turkey	Dominican Republic	Libya	Cabo Verde
Hong Kong SAR		Marshall Islands		Ecuador	Morocco	Eritrea
Iceland		Micronesia		El Salvador	Mauritania	Ethiopia
Ireland		Mongolia		Grenada	Oman	Equatorial Guinea
Israel		Myanmar		Guatemala	Pakistan	eSwatini
Italy		Nauru		Guyana	Qatar	Gabon
Japan		Nepal		Haiti	Saudi Arabia	Ghana
Korea		Palau		Honduras	Sudan	Guinea
Latvia		Papua New Guinea		Jamaica	Somalia	Gambia, The
Lithuania		Philippines		Mexico	Syria	Guinea-Bissau
Luxembourg		Samoa		Nicaragua	Tunisia	Kenya
Macao SAR		Solomon Islands		Panama	Yemen	Liberia
Malta		Sri Lanka		Paraguay		Lesotho
Netherlands		Thailand		Peru		Madagascar
New Zealand		Timor-Leste, Dem. Rep. of		St. Kitts and Nevis		Mali
Norway		Tonga		St. Lucia		Mozambique
Portugal		Tuvalu		St. Vincent and the Grenadines		Mauritius
San Marino		Vanuatu		Suriname		Malawi
Singapore		Vietnam		Trinidad and Tobago		Namibia
Slovak Republic				Uruguay		Niger
Slovenia				Venezuela		Nigeria
Spain						Rwanda
Sweden						Senegal
Switzerland						Sierra Leone
United Kingdom						South Sudan
United States						São Tomé and Príncipe
						Seychelles
						Chad
						Togo
						Tanzania
						Uganda
						South Africa
						Zambia
						Zimbabwe

Appendix 5. Energy Subsidies in Selected Countries, 2015

Country	Post-tax Subsidies, US$ billion	Post-tax Subsidies, % GDP	Post-tax Subsidies, per Capita US$
Argentina	19	2.9	435
Australia	29	2.3	1,198
Canada	43	2.7	1,191
China	1,432	12.8	1,025
Colombia	13	4.6	278
Costa Rica	1	2.2	257
Côte d'Ivoire	2	5.6	81
Ethiopia	2	2.5	16
France	35	1.4	545
Germany	72	2.1	885
India	209	10.0	160
Indonesia	97	11.3	377
Iran	111	29.6	1,399
Jamaica	1	4.4	217
Japan	177	4.0	1,382
Kazakhstan	29	15.6	1,617
Mexico	54	4.6	431
Morocco	3	2.9	84
Pakistan	18	6.8	97
Philippines	10	3.4	99
Russia	551	40.3	3,832
Saudi Arabia	117	17.9	3,709
South Africa	45	14.0	806
Tanzania	2	4.0	34
Thailand	40	9.9	577
Turkey	64	7.4	814
Ukraine	61	66.7	1,357
United Arab Emirates	22	6.3	2,452
United Kingdom	28	1.0	427
United States	649	3.6	2,028

Source: Authors’ calculations.

Appendix 6. Decomposition of the Difference between Current and Earlier Estimates

The following formula is used to decompose changes in post-tax consumer subsidy estimates for countries where both earlier (from Coady and others 2015) and current estimates are available:

$$Q_1[S_1+E_1+(S_1+E_1)C_1V_1 - R_1] - Q_0[S_0+E_0+(S_0+E_0)C_0V_0 - R_0]$$
$$=[S_0+E_0+(S_0+E_0)C_0V_0 - R_0](Q_1-Q_0) + Q_1[(S_1+E_1+(S_1+E_1)C_1V_1 - R_1) - (S_0+E_0+(S_0+E_0)C_0V_0 - R_0)]$$
$$=[S_0+E_0+(S_0+E_0)C_0V_0 - R_0)(Q_1-Q_0) + Q_1[(S_1-S_0)+(E_1-E_0)+(S_1+E_1)C_1V_1- (S_0+E_0)C_0V_0-(R_1 - R_0)]$$
$$=[S_0+E_0+(S_0+E_0)C_0V_0 - R_0)(Q_1-Q_0) + Q_1(1+C_0V_0)(E_1-E_0) +V_1(S_1+E_1)(C_1-C_0) + Q_1(1+C_0V_0)(S_1-S_0)$$
$$+C_0(S_1+E_1)(V_1-V_0) -Q_1(R_1 - R_0)$$

Here 0 and 1 denote earlier and current estimates; Q fuel consumption; R domestic retail prices; S supply costs; E externality costs; C final consumption share; and V consumption tax rate.

The first term represents the differences in subsidy estimates due to changes in consumption, the second and third terms due to changes in environmental cost estimates, the fourth and fifth due to changes in both consumer prices and supply costs.

For countries where post-tax subsidies are not available in Coady and others (2015), their contributions to the changes in subsidies are summarized by the line “differences in country coverage” (note that all countries in Coady and others (2015) are covered by the update). Differences due to changes in producer subsidies are based on the differences between OECD 2010 and 2015 estimates (OECD, 2013 and 2018).

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