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How Large Are Global Fossil Fuel Subsidies?

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Summary. — This paper estimates fossil fuel subsidies and the economic and environmental benefits from reforming them, focusing mostly on a broad notion of subsidies arising when consumer prices are below supply costs plus environmental costs and general consumption taxes.

Estimated subsidies are $4.9 trillion worldwide in 2013 and $5.3 trillion in 2015 (6.5% of global GDP in both years). Undercharging for global warming accounts for 22% of the subsidy in 2013, air pollution 46%, broader vehicle externalities 13%, supply costs 11%, and general consumer taxes 8%. China was the biggest subsidizer in 2013 ($1.8 trillion), followed by the United States ($0.6 trillion), and Russia, the European Union, and India (each with about $0.3 trillion). Eliminating subsidies would have reduced global carbon emissions in 2013 by 21% and fossil fuel air pollution deaths 55%, while raising revenue of 4%, and social welfare by 2.2%, of global GDP.

Key words — energy subsidies, global warming, air pollution, efficient taxation, deadweight loss, revenue

1. INTRODUCTION

The issue of energy subsidy reform remains high on the international policy agenda. This reflects the need for countries to act on emissions reduction pledges submitted for the December 2015 Paris Agreement on climate change, opportunities for reform created by lower energy prices, and continuing fiscal pressures (set to worsen as populations age) in many countries.

The sustained interest in energy subsidy reform also reflects increasing recognition of the perverse environmental, fiscal, macroeconomic, and social consequences of fossil fuel subsidies—in fact it is difficult to think of products that are more harmful to subsidize than fossil fuels. These subsidies:

- Damage the environment, causing more premature deaths through local air pollution, exacerbating congestion and other adverse side effects of transportation systems, and increasing greenhouse gas emissions; [1]
- Impose large fiscal costs, which need to be financed by some combination of higher public debt, higher tax burdens, and lower public spending, all of which can be a drag on economic growth; [2]
- Discourage needed investments in energy efficiency, renewables, and energy infrastructure, and increase the vulnerability of countries to volatile international energy prices; [3] and
- Are a highly inefficient way to support low-income households, since most of the benefits from low energy prices leak away to the non-poor. [4]

The economic case for removing fossil fuel subsidies is clear, but in reality reform has proven difficult. [5] Understanding the size of energy subsidies, and the environmental, health, fiscal, and economic benefits from reducing them, is critical for moving the policy agenda forward as it helps policymakers craft legislation and communicate the case for reform to the general public. There is, however, an enormous range in the estimated size of energy subsidies at the global and country level (see Appendix 1). The central reason for this striking variation is a critical difference in the *definition* of what constitutes energy subsidies.

While the term "subsidy" has been widely used in the literature, its definition often varies, depending on the circumstance and application. The WTO Agreement on Subsidies and Countervailing Measures states that a "subsidy" exists when there is a "financial contribution" by a government or public body conferring a "benefit" (i.e., a "financial contribution" provided on terms more favorable than those the recipient could have obtained from the market). One definition by the OECD describes a subsidy as "any measure that keeps prices for consumers below market levels, or for producers above market levels or that reduces costs for consumers or producers". [6] However, whether "market levels" are defined as prices without government intervention (or taxes), or more broadly to include both corrective and consumption taxes, makes a critical difference.

As discussed in Appendix 1, most prior studies have focused on a narrow measure of energy subsidies—what we term "pre-tax subsidies"—which arise when consumer prices paid by fuel users are below the opportunity costs of fuel supply (e.g., many oil producers in the Middle East and North Africa traditionally subsidized petroleum consumption by setting domestic prices below international prices). This is the definition that leaders had in mind at the 2009 G20 Pittsburg meeting when they called for a phase out of energy subsidies (IEA, OPEC, OECD, & World Bank, 2010). However, economic efficiency requires that energy prices reflect not only supply costs but also (i) (most importantly) environmental costs like global warming and deaths from air pollution and (ii) taxes applied to consumer goods in general. The broader notion of energy subsidies—what we term "post-tax subsidies"—arises when consumer prices are below supply costs, plus a "Pigouvian" tax to reflect environmental damages and general consumer taxes.

Post-tax subsidies, which are the main focus here, are the relevant concept from an economic perspective, as they reflect the gap between consumer prices and economically efficient prices—the portion of this gap due to undercharging for supply costs, environmental costs, and general consumer taxes, is

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irrelevant from an efficiency perspective. Moreover, environmental damages from energy consumption are just as real as are supply costs (even if harder to measure), and any failure to fully internalize them means that some of the damages from fossil fuel use are not borne by fuel consumers and this constitutes a form of subsidy.

Clements *et al.* (2013) developed a rudimentary estimate of post-tax fossil fuel energy subsidies at a global level, using a simple extrapolation of environmental costs from a handful of country case studies available at the time. A key finding was that post-tax subsidies were much larger than pre-tax subsidies—these were estimated at $2 trillion and $492 billion worldwide respectively in 2011—reflecting the substantial, and pervasive, undercharging for environmental costs. Another finding was that, while pre-tax subsidies were mainly concentrated in developing countries, advanced economies accounted for a sizable portion of post-tax subsidies, underscoring that "getting energy prices right" is a pressing issue for advanced and developing economies alike.

Since the Clements *et al.* (2013) study, Parry, Heine, Lis, and Li (2014) have developed much more refined estimates—at the country-level for over 150 countries—of the environmental costs of fossil fuel products. For example, their estimates of air pollution costs incorporate country-level data on emission rates, population exposure to pollution, mortality rates for pollution-related illness, and the value of a statistical life.

This paper expands the emerging literature on post-tax energy subsidies in several dimensions. First, it provides a far more sophisticated estimate of global energy subsidies using the country-level estimates of environmental costs in Parry *et al.* (2014), combined with data on fuel consumption, prices, and actual taxes/subsidies compiled from a variety of sources. Second, it provides the first detailed estimates of regional and country-level energy subsidies using individual estimates for 155 countries. [7] Third, it provides simplified estimates of the global and regional environmental, fiscal, and social welfare gains from eliminating these energy subsidies.

The main findings of the paper are as follows:

- Global energy subsidies are large: post-tax energy subsidies are estimated at $4.9 trillion worldwide in 2013 and projected to reach $5.3 trillion in 2015, or 6.5% of global GDP in both years. The 2015 post-tax subsidies are 16 times as high as pre-tax subsidies ($333 billion). The post-tax subsidy estimate for 2011 is over twice that in Clements *et al.* (2013) and the difference reflects several factors, most importantly a large increase in estimated damages from local air pollution (see Appendix 4).
- Mispricing from a domestic perspective accounts for the bulk of the global subsidy: local air pollution accounted for 46% of the subsidy in 2013, under-taxation of broader vehicle externalities (e.g., congestion, accidents) 13%, undercharging for supply costs 11%, and for general consumer taxes 8%, while global warming accounted for 22% of the subsidy. In other words, 78% of the subsidy reflects domestic pricing distortions, implying that unilateral reform of energy subsidies is mostly in countries' domestic interests.
- Coal subsidies are especially large: coal accounted for 52% of the post-tax subsidy in 2013 (given its high environmental damage and that no country imposes meaningful excises on its consumption), petroleum 33%, and natural gas 10%.
- Post-tax subsidies are pervasive across advanced and developing economies and among oil-producing and non-oil-producing countries alike. But these subsidies are especially large (about 13–18%) relative to GDP in Emerging and Developing Asia, the Middle East and North Africa region, and the Commonwealth of Independent States. [8]
- In absolute terms, subsidies are highly concentrated in a few large countries: China's subsidy was $1.8 trillion in 2013, followed by the United States ($0.6 trillion), Russia, the European Union and India (each about $0.3 trillion), and Japan ($0.2 trillion).
- The gains from subsidy reform are substantial and diverse: getting energy prices right (i.e., replacing current energy prices with prices fully reflecting supply and environmental costs) would have reduced global carbon emissions in 2013 by 21% and fuel-related air pollution deaths by 55%, while raising extra revenue (accounting for smaller fuel tax bases) of 4% of global GDP and raising social welfare by 2.2% of global GDP. There is considerable variation in these gains across regions and countries however.

While there are many caveats (discussed below) to the estimation procedures and findings, the policy implications of the paper are clear: energy subsidies are very large and their removal (which entails levying Pigouvian taxes) would generate substantial environmental, fiscal, and economic welfare gains.

The rest of the paper is organized as follows. Sections 2 and 3 describe respectively the conceptual framework and estimation procedures. Section 4 presents the main results and sensitivity analyses. Section 5 offers concluding remarks.

2. CONCEPTUAL FRAMEWORK

This section discusses in turn the concept of efficient energy prices, the definition of energy subsidies, and the methodology used for measuring the benefits of price reform. We focus on subsidies for primary fuels—coal, natural gas, gasoline, diesel, and kerosene—and also electricity. Data constraints (e.g., lack of external cost estimates by country) prevent inclusion of some broader oil products (jet fuels, home heating oil, etc.) and in this sense our energy subsidies are understated, but only moderately. [9]

(a) *Efficient energy prices*

The efficient consumer price for an energy product (against which post-tax subsidies are measured), consists of the supply cost, a Pigouvian tax, and a general consumption tax. We discuss each in turn.

(i) *Supply cost*

For products traded across regions, the supply cost can be measured by the international reference price of the finished product as this reflects the cost faced by importers or revenue forgone by exporters. [10] We assume that petroleum products, natural gas, and coal are all tradable products—natural gas is typically classified as a tradable good as it is transported through pipelines and in liquefied form (Energy Information Administration (EIA), 2014).

In contrast, electricity is treated as a non-traded good (due to limited integration of power grid networks across borders). Here the supply cost is the domestic production cost or "cost-recovery" price, with costs evaluated at international reference prices.

(ii) *Pigouvian taxation*

When use of a product by a firm or household generates an external cost, efficient pricing requires that consumers face a price reflecting this cost, or more precisely, a Pigouvian tax. This is especially pertinent for fossil fuel energy, which generates a range of externalities including:

- *CO_2 emissions*, the leading cause of global climate change.
- *Premature mortality from exposure to outdoor air pollution* from fine particulates, produced either directly during fuel combustion or formed indirectly from atmospheric reactions of other emissions like sulfur dioxide (SO_2) and nitrogen oxides (NO_x).[11]
- *Broader externalities associated with the use of road fuels in vehicles*, such as traffic congestion, accidents, and (less importantly) road damage. Although motorists may internalize some of these costs (e.g., the average costs of road congestion, the risk of injuring themselves in single-vehicle collisions), they do not take into account other costs (e.g., their own contribution to slowing travel speeds for other road users, injury risks their driving imposes on pedestrians and other vehicle occupants).

One caveat is that some broader externalities associated with fossil fuel production and consumption are excluded from the analysis because the externalities are not well defined (e.g., energy security, occupational hazards at fuel extraction sites), their damages are small in relative terms (e.g., impaired visibility and crop damage from local air pollution), or a systematic country level database to quantify them is not available (e.g., methane leakage from natural gas extraction).[12] Another caveat is that fuel taxes are a second-best instrument for some externalities—air pollution emissions should be taxed directly or, equivalently, fuel taxes should be combined with rebates for adoption of emissions control technologies (e.g., SO_2 scrubbers), while road-specific, peak-period pricing is the efficient policy for reducing congestion. Nonetheless, it is entirely appropriate to reflect unpriced externalities in fuel prices until externalities are fully internalized through other instruments (likely a long time)—not doing so can forgo substantial welfare gains (e.g. Parry & Small, 2005) and has perverse policy implications.[13]

(iii) *Consumption taxes*

Energy products should also be subject to the same standard rate of value-added tax (VAT) or general sales tax (GST) applying to consumer goods for revenue-raising purposes. These taxes should only apply to final consumption (e.g., for gasoline, residential electricity consumption) and not intermediate consumption (e.g., truck fuel, industrial electricity) to avoid distorting firms' input choices (e.g., Diamond & Mirrlees, 1971).

(b) *Defining energy subsidies*

Energy subsidies consist of both consumer subsidies and producer subsidies.

(i) *Consumer subsidies*

Consumer subsidies arise when the price paid by consumers is below a benchmark price which, for *pre-tax* subsidies, is the supply cost, and for *post-tax* subsidies, is the efficient price as just described.

Figure 1 illustrates these notions of fossil fuel energy subsidies for a single energy product, where P_s denotes the supply cost, P_c the consumer price, P_e the efficient price, and Q_c fuel consumption given the consumer price. In the left panel, where the consumer price is below supply cost, the pre-tax subsidy is the black rectangle (fuel consumption multiplied by the gap between supply and consumer prices) while the post-tax subsidy is the black and gray rectangles combined (fuel consumption multiplied by the gap between efficient and consumer prices). In the right panel, in which the consumer price is between the efficient and supply costs, the post-tax subsidy is the gray rectangle (there is no pre-tax subsidy). If existing taxes overcorrect for externalities (and general consumption taxes) we count the post-tax subsidy as zero (rather than negative).[14]

(ii) *Producer subsidies*

Producer subsidies arise when producers receive direct or indirect support (e.g., receiving prices above supply costs, preferential tax treatment, direct government budget transfers, paying input prices below supply costs) which increases profitability when this support is not passed forward into lower consumer prices (e.g., because prices are determined on world markets). For presentational purposes, we include producer subsidies in pre-tax subsidies, though they are very small in relative terms.

(c) *Benefits of energy subsidy reform*

Given our focus on 155 countries, we provide highly simplified calculations of the fiscal, welfare, and environmental benefits of subsidy reform. In particular, we use a long-run comparative static framework (comparing outcomes in 2013 and a counterfactual without energy subsidies) and we leave aside cross-price effects among different fuels (which will vary considerably across countries). A standard, constant price elasticity fuel demand curve is used, given by

$$Q = \beta P^{\varepsilon} \rightarrow Q_e = \left(\frac{p_e}{p_c}\right)^{\varepsilon} Q_c \quad (1)$$

where $\varepsilon < 0$ and $\beta > 0$ are parameters, ε is the price elasticity of demand, and subscripts e and c denote values at efficient and current prices respectively. Supply curves are taken to be perfectly elastic—relaxing this assumption would have the same effect as assuming more inelastic demand.

(i) *Fiscal benefits*

In Figure 2, the fiscal benefits from removing post-tax subsidies, or increasing the consumer price from P_c to P_e, are the black rectangles. In the left panel, fiscal benefits consist of the revenue $(P_e - P_s)Q_e$ from raising the price above the supply cost to P_e at consumption Q_e, plus the pre-tax subsidy, $(P_s - P_c)Q_c$. In the right panel, the fiscal gain is again the revenue from setting the price above the supply cost, but this time less initial revenue $(P_c - P_s)Q_c$. That is:

$$\textit{Fiscal impact} = (P_e - P_s)Q_e - (P_c - P_s)Q_c \quad (2)$$

(ii) *Social welfare benefits*

The welfare gains from subsidy reform are indicated by the gray triangles in Figure 2. These gains reflect the environmental benefits plus revenue gains less the losses in consumer surplus, the latter being the trapezoid to the left of the demand curve, integrated over the price increase $P_e - P_c$. The net social welfare gain can therefore be expressed:

$$\textit{Welfare gain} = (P_e - P_c)Q_c - \int_{P_c}^{P_e} \beta P^{\varepsilon} dP = (P_e - P_c)Q_c - \frac{\beta}{1+\varepsilon}(P_e^{1+\varepsilon} - P_c^{1+\varepsilon}) \quad (3)$$

where from (1), β can be estimated from Q_c/P_c^{ε}.

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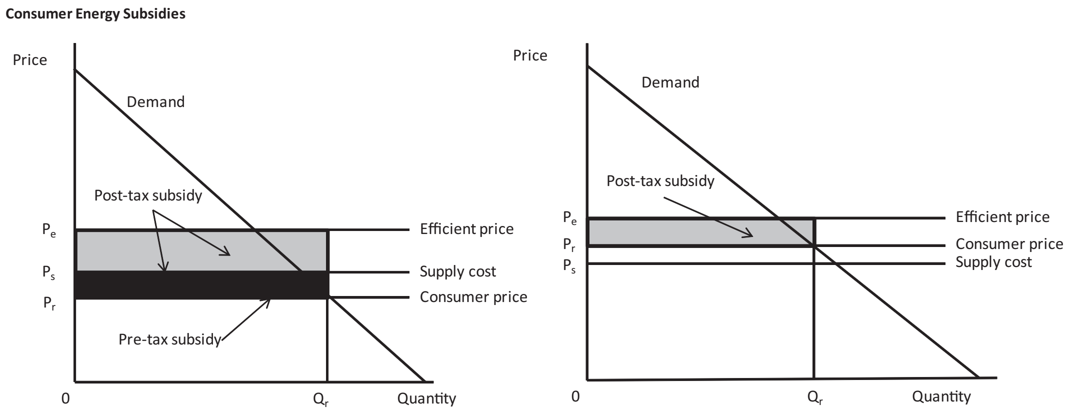

Figure 1. *Energy Subsidies.*

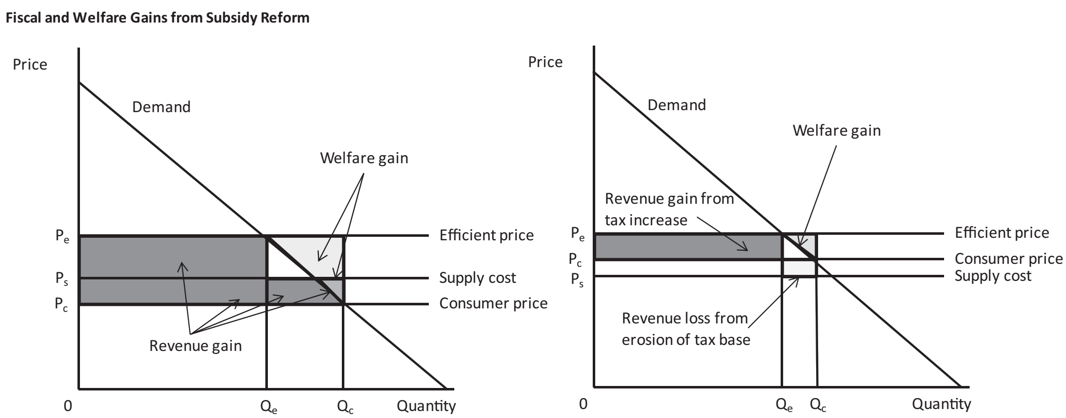

Figure 2. *Fiscal and Welfare Gains from Removing Post-Tax Subsidies.*

The welfare calculations here ignore linkages with distortions elsewhere in the economy from the broader fiscal system. Higher energy costs reduce real factor returns, which tends to exacerbate the efficiency costs of pre-existing tax distortions in factor markets (the "tax-interaction effect"), but on the other hand using the revenues from energy subsidy reform to cut other distortionary taxes produces efficiency gains (the "revenue-recycling effect"). The net impact can be a significant increase in overall welfare gains, if revenues are used to reduce an especially distortive tax. [15]

(iii) *Environmental benefits*

CO_2 reductions are computed by the primary fuel reductions multiplied by the fuel's CO_2 emissions factor, which varies substantially across products but not across countries, [16] and aggregated across primary fuels. Reductions in air pollution deaths from reducing petroleum and natural gas subsidies are computed by the fuel reductions multiplied by country-specific estimates of deaths per unit of fuel use.

For coal, there is substantial potential to reduce local air pollution emission rates through greater deployment of smokestack filtering technologies (e.g., SO_2 scrubbers) and we assume appropriate rebates would be provided for these technologies. That is, we assume local air emission rates at coal plants would fall from the existing fleet average to levels at representative plants with control technologies (country-specific data on both of these emission rates are available from Parry *et al.*, 2014, which can be converted into deaths per unit of coal use using estimates of deaths per ton of emissions). Thus, the reduction in deaths at coal plants is initial coal use multiplied by initial deaths per unit of coal use, less new coal use multiplied by new deaths per unit.

Figure 3 indicates the implications for revenue and welfare, where the initial consumer price equals the supply cost (which is most realistic for coal) and P_{eo} and P_{en} denote efficient prices at the old and new emission rates respectively. The revenue gain, net of crediting for control technologies, is now the black rectangle—the difference between the efficient prices at the new

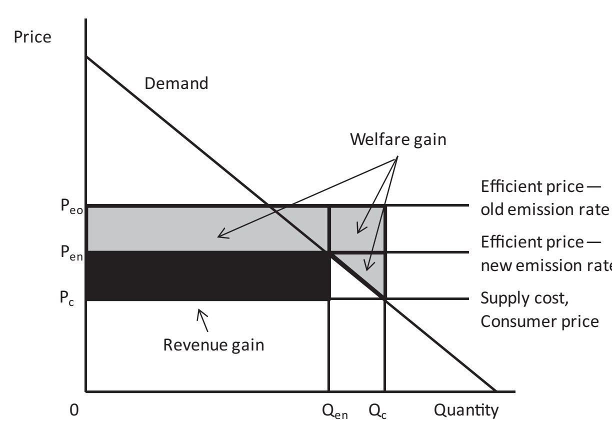

Figure 3. *Fiscal and Welfare Gains with Adoption of Emissions-Control Technologies.*

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emission rates and consumer prices, multiplied by output at the efficient price. The welfare gain is the gray area consisting of: (i) a trapezoid reflecting the difference between the efficient price at the old emission rate (P_{eo}) and marginal consumer benefit (the demand curve), integrated over the reduction in fuel use ($Q_c - Q_{en}$) and (ii) a rectangle equal to the new level of consumption (Q_{en}) multiplied by the difference between the unit environmental cost at the old and new emission rate ($P_{eo} - P_{en}$).[17]

3. DATA AND ESTIMATION

This section briefly discusses the data used to implement the conceptual approach described above. Appendix 3 provides more detail on data, estimation procedures, and updating data to 2015.

(a) *Pre-tax subsidies*

These are estimated using the "price-gap approach" (e.g., Clements, Coady, Fabrizio, Gupta, & Shang, 2014; Koplow, 2009), which involves multiplying existing fuel consumption by the difference between supply and consumer prices (for cases where this difference is positive). Country-level data on energy consumption by product and sectors are from the International Energy Agency (IEA) and the US Energy Information Administration (EIA). Consumer prices for petroleum products are compiled from IEA and IMF. For coal and natural gas, consumer prices are inferred from IEA for 41 countries and are assumed equal to supply costs in other cases. Consumer prices for electricity are compiled from IEA where available and in other cases from EIA, IMF, and World Bank sources.

For petroleum products, the supply costs are available from IEA for OECD countries. For other countries, they are measured using port (or hub) prices (taken from IEA) for the United States, NW Europe, and Singapore (with countries mapped to one of these regions). For natural gas, supply costs are measured by port prices (taken from IMF) for all countries, using either the United States, the Russian export price to Germany, or to Japan.[18] For coal, just one international price is used to measure supply costs for all countries, reflecting an average of prices (from IMF) for South Africa and Australia.[19] For oil importers, supply costs also include transport and distribution costs of $0.20 per liter (assuming $0.1 for transport cost from international hubs to the ports of importers and $0.1 for domestic distribution).[20] For electricity, supply costs for 100 countries with pre-tax subsidy estimates (from various sources including IEA, Di Bella *et al.* (2015), IMF and World Bank) are measured by the consumer price plus the unit pre-tax subsidy, while in other cases supply costs are assumed equal to consumer prices.

Producer subsidies are lumped into pre-tax subsidies but are relatively small ($17-$18 billion during 2011–15).[21]

(b) *Post-tax subsidies*

These are estimated using:

- Global warming damages, measured using CO_2 coefficients for primary fuels and a social cost of carbon (from US Interagency Working Group on Social Cost of Carbon, 2013) varying between $37.7 per ton of CO_2 in 2011 to $42.3 in 2015 in 2015 dollars.
- Air pollution damages are taken from Parry *et al.* (2014), which are based on concentration response functions and detailed country-level data on air emissions rates for different fuels, population exposure to emissions, baseline mortality rates for pollution-related illness, and the VSL.
- Broader vehicle externalities from Parry *et al.* (2014), including congestion, accidents, and road damage, are based on country-specific data or extrapolations.

The Pigouvian tax for transportation fuels takes account of the mix of light and heavy vehicles in the fleet (which have different external costs), that only around half of the price-induced fuel reduction comes from reduced driving (which reduces distance-related externalities) as opposed to improvements in vehicle fuel efficiency (which do not), and is defined net of existing fuel taxes which internalize some of the externality costs in fuel prices. For coal, natural gas, kerosene, and non-transportation diesel fuel, broader vehicle externalities do not apply and air pollution costs are taken to be the same irrespective of end use. For electricity, there are no environmental costs as these are attributed to primary fuels.

The consumption tax for final fuel consumption is calculated using the prevailing standard VAT or GST rate in the country, applied to the supply cost plus Pigouvian tax. For intermediate fuels, the consumption tax component is zero.

(c) *Fuel price elasticities*

In the absence of a consistently estimated database on how fuel price elasticities might vary systematically across countries, we use a common (long-run) own-price elasticity of –0.5 for petroleum products and electricity,[22] and an elasticity of -0.25 for coal and natural gas.[23] Reductions in electricity consumption are assumed to cause the same percent reduction in (the portion of) coal and natural gas used in power generation.

4. RESULTS

This section provides a picture of global energy subsidies and their breakdown by component, fuel product, and region/countries. It then discusses the fiscal, environmental, and social welfare benefits of removing energy subsidies. A sensitivity analysis is also provided followed by a discussion of further caveats.[24]

(a) *Energy subsidies: the global picture*

(i) *Global energy subsidies*

Figure 4 presents our estimates of pre- and post-tax global energy subsidies from 2011 to 2015. Pre-tax subsidies were 0.7% of global GDP in 2011 and 2013 and are projected to decline to 0.4% of global GDP, or $333 billion, in 2015.[25] This decline reflects falling international energy prices and an assumption for 2015 (based on historical experiences) that many countries only partially pass those reductions forward into consumer prices. Lower pre-tax subsidies for petroleum, natural gas, and electricity account, respectively, for 63%, 9%, and 28% of the reduction in total pre-tax subsidies during 2013–15 (the level and change in pre-tax subsidies for coal are negligible).

What is most striking in Figure 4 however is the dramatically larger size of post-tax subsidies, which are eight times as large as pre-tax subsidies in 2011 and 16 times as large in 2015. In fact, despite the sharp drop in international energy prices, post-tax subsidies have remained high, at $4.2 trillion or 5.8% of global GDP in 2011, $4.9 trillion or 6.5% in

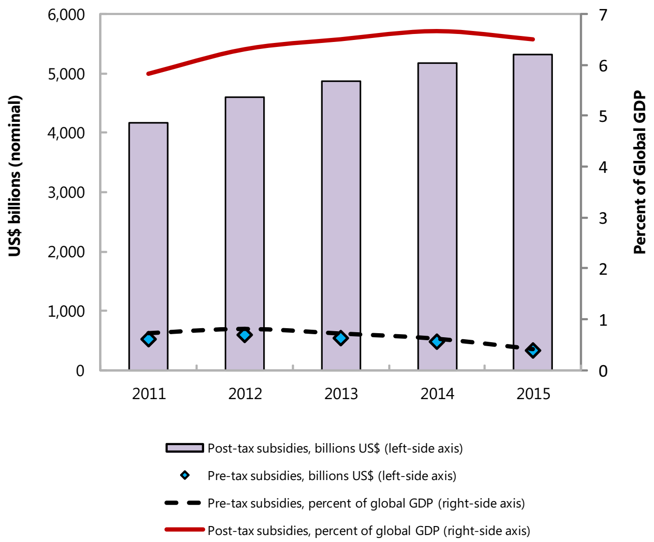

Figure 4. *Global Energy Subsidies, 2011–15.*

2013, and $5.3 trillion or 6.5% in 2015. The main reason for the rising absolute subsidy is growing energy consumption, especially for coal (see below).

The other striking finding from Figure 4 is the much higher estimate of post-tax subsidies—about twice as high for 2011—compared with Clements *et al.* (2013). As discussed in Appendix 4, this difference reflects a combination of factors, most importantly higher estimates of industrial air pollution damages.

(ii) *Breakdown by energy product and components of post-tax subsidies*

Figure 5 shows the breakdown by energy product of pre- and post-tax global energy subsidies in 2011, 2013, and 2015. In 2013, for pre-tax subsidies, petroleum contributes the biggest subsidy (0.34% of global GDP), followed by electricity (0.23%) and natural gas (0.16%), while the coal subsidy was very small (0.01%). All of the pre-tax subsidies for energy products (aside from coal) are projected to fall in 2015, especially for petroleum (which falls to 0.17% of global GDP).

Much more interesting and important however is the breakdown of post-tax subsidies. The most dramatic difference, compared with the pre-tax figures, is for coal which is the biggest source (52%) of post-tax subsidies, amounting to 3.0% of global GDP in 2011. The considerable size of coal subsidies reflects the substantial undercharging for its environmental impacts—coal is the most carbon-intensive and air-pollution intensive fuel per unit of energy, yet no country imposes meaningful taxes on coal from an environmental perspective (Parry *et al.*, 2014). In fact, the coal subsidy rises to a projected 3.9% of GDP in 2015, reflecting high growth in coal use in countries (especially China) with relatively high environmental damage per unit of coal.

Petroleum is the next most heavily subsidized product (33% of the total subsidy), with the projected post-tax subsidy remaining at 1.8% of global GDP in 2015 (despite declining petroleum prices). This is followed by natural gas (10% of the total subsidy) although, since underpricing of externalities for natural gas is less pronounced, the subsidy is only about one-third of that for petroleum. Last is electricity, for which the projected post-tax subsidy declines to just 0.2% of global GDP in 2015 (recall that environmental impacts are attributed to fuel inputs rather than power generation itself).

Figure 6 takes a closer look at the break-down of post-tax subsidies into different components, focusing on 2013. For all products combined, global warming accounts for 22% of the subsidy, local air pollution 46%, underpricing of other vehicle externalities 13%, pre-tax subsidies 11%, and forgone consumption tax revenue 8%. An important point, therefore, is that most (78%) of the underpricing of energy is due to domestic distortions rather than to global distortions (climate change). Energy pricing reform is therefore largely in countries' domestic interest and need not await globally coordinated action.

Taking a closer look at the decomposition for individual products (Figure 6), for coal (the fuel with the biggest subsidies) about three-fourths of the post-tax-subsidy is from undercharging for local air pollution and a quarter from undercharging for global warming. For petroleum, undercharging for broader vehicle externalities (congestion, accidents, road damage) accounts for 39% of post-tax subsidies, air pollution 18%, pre-tax subsidies 17%, foregone consumption tax revenue 14%, and global warming 13%. For natural gas, the main component is global warming (55%), followed by pre-tax subsidies (23%), local air pollution (12%) and forgone consumption tax revenue (10%). For electricity, pre-tax

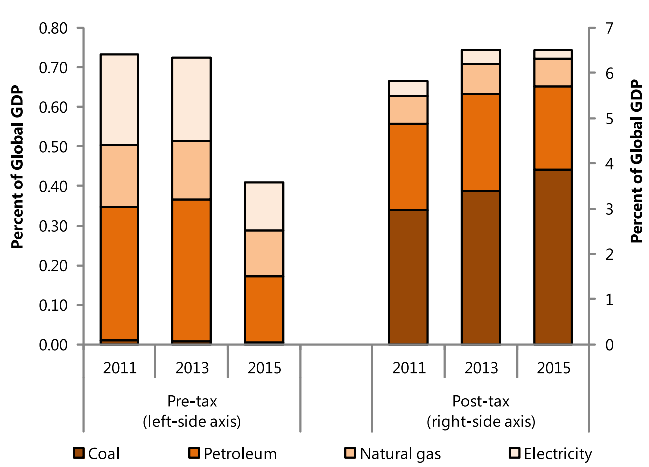

Figure 5. *Global Energy Subsidies by Energy Product, 2011–15.*

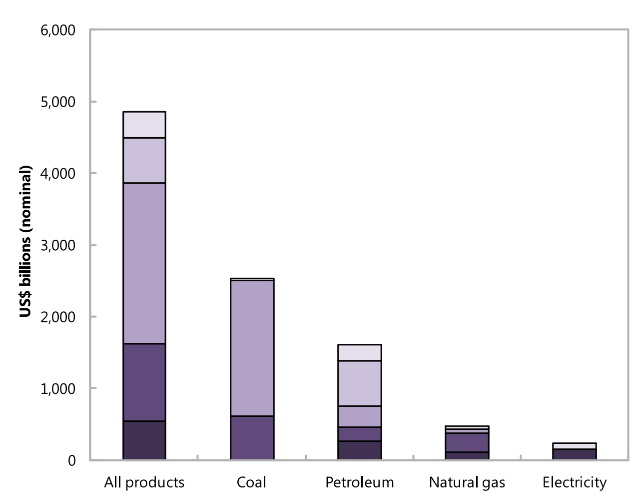

Figure 6. *Global Post-Tax Subsidies by Product and Subsidy Component, 2013.*

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subsidies are two-thirds of post-tax subsidies and foregone consumption tax revenue one-third.

(iii) *Regional breakdown*

According to our estimates for pre-tax subsidies in 2013, the Middle East, North Africa, and Pakistan region (MENAP), where petroleum prices are most often regulated, accounts for 47% of the global total, Emerging and Developing Asia 18% and advanced countries 4%. Figure 7 underscores that the regional breakdown looks radically different for post-tax subsidies (a point emphasized by Clements *et al.*, 2013). Emerging and Developing Asia now accounts for the largest share of subsidies (47%), followed by advanced countries (23%), Commonwealth of Independent States (CIS) (10%), MENAP (9%), Latin American Countries (LAC) (5%), Emerging Europe (3%) and Sub-Saharan Africa (2%). Energy price reform is therefore a pressing issue for all countries—developed and advanced economies and oil-producing and non-oil-producing countries alike.

Nonetheless, when expressed relative to regional GDP, advanced countries (where petroleum taxes are often high and air pollution emission rates relatively low) have the smallest post-tax subsidies, though at about 2½% of regional GDP they are still sizable. In contrast, post-tax subsidies are a staggering 13–18% of regional GDP in MENAP, CIS, and Emerging and Developing Asia. In the latter two cases, the large subsidies primarily reflect high coal use and high population exposure to coal's emissions and, in the former, substantial undercharging for both the supply and environmental costs of petroleum (Figure 8).

In terms of countries, China had the largest absolute post-tax subsidies in 2013 ($1,844 billion or 19.5% of GDP), followed by United States ($606 billion or 3.6% of GDP), Russia ($318 billion or 15.2% of GDP), European Union ($295 billion), India ($269 billion or 14.3% of GDP), Japan ($142 billion or 2.9% of GDP), Saudi Arabia ($129 billion or 17.2% of GDP) and Iran ($118 billion or 32.2% of GDP).[26]

(b) *The benefits of subsidy reform*

What matters most for policy—not only for its own sake, but also for convincing policymakers and stakeholders of the need for reform—are the benefits that reform will produce in terms of fiscal balances, carbon emissions, human health, and the economy. Here we discuss, focusing on 2013, the benefits to be realized from a complete elimination of post-tax energy subsidies—that is, a simple (static) comparison of outcomes that would have happened under a counterfactual with fully efficient energy prices, compared with outcomes under actual prices. At the global level, eliminating post-tax subsidies increases the price of coal, petroleum products, natural gas, and electricity by over 200%, 52%, 45%, and 69% respectively. Some regions have particularly high price increases, for example, for petroleum products about 400% in MENAP and 152% in CIS.

(i) *Fiscal benefits*

Figure 9 summarizes revenue gains. At a global level, these gains are estimated at about $3.0 trillion or 4% of global GDP. The revenue gain is significantly lower than the post-tax energy subsidy, as it accounts for the price-induced reduction in energy use and (as noted above) implicitly assumes tax rebates are used to promote adoption of air emission control technologies for coal. Nonetheless this is still a very large number, more than 10% of (global) government revenue or more than the entire revenue most governments collect from corporate income taxes.[27]

Revenue gains vary substantially across regions and the regional distribution largely resembles that of post-tax energy subsidies, with large potential revenue gains—about 9% of regional GDP or more—in Emerging and Developing Asia, CIS, and MENAP. It is worth noting that, generally speaking, these are also regions where the revenue potential from broader tax instruments is constrained by extensive informal activity, making revenue from (easier to tax) fuels especially

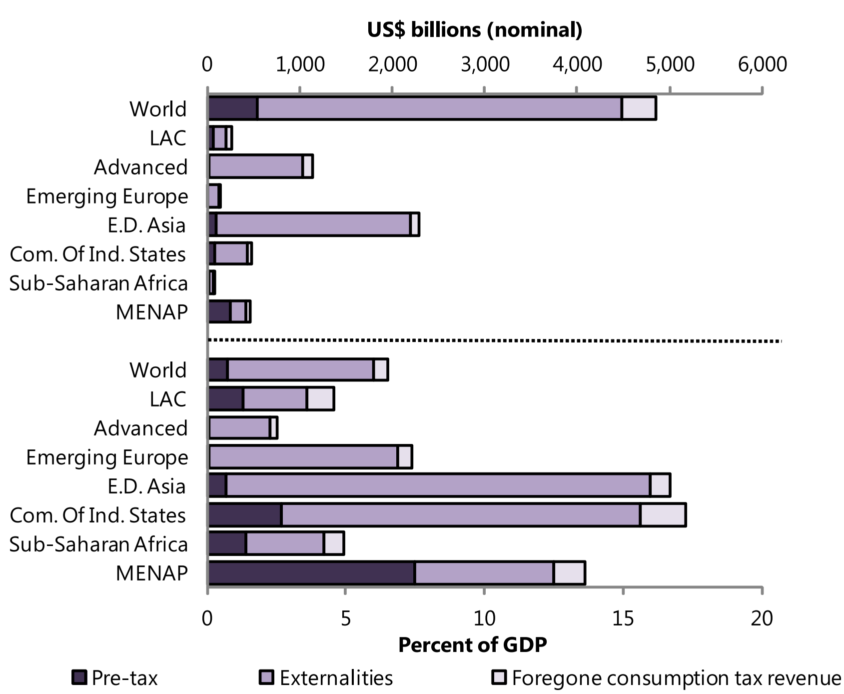

Figure 7. *Energy Subsidies by Region and Subsidy Component, 2013.*

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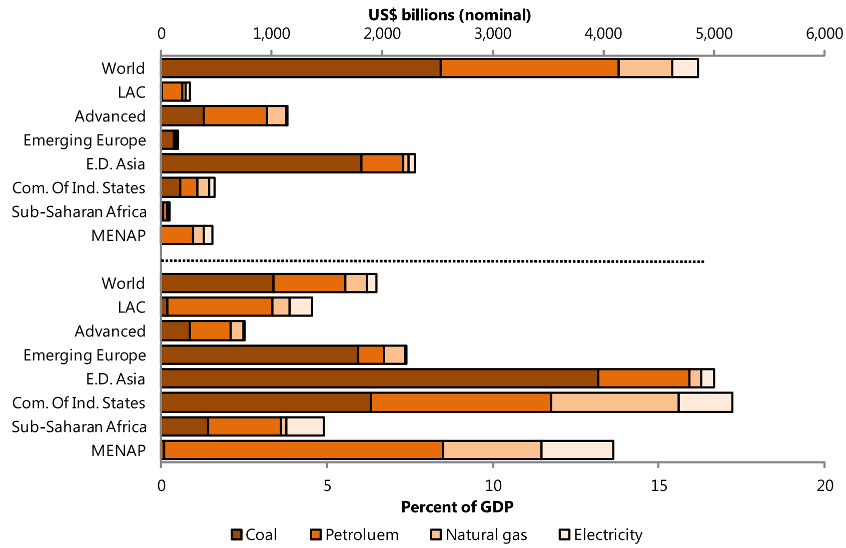

Figure 8. *Post-Tax Energy Subsidies by Region and Product, 2013.*

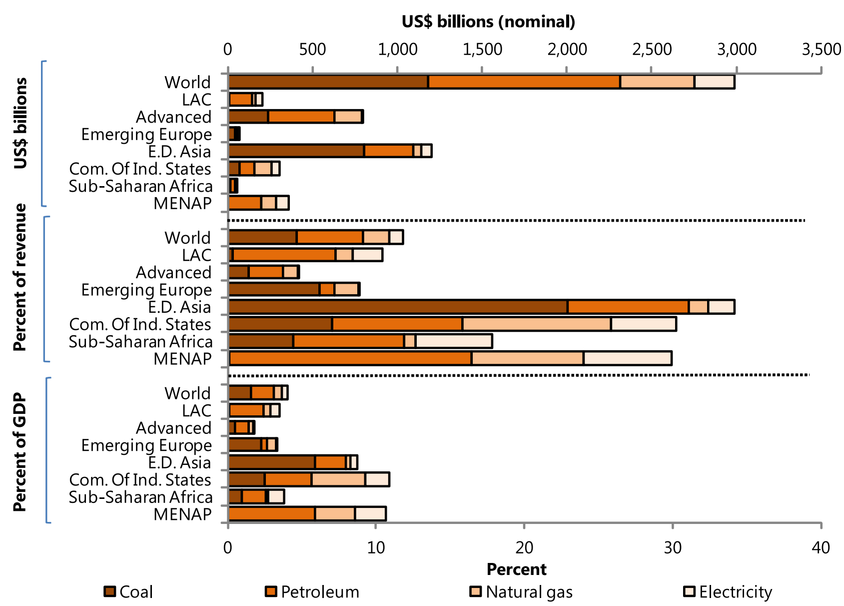

Figure 9. *Fiscal Gain from Removing Energy Subsidies, 2013.*

appealing on fiscal grounds. As regards the distribution of fiscal benefits by energy product, the share of coal in the fiscal gain is smaller than its share in the post-tax energy subsidy, partly reflecting the rebates assumed for air emissions control technologies.

Figure 10 indicates the changes in fuel use underlying these revenue impacts. The reduction in energy consumption is substantial for some regions and products. For example, reductions in gasoline and diesel consumption are about 50% in MENAP and 30% in CIS countries—regions where full energy price reform would lead to especially large price increases (see above). In the case of gasoline, the new per capita consumption in MENAP is similar to the pre-reform level of Emerging Europe and significantly higher than the pre-reform levels in Sub-Saharan Africa (SSA) and Emerging and Developing Asia. As expected, the reductions in coal consumption are most pronounced in Emerging and Developing Asia and CIS countries, where environmental damages per unit of coal use (and hence proportionate price increases) are highest. At a global level, consumption reductions range from just over 10% for natural gas to slightly more than 25% for coal.

(ii) *Environmental benefits*

Figure 11 summarizes the environmental benefits from eliminating post-tax energy subsidies for 2013 with the breakdowns by region and contribution of fuels. The global CO_2 reduction (based on assumptions about the price responsiveness of fossil fuels) is substantial, at 21%, and would represent a major step toward the de-carbonization ultimately needed to stabilize the global climate system. Reductions in coal use account for 61% of this CO_2 reduction (due to its high carbon intensity and the high coal taxes needed to cover carbon and air pollution damages), 87% of CO_2 reductions in Emerging and Developing Asia (where coal intensity is relatively high)

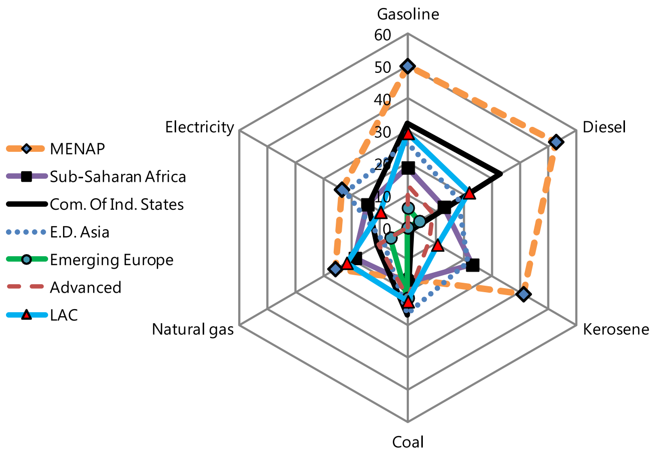

Figure 10. *Energy Subsidy Reform and Energy Consumption, 2013.*

and 36% of CO_2 reductions in MENAP (where coal intensity is relatively low).

The reduction in premature global air pollution deaths is even more striking at 55%. Coal accounts for a larger share of this reduction (93%) than in the case of CO_2, as energy price reform (coupled with rebates for control technologies) reduces both coal usage and air emission rates. Again, the global numbers mask some significant disparities. In LAC and advanced countries, the reduction in deaths is around 25% reflecting the limited use of coal in the former and relatively low air emission rates in the latter. In contrast, reductions in air pollution deaths are more than 60% in Central and Eastern Europe and Emerging and Developing Asia, given high coal usage there and the extensive population exposure to emissions due to high population density. Even in MENAP, the reduction in air pollution deaths is about 50%, due to the large reduction in petroleum consumption.

(iii) *Social welfare gains*

Figure 12 summarizes the net economic welfare gains from eliminating post-tax subsidies. At the global level, these amount to more than $1.4 trillion, or 2.0% of global GDP, in 2013. The breakdown of these gains by fuel product and region can largely be anticipated from the previous discussion—for example, the bulk of the gains come from coal (reductions in its use and adoption of emissions control technologies). Similarly, welfare gains as a percent of regional GDP are greatest in Emerging and Developing Asia (6.9% of regional GDP), CIS (5.0%), MENAP (4.7%) and Emerging Europe (4.4%). The small welfare gain in advanced economies, in particular relative to their share in global energy subsidies, mainly reflects their high deployment of emissions control technologies by coal users and the small gap (at least in Europe) between consumer prices and efficient prices for petroleum products.

(c) *Sensitivity analysis*

Some of the estimation methodologies and assumptions underlying the above results may be subject to significant uncertainties and controversies. This includes estimates of the pass-through of international price changes to domestic prices; price elasticities; transportation and distribution margins; and global warming, air pollution, and other vehicle externalities. Table 1 summarizes various sensitivity analyses, focusing on global energy subsidies, and reform benefits for 2013 and 2015. Often the results are only moderately sensitive to different assumptions.

For example, increasing or decreasing carbon damages, local air pollution damages, or other vehicle externalities one at a time by 50%, implies post-tax subsidies in 2013 of between 4.9% and 8.1% of global GDP, revenue gains between 3.4% and 4.6% of global GDP, reductions of CO_2 emissions between 18.1% and 22.9%, reduction in premature deaths between 52.7% and 57.1%, and welfare gains between 1.2% and 2.8% of global GDP.

Varying energy price elasticities affects only the gains from policy reform, although the results here are fairly sensitive to different assumptions. Increasing or decreasing all energy price elasticities by 50% relative to their baseline levels implies CO_2 reductions of 11.3–28.8% and premature death reductions of 48.7–60.7%. And using coal and natural gas price elasticities

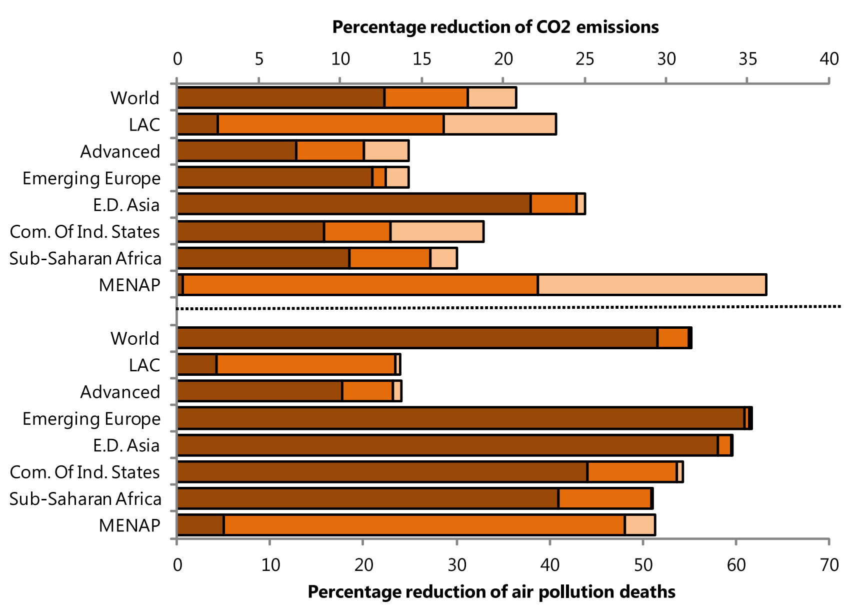

Figure 11. *Environment Gain from Removing Energy Subsidies, 2013.*

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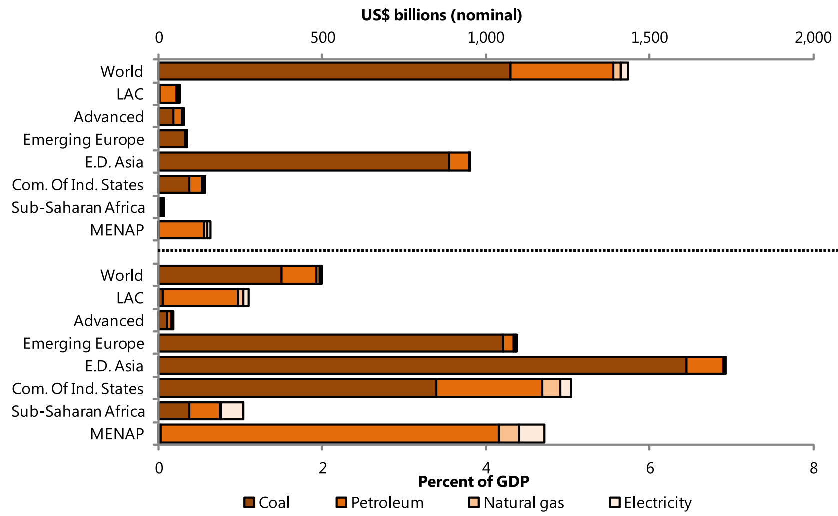

Figure 12. *Welfare Gain from Removing Energy Subsidies, 2013.*

Table 1. *Sensitivity analysis: global results for 2013 and 2015*

	Energy subsidies				Benefits from reform							
	Pre-tax, percent of GDP		Post-tax, percent of GDP		Revenue gain, percent of GDP		Percent reduction in CO_2 emissions		Percent reduction in premature deaths		Net welfare gain, percent of GDP	
	2013	2015	2013	2015	2013	2015	2013	2015	2013	2015	2013	2015
Baseline case	0.7	0.4	6.5	6.5	4.0	3.6	20.8	23.7	55.2	57.4	2.0	2.2
Fuel price pass-through												
Set to 0%	–	0.3	–	5.4	–	3.2	–	16.8	–	53.5	–	2.0
Set to 100% plus consumption tax rate	–	0.6	–	6.9	–	3.9	–	25.7	–	58.9	–	2.3
Fuel price elasticities (magnitude)												
Increased by 50%	0.7	0.4	6.5	6.5	3.5	3.0	28.8	32.5	60.7	63.3	2.3	2.6
Reduced by 50%	0.7	0.4	6.5	6.5	4.6	4.2	11.3	13.1	48.7	50.1	1.6	1.8
Coal and natural gas increased to 0.5	0.7	0.4	6.5	6.5	3.6	3.0	31.8	36.7	63.1	66.5	2.3	2.5
Transportation and distribution costs												
Increased by 50%	0.8	0.4	6.7	6.7	4.1	3.7	21.0	24.0	55.5	57.7	2.0	2.3
Reduced by 50%	0.7	0.4	6.3	6.4	3.9	3.4	20.5	23.3	55.0	57.1	2.0	2.2
Global warming damages												
Increased by 50%	0.7	0.4	7.3	7.4	4.5	4.1	22.8	26.0	56.3	58.6	2.1	2.4
Reduced by 50%	0.7	0.4	5.7	5.6	3.4	3.0	18.4	20.9	54.0	56.0	1.9	2.1
Air pollution damages												
Increased by 50%	0.7	0.4	8.1	8.3	4.6	4.1	22.9	26.0	57.1	59.4	2.8	3.2
Reduced by 50%	0.7	0.4	4.9	4.7	3.4	2.9	18.1	20.6	52.7	54.6	1.2	1.3
Other vehicle externalities												
Increased by 50%	0.7	0.4	7.2	7.3	4.4	4.0	21.8	24.9	55.7	57.9	2.1	2.4
Reduced by 50%	0.7	0.4	5.8	5.8	3.5	3.1	19.5	22.1	54.7	56.7	1.9	2.1

of −0.5 (i.e., the same as for petroleum elasticities), implies diminished revenue gains of 3.6% of global GDP in 2013 and larger environmental benefits, with reductions in CO_2 and premature deaths of 31.8% and 63.1%, respectively. Finally, 2015 projections are somewhat sensitive to different assumptions about the pass-through of price changes, and insensitive to the levels of transportation and distribution margins.

(d) *Further caveats*

Beyond parameter uncertainties, there are a number of further caveats to the above estimates. For one thing, the estimated benefits of subsidy reform are based on a long-run comparative static analysis—the environmental, health, and social welfare benefits (but not fiscal benefits) are smaller in the nearer term to the extent that shorter run fuel price responses are smaller than longer run responses. Our analysis also abstracts from cross-price effects among fuels and cross-country differences in fuel price elasticities—these may be significant in specific cases (e.g., countries with substantial competition between coal and natural gas in power generation) but there is no systematic way to introduce these complications into an analysis like ours with a large number of countries. In addition, supply-side responses are not modeled as well as

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other second round effects. Simplifying assumptions are also made when country-level price/cost data are not available, particularly in the case of natural gas and coal. They, however, either are expected to have small effects or tend to lead to conservative estimates.

5. CONCLUSIONS

In summary, global energy subsidies—as measured by the difference between what consumers should be paying for fossil fuel energy to cover supply costs, environmental costs, and general consumption taxes, and what they actually pay—are very large at an estimated $5.3 trillion for 2015, or 6.5% of global GDP. These subsidies are pervasive across advanced and developing, and oil-producing and non-oil-producing, economies alike. There are large climate, health, fiscal, and economic welfare benefits from reforming energy subsidies. And most of these benefits are domestic addressing national-level externalities and mispricing rather than addressing global climate change, implying that energy pricing reform is largely in countries' own interests.

So why do global energy subsidies persist? One possibility is that policymakers have not fully appreciated the case for reform, given that quantitative, country-level, estimates of reform benefits have only recently started to emerge. Another is that policymakers may not, in the past, have fully appreciated the inefficiency of helping the poor through subsidizing energy, compared with much more targeted measures. Up until now, the international community has also been sluggish in responding to the need to slow global climate change, and where governments have acted they have often used regulatory measures (e.g., for energy efficiency or renewables) instead of pricing. And fiscal pressures for subsidy reform may have been lacking.

But these factors appear to be changing. For example, the December 2015 Paris Agreement has galvanized interest in the most effective instruments for implementing emissions pledges. Historically high debt to GDP ratios (following the 2008 fiscal crisis) and collapsing petroleum revenues in oil-exporting countries have heightened interest in potential revenues from energy pricing reform. And in energy importing countries, lower energy prices should facilitate carbon pricing and broader green fiscal reform. In fact, a plethora of countries are taking steps in this direction—carbon pricing schemes are springing up at the national and sub-national level (WBG, 2015) and a number of countries (e.g., in MENAP region, Mexico, India, and Indonesia) have recently started to liberalize energy prices—though there is a long way to go.

One key barrier to reform appears to be political opposition to higher energy prices from public and industry groups. Although subsidies primarily benefit upper income groups, a sharp increase in energy prices can nevertheless have a significant impact on the budgets of poor households, both directly through higher energy prices and indirectly through the reduction in real income because of higher prices for other consumer goods (Clements *et al.*, 2013). Higher energy prices can also adversely affect the competitiveness of the industries, particularly in the short run (Fofana *et al.*, 2009).

How can the prospects for policy reform be enhanced? Clements *et al.* (2013) distill the key ingredients for successful reform based on a diverse range of case studies. For example, the poor need to be safeguarded, though the specific measures will vary with national circumstances (e.g., parameters of existing fiscal and social safety net systems). Impacts on vulnerable firms need to be addressed, with governments assisting the transition of resources away from firms that are no longer viable with efficient energy pricing. Reforms need to be gradual, to allow firms and households time to adjust, and perhaps with price increases for fuels consumed intensively by the poor delayed until adequate social safety nets are in place. Ideally the reform process is de-politicized, with energy prices set by independent authorities, or better still, markets. Policymakers also need an effective communications plan to inform the public of the case for reform and, in particular, how they benefit from use of the revenues.

Energy price reform is difficult. But the stakes have never been higher and, if not now, then when?

NOTES

1. See Burniaux, Chateau, Duval, and Jamet (2009), Ellis (2010).

2. See Breisinger, Engelke, and Ecker (2011), Di Bella, Norton, Ntamatungiro, Ogawa, Samake, and Santoro (2015), Ellis (2010), Kumar and Woo (2010), Lofgren (1995), United Nations Environment Programme (UNEP) (2008), von Moltke, McKee, and Morgan (2004).

3. See Clements, Jung, and Gupta (2007), Escribano, Guasch, and Pena (2008), Foster and Steinbuks (2008), Fofana, Chitiga, and Mabugu (2009), Gelb *et al.* (1988).

4. See Arze del Granado, Coady, and Gillingham (2012), Clements, Coady, Fabrizio, Gupta, Alleyne, and Sdralevich (2013), Coady, Flamini, and Sears (2015), International Energy Agency (IEA) (2011).

5. See Bárány and Grigonytė (2015), Clements *et al.* (2013), Clements, Coady, Fabrizio, Gupta, and Shang (2014).

6. See Organisation for Economic Co-operation (2005). A similar definition is used in De Moor (2001).

7. The country level results are available at www.imf.org/external/np/fad/subsidies/data/codata.xlsx.

8. See Appendix 2 for regional country classifications.

9. The petroleum products included in the analysis accounted for the majority (nearly 70%) of petroleum consumption in 2013.

10. For importers the total supply cost is the import cif price (which include international transport costs to the border) plus domestic distribution costs. For exporters, the total supply cost is the fob price minus the cost of international transport (since these are saved by redirecting exports to the domestic market) plus domestic distribution costs.

11. Outdoor air pollution from fossil fuels and other sources was responsible for an estimated 3.2 million premature deaths a year worldwide in 2012 (World Health Organization (WHO), 2014).

12. See for example Parry *et al.* (2014, pp. 16–17).

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13. For example, if congestion and accident externalities are excluded from assessments of efficient road fuel taxes, this would imply European countries should reduce fuel taxes toward US levels (Parry *et al.*, 2014, Chap. 6).

14. The effect of pre-existing environmental regulations is taken into account in estimates of external costs (e.g., requirements for SO_2 scrubbers reduce observed emission rates, though unlike taxes, they do not establish a price on the remaining emissions).

15. See, for example, Goulder (2002) and Parry and Bento (2000).

16. CO_2 emissions factors are defined per unit of energy for coal and natural gas, which reduces cross-country variation in these factors compared with emissions per unit of weight or volume.

17. In principle, the costs of operating and maintaining emission-control technologies should be subtracted from the welfare gain, though a quick calculation in Parry *et al.* (2014) suggests this would make little difference given the generally large size of environmental benefits.

18. IMF prices are available at http://www.imf.org/external/np/res/commod/index.aspx and IEA prices are available at http://www.oecd-ilibrary.org/energy/data/iea-energy-prices-and-taxes-statistics_eneprice-data-en.

19. Two main world spot prices for coal exports are the FOB spot price at Richards Bay, South Africa representing South African steam coal exports, and the FOB spot price at Newcastle, Australia, for Australian steam coal exports (Energy Charter Secretariat, 2010). As we either take pre-tax subsidies for natural gas and coal from the IEA or assume there is no pre-tax subsidies, supply costs for coal have little effect on our subsidy estimates (and similarly for natural gas).

20. For oil exporters, the $0.1 per liter transport cost from the ports of exporters to international hubs—which is already included in the international price—cancels out with the assumed domestic distributional cost. Natural gas and coal have been typically produced and consumed locally and omitting distribution/transport costs should have little effect on our estimates as we either take pre-tax subsidies for natural gas and coal from the IEA or assume there is no pre-tax subsidies.

21. These estimates are based on Organisation for Economic Co-operation (2013) (see Appendix 3).

22. Numerous studies have estimated motor fuel (especially gasoline) price elasticities for different countries and the value assumed here, −0.5 for both gasoline and diesel, reflects a central value from the literature. There is, however, significant variation among studies: for example, Sterner (2007) reports globally averaged (long-run) gasoline price elasticities of around −0.7 while individual country estimates in Dahl (2012) are closer to about −0.25 on average.

23. According to simulations from a variant of the US Department of Energy's National Energy Modeling System (NEMS) model in Krupnick, Parry, Walls, Knowles, and Hayes (2010), the price elasticity for coal use in the United States in response to a carbon tax (accounting for changes in natural gas prices) is about −0.15, although behavioral responses in the NEMS model tend to be less elastic than in other models. For example, the simple mean among eight studies of coal price elasticities (focusing on various OECD countries, China, and India) summarized in Trüby and Moritz (2011) is −0.28. Natural gas tends to be more responsive to changes in its own price, due to the ability of gas-fired power plants to act as intermittent suppliers although, in countries where coal and gas compete, this tendency is dampened as carbon pricing drives up the price of coal relative to gas. Liu (2004) estimates own-price elasticities for natural gas, with no change in coal prices, of −0.24 to −0.36.

24. The data for all figures are available at www.imf.org/external/np/fad/subsidies/data/wpdata.xlsx.

25. Pre-tax consumer subsidies are comparable to those of IEA for the years 2011–13 where IEA estimates are available, though estimation procedures differ (see Appendix 1).

26. For the full set of country-level post-tax subsidies and their breakdown by fuel and component, see www.imf.org/external/np/fad/subsidies/data/codata.xlsx.

27. In principle, reform of fossil fuel prices could be accompanied by a reduction of subsidies for renewables, enhancing the fiscal benefit, though in relative terms this effect is small—global renewable subsidies were $121 billion in 2013 (International Energy Agency (IEA), 2014).

28. For a summary graphic comparing prior studies see www.iisd.org/gsi/sites/default/files/ffs_methods_estimationcomparison.pdf.

29. Data pertaining to the composition of consumption (shares of final consumption and transport consumption), the electricity production input mix, electricity price, and the prevailing VAT or GST rates are not always available in all countries. When unavailable, they are assumed to equal the average value for countries in the same region with similar income levels.

30. Where only end-of-year prices are available, these are assumed equal to prices at the start of the following year, and are included in the calculation of average price for both years.

31. Any pre-tax subsidy rate taken from IEA is adjusted to take out the VAT component which instead appears in our post-tax subsidy estimates.

32. A draft version of the book was presented at an IMF workshop attended by leading experts on externality valuation and the book itself was subject to extensive peer review. The methodology underlying the externality estimates has since been discussed and extended in the academic literature (e.g., Parry, 2015; Parry, Heine, & Veung, 2015).

33. In principle, a notable example is existing carbon pricing programs. However, given that only about 12% of global emissions are currently covered, and often with prices below $10 per ton (WBG, 2015), our calculations suggest that this adjustment would lower post-tax subsidies by only about 1%.

34. More precisely, Parry *et al.* (2014) extrapolate estimates of intake fractions for pollutants from a widely cited study for China to other countries based on differences in the average number of people at different proximities to coal plants in other countries compared with China. The approach does not therefore take into account differences in meteorological conditions affecting pollution formation across countries. However some cross-checks with simulations from a computable model allowing for differences in factors affecting regional air quality suggest there is no systematic source of bias.

35. Generally speaking, estimates of environmental costs are less reliable for developing countries. For example, there is less information to assess air pollution emission rates and the value of life and value of travel time are extrapolated from evidence for advanced countries.

36. For countries that have indicated their energy pricing policies in 2015, this information is used in place of estimates of historical pass-through.

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APPENDIX 1. EXISTING ESTIMATES OF ENERGY SUBSIDIES

The IEA reports its estimate of global energy subsidies in its annual *World Energy Outlook*. This estimate is based on the price-gap approach, which compares the end-user prices with international reference prices. The reference prices consist of supply cost inclusive of shipping cost and margins and any value-added tax. The latest estimate indicates that fossil-fuel consumption subsidies worldwide amounted to $548 billion in 2013 (International Energy Agency (IEA), 2014). This estimate corresponds to the pre-tax energy subsidy in the current paper, which is $541 billion for 2013. However, the two studies use different data and (unlike the present paper) the IEA estimate includes undercharging for general consumption taxes but excludes producer subsidies.

The estimate by the Organization for Economic Co-operation and Development (OECD) is based on the so called *inventory approach.* It includes consumer subsidies and also direct budgetary support and tax expenditures that provide a benefit or preference for fossil-fuel production, either in absolute terms or relative to other activities or products. The OECD estimate for energy subsidies in 34 OECD countries amounted to $50–90 billion annually during 2005–11 (OECD, 2013). This is substantially smaller than our pre-tax subsidy figures as ours also include subsidies in non-OECD countries.

The Global Subsidies Initiative (GSI) also provides estimates of energy subsidies, typically for specific countries and sectors and based on the inventory approach similar to that of the OECD. For example, GSI estimated that government support for upstream oil and gas activities amounted to US$ 1.8 billion in Indonesia in 2008, to US$ 4 billion in Norway in 2009 and to US$ 14.4 billion in 2010 (Braithwaite *et al.*, 2010; Gerasimchuk, 2012; Pöyry Management Consulting (Norway), Aarsnes, and Lindgren, 2012).

Clements *et al.* (2013) estimate for 2011 pre-tax subsidies of $492 billion and post-tax subsidies of $2.0 trillion. Appendix 4 reconciles their estimates with those in the current paper.[28]

Table 2. *Regional classification of countries*

Advanced Economies	Commonwealth of Independent States	Emerging and Developing Asia	Emerging Europe	Latin America and the Caribbean	Middle East, North Africa, and Pakistan	Sub-Sahara Africa
Australia	Armenia	Bangladesh	Albania	Antigua and Barbuda	Afghanistan	Angola
Austria	Azerbaijan	Brunei Darussalam	Bosnia and Herzegovina	Argentina	Algeria	Benin
Belgium	Belarus	Cambodia	Bulgaria	Bahamas, The	Bahrain	Botswana
Canada	Georgia	China	Croatia	Barbados	Djibouti	Burkina Faso
Cyprus	Kazakhstan	India	FYR Macedonia	Belize	Egypt	Cameroon
Czech Republic	Kyrgyz Republic	Indonesia	Hungary	Bolivia	Iran	Cape Verde
Denmark	Moldova	Malaysia	Latvia	Brazil	Iraq	Congo, Republic of
Estonia	Russia	Mongolia	Lithuania	Chile	Jordan	Côte d"Ivoire
Finland	Tajikistan	Myanmar	Montenegro, Rep. of	Colombia	Kuwait	Democratic Republic of the Congo
France	Turkmenistan	Nepal	Poland	Costa Rica	Lebanon	Equatorial Guinea
Germany	Ukraine	Papua New Guinea	Romania	Dominica	Libya	Ethiopia
Greece	Uzbekistan	Philippines	Serbia	Dominican Republic	Mauritania	Gabon
Hong Kong SAR		Sri Lanka	Turkey	Ecuador	Morocco	Ghana
Iceland		Thailand		El Salvador	Oman	Kenya
Ireland		Vietnam		Grenada	Pakistan	Lesotho
Israel				Guatemala	Qatar	Madagascar
Italy				Guyana	Saudi Arabia	Malawi
Japan				Haiti	Sudan	Mali
Korea				Honduras	Tunisia	Mozambique
Luxembourg				Jamaica	United Arab Emirates	Namibia
Malta				Mexico	Yemen	Nigeria
Netherlands				Nicaragua		Rwanda
New Zealand				Panama		Senegal
Norway				Paraguay		South Africa
Portugal				Peru		Tanzania
Singapore				St. Kitts and Nevis		Uganda
Slovak Republic				Suriname		Zambia
Slovenia				Trinidad and Tobago		Zimbabwe
Spain				Uruguay		
Sweden				Venezuela		
Switzerland						
Taiwan Province of China						
United Kingdom						
United States						

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Table 3. *Data sources: year and country coverage*

Source	Countries covered	Time period
International Energy Agency		
Petroleum product consumption	134	2010–12
Coal consumption	107	2010–12
Natural gas consumption	110	2010–12
Electricity production input mix	137	2010–12
Petroleum product and electricity prices and taxes	33	2010–14
Pre-tax subsidy estimates (coal, natural gas, electricity)	40	2010–13
Fuel product spot prices (USA; NW Europe; Singapore)	–	2010–14
USA Energy Information Agency		
Natural gas consumption growth (2013)	40	2013
Fuel consumption growth (2013)	134	2013
Electricity consumption	91	2010–12
Electricity retail price	14	2010–12
Organization of Economic Co-operation and Development		
Producer support estimates	33	2010–11
IMF		
Fuel retail prices	100	2010–14
Corrective tax estimates	150	2010
VAT database	147	2010–13
Electricity subsidy estimates (including update of World Bank estimates)	27	2009–11
Electricity subsidy estimates from Di Bella and others, 2015	32	2011–13
Electricity tariff and cost-recovery price	27	2007–10
Oil international port price projections (US WTI; Brent; Dubai)	–	2010–15
Natural gas international port price (US Henry Hub; Germany; Japan)	–	2010–15
Coal international port price (Australia; South Africa)	–	2010–15
Other macroeconomic data	–	2010–15
British Petroleum		
Electricity consumption	31	2012–13
World Bank		
Electricity subsidy estimates	4	2009
Other press reports		
Electricity retail price	12	2010–11

APPENDIX 2. REGIONAL CLASSIFICATION OF COUNTRIES

See Table 2

APPENDIX 3. DATA SOURCES

This appendix, and Table 3, summarize the data sources used to estimate energy subsidies and the benefits of subsidy reform.

(a) *Energy consumption*

Data on energy consumption are taken for all countries from IEA for petroleum products, coal, and natural gas, and from British Petroleum for electricity—in both cases, the most recent year available is 2012. Consumption data for all petroleum products combined are available from EIA for 2013 and the same growth rate is applied to International Energy Agency (IEA) (2012) data to project petroleum consumption in 2013. For other fuels, and for petroleum beyond 2013, consumption is assumed to growth with real GDP. For all fuel use, IEA provides the breakdown for final consumption (residential use, commercial, and public services) versus intermediate use (which is needed to compute the average consumption tax).[29]

(b) *Retail prices*

These are obtained in various frequencies—monthly, quarterly, annual average, end-of-period—and are converted to a single annual average price for each country.[30]

For petroleum products, prices are compiled (where available for 35 countries) from IEA's quarterly database on retail fuel prices, pre-tax prices, and taxes, and supplemented (where needed) from the IMF's fuel price dataset. The latter—which is from data provided by national regulatory agencies, IMF staff, and monitoring of news reports (see Kpodar, Abdallah, & Sears, 2016)—is mostly monthly (though sometimes just mid-year and/or end-year) and only includes retail petroleum product prices.

For coal and natural gas, consumer prices are obtained by subtracting estimates of pre-tax subsidies from IEA[31] from the international reference price. Consumer prices are assumed equal to supply costs for countries where estimates of pre-tax subsidies are not available.

For electricity, prices are taken from the IEA quarterly database on household electricity prices when available. Otherwise they are taken from the EIA, IMF and World Bank staff, or from monitoring of news reports. Prices from the IEA and EIA are annual average prices. All other prices are a mix of annual average price and prices at specific points in time. Since supply cost is difficult to estimate across countries, pre-tax and post-tax subsidies are only estimated for countries with detailed estimates done by the IEA or by IMF and World Bank staff.

(c) *Supply cost*

This is calculated on an annual basis. The observations used to calculate supply cost correspond to the given fuel"s retail price. So, if a country has only an end-year retail price then the only supply cost used should be based on end-year data. Conversely, if a country has an annual average retail price, or monthly price data, then an average supply cost is calculated.

For petroleum products, the supply cost has two components: port (or hub) price and the cost of transportation and distribution. Port prices are taken from the IEA and correspond to the United States, NW Europe, and Singapore. Countries are mapped to one of these three ports based on region. The cost of transportation and distribution are included in the pre-tax price provided by the IEA. For all other countries these costs are assumed to be $0.20 per liter if the country is a net-importer of oil and zero otherwise.

For natural gas, the supply cost is taken from the IMF and has only one component, the port price. Port prices come from Henry Hub USA, the Russian export price to Germany, and Japan. Countries are mapped to one of these three prices based on region. No adjustment is done for shipping and margins.

For coal, the supply cost is taken from the IMF and has only one component, the port price. Port prices come from South Africa and Australia. An average of the two is used for all countries. No adjustment is done for transport and distribution.

Electricity supply costs are difficult to measure as they vary greatly depending on the fuel mix and scale of operations, so the supply cost is taken from other sources. For countries with pre-tax subsidy estimates (including IEA, Di Bella *et al.*, 2015, IMF, and World Bank studies) supply cost is assumed to equal the electricity retail price plus the unit pre-tax subsidy. For all other countries, the supply cost is unknown and subsidies are not estimated.

(d) *Producer subsidies*

OECD (2013) provides estimates of these subsidies for 2011—we assume they are constant as a share of GDP to extrapolate them for later years. Different items of producer subsidies from the OECD could potentially overlap with each other. In the event that some of the producer subsidies are passed to consumers as lower consumer prices, these producer subsidies could also overlap with consumer subsidies. But since producer subsidy estimates are very small in relative terms, these issues have little relevance for our results.

(e) *External costs*

Externality cost estimates at the country level are used for petroleum products, natural gas, and coal (but not for electricity, to avoid double-counting). These estimates are taken from an IMF book by Parry *et al.* (2014), and we refer the reader to that study for an in-depth discussion of estimation procedures and data sources.[32] Estimates are available for 150 countries—for other countries, estimates are inferred using a simple average from countries in the same region with similar per capita income.

Global warming damages from fuel use are inferred using CO_2 damage values (in current dollars) varying between $37.7 per ton for 2011 and $42.3 per ton for 2015 in 2015 dollars, taken from US Interagency Working Group on Social Cost of Carbon (2013) and Parry *et al.* (2014)'s country-level CO_2 emission rates for individual fuels (though there is little cross-country variation in these rates).[33]

Parry *et al.* (2014) estimate air pollution damages at the country level in several steps. First, they estimate "intake fractions", or the average fraction of emissions (for SO_2, NO_x and direct fine particulate emissions) inhaled by exposed populations (as fine particulates) by mapping data on the geographical location of coal plants in each country to very granular data on the number of people living at different distance classifications from those plants (up to 2,000 km).[34] This is converted using, from the Global Burden of Disease, baseline mortality rates for each country for illnesses whose prevalence is potentially increased by exposure to air pollution and aggregate level data on the relative change in these mortality rates callused by exposure to air pollution. These health effects are then monetized using a meta-analysis of the value of life by the OECD suggesting a baseline VSL (updated to 2010) of $3.7 million for the average OECD country and extrapolated to all other countries using their estimate of 0.8 for the income elasticity of the value of life. The health damages are then expressed per unit of fuel use using an international database (compiled by the International Institute for Applied Systems Analysis) of country-specific emission rates (for SO_2, NO_x, and direct fine particulates) from coal use. An analogous approach is used to quantify air pollution damages from natural gas plants.

For air pollution from motor vehicles, Parry *et al.* (2014) extrapolate these to the country level based on cross-country database for about 3,600 cities of these fractions and then follow analogous procedures (including data on average air pollution emission rates for gasoline and diesel vehicles available at the country-level) to obtain damages per unit of road fuel use.

Country-level data on traffic congestion costs are not available. Instead, these costs are inferred by extrapolating average travel delays from a database of approximately 90 cities in different countries to the country level, using standard functional relations to convert average travel delays into marginal delays (i.e., the delay one driver imposes on other road uses), and monetizing the result using country-level wages and evidence relating the value of travel time to the wage rate. Accident externalities are estimated by apportioning country-level data on road fatality rates into internal risks (e.g., those to occupants in single-vehicle collisions) versus external risks (e.g., to pedestrians and other vehicle occupants in multi-vehicle collisions). Other components of external costs (e.g., non-fatal injury risks, third-party property, and medical costs) are extrapolated to other countries from several country-level case studies. External costs are calculated for both cars and heavy-duty vehicles (e.g., all road damage is attributed to the latter and per mile congestion costs are larger as they take up more road space).[35]

In computing Pigouvian taxes for motor fuels, gasoline is assumed to be used by cars and diesel a mixture of cars and heavy vehicles. Externalities related to distance driven (rather than fuel use) are scaled back accordingly based on assumptions about the fraction of the tax-induced fuel reduction that comes from reduced driving (versus the other fraction coming from long run improvements in vehicle fuel efficiency). Finally, existing fuel taxes are subtracted from Pigouvian taxes to infer any fuel subsidy due to undercharging for vehicle externalities.

In computing the impacts of higher coal taxes, it is assumed that rebates would be provided for the adoption of emissions control technologies (e.g., SO_2 scrubbers). The resulting implications for emissions and fuel prices are inferred using country-specific estimates of emissions rates for representative samples of plants with control technologies.

External costs from Parry *et al.* (2014) are for 2010 and are updated to later years to account for inflation and growth in real per capita GDP (which increases the VSL according to the income elasticity of the VSL).

(f) *Consumption tax*

Energy consumption should generally be taxed at the same rate as other consumption goods for revenue purposes. The consumption tax (VAT or GST) is assessed on the sum of the supply cost and the Pigouvian tax. For all products, this is applied only to final consumption not intermediate use.

(g) *Projections*

For petroleum products, the most recent year of available data is 2014. Energy subsidies in 2015 are projected by assuming that changes in international crude oil prices are fully passed on to the supply costs of petroleum projects. For domestic prices, the changes in international prices are assumed to be passed to domestic prices based on the pass-through estimates (capped between 0 and 100% plus the consumption tax rate) in 2014 in each country.[36]

For coal and natural gas prices, a similar methodology is used. However, as pass-through estimates are typically only available for petroleum products, the average of pass-through estimates of petroleum products in the previous year is applied. In addition, the projections are only done in countries where subsidy estimates are available for 2013.

For electricity, subsidies are assumed to be a constant share of GDP up to 2014 from whenever the most recent estimates are available. The reason we do not apply the previously described methodology is because it does not appear to produce reliable estimates for some countries during this time period: pass-through estimates are subject to large uncertainty, and the most recent electricity subsidy estimates in some countries date back as far as 2009. For 2015, to incorporate the dramatically lower international energy prices, we again adopt the above methodology and assume that the production fuel mix and costs of other inputs remain unchanged. A sensitivity analysis is performed to check how the results vary with different assumptions of the pass-through estimates.

APPENDIX 4. RECONCILING PREVIOUS ESTIMATES OF POST-TAX SUBSIDIES

The estimate of post-tax subsidies for 2011 in Figure 4 is more than double the comparable estimate in Clements *et al.* (2013), reflecting three main factors.

First is expanded coverage of air pollutants. The earlier estimate of air pollution damages from coal considered only damages from SO_2, whereas the estimates used also include damages from NO_x and direct fine particulate emissions, which increases post-tax subsidies by 24%. The new estimates also include local air pollution damages from natural gas, which add another 2%.

Second, the previous estimate of local air pollution damages from coal plant SO_2 emissions was obtained by extrapolating a study for the United States to other countries, adjusting only for the VSL. Current damage estimates are five times higher, accounting for 45% of the increase in post-tax subsidy, reflecting:

- more recent evidence from the Global Burden of Disease project suggesting a stronger link (67% higher than assumed in Clements *et al.*, 2013) between air pollution and mortality risk;
- adjustments for country-specific SO_2 emission rates (e.g., emission rates are 2.6 times as high in China as in the United States);
- adjustments for country-specific population exposure to pollution; and
- adjustments for country-specific, baseline mortality rates (less healthy populations being more vulnerable to pollution).

Third, as regards non-carbon externalities from vehicles (congestion, accidents, air pollution, and road damage), Clements *et al.* (2013) extrapolated them to other countries using case studies for the United States, United Kingdom, and Chile, adjusting only for the valuation of travel time and injury risk. The updated estimates use country-level estimates of externalities, which on average are significantly higher, especially for diesel vehicles due to higher local air emission rates. The net result is an increase in post-tax subsidies of 23%.

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