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Reforming Energy Policy in India: Assessing the Options

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Reforming Energy Policy in India: Assessing the Options

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Abstract

Spreadsheet models are used to assess the environmental, fiscal, economic, and incidence effects of a wide range of options for reducing fossil fuel use in India. Among the most effective options is ramping up the existing coal tax. Annually increasing the tax by INR 150 ($2.25) per ton of coal from 2017 to 2030 avoids over 270,000 air pollution deaths, raises revenue of 1 percent of GDP in 2030, reduces CO2 emissions 12 percent, and generates net economic benefits of approximately 1 percent of GDP. The policy is mildly progressive and (at least initially) imposes a relatively modest cost burden on industries.

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I. INTRODUCTION

India has recently made considerable progress in reforming energy prices. Gasoline prices were liberalized in 2010, and diesel and natural gas prices in 2014. Additionally, India has introduced a (quite novel from an international perspective) excise tax (the Clean Environment Cess) on coal production and imports, amounting to INR 400 ($6.00) per ton of coal in 2016.[3] Subsidies remain for liquefied petroleum gas (LPG), kerosene, and electricity, given the first two fuels are consumed disproportionately by low-income households, while substantially higher electricity prices might run counter to the goal of displacing household biomass use with power grid access. There are nonetheless reasons why policymakers may wish to continue the direction of recent fuel price reforms, particularly by continued increases in the coal tax.

One reason is that further reform can be in India's own interest due the environmental benefits. The main domestic environmental cost of burning coal is outdoor air pollution, which exacerbates mortality rates for various (e.g., cardiovascular and pulmonary) diseases. Outdoor air pollution from fossil and non-fossil sources prematurely killed an estimated 0.53 people per 1,000 of the population in 2010 in India, or about 650,000 in total.[4] Mortality rates, and average air pollution concentrations, in India are already on the high side relative to those in most other selected countries shown in Figure 1, but they are set to worsen especially rapidly in India with growth in future fuel use and rising urban population exposure to its emissions.[5] Reflecting domestic health costs in fossil fuel prices promotes a more efficient allocation of India's scarce resources, by helping to curb use of polluting fuels that would otherwise be excessive.[6]

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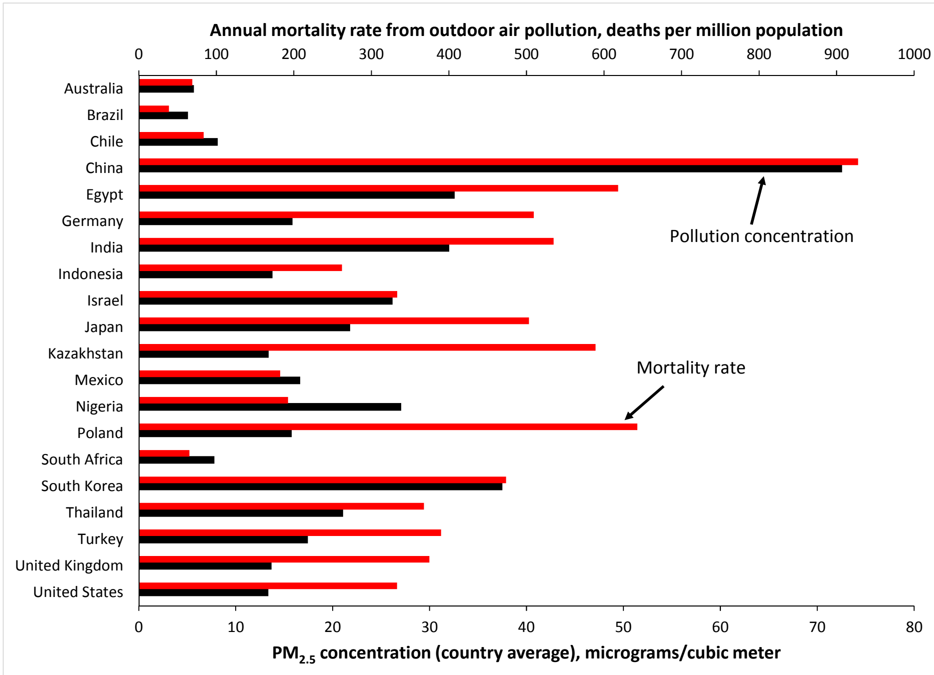
[3] This excise tax applies directly to the amount of raw/unprocessed coal extracted from a mine.

[4] Lelieveld and others (2015).

[5] The urban population is projected to rise from 377 to 609 million between 2011 and 2030 (Government of India 2015).

[6] Put another way, failing to fully reflect supply and environmental costs in fuel prices is tantamount to subsidizing fuel use relative to other products (Coady and others 2015). Coal taxes would have only modest implications for the balance of payments (given that oil imports are far larger than coal imports—IMF 2017, Figure 2).

Figure 1. Outdoor Air Pollution Mortality Rates and Pollution Concentrations, Selected Countries, 2010



Notes: PM2.5 is fine particulate matter (with diameter up to 2.5 micrometers) which is respirable and therefore harmful to human health. Pollution concentrations are averages of regional concentrations (measured by satellite data) weighted by regional population shares. The mortality data is air pollution deaths (from fossil fuels and other sources) estimated in the Global Burden of Disease project, divided by country population.
Sources: Brauer and others (2012), IHME (2013), IMF (2016).

Continued fuel price reform can also be in India's own interest for fiscal reasons. Fossil fuel taxes can provide a significant source of easily-collected revenue, which is especially valuable when revenues from broader taxes on labor, capital, and consumption are insufficient due to a large concentration of economic activity occurring in the informal sector.[7]

Meanwhile at a global level, 197 parties submitted 'nationally determined contributions' (NDCs) to reduce greenhouse gases (GHGs) for the 2015 Paris Agreement on climate change. NDCs are not legally binding, however all countries are required to report (every two years starting in 2018) progress on NDCs and submit updated NDCs every five years starting 2023, which are expected

[7] Fiscal consolidation needs in India are discussed in IMF (2015), pp. 10–13, and Kelkar and others (2012). Currently coal tax revenues go to the National Clean Environment Fund (NCEF) to finance clean energy innovation and investment and broader environmental conservation and development projects, though enhanced revenues from the tax could go to the general budget.

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to be progressively more stringent.[8] For most G20 countries, NDCs take the form of emission reduction targets by 2030 (or thereabouts), though for China and India they take the form of reductions in the emissions intensity of GDP (Table 1)—in India's case a 33–35 percent reduction by 2030 relative to 2005. Intensity targets accommodate more rapid and uncertain emissions growth, while equity considerations might warrant less onerous targets for countries with lower per capita emissions (India's is the lowest among G20 countries—Table 1). There will also be considerable peer pressure on countries (especially large emitters) to demonstrate progress on mitigating GHGs—and countries like India, that are especially vulnerable,[9] have the most at stake in global action to slow climate change. Mitigation opportunities should therefore be of interest to Indian policymakers, despite more immediate goals of poverty reduction and development.

Table 1. Paris Mitigation Pledges, Emissions Intensity, and Emissions Per Capita, G20 Countries, 2013

Country	Mitigation pledge: Reduce…	Share of global CO_2, 2013	CO_2/GDP	CO_2 per capita
Argentina	GHGs 15% below BAU in 2030	0.6	0.29	4.3
Australia	GHGs 26-28% below 2005 by 2030	1.3	0.25	16.7
Brazil	GHGs 37% below 2005 by 2025	1.5	0.18	2.3
Canada	GHGs 30% below 2005 by 2030	1.7	0.28	15.3
China	CO_2/GDP 60-65% below 2005 by 2030	29.0	0.92	6.6
France	GHGs 40% below 1990 by 2030	1.0	0.11	5.0
Germany	GHGs 40% below 1990 by 2030	2.5	0.20	9.4
India	GHG/GDP 33-35% below 2005 by 2030	6.0	0.98	1.5
Indonesia	GHGs 29% below BAU in 2030	1.4	0.45	1.7
Italy	GHGs 40% below 1990 by 2030	1.1	0.15	5.7
Japan	GHGs 25% below 2005 by 2030	4.0	0.25	9.7
Korea	GHGs 37% below BAU in 2030	1.8	0.43	11.4
Mexico	GHGs 25% below BAU in 2030	1.5	0.35	3.7
Russia	GHGs 25-30% below 1990 by 2030	5.0	0.67	10.7
S. Arabia	GHGs 130 mn tons below BAU by 2030	1.5	0.62	15.7
S. Africa	GHGs 398-614 mn tons in 2025 and 2030	1.4	1.12	7.9
Turkey	GHGs up to 21% below BAU by 2030	0.9	0.34	3.7
UK	GHGs 40% below 1990 by 2030	1.4	0.16	7.0
US	GHGs 26-28% below 2005 by 2025	16.5	0.30	16.2

Source: http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx, IMF *World Economic Outlook*, and IEA *World Energy Balances*.

[8] The Paris Agreement came into force on November 4 2016, following ratification by at least 55 countries representing 55 percent of global emissions. Initially NDCs were called INDCs with 'I' referring to 'independent,' though after ratification they reverted to NDCs.

[9] India's large agrarian economy, expansive coastal areas, and sensitivity to extreme weather make it especially vulnerable to climate change (Government of India 2015).

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In short, it is important (and increasingly so in the future) to understand the potential role, and impacts, of additional reforms to fossil fuel pricing that might be phased in over the next 10–15 years, and how these policies compare with other options, like more traditional regulatory approaches. Conceptually, it is widely recognized that fiscal instruments are potentially the most efficient policies for reducing the environmental costs of fuel use.[10] If carefully targeted they exploit the full range of mitigating behavior across firms and households; if set at economically efficient levels they strike the right balance between environmental benefits and economic costs; and in contrast to regulatory approaches and emissions trading systems (ETS) with free allowances, productive use of their revenues helps to offset harmful effects on the economy from higher energy prices.[11]

To make sound choices across instruments, to design the stringency of specific policies, and to communicate the case for reform to legislators and stakeholders, policymakers need an overarching quantitative framework for comparing options against key metrics. To help address this need, this paper uses a practical spreadsheet model parameterized for India to compare taxes on individual fuels, carbon taxes, ETS, renewables subsidies, fiscal incentives to lower emissions intensity, and energy efficiency policies, in terms of their impacts on local air pollution deaths, carbon dioxide (CO_2) emissions, revenue, economic benefits and costs and incidence across household and industry groups.

The model begins with recent data on fuel use across different energy sectors, projects these out to 2030, and computes the environmental, fiscal, and economic impacts of alternative policies using assumptions about fuel price elasticities, emission and mortality rates associated with different fuels, and extensions of standard formulas for economic welfare impacts. Incidence impacts are assessed by feeding policy-induced changes in energy prices into an input-output table for India indicating price and cost changes for a wide range of consumer products and industries and then linking the results to a survey of household expenditures on different products.

Some of the main findings are summarized as follows:[12]

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[10] For modelling exercises see, for example, Krupnick and others (2010) and for high-level support of pricing policies see www.carbonpricingleadership.org/carbon-pricing-panel.

[11] See, for example, Parry and others (2014a). Other policies are also needed to address related market failures (e.g., that might deter adoption of cleaner technologies), infrastructure needs, and so on, though the net benefits from these individual measures are likely on a much smaller scale than those from comprehensive energy price reform.

[12] See also Parry and others (2017).

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- In the "business as usual" (BAU) case, the projected CO_2 intensity of GDP is 29 percent lower in 2030 relative to 2005, implying emission mitigation policies would be needed to meet India's Paris pledge (though projections are sensitive to different assumptions).[13]

- Raising the coal tax by INR 150 per ton of coal (US $2.25) each year from 2017 to 2030 prevents over 270,000 air pollution deaths over this period, raises approximately 1 percent of GDP in new tax revenue in 2030, reduces CO_2 emissions by 12 percent, and generates net economic benefits (domestic environmental benefits less economic costs) of approximately 1 percent of GDP. A more aggressive coal tax (with twice the annual tax increases) has about 75 percent greater environmental and fiscal effectiveness.

- A broader carbon tax applying the same CO_2 price to emissions from other fossil fuels besides coal achieves modest additional CO_2, health, and net economic benefits compared with the coal tax (though it does raise about 40 percent more revenue).

- An ETS applied to CO_2 emissions from large stationary sources, with emissions prices equivalent to those under the carbon tax and auctioned allowances, has CO_2, health, and fiscal effectiveness of about 70–80 percent of that for the carbon tax.

- Tax/subsidy schemes (known as fee/rebate or 'feebates') to lower the CO_2 intensity of the power sector achieve about half of the CO_2 and health benefits of the (equivalently scaled) coal tax and might have greater political acceptability as they induce much smaller increases in electricity prices, though they have no revenue benefits.

- All other policies considered (incentives for renewables and energy efficiency, electricity taxes, road fuel taxes) have (by themselves) much smaller CO_2, health, and fiscal benefits (in some cases fiscal benefits are zero or negative) than the coal tax.

- Coal taxes are mildly progressive (the modest tax imposes a burden of 0.14 percent and 0.18 percent of consumption for the bottom and top household consumption deciles respectively in 2020) while raising costs across all industries by on average 0.2 percent, or for the 10 percent of most vulnerable industries (e.g., iron and steel) by on average 1.1 percent.

In short, given the coal tax is already in place, our recommendation would be to keep ramping it up progressively, though with accompanying measures to protect vulnerable households, workers, and ease transitions away from firms becoming uneconomic. If there are political

[13] It is assumed that CO_2 emissions are required to fall in the same proportion as all GHGs to meet the pledge.

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constraints on higher coal prices,[14] the tax might be supplemented with a tax/subsidy scheme to strengthen switching away from coal generation.

The rest of the paper is organized as follows. The next section discusses the conceptual design of efficient fuel prices, the measurement of environmental costs, and compares efficient fuel prices across countries. Section 3 overviews the spreadsheet model and its parameterization (relegating details to the Appendix). Section 4 presents the main policy results. Section 5 offers some concluding thoughts.

II. Efficient Pricing of Fossil Fuels

A. Conceptual Issues

The economically efficient price for a fuel (e.g., coal, gasoline) consists of the unit supply cost, a corrective tax to reflect the unit environmental costs, and (for fuels consumed at the household level) any general sales tax applied to consumer goods in general. The corrective component comprises three main elements:[15]

- *A carbon charge*, equal to the fuel's CO_2 emissions factor (tons of CO_2 per unit of fuel use) times the value per ton attached to CO_2 emissions. Although a literature attempts to value the discounted global environmental damages from CO_2 emissions,[16] in light of the Paris Agreement a more practically relevant notion (and as projected by the spreadsheet model below) is the emissions price consistent with countries' mitigation goals.[17]

- *A local air pollution charge*, equal to the fuel's emissions factor times the environmental damage per ton of emissions, and summed over the three main air pollutants—directly emitted fine particulates ($PM_{2.5}$), sulfur dioxide (SO_2), and nitrogen oxides (NO_x).[18] Ideally these upfront fuel charges would be combined with crediting for downstream fuel users

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[14] See, for example, Jenkins and Karplus (2016) for a discussion of political economy aspects.

[15] See Coady and others (2015), Parry and others (2014a).

[16] See, for example, Nordhaus (2016), USIAWG (2013).

[17] Instead of levying charges upstream on fuel supply, they can instead (though with greater administrative complexity) be levied downstream on CO_2 emissions from large stationary sources, and combined with upstream charges on fuels used by small-scale sources (e.g., from buildings and vehicles).

[18] The latter two pollutants react in the atmosphere to form fine particulates which are small enough to penetrate the lungs and bloodstream thereby elevating risks of various (e.g., heart and lung) diseases. $PM_{2.5}$ is particulate matter with diameter up to 2.5 micrometers. Fuel combustion also leads to the formation of (low-lying) ozone, but the resulting mortality impacts are on a smaller scale to those from $PM_{2.5}$.

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demonstrating emissions mitigation at the point of combustion (e.g., application of SO_2 'scrubbers' at coal plants).[19] While there is a wide range of other domestic environmental costs associated with extraction, processing, storage, distribution, and use of fossil fuels, the focus here is mostly limited to mortality from outdoor air pollution.[20]

- *Additional charges on road fuels, for the interim, to reflect congestion, accident, and road damage externalities*, though ultimately transitioning to mileage-based taxes (e.g., peak period pricing of congested roads). Fuel taxes are a very blunt instrument for addressing these problems (e.g., these taxes do not vary according to where or when driving occurs). It is, nonetheless, still efficient (in a second-best sense) to reflect all of the environmental costs in fuel taxes (until they are comprehensively priced through other policies)—not doing so foregoes significant economic welfare gains and has highly perverse policy implications.[21]

B. Valuing Externalities

Local air pollution

The mortality damages from air pollution in India due to fossil fuel combustion are taken from the country-level database in Parry and others (2014a), after some updating.[22]

Parry and others (2014a) estimate country-level air pollution damages from coal plants in several steps. The starting point is to extrapolate 'intake fractions'—the fraction of smokestack emissions inhaled by exposed populations—from a widely-cited study for China, after adjusting for the

[19] Putting the onus on firms to demonstrate valid emissions reductions to obtain credits eases the burden on administrative capacity. For large stationary emitters in countries with emissions monitoring capacity, smokestack emissions can be charged directly, and can be varied with local population exposure.

[20] Other environmental costs tend to be smaller in magnitude (e.g., impaired visibility, building corrosion, crop damage, annualized costs of leakage during transport and storage), difficult to quantify (e.g., despoiling of the environment at extraction sites), or the nature of the externality is unclear (e.g., energy security). Mortality impacts account for upwards of 85 percent of total air pollution damage estimates in U.S. EPA (2011), EC (1999), World Bank and State Environmental Protection Agency of China (2007), and Watkiss and others (2005).

[21] For example, that European countries should lower their road fuel taxes to U.S. levels (Parry and Small 2005, Parry and others 2014a, Chapter 5). In computing efficient road fuel taxes, mileage-related externalities are multiplied by the fraction of the fuel reduction that comes from reduced mileage (usually assumed to be about half) as opposed to the fraction that comes from higher fuel economy (e.g., Parry and Small 2005), as only the former directly affects congestion, accidents, and road damage.

[22] The estimates are broadly consistent with those for India reported in Lelieveld and others (2015).

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average number of people living in proximity to coal plants.[23] Population exposure is then converted into deaths per ton of emissions using country-level mortality rates for heart and pulmonary disease, strokes, and lung cancer and evidence on the sensitivity of these mortality rates to changes in pollution exposure.[24] For India in 2010, this results in estimated deaths per 1,000 tons of emissions of 16 for direct PM2.5, 13 for SO2, and 10 for NOx.[25] Health damages can then be expressed per ton of coal using estimated emission rates from combustion for these pollutants (averaging over emissions sources with and without emissions control technologies). And for the (albeit contentious) purpose of valuing environmental impacts, health effects can be monetized using empirical evidence on people's willingness to pay for mortality risk reductions.[26] Parry and others (2014a) estimate air pollution damages from gas-fired power plants using the same steps, while intake fractions for air pollutants released at ground level (e.g., from vehicles) are extrapolated from a database of estimates for about 3,500 urban centers in different countries.

Other externalities from road transport

Parry and others (2014a) crudely extrapolate traffic congestion costs by first estimating statistical relationships between travel delays and transportation indicators using a database for over 90 cities across developed and developing countries. The regression coefficients were then combined with nationwide measures of the same transportation indicators to project nationwide travel delays. Average travel delays (which drivers consider) were converted into delays one driver imposes on other road users using functional relationships from the literature. The result

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[23] This is based on mapping geographic data on the precise location of coal plants in a country to very granular data on population density. The approach ignores differences in meteorological and other factors between India and China that might affect pollution formation, though some cross-checks with an air quality model suggest any resulting bias may not be large (Parry and others 2014a, pp. 83–7).

[24] Parry and others (2014a) assume that each one microgram increase in ambient $PM_{2.5}$ concentrations would increase all causes of mortality by 1 percent, which is roughly consistent with U.S. studies (e.g., Krewski and others 2009, Lepeule and others 2012), current practice by the U.S. Environmental Protection Agency and (albeit limited) evidence for other countries (e.g., Burnett and others 2013). A caveat is that the responsiveness of mortality to additional pollution exposure could eventually flatten out at severe air pollution concentrations as people's channels for absorbing pollution become saturated (paradoxically implying lower health benefits from incremental pollution reductions) though evidence on this is mixed (e.g., Goodkind and others, 2012).

[25] For comparison, Cropper and others (2012) estimate corresponding deaths of 23, 10, and 9 per 1,000 tons of $PM_{2.5}$, SO_2, and NO_x for India in 2008.

[26] Parry and others (2014a) assume a value of INR 50 million ($0.75 million) per death, updated to 2013. For comparison, Madheswaran (2007) and Shanmugam (2001) report values for India of INR 15 million and INR 56 million respectively.

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was then monetized based on evidence suggesting the value of travel time for urban driving is around 60 percent of the market wage.

Traffic accident externalities include injury risks drivers pose to pedestrians and to other vehicle occupants (in multi-vehicle collisions) and property and medical costs borne by third parties. Parry and others (2014a) roughly estimate these external costs using road fatality data and extrapolations of non-fatal injury costs, property damages, and medical costs from several country case studies. Road damage externalities are estimated from road maintenance expenditures and assumptions about the respective contribution of (heavy) vehicles as opposed to other factors (weather, natural decay) causing pavement deterioration.

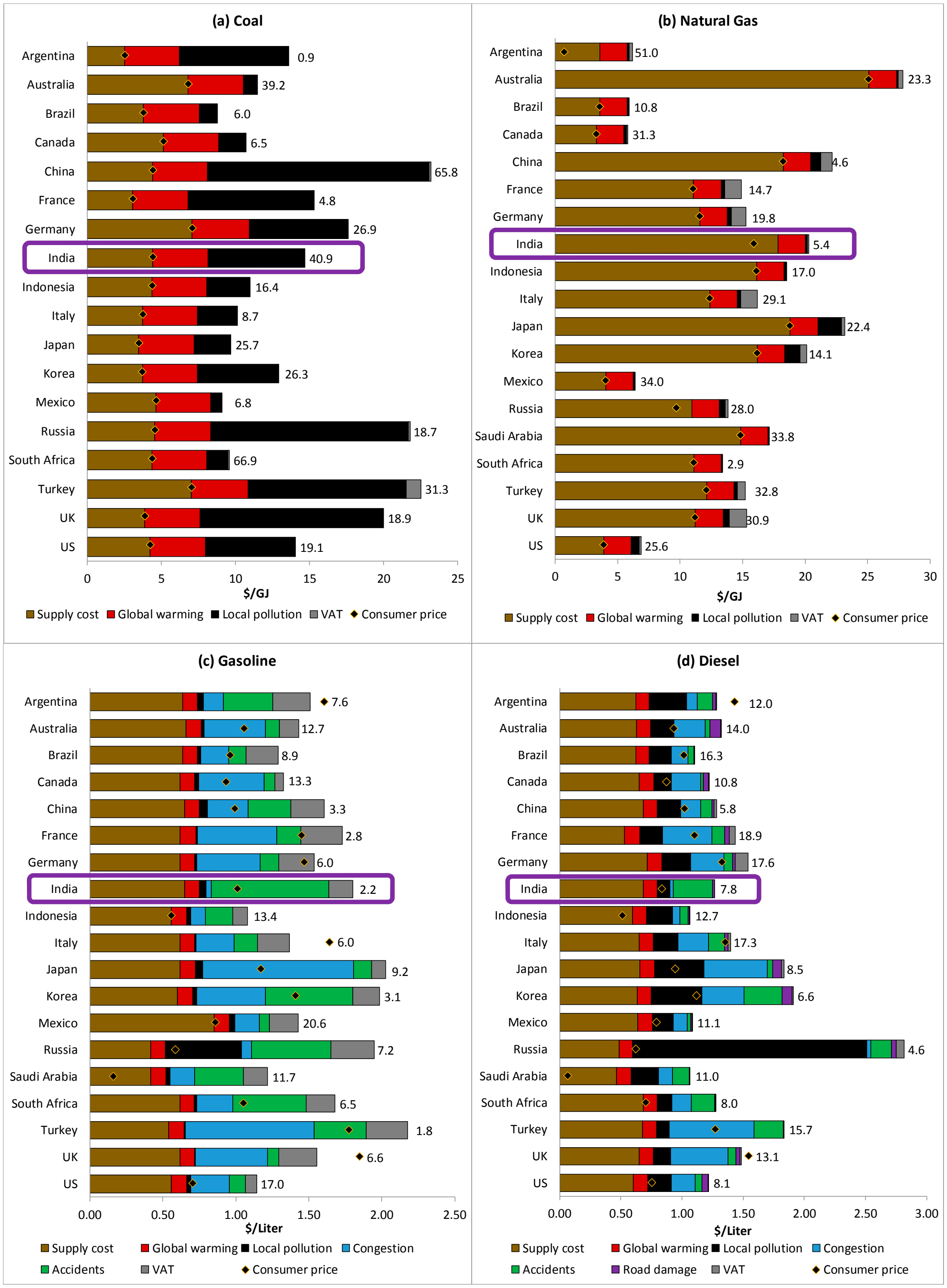
Comparison of efficient fuel pricing

Figure 2 compares estimates of fossil fuel prices in 2013 with their efficient levels across G20 countries. Countries do not significantly tax or subsidize coal, so current prices essentially reflect supply costs (panel a). The red bars indicate the climate change damages assuming (purely for illustration) a damage value of IDR 2,680 ($40) per ton of CO_2,[27] which in many cases implies carbon charges of about the same magnitude as supply costs. The air pollution damages exceed the carbon damage in nine cases, including India where these damages are equivalent to IDR 440 ($6.50) per gigajoule (IDR 12,895 or $190.50 per ton of coal), or more than 150 percent of supply costs. In other countries air pollution damages are far more moderate, for example in Australia which is sparsely populated (limiting exposure to air pollution) and most coal plants are coastally located (so much of the pollution disperses harmlessly over the oceans). Like coal, natural gas is also pervasively undercharged for environmental costs (panel b) but the degree of undercharging is far less severe, as air pollution emissions rates, in particular, are much smaller than for coal. All but three G20 countries undercharge for the full environmental costs of gasoline use (panel c), though the biggest externalities tend to be traffic congestion and accidents rather than local pollution and global warming. For India, even excluding global warming, the efficient gasoline price exceeded the 2013 price by about INR 53 ($0.80) per liter, with most of the difference reflecting undercharging for accident externalities. Estimated efficient prices for diesel fuels (averaging over heavy and light vehicle use) exceeded 2013 prices for all but two G20 countries though the relative contribution of externalities is different than for gasoline, local pollution being larger and congestion and accidents smaller (panel d).[28] For India, the shortfall between existing and estimated efficient prices is somewhat smaller for diesel than for gasoline.

[27] Updated from U.S. IAWG (2013).

[28] The latter is because, per liter of fuel, heavy vehicles drive a shorter distance, implying smaller mileage costs per liter.

Figure 2. Current and Efficient Energy Prices in G20 Countries, 2013



Source: Coady and others (2016).

Note: Figures to the right of the bars are the share of fuels in primary energy.

III. SPREADSHEET MODEL

A. Analytical Framework

A broad sense of the environmental, fiscal, and economic welfare impacts of fiscal and regulatory policies affecting fuel use can be inferred from a simplified ('reduced form') model, capturing policy-induced changes in fuel use in different sectors, and parameterized such that projections for fuel, and the price-responsiveness of fuel use, are broadly consistent with available evidence (i.e., fuel use projections from more sophisticated models and empirical evidence and modelling results on the sensitivity of fuel use to prices). The attractiveness of a simplified model is its transparency and flexibility—the implications of alternative assumptions for the key underlying parameters are easily seen. The model used here, which is based on Parry and others (2016), is briefly outlined below, with the equations of the model provided in Appendix 1.

Seven fossil fuels are distinguished, namely coal, natural gas, gasoline, road diesel, kerosene, LPG, and an aggregate of other oil products (used in power generation, domestic aviation and maritime, petrochemicals, home heating, etc.). The model projects, out to 2030, annual fuel use in three sectors—power generation, road transport, and an "other energy" sector, where the latter represents an aggregation of direct energy use by households, firms, and non-road transport.

Power sector

In the power sector, electricity demand in the "business-as-usual" (BAU) scenario—that is, with no fiscal or regulatory policy changes to reduce fossil fuel use beyond those already implicit in recently observed fuel use and price data—increases over time with growth in GDP according to the income elasticity of demand for electricity. Higher electricity prices reduce electricity demand through improvements in energy efficiency and reductions in the use of electricity-consuming products. The efficiency of electricity-using products also improves over time with autonomous technological progress.

Power can be generated from coal, natural gas, oil, nuclear, hydro, biomass, and (non-hydro) renewables like solar and wind. Increases in the unit generation cost for one fuel lead to switching away from that fuel to other generation fuels. Unit generation costs also decline gradually over time with autonomous technological progress, where the rate of decline is assumed to be faster for renewables (a relatively immature technology). Changes in electricity demand result in proportional changes in generation from the different fuel types.

Road transport

The road transport sector distinguishes gasoline (i.e., light-duty) vehicles and diesel (primarily heavy-duty) vehicles. Again, future fuel use in the BAU varies positively with future GDP growth (through income elasticities for vehicle use), negatively with higher fuel prices (which promote use of more fuel-efficient vehicles and less driving) and autonomous improvements in vehicle fuel efficiency.

Other energy sector

The other energy sector distinguishes small-scale fuel users (e.g., households, small emitters in the informal sector) from large industrial users (e.g., steel, aluminum, cement, refining, chemicals, construction) as this allows the modelling of downstream ETSs and regulations which can only cover the latter. Fuels potentially used by the other energy sector include coal, natural gas, kerosene, LPG, other oil products, biomass, and renewables. And again, baseline fuel use varies positively with GDP (through income elasticities) and negatively with fuel prices (through changes in energy efficiency and product usage) and autonomous improvements in energy efficiency.

Model simplifications and solution

One simplification is that the model is static meaning that fuel use adjusts instantly and fully to changes in fuel prices, whereas in reality the adjustment occurs progressively over time as capital turns over—in other words, the price responsiveness of fuel use is smaller in the shorter term than the longer term. However, given that policies are likely to be anticipated and phased in gradually, and the focus is on their longer term impacts, there is less need to distinguish shorter term responses (which would add considerable analytical complexity).

Another simplification is that fossil fuel supply prices are taken as invariant to policy changes, therefore fuel tax increases are fully passed forward into user prices of fuels and electricity. This is generally a reasonable approximation, at least for the longer term when capital mobility across sectors is greater.[29] Linkages with international trade are also ignored, given that fuel tax reforms are imposed on fuel consumption (from both domestic and imported sources) and the impacts of mitigation in other countries through changes in international fuel prices are beyond our scope.[30]

The model is solved by first developing BAU fuel use by sector going forward to 2030, using equations of the model and projections of energy prices and GDP. The impacts of policy reform are then calculated by computing induced changes in fuel and electricity prices, and the resulting changes in energy efficiency, use of energy products, and hence fuel demand across the three sectors. The resulting change in air pollution deaths, carbon emissions, and revenue are calculated from the changes in fuel use and the deaths, CO_2 emissions, and prior taxes/subsidies per unit of fuel use. Economic welfare costs and net benefits are calculated by applying standard formulas in the literature (Appendix 1).

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[29] The model also abstracts from the possible use of carbon capture and storage technologies at power and large industrial plants, therefore taxing the carbon content of fuels upstream is equivalent to taxing CO_2 emissions when these fuels are combusted.

[30] Cross-price effects among the three energy sectors are also ignored as they are likely small for the foreseeable future, due to products being weak substitutes (e.g., higher prices for road fuels will have a minimal effect on the demand for residential and industrial electricity).

B. Data

The International Energy Agency's Extended World Energy Balances is used to aggregate fuel use by sector in India, the latest available year being 2014. Current and projected GDP, fuel prices, and fuel taxes/subsidies are taken from IMF sources and behavioral response parameters are based on reviews of empirical evidence, occasionally with an adjustment for factors specific to India. Details are provided in Appendix 2.

Supply prices for fossil fuels are inferred from an international reference price (adjusted for transport and distribution costs), user prices are based on publicly available sources, and the difference between the two (after adjusting for general consumption taxes that should be applied to household fuels) is the specific fuel tax (or subsidy). Supply prices are projected forward using an average of (most recent) projections from the U.S. Energy Information Administration and the IMF (based on futures markets), while (real) fuel taxes and subsidies are taken as constant.

Fuel use is projected forward using the relationships described above, GDP forecasts, income elasticities for energy products of between 0.65 and 1, and assumptions about autonomous technological change by fuel and sector taken from other studies. Fuel price elasticities are taken to be invariant to policies (a reasonable assumption, at least for modest fuel price changes). Price elasticities for electricity demand and road fuels are taken to be -0.5, with half of the response coming from reductions in the use of energy-consuming products and half from improvements in energy efficiency,[31] while the coal price elasticity is -0.35.

C. Policy Scenarios

This subsection provides a brief rationale for the policy scenarios below and detail on their specifics. Each policy is phased in progressively (in practice, allowing firms and households time to adjust) and considered in isolation (though, loosely speaking, percent reductions in CO_2 and local air emissions would be largely additive in policy combinations).

Coal tax. We consider an increase in the coal tax of INR 300 ($4.50) per ton of coal each year from 2017 to 2030, bringing the total tax in 2030 to INR 4,600 ($70) per ton of coal. This policy is equivalent to an extra charge of about INR 2,450 ($37) per ton of CO_2 emissions from coal use[32] to enable a clean comparison with a carbon tax (see below). In fact, a higher tax—one of INR 8,730 ($131) per ton of coal—would be warranted at present by our current estimate of the local air pollution damages alone, though this is likely quite impractical. The INR 4,600 per ton coal tax is termed 'aggressive', as it represents a radical (and politically difficult) departure from

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[31] Improvements in energy efficiency reduce unit operating costs for energy consuming products, hence increasing their demand, though the resulting extra energy use from this 'rebound effect' offsets only about 10 percent of the savings from higher efficiency.

[32] On average, combusting a ton of coal causes about 1.87 tons of CO_2 emissions (see www.eia.gov/tools/faqs/faq.cfm?id=82&t=11).

current practice—over ten times the 2016 tax rate. A ‘modest’ coal tax is also considered, where the annual tax increase is INR 150 ($2.25) per ton of coal, bringing the 2030 tax to INR 2,500 ($37.50) per ton of coal. Even this modest policy phases in a coal tax increase of more than five times the 2016 tax (implications of smaller increases in the coal tax can be roughly inferred by interpolations in the figures below). Other policies below are generally scaled to the aggressive coal tax increase and therefore might be viewed as upper bounds on what is practically feasible.

The possibility of combining the coal tax with credits for the adoption of local air emissions control technologies by downstream fuel users is not considered, given the difficulty of pinning down the effect of these credits on future fleet average emission rates, though (as noted above) air emission rates are assumed to be declining over time in the BAU (implicitly due to retirement of older, more polluting capital).

Carbon tax. At present, Indian policymakers may be reluctant to commit to major reductions in future carbon emissions from energy, given advanced countries’ responsibility for historically accumulated emissions and domestic needs to expand power grid access and vehicle ownership. As noted above, however, the Paris process should create pressure for increasing the stringency of NDCs over time, so it is important to understand of the future impacts of alternative carbon mitigation options.

A carbon tax—that is a tax imposed on the carbon content of fossil fuels—promotes (with one instrument) the full range of emissions mitigation opportunities (switching from coal to gas and from these fuels to lower carbon fuels, improvements in energy efficiency, and less use of energy-consuming products) across all sectors. Collecting the tax upstream maximizes coverage and minimizes administration costs, at the point of fuel extraction and import, after fuel processing, or at fuel distribution points—whichever simplifies extension of existing fuel tax administration.[33] In India, for example, the existing coal excise on producers and importers could easily be modified so the rate is equal to CO_2 emissions per ton of coal multiplied by a CO_2 price, with minimal increase in administrative costs. A scenario is considered where the tax on CO_2 increases in equal yearly increments of INR 165 ($2.50) per ton from 2017 to reach 2,310 ($35) per ton by 2030, that is, about the same emissions price increase as in the aggressive coal tax.[34]

ETS. Instead of levying fuel charges, emissions could be reduced through introducing an ETS. As regards the choice between carbon taxes and ETS, either instrument is fine in principle, so long as it gets the design basics right—covering all emissions, using potential revenues productively, and establishing predictable emissions prices (which is important for mobilizing major clean technology investments) in line with environmental objectives.[35]

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[33] See Calder (2015) for a discussion of administrative issues.

[34] For comparison, this rate is in line with (albeit uncertain) estimates of the CO_2 price needed by China to meet its INDC in 2030, though advanced countries would generally require substantially higher prices (e.g., Aldy and others 2016).

[35] See Farid and others (2016).

Achieving these design features is more convoluted under ETSs however: they are usually imposed on large stationary sources and exclude (for administrative reasons) numerous small-scale emissions sources (e.g., from vehicles, buildings, small entities); they are administered by environmental agencies, which might increase the risk that fiscal opportunities are not fully exploited (e.g., because allowances are allocated freely or revenues from auctioned allowances might be earmarked for low value spending); and, in the absence of price floors and ceilings, emissions prices tend to be volatile. ETSs also require substantial set up costs in terms of establishing new systems for monitoring emissions (e.g., continuous emission monitoring technologies where feasible and estimated emissions where not).

In practice, ETSs are more commonly used to reduce GHGs and local air pollution emissions—for example, ETSs cover about two thirds of global GHGs currently subject to formal emissions pricing schemes[36]—so it is useful to compare them with carbon and coal taxes. To facilitate this comparison, the ETS is modelled by its implicit tax, that is, the emissions price that would be established by the cap, and this implicit price is set equal to the emissions price under the aggressive carbon tax. The ETS is applied to CO_2 emissions from the power sector and large users in the other energy sector (petro and other chemicals, building materials, iron and steel, non-ferrous metals, paper, etc.)

Electricity excise. Excises on (mostly residential) electricity are applied in many countries, in part rationalized on environmental grounds, though their environmental effectiveness is very limited as they do not promote switching to cleaner generation fuels or emissions reductions beyond the power sector. Electricity taxes (applied to all uses) are considered here, with the rates matched to the increase in electricity prices generated by the aggressive carbon tax.

Increased renewable generation subsidies. Here the focus is on renewables (wind and solar) in power generation, given their greater potential for use in that sector than elsewhere. Renewable subsidies have limited effects on reducing CO_2 emissions as they do not promote some fuel switching possibilities (e.g., from coal to gas), nor do they reduce electricity demand, or emissions beyond power. A scenario is considered that introduces a subsidy of INR 0.7 ($0.01) per kWh in 2013 [37] and progressively raises it to INR 5 ($0.075) per kWh by 2030 (higher subsidies than this start to imply negative generation costs).

Power sector "feebate." A policy that efficiently promotes shifting to cleaner fuels in the power sector can have significant CO_2 and local air pollution benefits. Moreover, so long as the policy does not impose a charge on the remaining CO_2 emissions it has a much weaker impact on electricity prices than the above policies, as it does not involve the pass through of a large new charge on emissions or coal use into higher generation prices, though this forgoes a new

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[36] WBG (2016). This share will increase to about 80 percent if China implements a nationwide ETS in 2017.

[37] Approximately the federal subsidy for solar and wind power generation in 2015 as reported by the Indian Renewable Energy and Energy Efficiency Policy Database.

revenue source. CO_2 emission rates can be reduced through regulations, though without extensive credit trading to equalize implicit CO_2 prices across different generators the policy is not cost effective. Instead we consider a tax-subsidy, or feebate policy that in practice would involve taxes in proportion to the difference between generators' CO_2 per kilowatt hour (kWh) and a 'pivot point' CO_2 per kWh and subsidies for generators with CO_2 per kWh below the pivot point in proportion to the difference in the emission rate. In our model, which does not incorporate heterogeneity among generators, the feebate can be represented by a carbon tax applied only to power generation fuels with the resulting revenues returned in per unit subsidy for power generation output, as this promotes shifting to lower carbon fuels without a first order increase in electricity prices.[38] The implicit price on CO_2 in the fee or rebate in each period is set equal to the CO_2 price in the aggressive carbon tax.

Increasing the efficiency of electricity-using capital. Regulations are commonly used to raise the efficiency of electricity-using capital.[39] The policy scenario considered here provides an upper bound on effectiveness and cost-effectiveness in the sense that it implicitly improves the efficiency of all electricity-using capital (industrial machinery, appliances, lighting, buildings, heating and cooling equipment, etc.), and with equalized incremental costs per ton of CO_2 reduced across all products.[40] The policy is modelled by applying an implicit tax (with rates equal to those in the electricity tax scenarios) to reduce the electricity consumption rate, but not applying it to the demand for electricity-using capital.

Higher road fuel taxes. Effective road fuel taxes in India are INR 21 ($0.32) and INR 18 ($0.26) per liter for gasoline and diesel respectively in 2016.[41] These taxes are the most effective policies for reducing road fuel use as they promote higher fuel economy and less driving. A scenario is considered where gasoline and diesel taxes are increased in each period by twice as much as they are in the aggressive carbon tax scenario.

Increasing efficiency in the other energy sector. The final policy increases the energy efficiency of fossil fuel-using capital for large users in the other energy sector (but not small users who are more difficult to regulate). As above, the policy is modelled by applying an implicit tax to reduce

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[38] See, for example, Bernard and others (2007) and Krupnick and Parry (2010) for more discussion.

[39] Besides their environmental benefits, it is sometimes suggested that these policies address an additional market failure due to the private sector undervaluing the discounted energy savings from higher energy efficiency, though the evidence on this for advanced countries is mixed (e.g., Allcott and Wozny 2013, Helfand and Wolverton 2011). Allowing for this market failure could imply that, up to a point, policies to increase energy efficiency could have net economic benefits (before counting environmental benefits), though these net benefits appear to be small relative to those from directly pricing emissions (e.g., Parry and others 2014b).

[40] In reality, much of this capital is difficult to regulate (e.g. smaller appliances, audio and entertainment equipment, industrial processes like assembly lines) and without extensive credit trading incremental costs may differ substantially across different efficiency programs.

[41] The prices in New Delhi as reported by the India PPAC. The tax includes specific and ad-valorem portions.

the consumption rate of coal, natural gas, and oil products but not applying it to the price in the demand for use of energy products. The implicit tax is chosen to mimic the increase in fuel price under the aggressive carbon tax scenario.

D. Incidence Analysis

Methods for assessing the future household and industry incidence of coal taxes and other pricing reforms are discussed in turn below.

Household incidence

Methodology. A first approximation of the burden on different household groups from higher consumer product prices caused by energy pricing reform can be inferred from the first-order losses in consumer surplus, given by:

$$\sum_g \pi_t^{hg} \cdot \rho_t^{hg} \tag{1}$$

Here h denotes a household income group, $g = 1 \ldots G$ denotes major categories of consumer goods whose prices are increased, π_t^{hg} is the share of household h's budget spent on good g at time t and ρ_t^{hg} is the percent increase in the price of good g. According to this formula, if the budget share for a product is, say, 5 percent, a 10 percent increase in its price will decrease the household group's real income by the equivalent of 0.5 percent.

The budget shares needed for implementing (1) are taken from the 68th Round of the National Sample Survey (NSS), which interviewed 101,724 households (59,700 rural and 42,024 urban) during the period July 2011-June 2012. Budget shares are defined relative to annual consumption, which is viewed as a better proxy for 'permanent' or lifetime income than annual income.[42] Households were first separated into income deciles using consumption as a proxy for permanent income and budget shares were calculated by dividing expenditure on individual goods and services by total household consumption. The direct increases in energy prices (fuels and electricity) are computed from the spreadsheet model while indirect impacts on the prices of other consumer goods are estimated, assuming full pass through, from the 2007-2008 National Input-Output Table.[43] Projections for 2020 are made assuming household spending patterns and industry structure in 2020 are the same as in the years of the survey and input/output data.[44]

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[42] See for example Poterba (1991), Hassett and others (2009).

[43] The table was obtained from the Central Statistics Office, Ministry of Statistics and Programme Implementation of India. Although more recent tables are available from other sources, they lack the disaggregation of consumer products in the data used here.

[44] As long as any trends reduce (or increase) energy budget shares for all household groups in roughly the same proportion, the relative incidence of fuel price reforms across households is largely unaffected. One exception

(continued)

There are a number of caveats to using the formula in (1). The mix of fuels used in the power generation and other production sectors will change in response to higher energy prices—in particular, coal use per unit of production will decline—and as a result use of input/output tables overstates the consumer price increases, though this overstatement is fairly modest for the energy price reforms considered here. The formula in (1) also overstates the loss of consumer surplus as it ignores price-induced reductions in demand for energy-intensive products, though again the difference is relatively modest.[45]

Another caveat is that some (probably minor) fraction of the burden of fuel taxes may be passed backwards in lower producer prices, if fuel supply curves are upward sloping in the medium to longer term. To the extent this reduces the net of tax return to capital, some of the incidence of the fuel tax incidence is borne by owners of capital, though if the net of tax returns is largely determined in world capital markets, the burden of lower producer prices is mainly borne by workers in the form of lower wages. The resulting incidence effects become tricky to estimate as they depend, for example, on whether energy-intensive firms disproportionately hire high- or low-wage workers and substitution elasticities between energy and other inputs,[46] though some studies [47] for advanced countries suggest these incidence effects are not that large and may disproportionately harm higher income groups.[48]

Industry incidence

Fuel price reform increases production costs across industries and a particular concern is impacts on energy-intensive, trade-exposed sectors though competitiveness concerns may be ameliorated, to some extent, if other countries progress on their Paris mitigation pledges. The incidence of fuel price reform on different sectors comes from the first step of the household incidence analysis and is done for 125 industry classifications. Some of the caveats just noted (e.g., whether taxes are fully passed forward) therefore apply.

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might be the prospects for rising budget shares for gasoline among middle and lower income households with potential for growth in vehicle ownership rates among these groups.

[45] For example, the first-order approximation (a rectangle) overstates the loss of consumer surplus (a trapezoid) by only about 5 percent when demand for a fuel product falls by 10 percent.

[46] See for example Fullerton and Heutel (2011).

[47] For example Rausch and others (2011).

[48] A further caveat is that the distributional incidence of the domestic environmental benefits of fuel price reform are not considered. These benefits may be skewed to lower income households if these households are more likely to reside in severely polluted areas.

IV. RESULTS

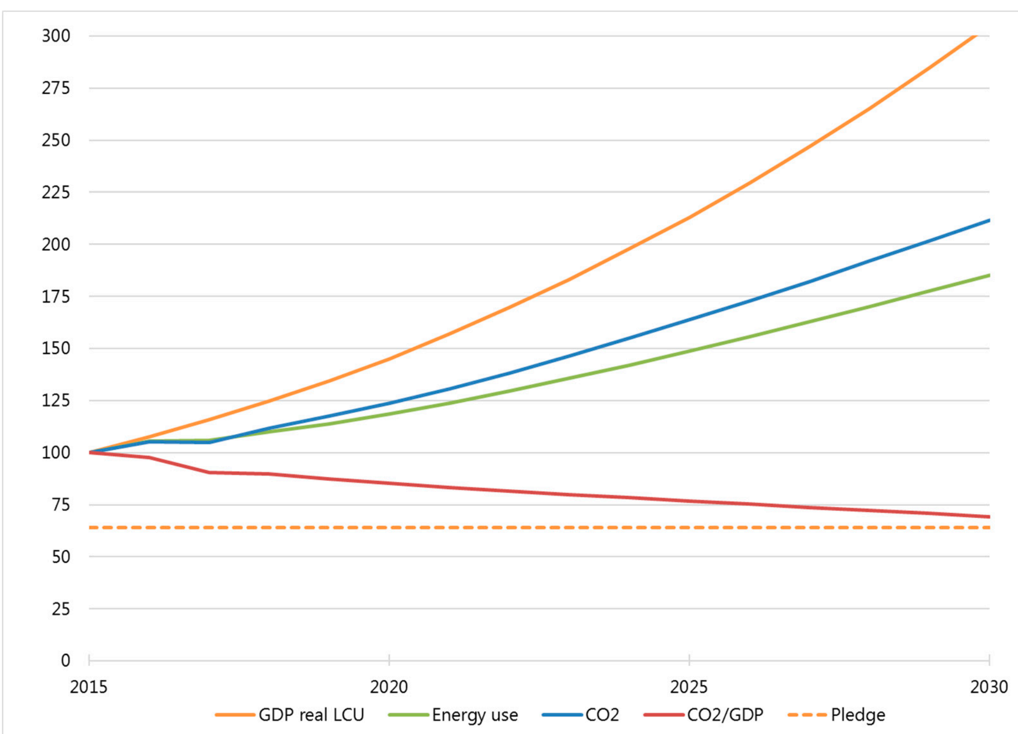
This section describes the BAU scenario, policy comparisons across different metrics, sensitivity analyses, comparisons with a fully efficient pricing policy, and the incidence analysis for different policies.

A. BAU Projections

The BAU projections assume no new (or change of existing) policies beyond those that are implicit in observed data for 2014 (aside from an implicit assumption that regulations progressively reduce local air emission rates for coal generation plants).

Figure 3 shows baseline projections of energy and CO_2 emissions trends. Real GDP expands rapidly (by over 7 percent a year) from 2015 onwards implying it is about three times as large in 2030 compared with 2015. Total energy consumption expands, but at a much slower rate, and is about 85 percent higher in 2030 compared with 2015 and as a result the energy intensity of GDP falls by 37 percent. This declining energy intensity reflects a combination of improving energy efficiency (mostly rising at an annual rate of 1.0 percent across sectors), generally rising fuel prices (see below) which dampen the growth in energy demand, and an assumption that income elasticities for energy products are (slightly) below unity. CO_2 emissions grow by 112 percent between 2015 and 2030 (faster than the growth in energy due to a rising coal share—see below) and the CO_2 intensity of GDP falls by 27 percent relative to 2015, or 24 percent relative to 2005, so policy intervention would be needed to meet India's NDC.

Figure 3. Energy Use and CO_2, BAU Scenario (2015 = 100)

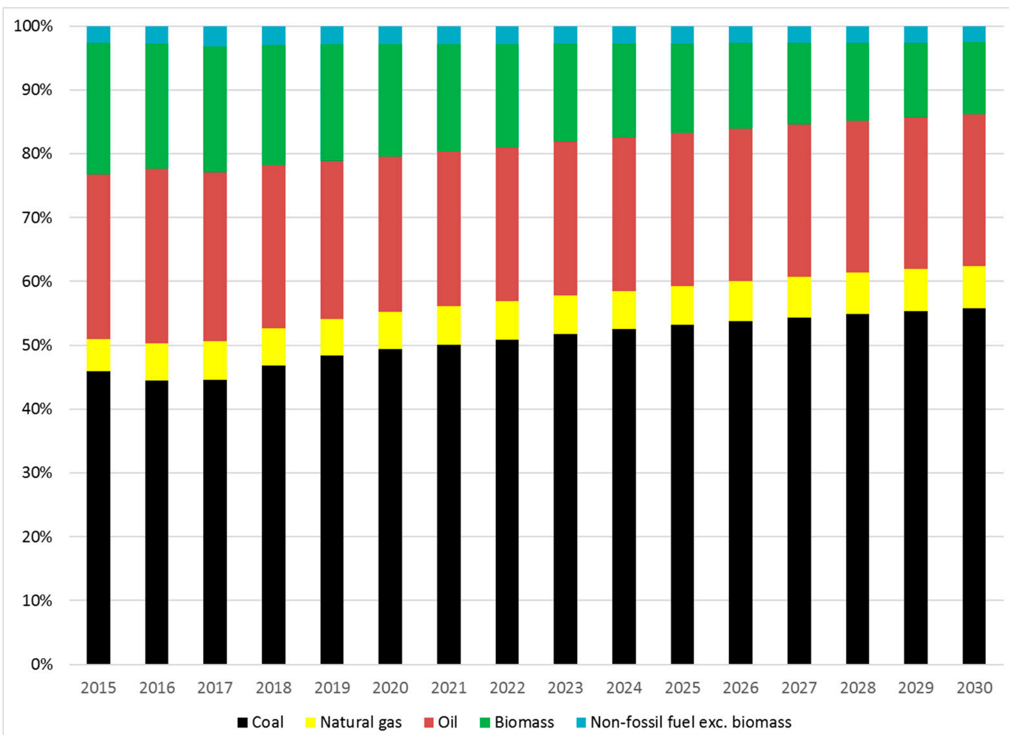


Source: From equations and parameter assumptions in Appendices A and B.

Our energy and CO_2 emissions projections would be similar [49] to those for India in IEA (2016) if their energy price projections had been used. However, since we consider the average of IEA and IMF World Economic Outlook projections, future oil prices rise more gradually (by 52 percent) and decline slightly (by 3 and 10 percent respectively for coal and natural gas) by 2030 relative to 2015. This is the main reason why our BAU CO_2 emissions in 2030 is about 26 percent higher than in IEA (2016), underscoring the sensitivity of projections to future fuel price assumptions.

As indicated in Figure 4, the composition of primary energy in the BAU changes notably as coal's share increases from 45 to 55 percent between 2015 and 2030 while that for biomass declines from 21 to 10 percent, in part reflecting the expansion of electricity (largely generated by coal) to low-income households previously using biomass. Primary energy shares remain relatively small for natural gas and renewables and remain at a little under a fifth for oil.

Figure 4. Primary Energy by Product, BAU Scenario (Percent)



Source: From equations and parameter assumptions in Appendices A and B.

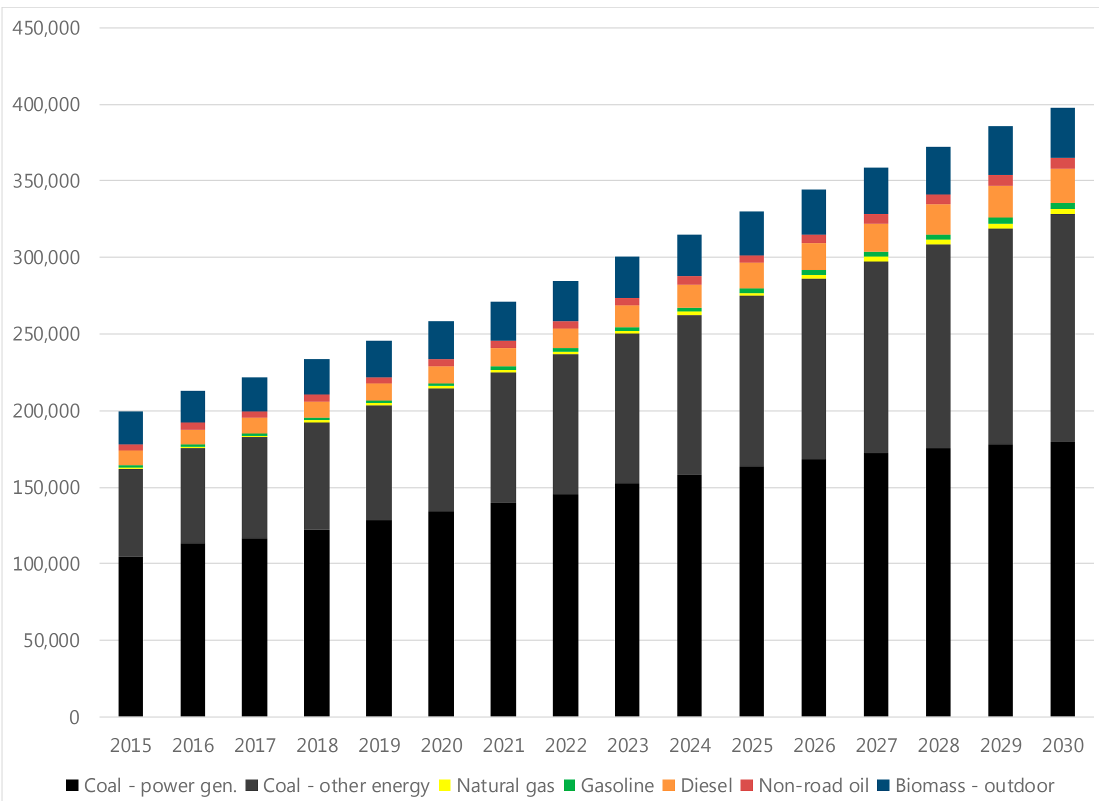
Given its high carbon intensity (about 70 percent greater per unit of energy than for natural gas and 40 percent greater than for gasoline), coal accounts for a disproportionately larger share (71 percent in 2015) of CO_2 emissions than it does for primary energy, while natural gas accounts for 3 percent and oil for 26 percent. The CO_2 emissions share for coal increases to 77 percent by 2030 in the BAU while that for oil falls to 20 percent. In terms of sectors, power generation

[49] 1 percent higher and 5 percent lower respectively in 2030.

accounts for 50 percent of CO_2 emissions in 2015, road transportation 8 percent, and the other energy sector 42 percent—power's share of CO_2 emissions increases over the BAU to 57 percent by 2030 at the expense of the other energy sector.

Finally, estimated premature deaths from *outdoor* air pollution resulting from fossil fuel combustion are just under 200,000 in 2015 with coal use in the power and other energy sectors accounting for just over 80 percent of these deaths and biomass most of the remainder (Figure 5). These figures are based on estimates of deaths per unit of air pollutants, fuel use, and air pollution emission rates and are conservative relative to some other estimates.[50] Outdoor air pollution deaths rise by over 80 percent to reach 400,000 by 2030 with increased coal use and rising population exposure to urban pollution more than offsetting the assumed decline in air emission rates at power plants. Also indicated in Figure 5 is the very large amount, about 340,000 in 2015, of indoor air pollution deaths due to household biomass combustion—these deaths grow more slowly (by 24 percent) out to 2030 with the progressive substitution of electricity for home biomass fuels.

Figure 5. Air Pollution Deaths by Fuel Product, BAU Scenario



[50] For example, Lelieveld and others (2015), Extended Data Table 3, put outdoor pollution deaths in India at about 640,000 for 2010 (see also World Bank and Institute for Health Metrics and Evaluation 2016), though this includes some additional sources (e.g., agriculture, natural pollution).

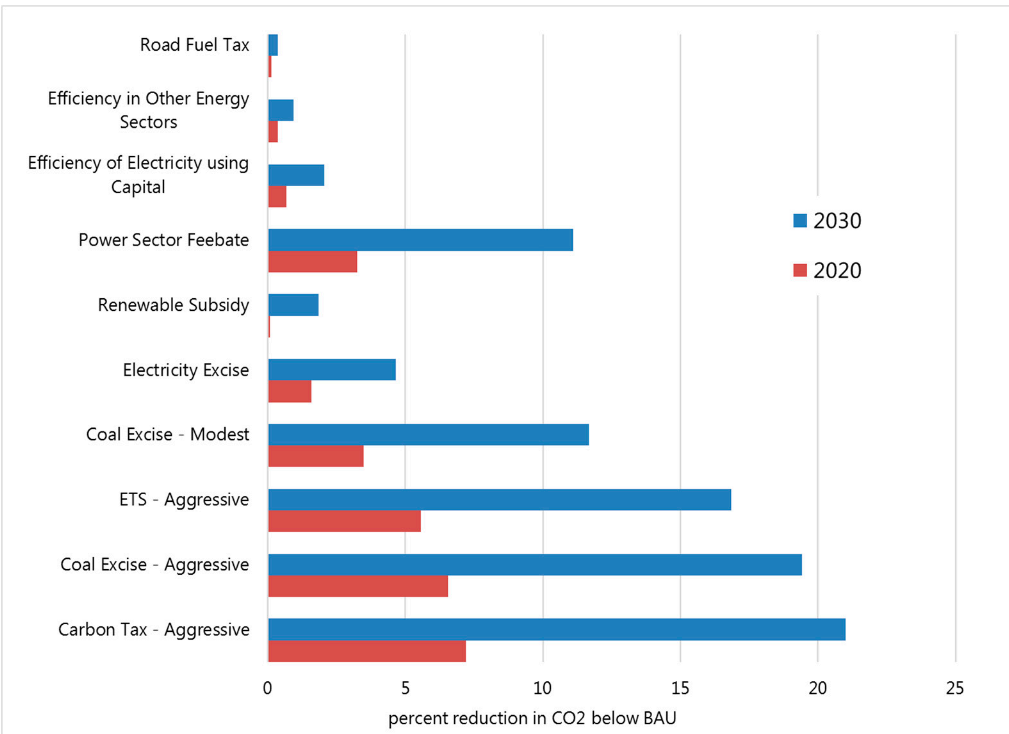
Source: From equations and parameter assumptions in Appendices A and B.

B. Policy Comparison

CO_2 emissions

Figure 6 indicates the percent reduction (relative to the BAU in the corresponding year) in CO_2 emissions in 2020 and 2030 under the policy scenarios and Figure 7 indicates the breakdown of the CO_2 reductions by fuel type and sector for 2020.

Figure 6. CO_2 Reductions Under Alternative Policies, 2020 and 2030 (Percent)



Source: From equations and parameter assumptions in Appendices A and B.

As shown in Figure 6, the carbon tax is the most effective policy for reducing energy-related CO_2 emissions, reducing them by about 8 percent and 22 percent below BAU levels in 2020 and 2030 respectively. These results are driven almost entirely by reductions in coal use, which account for 98 percent of the CO_2 reductions with 2 percent coming from reductions in oil use.[51] By sector, power generation accounts for 62 percent of the reductions and the other energy sector 32 percent (Figure 7).

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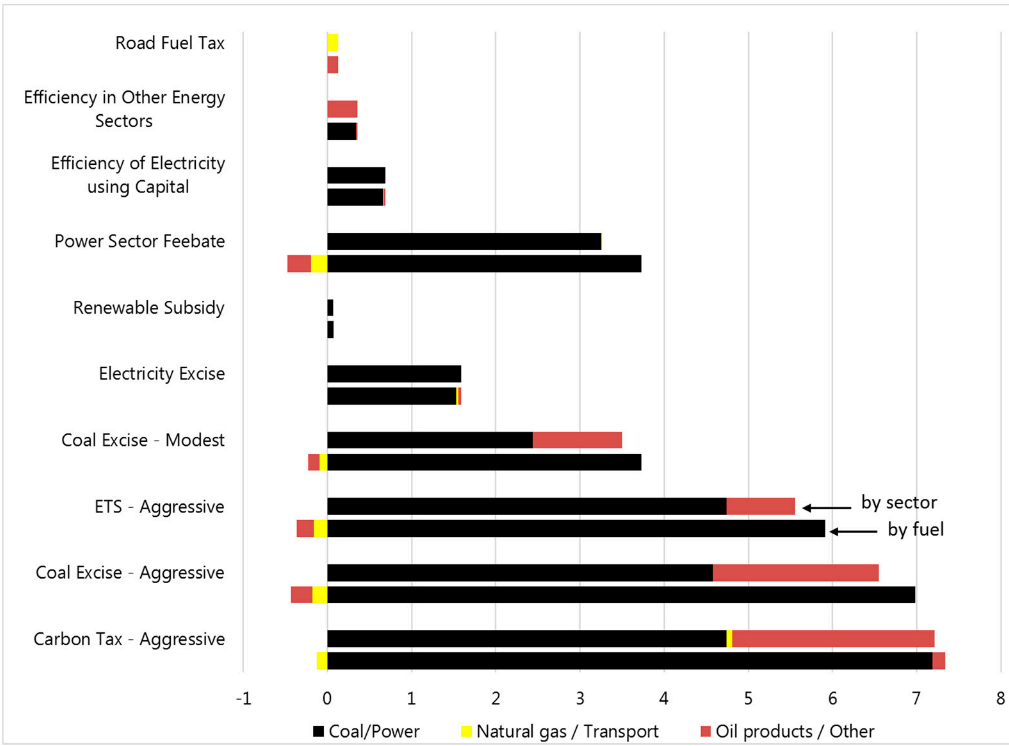
[51] Natural gas increases slightly due to switching to this fuel from coal.

Figure 7. Percent CO_2 Reductions Under Alternative Policies by Product and Sector, 2020 (Percent)



Source: From equations and parameter assumptions in Appendices A and B.

The aggressive coal tax is only slightly less effective than the carbon tax, reducing emissions by about 95 percent of the reductions under the carbon tax in 2020 and 2030 (Figure 6). This small difference reflects the relatively small emissions reductions forgone from failing to charge for CO_2 from other fossil fuels. The modest (and perhaps more realistic) coal tax cuts CO_2 emissions by 4 and 12 percent below BAU levels respectively in 2020 and 2030.

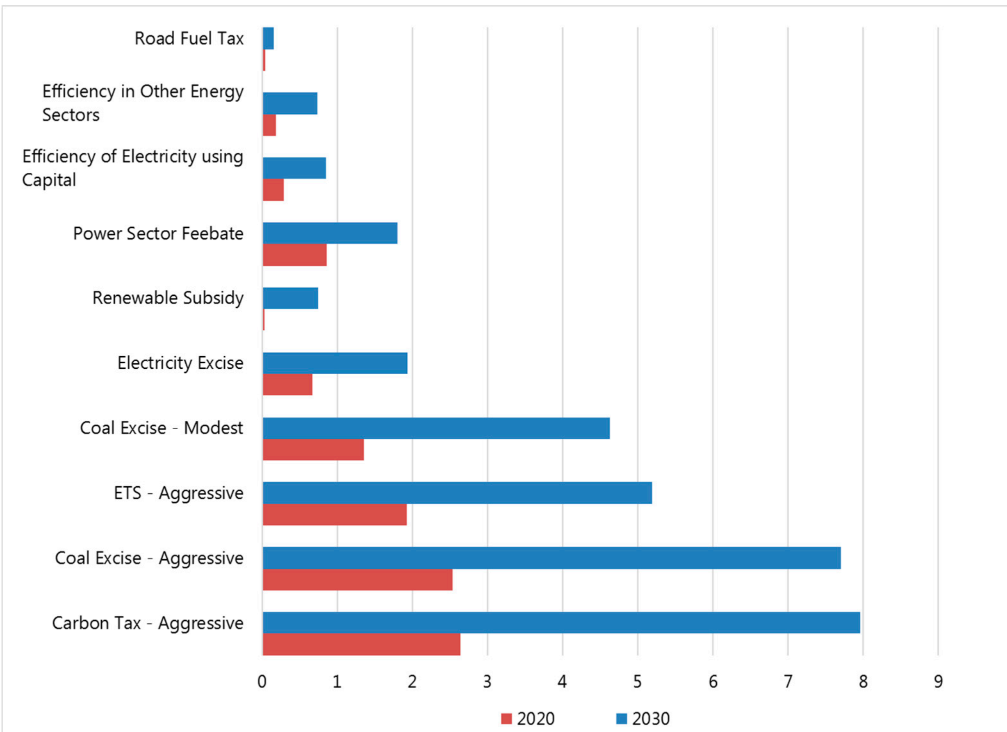
The ETS achieves CO_2 reductions of about 80 percent of those under the equivalently priced carbon tax as it produces nearly the same CO_2 reductions from the power sector as does the carbon tax, but only about a third of those from the other energy sector (Figure 7).

The power sector feebate has roughly half of the effectiveness of the equivalently priced carbon tax, and the electricity excise about 20 percent, while all other policies have effectiveness of, at best, 10 percent of that for the carbon tax.

Local air pollution deaths

Figure 8 indicates the percent reduction in total (outdoor plus indoor) pollution deaths in 2020 and 2030 under the different policies—these percent reductions are around 30-40 percent of the corresponding percent reductions in CO_2 emissions, as these policies only reduce outdoor pollution deaths (which account for about 40 percent of outdoor and indoor deaths combined).[52] The relative performance of different policies in reducing air pollution deaths follows a similar pattern to the relative reductions in CO_2 emissions. For example, the coal tax is marginally less effective at reducing deaths than the corresponding carbon tax, while the ETS is about 70 percent as effective.

Figure 8. Reductions in Pollution-Related Deaths from Fuel Use, 2020 and 2030 (Percent)



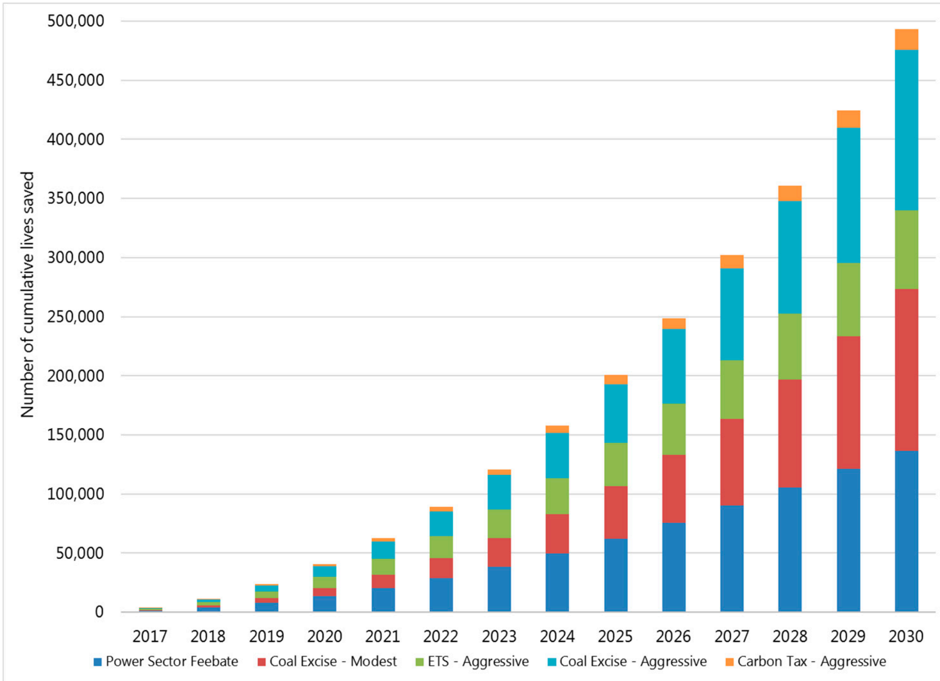
Source: From equations and parameter assumptions in Appendices A and B.

Figure 9 shows the cumulated savings in outdoor air pollution deaths under the five most effective policies as they are phased in progressively over the 2017–30 period. The aggressive carbon tax saves about 490,000 lives while the aggressive coal tax saves about 470,000 lives over

[52] Focusing on total, rather than outdoor, deaths takes account of increases in indoor air pollution deaths from policies that raise electricity prices, thereby causing a substitution from electricity to home biofuel use. This offsets about 7 percent of the reductions in outdoor air pollution deaths from less fossil fuel use under the coal and carbon tax and ETS. The offset is smaller for the policy to reduce the emissions intensity of the power sector, given the minimal impact of this policy on electricity prices.

the period. On the other hand, the ETS saves about 340,000, the modest coal tax 270,000 and the power sector feebate 140,000.

Figure 9. Pollution-Related Deaths Avoided, 2017–30

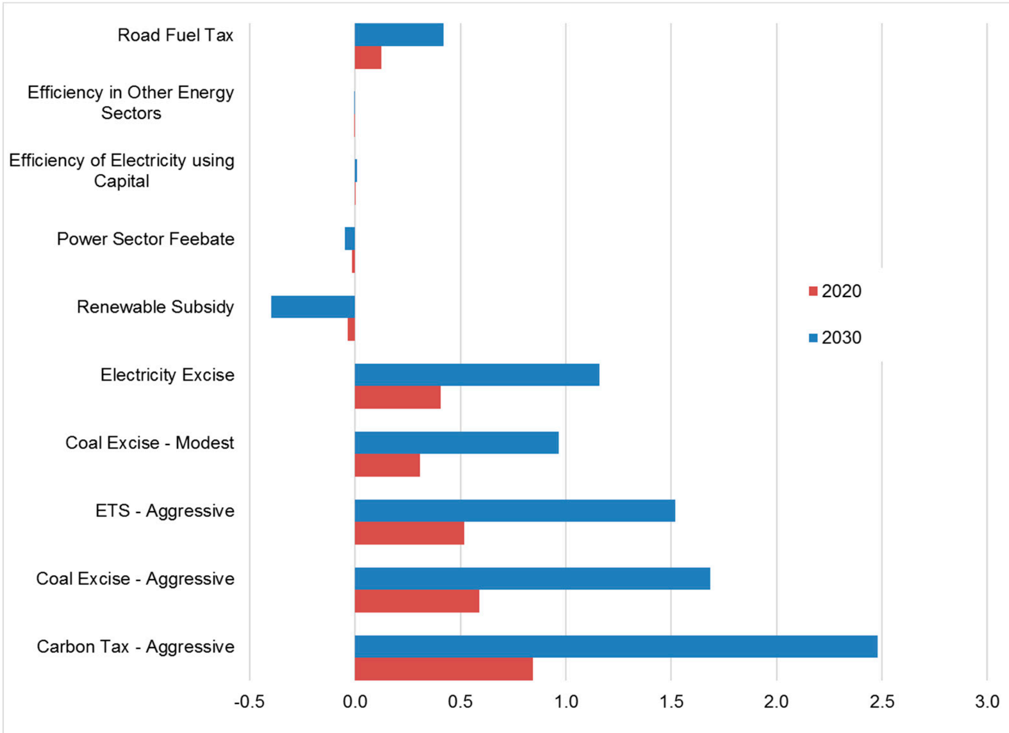


Source: From equations and parameter assumptions in Appendices A and B.

Revenue

As indicated in Figure 10, the modest coal tax raises revenues of about 0.3 and 1.0 percent of GDP in 2020 and 2030 respectively, while the aggressive coal tax raises about 70 percent more revenue. The carbon tax raises about 40 percent more revenue than the equivalently scaled coal tax (due to its greater coverage) while the ETS—*if* allowances are auctioned—and the electricity tax raise revenues of about 60 and 45 percent respectively compared with the equivalently priced carbon tax (the ETS, for example, does not raise revenue from road transportation and small users in the other energy sector). Road fuel taxes raise about 15 percent of the revenue raised from the carbon tax. The renewable generation subsidy loses revenue, and by quite a significant amount (approaching 0.4 percent of GDP by 2030).

Figure 10. Fiscal Gains, 2020 and 2030 (Percent of GDP)

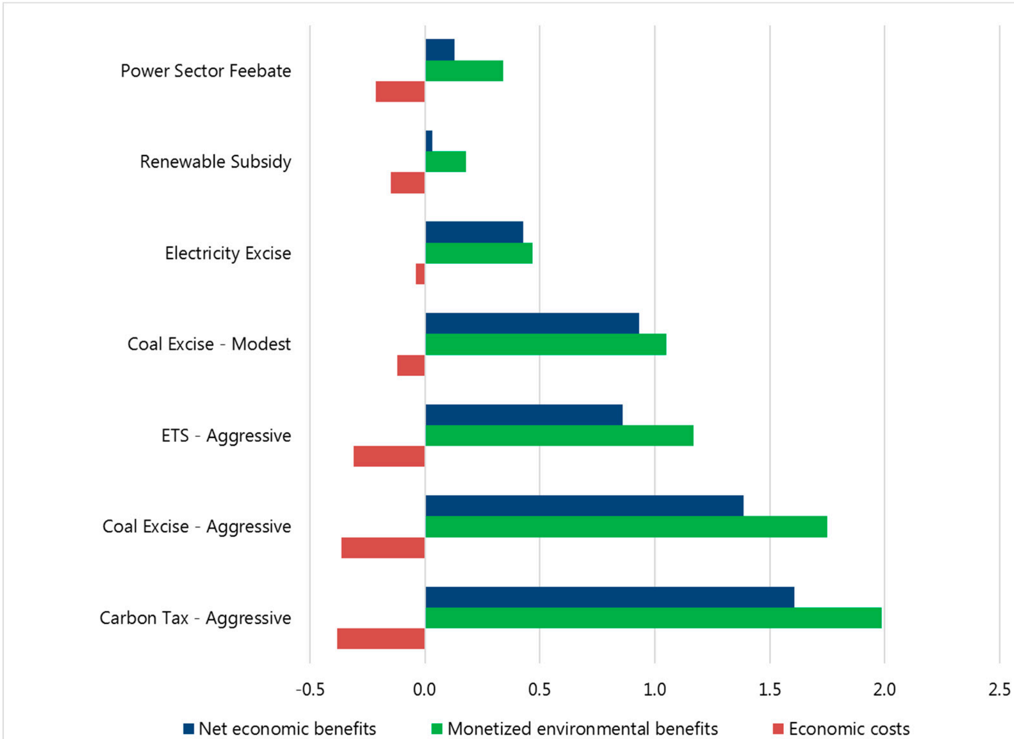


Source: From equations and parameter assumptions in Appendices A and B.

Domestic welfare benefits and costs

Figure 11 indicates the economic welfare costs, monetized domestic environmental benefits (excluding global climate benefits), and net welfare benefits (domestic environmental benefits less economic costs). The environmental benefits essentially reflect the value of lower air pollution mortality (congestion and other environmental benefits of reduced vehicle use are included but are small in relative terms).

Figure 11. Domestic Welfare Benefits and Costs, 2030 (Percent GDP)



Source: From equations and parameter assumptions in Appendices A and B.

Not surprisingly, the aggressive carbon tax and coal tax perform the best, causing costs of about 0.4 percent of GDP but generating net welfare gains of about 1.5-1.7 percent of GDP when domestic environmental benefits are taken into account. Net economic benefits are about 1 percent of GDP for the modest coal tax, 0.9 percent for the ETS, 0.4 percent for the electricity tax, and 0.2 percent for the power sector feebate.

C. Sensitivity Analyses

Table 2 presents some sensitivity analysis for the coal taxes, carbon tax, and ETS for 2030, under different assumptions about income elasticities, fuel price elasticities, rates of technological change, mortality rates from air pollution, and projected energy prices.

Table 2. Sensitivity Analysis: 2030

		CO2 reduction (%)				Revenue gain (% of GDP)				Cumulative lives saved				PDV welf. gain (% 2015 GDP)			
		Aggressive			Modest	Aggressive			Modest	Aggressive			Modest	Aggressive			Modest
		carbon tax	coal excise	ETS	coal excise	carbon tax	coal excise	ETS	coal excise	carbon tax	coal excise	ETS	coal excise	carbon tax	coal excise	ETS	coal excise
Central case		21.0	19.4	16.9	11.7	2.5	1.7	1.5	1.0	493	476	340	273	18.0	15.9	10.8	9.9
Income elasticities	Low	20.7	19.1	16.7	11.5	1.8	1.2	1.1	0.7	376	362	261	208	13.8	12.1	8.3	7.5
	High	20.9	19.2	16.6	11.6	3.6	2.4	2.2	1.4	652	629	446	363	23.9	21.0	14.2	13.2
Price elasticities	Low	11.2	10.4	9.2	6.0	2.7	1.9	1.6	1.0	229	221	160	123	8.1	7.2	4.9	4.4
	High	29.0	26.8	23.4	16.8	2.3	1.5	1.4	0.9	732	709	514	419	26.7	23.7	16.5	15.2
Productivity growth	Low	20.4	18.7	16.2	11.2	2.7	1.8	1.6	1.0	508	489	347	281	18.6	16.4	11.1	10.2
	High	21.8	20.2	17.6	12.2	2.3	1.6	1.4	0.9	478	462	332	266	17.3	15.3	10.5	9.6
Mortality rates	Low	21.0	19.4	16.9	11.7	2.5	1.7	1.5	1.0	273	263	181	151	8.8	7.5	4.6	5.1
	High	21.0	19.4	16.9	11.7	2.5	1.7	1.5	1.0	724	702	571	405	27.7	25.4	20.6	15.5
Fuel Prices	IMF	21.2	19.0	16.4	11.5	2.6	1.7	1.6	1.0	534	516	368	298	20.0	17.1	11.7	10.7
	IEA	15.1	14.0	11.9	8.0	2.1	1.4	1.3	0.8	338	325	228	181	12.2	11.0	7.4	6.6

Source: From equations and parameter assumptions in Appendices A and B.

The percent reduction in CO_2 emissions under different policies is obviously sensitive to fuel price elasticities—for example, if fuel price responses are assumed to be more elastic, the percent reductions in CO_2 under different polices are increased by about 40 percent. On the other hand, changing income elasticities for energy products affects the baseline level of future CO_2 emissions but has essentially no effect on the policy-induced percent reductions in CO_2.

Revenue gains from fiscal policies as a percent of GDP are sensitive, but only moderately so, to different income elasticities, price elasticities, and productivity trends (as these all have some effect on the future size of tax bases relative to GDP).

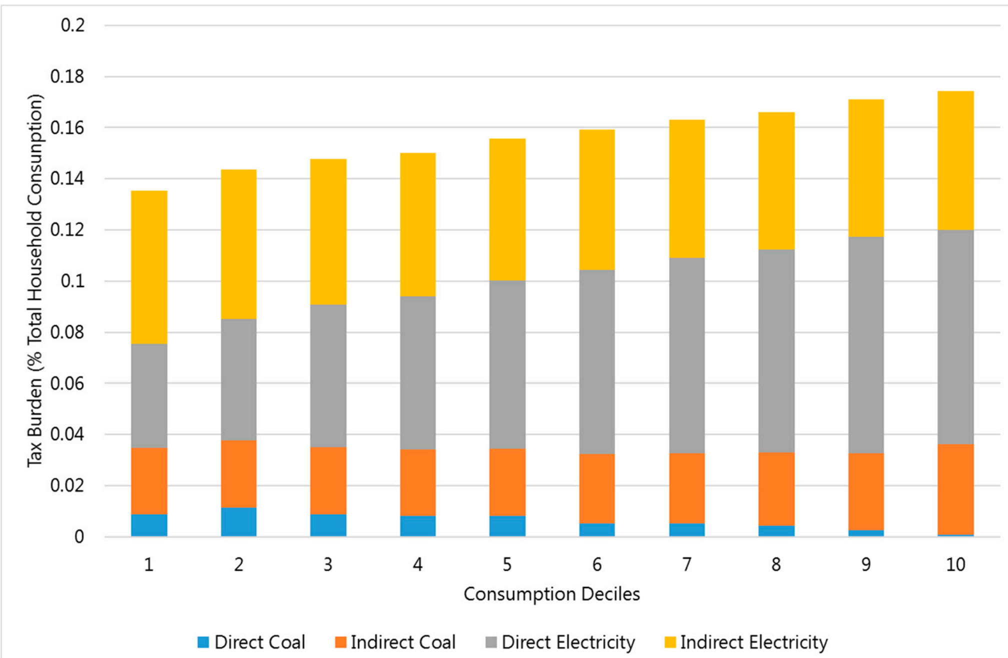
Cumulative lives saved under policies over the 2017–30 period vary somewhat with all of the sensitivity cases in Table 2 as they affect either baseline deaths and/or policy responsiveness. For example, when fuel price responsiveness is less elastic the policies save 25 percent fewer lives than in the central case. Economic welfare gains (calculated as a present discounted value over the 2017–30 period and expressed as a percent of 2015 GDP) vary significantly in absolute terms under alternative parameter scenarios but the relative welfare gains from policies are fairly robust—in all cases in Table 2 the aggressive and moderate coal taxes achieve around 90 and 60 percent respectively of the net benefits of the (aggressive) carbon tax.

D. Incidence Analyses

Household incidence

Figure 12 illustrates the burden of the modest coal tax in 2020 on household deciles grouped by their total consumption. Overall, the coal tax is mildly progressive as the burden rises steadily from 0.14 percent of consumption for the lowest consumption decile to 0.18 percent of consumption for the highest decile. The main driver of the progressive impact is the substantially higher burden of electricity purchases for better off households (about 0.08 percent of their consumption compared with 0.04 percent for the bottom decile) and reflecting in part the lower rate of power grid access among the poor. Indirect burdens from the pass through into consumer product prices of higher prices for coal and electricity inputs used by firms are, roughly speaking, evenly distributed imposing a similar burden relative to consumption across households. The impact of higher prices for coal directly consumed by households is regressive but the burdens are small relative to those from other price impacts.[53] Compensating the bottom two deciles for the burden of a coal tax in 2020 need only use 6 percent of coal tax revenues.

Figure 12. Burden of Moderate Coal Tax on Household Consumption Deciles, 2020 (Percent of household consumption)



Source: See text.

Note: Households are grouped into deciles according to their total consumption as reported in the National Sample Survey where the first and tenth deciles are the lowest and highest consumption groups respectively.

Figure 13 compares the distributional incidence of a broader range of policies in 2020, this time grouping households by consumption quintiles. All policies are mildly progressive. The (aggressive) carbon tax imposes the largest burdens on households (0.4 and 0.5 percent of consumption for the lowest and highest consumption quintiles) as it is the most comprehensive in terms of raising fuel prices. The ETS imposes the next largest burden, followed by the aggressive coal tax, the electricity tax, the moderate coal tax, and lastly higher road fuel taxes.

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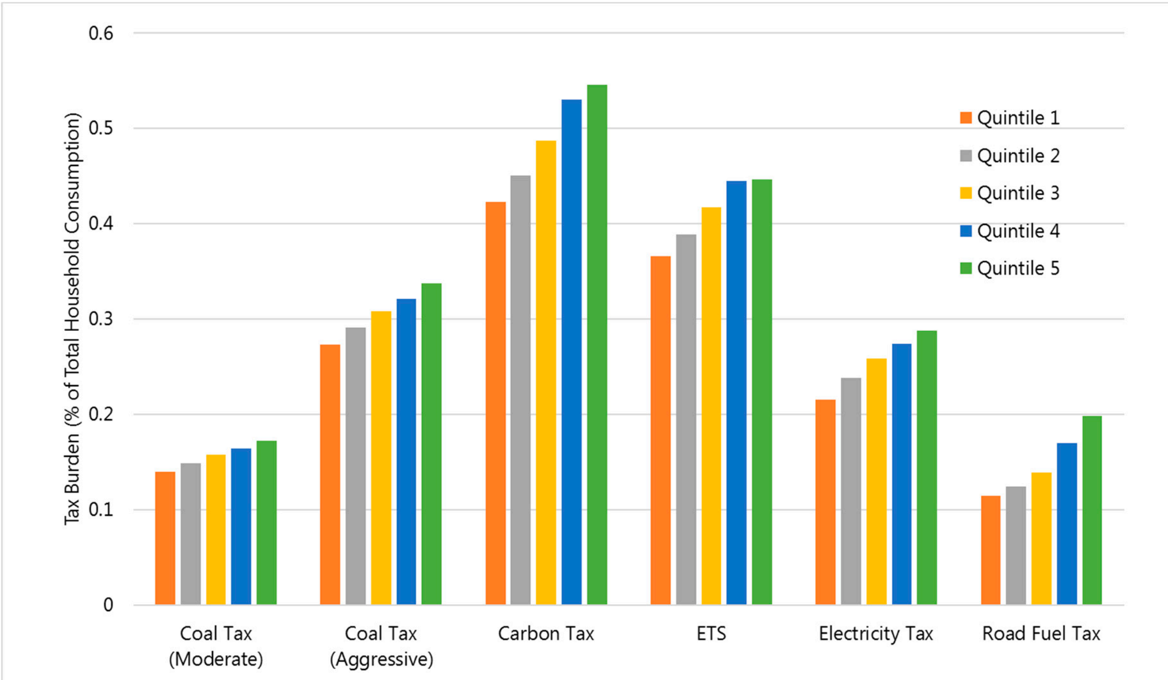
[53] Abdallah and others (2015) find that energy price reform in India is mildly regressive though the reason is that they focus on a large price increase for kerosene (which is heavily consumed by the poor) and a moderate increase in road fuel prices, rather than an increase in coal and electricity prices.

Figure 13. Burden of Selected Policies on Household Consumption Quintiles, 2020 (Percent of household consumption)



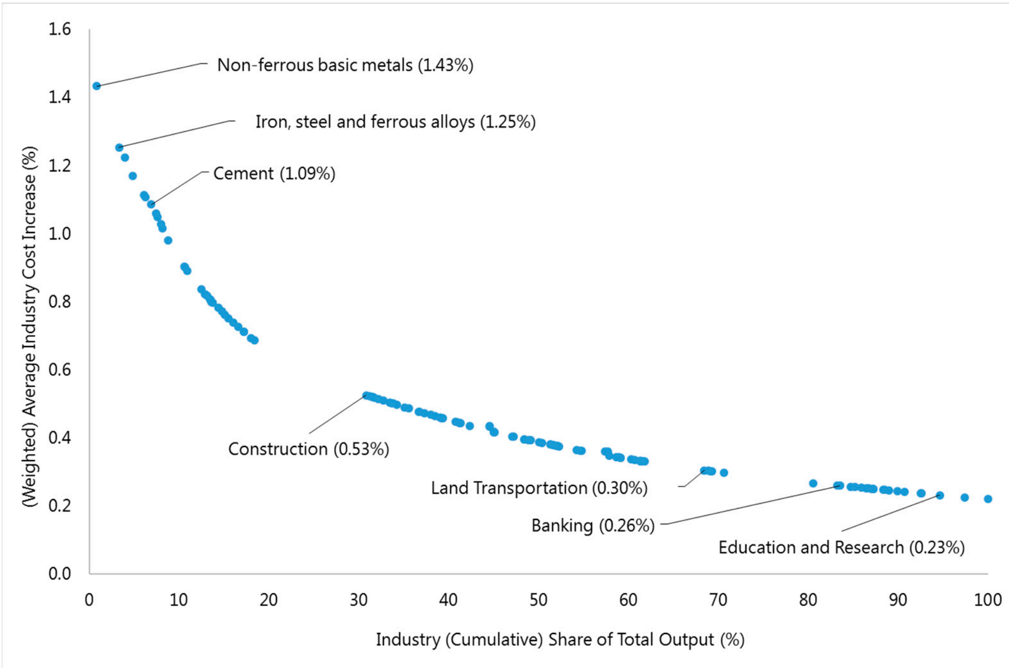
Source: See text.

Note: Households are grouped into quintiles according to their total consumption as reported in the National Sample Survey where the first and fifth quintiles are the lowest and highest consumption groups respectively.

Industry incidence

Figure 14 summarizes the impacts of the modest carbon tax on industry costs in 2020 (aside from coal and power producers). For example, taking the 10 percent of most affected industries, their costs increase on average by 1.1 percent; for the 30 percent of most affected industries the average cost increase is 0.6 percent; and the average across all industries is 0.2 percent. Especially vulnerable industries include, for example, non-ferrous basic metals and iron, steel and ferrous alloys, whose costs increase by 1.4 and 1.2 percent respectively. Construction is an intermediate case with a cost increase of 0.29 percent, while costs for banking and education and research increase by less than 0.1 percent. These figures are clearly an upper bound on any temporary compensation that might be provided to firms to ease transitions as, at least for non-export-intensive industries, most if not all of the cost increases are likely passed forward in higher consumer prices.

Figure 14. Cumulative Average Industry Cost Increase for Moderate Coal Tax, 2020 (Average percent increase in industry cost)



Source: See text.

Note: Industries are ranked according to the percent increase in their costs caused by higher electricity and coal prices under the moderate coal tax. The height of the curve at, for example, a 10 percent cumulative share of industry output indicates that the (weighted) average cost increase for the 10 percent of industries most affected is 1.1 percent. The gap between one dot and the next indicates the increase in the share of industry output as the next most affected industry is included (for example, construction accounts for 11 percent of total output).

Finally, Table 3 indicates the cost increases for different policies relative to those under the modest coal tax, for highly, intermediately, and lowly impacted sectors. Roughly speaking, the aggressive coal tax, carbon tax, and ETS impose burdens on industries that are about 95 percent, 120 percent, and 105 percent larger than under the modest carbon tax. Electricity and road fuel taxes have a much weaker impact on industries most affected by coal and carbon taxes, as in the latter case most of the impact operates through the increase in price of coal rather than electricity or transport fuels.

Table 3. Cost Increases for Selected Industries and Selected Policies, 2020

	Moderate Coal Tax		Impact of Other Policies Relatie to Moderate Coal Tax				
	Cost Increase (%)	Cumulative Share in Total Output (%)	Aggressive Coal Tax	Carbon Tax	Electricity Tax	ETS	Road Fuel Tax
Highest-impact Sectors							
Non-ferrous basic metals	1.43	0.83	2.00	2.16	0.18	2.10	0.11
Iron, steel and ferro alloys	1.19	3.31	1.99	2.23	0.21	2.17	0.13
Iron and steel casting & forgin	1.07	3.93	1.99	2.22	0.26	2.13	0.18
Iron and steel foundries	0.93	4.84	1.99	2.25	0.24	2.16	0.18
Miscellaneous metal products	0.89	6.07	1.99	2.21	0.25	2.13	0.17
Coal tar products	0.89	6.26	2.00	2.63	0.13	2.17	0.93
Cement	0.87	6.89	1.99	2.38	0.36	2.21	0.33
Other electrical Machinery	0.70	7.38	1.99	2.23	0.37	2.12	0.23
Electrical wires & cables	0.64	7.59	1.99	2.26	0.41	2.13	0.26
Hand tools, hardware	0.56	7.93	1.99	2.27	0.36	2.13	0.27
Intermediate-impact Sectors							
Readymade garments	0.13	42.35	1.96	2.77	1.32	2.22	1.10
Paddy	0.13	44.52	1.95	2.84	1.79	2.24	1.20
Lime stone	0.13	44.98	1.96	2.59	1.54	2.14	0.91
Furniture and fixtures-wooden	0.13	44.49	1.98	2.58	0.71	2.15	0.85
Renting of machinery & equip	0.13	45.03	1.95	2.22	1.74	2.11	0.22
Bauxite	0.12	45.04	1.96	2.49	1.43	2.12	0.75
Miscellaneous food products	0.12	47.01	1.96	2.65	1.60	2.16	0.98
Legal services	0.12	47.20	1.95	2.17	1.92	2.09	0.16
Wheat	0.12	48.41	1.95	2.78	1.78	2.26	1.05
Mica	0.12	48.41	1.95	2.68	1.90	2.10	1.14
Lowest-impact Sectors							
Forestry and logging	0.02	88.29	1.97	3.85	1.04	2.15	3.41
Real estate activities	0.02	88.46	1.96	2.34	1.58	2.11	0.45
Fishing	0.02	88.97	1.97	3.62	0.94	2.19	2.86
Vegetables	0.02	89.93	1.96	3.33	1.48	2.30	2.05
Fruits	0.02	90.67	1.96	3.21	1.47	2.28	1.85
Milk and milk products	0.02	92.50	1.96	3.16	1.51	2.23	1.87
Tea	0.02	92.55	1.97	4.66	1.25	2.61	4.10
Education and research	0.01	94.61	1.97	3.32	1.18	2.15	2.34
Ownership of dwellings	0.01	97.39	1.98	2.42	0.57	2.16	0.53
Public administration	0.00	100.00	0.00	0.00	0.00	0.00	0.00

Source: See text.

V. CONCLUSION

While India has recently taken major steps to reform energy prices, this paper recommends that policymakers build on these efforts (regardless of actions in other countries), in particular by continuing to ramp up the recently introduced coal tax. This would significantly reduce local outdoor air pollution deaths, raise revenue (for funding high priority spending or lowering other burdensome taxes), and is about the most efficient policy for reducing CO_2 emissions (which should encourage mitigation actions in other countries, in turn benefiting climate-vulnerable countries like India).

Continued energy price reform is not easy from a political perspective, nonetheless previous reform episodes from a variety of different countries and time periods suggest several ingredients enhance the prospects of successful reform (Clements and others 2012). One is to have a comprehensive reform plan with clearly stated objectives and timetables for meeting those objectives, specifics on how the revenues from the reform will be used, and taking into account concerns (e.g., relocation needs for displaced workers) raised in consultations with legislators, industry groups, consumer groups, unions and others. Another ingredient is an effective communications plan informing the public about the environmental and health benefits from the reform, the fiscal benefits (e.g., in terms of how many extra schools and hospitals will be built or what tax burdens will be reduced) and fairness (given that nearly 95 percent of the burden of higher energy prices is borne by households not in the bottom two deciles). Gradual and well-publicized reforms are also recommended to give firms and households time to adjust in anticipation of higher energy prices and to allow time for strengthening social safety nets. Higher kerosene prices might also be avoided for the time being (one reason for the focus here on coal taxes) given that kerosene is heavily consumed by the poor.

The biggest challenges are often the potentially harmful effect of reform on vulnerable households and firms. Improved targeting of social safety nets (the Public Distribution System and the Mahatma Gandhi National Rural Employment Guarantee Act public works program), can help to compensate many poor households for higher energy prices.[54] Programs to assist displaced workers from coal mining in particular will be needed.[55] Finally, tax reliefs for energy-intensive industries may also be needed to reduce industry opposition to reform, though these should not exceed estimated cost impacts and should be phased out over time.

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[54] See Abdallah and others (2015). Subsidies for a 'subsistence' amount of electricity consumption, or for clean fuel technologies (e.g., solar water heaters) used by the poor, may also have a role.

[55] See Morris (2016) for a discussion of the options.

Appendix 1. Model Equations

A discrete time period model is used where t = 0…$\bar{t}$ denotes a particular year. Fossil fuels are first discussed, followed by fuel use in the power, road transport, and "other energy" sectors.

A. Fossil Fuels

Coal, natural gas, gasoline, road diesel, kerosene, LPG, and an aggregate of other oil products, are denoted by i = *COAL*, *NGAS*, *GAS*, *DIES*, *KER*, *LPG*, and *OIL* respectively. The consumer fuel price at time t, denoted p_t^i, is:

$$p_t^i = \tau_t^i + \hat{p}_t^i \qquad \text{(A1)}$$

τ_t^i is the specific tax on fuel i (or subsidy in the case of kerosene and LPG) including any excise or (future) carbon charge. $\hat{p}_t^i$ is the pre-tax fuel price or supply cost. For fuels used in multiple sectors pre-tax prices and taxes are taken to be the same for all fuel users.

B. Power Sector

Residential, commercial, and industrial electricity consumption is aggregated into one economy-wide demand for electricity in year t, denoted Y_t^E, and determined by:

$$Y_t^E = \left(\frac{U_t^E}{U_0^E} \cdot \frac{h_t^E}{h_0^E}\right) \cdot Y_0^E, \qquad \frac{U_t^E}{U_0^E} = \left(\frac{GDP_t}{GDP_0}\right)^{\upsilon^E} \cdot \left(\frac{h_t^E p_t^E}{h_t^E p_0^E}\right)^{\eta^{UE}}, \qquad \frac{h_t^E}{h_0^E} = (1+\alpha^E)^{-t} \cdot \left(\frac{p_t^E}{p_0^E}\right)^{\eta^{hE}} \qquad \text{(A2)}$$

U_t^E is usage of electricity-consuming products or capital or the stock of electricity-using capital times its average intensity of use. h_t^E is the electricity consumption rate (e.g., kWh per unit of capital usage), or the inverse of energy efficiency. Product use increases with gross domestic product (GDP_t) according to υ^E, the (constant) income elasticity of demand for electricity-using products. Product use also varies inversely with proportionate changes in unit electricity costs, or the user electricity price p_t^E times the electricity consumption rate. $\eta^{UE} < 0$ is the (constant) elasticity of demand for use of electricity-consuming products with respect to energy costs. The electricity consumption rate declines (given other factors) at a fixed annual rate of $\alpha^E \geq 0$, reflecting autonomous energy efficiency improvements. Higher electricity prices increase energy efficiency, implicitly through adoption of more efficient technologies: η^{hE} is the elasticity of the energy consumption rate with respect to energy prices.

Power generation fuels potentially include coal, natural gas, oil, nuclear, hydro, (non-hydro) renewables (wind, solar, biofuels), and biomass, where the latter are denoted by i = *NUC*, *HYD*, *REN*, *BIO*. To accommodate flexible assumptions for the degree of substitution among fuels, the share of fuel i in generation, denoted θ_t^{Ei}, is defined:

$$\theta_t^{Ei} = \theta_0^{Ei} \left\{ \left(\frac{g_t^i}{g_0^i}\right)^{\tilde{\varepsilon}^{Ei}} + \textstyle\sum_{j \neq i} \theta_0^{Ej} \left[1 - \left(\frac{g_t^j}{g_0^j}\right)^{\tilde{\varepsilon}^{Ej}}\right] \Big/ \textstyle\sum_{l \neq j} \theta_0^{El} \right\} \qquad \text{(A3)}$$

where *i*, *j*, *l* = *COAL*, *NGAS*, *OIL*, *NUC*, *HYD*, *REN*, *BIO*. g_t^i is the cost of generating a unit of electricity using fuel i at time *t* and $\tilde{\varepsilon}^{Ei} < 0$ is the conditional (indicated by ~) own-price elasticity of generation from fuel i with respect to generation cost. Conditional means the elasticity reflects the percent reduction in use of fuel i due to switching from that fuel to other generation fuels, per one-percent increase in generation cost for fuel i, for a given amount of electricity. Generation cost elasticities are larger than corresponding fuel price elasticities as an increase in all (fuel and non-fuel) generation costs has a bigger impact than an increase in fuel costs alone.

From (A3) fuel i's generation share decreases in own generation cost and increases in the generation cost of other fuels, where the increase in fuel i's generation share is the reduced share for fuel *j*≠i times the (initial) share of i in generation from all fuel alternatives to *j*.

Use of fossil fuel i in power generation at time *t*, denoted F_t^{Ei}, is given by:

$$F_t^{Ei} = \frac{\theta_t^{Ei} \cdot Y_t^E}{\rho_t^{Ei}} \qquad \text{(A4)}$$

Fuel use equals the generation share times total electricity output and divided by ρ_t^{Ei}, the productivity of fuel use or electricity generated per unit of F_t^{Ei}. The total supply of power generation in each period is assumed equal to total electricity demand.

Unit generation costs are determined by:

$$g_t^{Ei} = \frac{p_t^i + k_t^{Ei}}{\rho_t^{Ei}},\ i\text{=}COAL,\ NGAS,\ OIL; \qquad g_t^{Ei} = \frac{k_t^{Ei}}{\rho_t^{Ei}},\ i\text{=}NUC,\ HYD,\ REN,\ BIO;$$

$$\rho_t^{Ei} = (1 + \alpha^{\rho i})^t \rho_0^{Ei} \qquad \text{(A5)}$$

k_t^{Ei} is unit capital, labor and other non-fossil fuel costs. Unit generation costs for fossil fuels decline with rising productivity (which is assumed to reduce fuel and non-fuel costs by the same proportion). Similarly, productivity improvements lower generation costs for non-fossil fuels. Productivity of generation by fuel i increases at rate $\alpha^{\rho i} \geq 0$ per year implicitly from better production technologies and retirement of older, less efficient plants. Finally:

$$p_t^E = \sum_i q_t^{Ei} \theta_t^{Ei} + k_t^{ET} + \tau_t^E \qquad \text{(A6)}$$

The consumer price of electricity is the generation share times unit generation costs summed over fuels, plus unit transmission costs denoted k_t^{ET}, and any excise tax on electricity consumption τ_t^E (or subsidy if τ_t^E <0).[56]

[56] The model abstracts from power outages which, according to Alcott et al. (2016), reduce revenues from the manufacturing sector by about 5 percent. Ideally, energy price reform would be accompanied by other measures to reduce outages, such as rising price schedules during periods of peak demand.

C. Road Transport Sector

Analogous to (A1), gasoline and road diesel fuel demand at time *t*, denoted F_t^{Ti} , where *i* = *GAS*, *DIES, LPG* is gasoline, diesel and LPG respectively, is:

$$F_t^{Ti} = \left(\frac{U_t^{Ti}}{U_0^{Ti}} \cdot \frac{h_t^{Ti}}{h_0^{Ti}}\right) F_0^{Ti}; \qquad \frac{U_t^{Ti}}{U_0^{Ti}} = \left(\frac{GDP_t}{GDP_0}\right)^{\upsilon^{Ti}} \cdot \left(\frac{h_t^{Ti} p_t^i}{h_0^{Ti} p_0^i}\right)^{\eta^{UTi}}; \qquad \frac{h_t^{Ti}}{h_0^{Ti}} = (1+\alpha^{hTi})^{-t} \cdot \left(\frac{p_t^i}{p_0^i}\right)^{\eta^{hTi}} \tag{A7}$$

U_t^{Ti} is kilometers (km) driven by vehicles with fuel type i and h_t^{Ti} is fuel use per vehicle km (the inverse of fuel economy). km driven in vehicle type i increases with GDP, according to the income elasticity of demand υ^{Ti}, and varies inversely with proportionate changes in fuel costs per km $h_t^{Ti} p_t^i$, where $\eta^{UTi} < 0$ is the elasticity of vehicle km driven with respect to per km fuel costs.[57] $\alpha^{Ti} \geq 0$ is an annual reduction in the fuel consumption rate due to autonomous technological change that improves fuel economy. Higher fuel prices also reduce fuel consumption rates (e.g., through promoting engine efficiency increases, lighter weight materials, encouraging people to drive smaller vehicles) according to $\eta^{hTi} \leq 0$, the elasticity of the fuel consumption rate.

D. Other Energy Sector

The other energy sector is decomposed into large and small energy users, the latter representing households and small entities (in the formal or informal sectors) with emissions below a threshold, denoted by *q* = *LARGE*, *SMALL*, respectively. Use of fuel *i* in the other energy sector, by group *q*, at time *t*, denoted F_t^{Oqi}, is:

$$F_t^{Oqi} = \left(\frac{U_t^{Oqi}}{U_0^{Oqi}} \cdot \frac{h_t^{Oqi}}{h_0^{Oqi}}\right) F_0^{Oqi}; \quad \frac{U_t^{Oqi}}{U_0^{Oqi}} = \left(\frac{GDP_t}{GDP_0}\right)^{\upsilon^{Oi}} \cdot \left(\frac{h_t^{Oqi} p_t^i}{h_0^{Oqi} p_0^i}\right)^{\eta^{UOi}}; \quad \frac{h_t^{Oqi}}{h_0^{Oqi}} = (1+\alpha^{Oi})^{-t} \cdot \left(\frac{p_t^i}{p_0^i}\right)^{\eta^{hOi}} \tag{A8}$$

where *i* = *COAL*, *NGAS*, *KER*, *LPG*, *OIL*, *REN*, and *BIO*. The interpretation for (A8) is analogous to that for (A2) and (A7) with U_t^{Oqi} and h_t^{Oqi} denoting respectively, use of products requiring fuel *i* at time *t* by group *q* and its fuel consumption rate. Parameters υ^{Oi}, η^{UOi}, η^{hOi}, and α^{Oi} have analogous interpretations to previous notation and are taken to be the same across large and small users. Given the limited scope for substituting among different fuels used for very different products (compared with fuels producing a homogeneous product in the power sector), fuel switching possibilities are not modelled in the other energy sector.

E. Metrics for Comparing Policies

CO_2 emissions. CO_2 emissions from fossil fuel use at time *t* are:

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[57] The model abstracts from substitution between use of gasoline and diesel vehicles given the different vehicle types (light-duty vehicles for gasoline and mostly heavy-duty vehicles for diesel) and that carbon pricing tends to increase user prices for gasoline and diesel in roughly the same proportion.

$$\sum_{ji} F_t^{ji} \cdot \mu^{CO2i} \tag{A9}$$

where $j = E, T, O$ denotes a sector and μ^{CO2i} is fuel i's CO_2 emissions factor (which is taken as zero for renewables, hydro, nuclear, and—in a lifecycle context—biomass).

Revenue. Revenue from fuel and electricity taxes is:

$$\sum_{ji} F_t^{ji} \cdot \tau_t^i + Y_t^E \cdot \tau_t^E \tag{A10}$$

Deaths from fossil fuel air pollution. At time t these are given by:

$$\sum_{ij} F_t^{ji} \cdot m_t^{ji} \tag{A11}$$

m_t^{ji} is mortality per unit of fuel i used in sector j, which may differ by sector due to differing use of control technologies.

Economic welfare gains. The economic welfare costs and benefits of policies are measured using applications and extensions of long-established formulas in the public finance literature (see Harberger 1964), based on second order approximations[58] which simplifies the formulas. The information required to apply these formulas includes the size of price distortions in fuel markets (i.e., the difference between social costs of fuel use and private costs due to domestic environmental costs in fuel markets net of any fuel taxes/subsidies), any induced quantity changes in markets affected by these distortions (an output from the model), and any new source of distortions created by the policy scenarios.[59]

The economic welfare gains (excluding the global climate benefits) from a carbon tax in period t is computed using:

$$\sum_{ji} \left(\Gamma_t^{ji} - \frac{\mu^{CO2i} \cdot \tau_t^{CO2}}{2}\right) \cdot \left(-\Delta F_t^{ji}\right) \tag{A12}$$

$$\Gamma_t^{ji} = VMORT_t \cdot m_t^{ji}, \text{ for } j \neq T \text{ and } ji \neq EREN;$$

$$\Gamma_t^{Ti} = VMORT_t \cdot m_t^{Ti} + \left(\frac{\eta^{hTi}}{\eta^{hTi} + \eta^{UTi}}\right) \beta_t^{Ti} - \hat{\tau}_t^i; \qquad \Gamma_t^{EREN} = s_t^{EREN} \tag{A13}$$

$$\Delta F_t^{ji} = F_t^{ji} - \hat{F}_t^{ji} \tag{A14}$$

where a ^ denotes a value in the BAU with no new mitigation policy and Γ_t^{ji} is the price distortion in a fuel market.

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[58] That is, taking fuel demand curves to be linear over the range of policy-induced fuel changes.

[59] Induced quantity changes in markets with no price distortions have no implications for economic welfare costs (Harberger 1964).

In (A13), Γ_t^{ji} consists (for fossil fuels and biomass) of local air pollution costs, equal to premature mortalities per unit of fuel use times $VMORT_t$, the value per premature mortality. For road fuels, there is an additional environmental cost equal to the external costs of traffic congestion, accidents, and road damage expressed per unit of fuel use, β_t^{Ti}, and multiplied by the term in parentheses, which is the fraction of the change in fuel use in response to changes in fuel prices that comes from changes in vehicle miles driven as opposed to the other fraction that comes from (long run) improvements in average fleet fuel economy (which are assumed to have no effect on congestion, accidents, or road damage).[60] For road fuels, the price distortion is also defined net of pre-existing road fuel taxes $\hat{\tau}_t^i$, which drive up private costs and partly internalize environmental costs. For the renewable general fuel, the price distortion is the per unit subsidy s_t^{EREN}. In (A14), ΔF_t^{ji} is the change in fuel use, relative to its baseline level $\hat{F}_t^{ji}$.

According to equation (A12), the net welfare gain from the increase in tax in the market for a particular fossil fuel product in a particular sector consists of: (i) the reduction in fuel use times the price distortion in that market less (ii) the 'Harberger triangle' equal to the reduction in fuel use times one-half of the tax increase, where the latter is the product of the fuel's CO_2 emissions factor and τ_t^{CO2}, the price on CO_2 emissions at time *t*. There is also a small economic welfare loss from the increase in renewable generation, times the unit subsidy for renewables.

The above formula is also used to calculate the net welfare gain from the ETS and coal tax. For the ETS no carbon charge applies to the transport sector or fuel consumption by small users in the other energy sector, while for the coal tax the CO_2 charge applies only to coal use in the power and other energy sector.

[60] See Parry and others (2014), Ch. 5, for a detailed discussion.

Appendix 2. Model Parameterization

Data for each sector is described below, where the latest data available on fuel use and fuel price and taxes/subsidies is 2014.

A. Fossil Fuels

Pre-tax prices for coal, natural gas, gasoline, diesel, kerosene, LPG, and other oil products for 2013–16 are from a combination of the India PPAC,[61] IEA (2016) and a country-level database compiled by the IMF [62] based on international reference prices of the finished product (e.g., gasoline), as this reflects revenue forgone by selling it domestically rather than overseas, and then adjusted for transport and distribution costs. These prices are then projected forward to 2030 based on averaging over IMF price projections and projections from the U.S. Energy Information Administration (EIA) where the latter offer more detailed (year-on-year) information with respect to the IEA (2016). The IMF projections are based on international commodity price indices for coal, natural gas, and crude oil out to 2021 and are approximately constant (they reflect futures prices) [63]—from 2021 to 2030 we assume these prices remain constant. In the EIA projections, real crude oil prices double between 2015 and 2030, coal prices fall 6 percent, natural gas prices (averaging over LNG and non-LNG prices) rise 47 percent. For electricity, which is generally a non-traded good, the supply cost for 2013 and 2014 in the IMF database is the domestic production cost or cost-recovery price (from IEA 2016) with costs evaluated at international reference prices. Electricity prices are then projected forward using (A6) as a price index, and changes in fuel prices and generation shares in a future year relative to that in 2013.

The IMF database also provides estimates of prices to fuel users and the difference between these prices and producer prices is the estimated fuel tax (or subsidy), where for fuels consumed at the household level value-added tax (which is applied to general consumer goods) is subtracted from the household price, and for coal the tax is given by the statutory rate Rs 200 ($3) per ton in 2016. These prior taxes/subsidies are taken as constant for the projection period (from 2016 onwards), so future fuel user prices are given by the sum of these taxes/subsidies and the future supply prices.

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[61] See http://ppac.org.in.

[62] See www.imf.org/external/np/fad/subsidies/data/subsidiestemplate.xlsx.

[63] See www.imf.org/external/pubs/ft/weo/2015/02/weodata/weoselagr.aspx. The indices are for Australian thermal coal; Indonesian liquefied natural gas in Japan; and an average of Brent, West Texas Intermediate, and Dubai Fateh spot crude oil prices.

(continued)

B. Power Sector

Electricity consumption. This is obtained from IEA (2016) focusing on generation, as this is what matters for domestic emissions.

Income elasticity of demand for electricity-using products. Empirical studies for different countries suggests a range for this elasticity of around 0.5–1.5.[64] We use a value of 0.9 which (along with other assumptions) leads to projected electricity use for India that is roughly consistent with projections (accounting for structural transformations in the Indian economy) from IEA (2015), when IEA price projections are used.

Price elasticities for electricity. A simple average across the 26 estimates of long-run electricity demand elasticities reported in Jamil and Ahmad (2011), Table 1, is about –0.5, and nearly all estimates lie within a range of about –0.15 to –1.0.[65] A recent study for China by Zhou and Teng (2013) suggests an elasticity of –0.35 to –0.5. Evidence for the United States suggests the long-run price elasticity for electricity demand is around -0.4, with about half the response reflecting reduced use of electricity-consuming products and about half improvements in energy efficiency.[66] Values of –0.25 are assumed for both the usage and energy consumption rate elasticities, implying a total electricity demand elasticity of –0.5.

Annual rate of efficiency improvement for electricity-using products. This parameter (which is of moderate significance for the BAU projection) is taken to be 0.01.[67]

Generation shares. These are obtained from IEA (2016) by the electricity produced from each fuel type divided by total electricity generation.

Own-price elasticities for generation fuels (conditional on total electricity output). Short run coal price elasticities among eight studies for various advanced countries, China, and India summarized in Trüby and Paulus (2012), Table 5, are around -0.15 to -0.35 (aside from one study where the elasticity is –0.6). For the United States, simulations from a variant of the U.S. Department of Energy's National Energy Modeling System (NEMS) model in Krupnick and others (2010), suggest a coal price elasticity of around –0.15 (with fuel switching rather than reduced electricity demand accounting for over 80 percent of the response).[68] On the other hand, Burke

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[64] For example, Jamil and Ahmad (2011), Table 1, report 26 estimates of long-run income elasticities for electricity from 17 studies, almost all of them lying within the above range.

[65] See Madlener and others (2011) for further discussion and broadly similar findings.

[66] See Myers and others (2009), Parry and others (2014), Sanstad and McMahon (2008).

[67] This is consistent with similar assumptions in other models, for example, for China in Cao and others (2012), pp. 389–90.

[68] NEMS tends to be less price responsive than other models and the above simulation was for a carbon price which also raises natural gas prices, thereby dampening the reduction in coal use.

and Liao (2015) report somewhat larger size coal price elasticities for China of –0.3 to –0.7. A coal price elasticity in the power generation sector of –0.35 is assumed for India.

The elasticities in equation (A3) are defined with respect to (full) generation costs rather than fuel costs and can be obtained by dividing the fuel price elasticity by the share of fuel costs in generation costs, which is around 0.6 in 2013 (see below). This gives an approximate generation cost elasticity of –0.6. In the absence of solid evidence to the contrary, the same generation cost elasticity is assumed for other generation fuels as for coal.

Fossil fuel consumption and productivity. Consumption of power generation fuels is taken from IEA (2015). Electricity generated from a particular fossil fuel, divided by that fuel's consumption, gives the productivity of that fuel.

Annual rate of productivity improvement. Productivity improvements at power plants reflect improvements in technical efficiency and retirement of older, less efficient plants. For coal, annual average productivity growth is taken to be 0.5 percent based approximately on IEA (2016), Figure 2.16. For natural gas, biomass, nuclear and hydro, there is likely more room for productivity improvements and baseline annual growth rate of 1 percent is assumed. For renewables, a productivity growth rate of 4.5 percent is used in the baseline case for this fuel. The resulting projected fuel mix for 2030 (when EIA energy price projections are used in our model) is very similar to that projected for India in IEA (2016).

Non-fuel generation costs. For coal plants these are taken to be 60 percent as large as 2013 fuel costs.[69] For natural gas plants (which have low fixed and high variable costs), non-fuel generation costs are taken to be one quarter of those for coal plants.

Power transmission cost. This is taken to be 60 percent of the electricity generation cost in 2013.[70]

C. Road Transport Sector

Fuel use. Consumption of road gasoline and diesel is taken from IEA (2016) for 2013.

Income elasticity of demand for vehicle miles. Estimates of this parameter are typically between about 0.35 and 0.8, although a few estimates exceed unity (Parry and Small, 2005). However, these estimates come from countries (unlike India) with widespread vehicle ownership so they mainly reflect changes in the intensive margin. An elasticity of 0.9 is used for India, given the likely greater price responsiveness at the extensive margin.

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[69] This is the same as assumption as used by Parry and others (2016) for China.

[70] This is approximately consistent with Cao and others (2013), pp. 343.

(continued)

Price elasticities. Numerous studies have estimated motor fuel (especially gasoline) price elasticities for different countries and some studies decompose the contribution of reduced vehicle miles from longer improvements in average fleet fuel efficiencies. Based on this literature, a value of –0.25 is used for each of these elasticities and for both gasoline and diesel—the total fuel price elasticities are therefore –0.5.[71]

Annual rate of decline in vehicle fuel consumption rates (from technological improvements). These are set at 1 percent a year (e.g., Cao and others 2013).

D. Other Energy Sector

Fuel use. We assume 50 percent of industrial fuel consumption is by large firms that are potentially covered by the ETS.[72]

Income and price elasticities for other energy products. Evidence on income and price elasticities for fuels used in the industrial and residential sectors is more limited. Income elasticities are chosen such that baseline projections of fuel use to GDP in 2030 are broadly consistent with those in IEA (2016), Annex A (Current Policies scenario), when IEA price projections are included in our model, implying elasticities of between 0.65 and 1.0. The price elasticities are taken to be the same as for electricity and road fuels.

Annual rate of productivity improvements. These are assumed to follow those for the same fuel as used in the power sector.

E. Miscellaneous

GDP growth. Projected GDP out to 2021 is from the IMF's WEO and thereafter is assumed to gradually decline (from 7.8 percent a year in 2022 to 6.8 percent in 2030).

Mortality rates from fuel combustion. The major pollutant from coal combustion at power plants causing premature mortality is $PM_{2.5}$, fine particulate matter with diameter up to 2.5 micrometers, which is small enough to penetrate the lungs and bloodstream. These emissions can be produced directly during fuel combustion and are also formed indirectly (and generally in greater quantities) from chemical reactions in the atmosphere involving sulfur dioxide (SO_2) and nitrogen

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[71] These values represent a compromise between Sterner (2007), who reports globally averaged (long-run) gasoline price elasticities of around –0.7, and Dahl (2012) whose average estimate is about –0.25. For a summary of evidence on the decomposition of the fuel price elasticities into the vehicle mileage and fuel efficiency responses see Parry and Small (2005).

[72] This fraction will depend on the threshold emissions level determining whether entities are covered by pricing schemes, which will depend in part on administrative considerations.

(continued)

oxide (NO_x) emissions. India is just starting to take steps to reduce local air emission rates through emissions control requirements on new plants.

Air pollution mortality and damage estimates are taken from Parry and others (2014), with some adjustments. Parry and others (2014) estimate damages from representative coal plants with emissions control technologies, and industry wide damages averaging over plants with and without control technologies. In the absence of other factors, we assume the mortality rate from coal combusted at power plants would converge linearly from the industry average in 2010 to the mortality rate from plants with control technologies by 2030 (as new plants with control technologies penetrate the coal plant fleet). However, in India the share of the population residing in urban areas is projected to rise over time, with both population growth and migration from rural to urban areas, increasing exposure to urban air pollution. A linear upward adjustment in the mortality rate each year is made to account for this.[73] For large industrial coal users (e.g., steel plants) we assume the same mortality rates as for coal power plants. For small-scale coal users, mortality rates in 2010 are assumed equal to the industry average for coal plants emission, rising over time with urban population growth. Deaths from outdoor use of biomass is based approximately on Lelieveld et al. (2015).

Mortality rates for natural gas, gasoline, diesel, and oil products are also based on Parry and others (2014), adjusted for changes in population exposure.[74]

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[73] An increase of 2.56 percent was used in the model. This figure comes from India's NDC documentation. The urban population increase accounts for 77 percent of the increase in air-pollution deaths between 2015 and 2030 in the BAU scenario.

[74] Mortality rates for other oil products (which were not estimated by Parry and others 2014) are taken to be the same as for road diesel. For gasoline and road diesel, mortality rates (prior to adjusting for rising urban population shares) are assumed to linearly converge between 2010 and 2030 from the vehicle fleet average in 2010 to the mortality rates for representative vehicles in 2010 with advanced emission control technologies. The same adjustment is made for other oil products but not (due to lack of data) for natural gas, though air pollution damages from gas are relatively small.

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