



IMF Working Paper

Environmental Tax Reform:
Principles from Theory and Practice to Date

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Fiscal Affairs Department

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Abstract

This paper recommends a system of upstream taxes on fossil fuels, combined with refunds for downstream emissions capture, to reduce carbon and local pollution emissions. Motor fuel taxes should also account for congestion and other externalities associated with vehicle use, at least until mileage-based taxes are widely introduced. An examination of existing energy/environmental tax systems in Germany, Sweden, Turkey, and Vietnam suggests that there is substantial scope for policy reform. This includes harmonizing taxes for pollution content across different fuels and end-users, better aligning tax rates with values for externalities, and scaling back taxes on vehicle ownership and electricity use that are redundant (on environmental grounds) in the presence of more targeted taxes.

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Acronyms and Abbreviations

ETS	EU Emissions Trading System
GHG	Greenhouse gas
OECD	Organisation for Economic Co-operation and Development
TA	Technical Assistance
VAT	Value-Added Tax
VSL	Value of a Statistical Life

I. INTRODUCTION

This paper provides guidelines for the design of environmental taxes drawn from the literature, and then uses these recommendations to evaluate actual tax systems across several diverse countries. The aim is to illustrate how economic analysis and work on externality measurement can provide a useful sense of what ideal tax systems look like in terms of what should be taxed, by how much, at what point in the production chain, as well as what should not be taxed. Our approach is based on standard principles of (1) exploiting, insofar as possible, emissions-reduction opportunities, or welfare gains; (2) striking the right balance across these opportunities; and (3) minimizing administrative complications.

For most environmental problems, well-designed fiscal policies (emissions taxes or their cap-and-trade equivalents with allowance auctions) are the most natural instruments for incorporating environmental damages into the price of products and non-market activities (like driving). In fact, taxes that are, at least in part, justified on environmental grounds have long been a significant source of government revenue; environmental tax revenues (primarily taxes on motor fuels and vehicles) constitute approximately 3–10 percent of total tax revenues in typical OECD countries (Figure 1).² Some Nordic countries took the first steps in environmental tax reform—broadly speaking, the restructuring of the tax system to more effectively promote environmental objectives—during the early 1990s. The reform movement spread fairly quickly to other countries like the Netherlands, the United Kingdom, and Germany, and is now under serious consideration in emerging and developing countries, such as China, Vietnam, Cambodia, South Africa, Thailand, and Tunisia. Moreover, the IMF is providing an increasing amount of technical assistance on environmental tax issues.

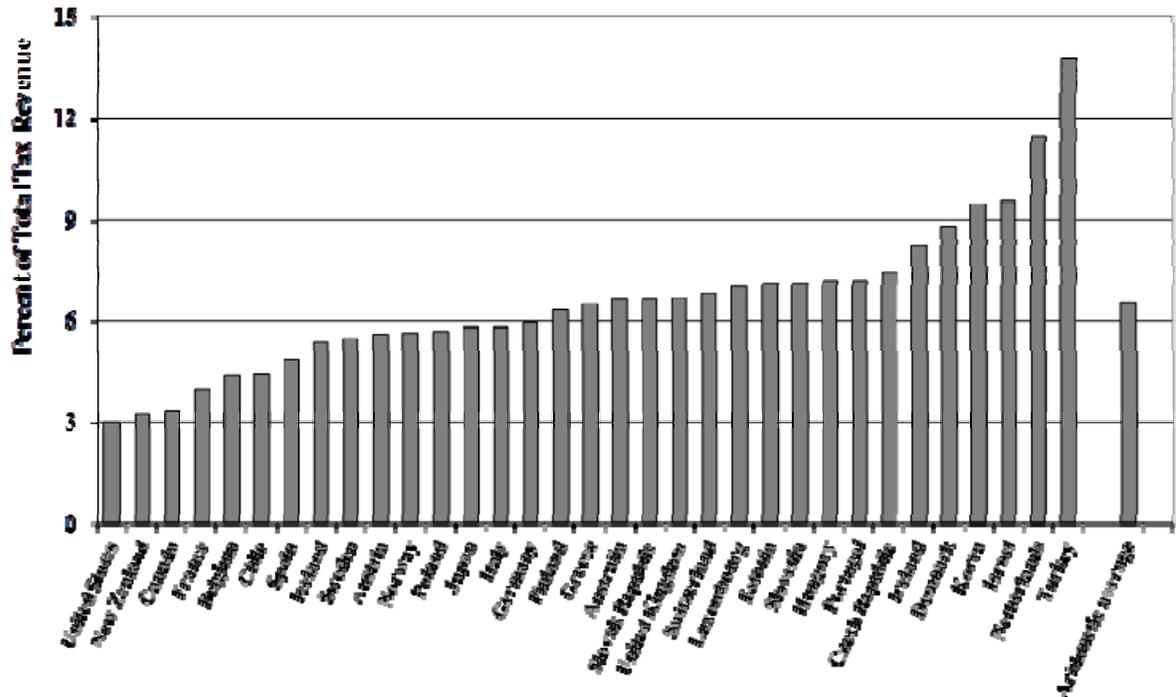
Several factors point to continued momentum for environmental tax reform. One is pressure for new revenues to strengthen fiscal positions. Another is growing acceptance among policymakers that emissions pricing instruments are far more effective at exploiting the entire range of emissions reduction opportunities than are regulatory approaches (e.g., European Commission, 2007; and TemaNord, 2011a). Swapping environmental taxes (that apply to traded goods) for labor taxes might also be means to improve competitiveness. And environmental problems are of growing concern, from rising greenhouse gas (GHG) concentrations to deteriorating urban air quality in industrializing nations to increasing congestion (a related externality) of transportation systems.

The analytical and empirical literature provides insights on the design of environmental taxes with regard to the efficient tax level (and adjustment over time), tax base, and revenue use, accounting for potential complications like multiple externalities, pre-existing policies, and other distortions, and linkages with the broader fiscal system. In practice, gauging efficient tax levels is challenging, given data and methodological difficulties in measuring

² The OECD defines environmental taxes quite broadly as any compulsory, unrequited payment to general government levied on tax bases deemed to be of particular environmental relevance (e.g., energy products, motor vehicles, waste, emissions, natural resources).

environmental damages. Moreover, distributional, competitiveness, and revenue considerations may all complicate policy design.

Figure 1. Revenues from Environmentally Related Taxation, 2008



Source: OECD (2010).

The first half of this paper reviews core principles from the literature on environmental tax design.³ The second takes a first stab at applying these principles in practice.⁴ We consider a diverse mix of countries, including Sweden (a pioneer of environmental taxes), Germany (where earlier environmental tax reforms have lost momentum), Turkey (where environmental tax revenues are atypically high—see Figure 1), and Vietnam (a low income-country undertaking environmental tax reform). For each country, appropriate taxes to internalize CO₂, local air pollutants, and broader externalities in transportation are considered.⁵

³ For other discussions that cover some of the same issues, see, for example, Bovenberg and Goulder (2002); Fullerton and others (2008); and Metcalf (2009).

⁴ For other assessments of environmental tax reforms, see, for example, Sterner (2002); and Schlegelmilch (1999).

⁵ For some discussion of environmental taxes in other contexts, see, for example, Fullerton (2005) on household waste; Boyd (2003) on water pollution taxes; Sigman (2003) on hazardous waste charges; and Daniel and others (2010) on the taxation of resource rent.

We recommend levying environmental taxes directly on potential damages from the carbon and local pollution content of coal, natural gas, and oil products as these fuels enter the economy, with a system of refunds for emissions capture at downstream facilities (though downstream pricing systems can be reasonable alternatives in some cases). For motor fuels, congestion and accident externalities should also factor into these taxes (and road damages into fuels used by heavy trucks), but only until these externalities are more effectively addressed through the introduction of per-mile charges. Productive use of environmental tax revenues (e.g., using them to reduce other distortionary taxes) is important for containing their costs, however. And concerns about impacts on vulnerable (or politically powerful) firms and households are better addressed through compensation schemes (e.g., scaling back other, redundant energy taxes, recycling revenues in tax cuts that disproportionately benefit low-income households, or output subsidies for vulnerable firms) rather than setting lower environmental taxes or imposing taxes downstream with exemptions for favored sectors.

Our brief look at existing tax systems suggests that there is ample room for improvement in terms of leveling tax rates (for the same pollution content) across both fuels and end users and better aligning tax rates to our, albeit back-of-the-envelope externality estimates. We also observe substantial reliance on vehicle ownership taxes and excise taxes on electricity consumption that become redundant, at least from an environmental perspective, with appropriate fuel pricing. An especially pressing area for future research appears to be refining empirical estimates of major local externalities across a broad range of (developed and developing) countries.

II. PRINCIPLES OF ENVIRONMENTAL TAX DESIGN

Here we start with the Pigouvian framework and then consider a variety of potentially complicating factors. We do not linger on the case for environmental taxes over other policy instruments, as the issues have been reviewed extensively elsewhere.⁶

⁶ See, for example, Goulder and Parry (2008); Hepburn (2006); Krupnick and others (2010); and Nordhaus (2007). Basically, comprehensive market-based instruments (emissions taxes and emissions trading systems) exploit all emissions reduction opportunities, as the emissions price is reflected in the price of intermediate and final goods across the economy. In contrast, regulatory approaches (e.g., energy efficiency standards and renewable fuel mandates) by definition focus on a much narrower range of reduction opportunities. Packages of complementary regulations can be more effective, although some behavioral responses (e.g., inducing people to use their cars or air conditioners less) are always difficult to mandate. Market-based instruments are also cost-effective in the sense that a uniform emissions price equates incremental abatement costs across firms, households, and sectors (e.g., Dales, 1968; Kneese and Bower, 1968; and Montgomery, 1972). In the absence of fluid credit trading markets, regulatory policies imposing uniform standards across firms can cause a considerable loss of cost effectiveness when there is substantial heterogeneity in firm abatement costs (e.g., Newell and Stavins, 2003; and Tietenberg, 2006). In principle, cap-and-trade systems can be a reasonable alternative to (well-designed) carbon taxes, but only if they contain price stability provisions and (more importantly) if allowances are auctioned and revenues used productively (see below).

A. Tax Design in a (Hypothetical) Economy with a Single Externality Distortion

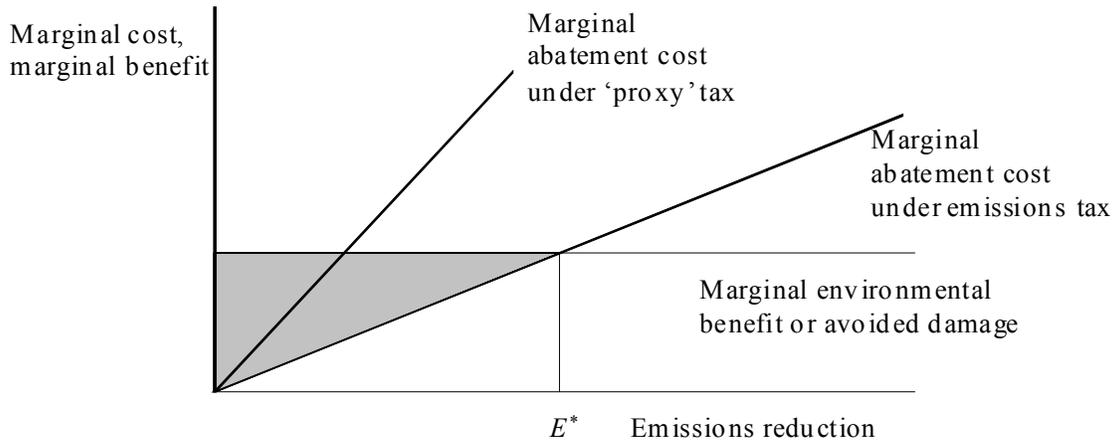
According to the traditional Pigouvian framework (Pigou, 1920), environmental taxes should equal marginal damages and be levied directly on the source of emissions. The framework has little to say about appropriate revenue use, as it leaves aside other sources of distortion in the economy, so there is no scope for efficiency-enhancing revenue recycling.

Corrective tax. In the Pigouvian framework, a tax equal to marginal damages induces the efficient level of emissions reduction, indicated by E^* in Figure 2, where the marginal benefit (or avoided incremental environmental damage) equals marginal abatement costs (ignore the steeper curve for now). This framework applies to both flow pollutants and stock pollutants: in the case of CO₂, for example, the marginal damage is the present value of future (worldwide) damages from an extra ton of emissions, accounting for the gradual uptake of CO₂ from the oceans and delayed adjustment of temperatures to higher concentrations (e.g., Nordhaus 1994).

With a flat marginal benefit curve, the Pigouvian tax is independent of the emission reduction. This seems reasonable for CO₂, for which the marginal benefit curve for one country in one year is essentially flat, given that future climate damages depend on the atmospheric stock of GHGs that have accumulated since the pre-industrial era. The assumption may also be reasonable for major air pollutants, for which the predominant damage is mortality risk to vulnerable populations, and the incidence of fatalities seems to increase roughly in proportion with ambient pollution concentrations over a range.⁷ The welfare gains from the corrective tax are shown by the shaded triangle in Figure 2. Note that, even if the tax is set at, say, 50 percent above or 50 percent below marginal damages, a large portion (roughly three-quarters) of the welfare gains from the true corrective tax are still achieved. Or put another way, given inherent imprecision in externality measurement (see below), a tax that is 50 percent above or 50 percent below true marginal damages may still perform fairly reasonably in terms of expected welfare gains.

⁷ According to some recent modeling, mortality risk might actually be concave, rather than linear, in pollution concentrations, implying some modest upward slope to the marginal benefit curve (e.g., Pope and others, 2004, 2006). The issue is complicated, however, because pollution concentrations may not increase linearly with pollution emissions. Furthermore, some studies suggest damages are not a smooth function of pollution concentrations (e.g., Oates and others, 1989). Nonetheless, uncertainty over the extent to which marginal damages may change in response to emissions taxes is probably less important than uncertainty about the overall height of the marginal damage schedule.

Figure 2. Welfare Effects of Environmental Taxes in the Pigouvian Framework



Externality measurement

Even for the United States, where there has been a large body of multi-disciplinary modeling, considerable uncertainty remains over the quantification of local pollution damages (see Box 1). This reflects, in particular, uncertainty over atmospheric chemistry and the value of a statistical life (VSL) to monetize pollution-fatality effects.

Box 1. Uncertainties in Measuring Local Pollution Damages

Assessing the local pollution damages from fuel combustion requires three steps (e.g., Mauzerall and others, 2005; Muller and Mendelsohn, 2009; and National Research Council, 2009). First is the use of an air quality model that links emissions to atmospheric concentrations—not only of primary pollutants, but also of secondary pollutants (e.g., fine particulates, ozone) that might be formed through subsequent chemical reactions—taking into account wind speeds, geographical factors that influence pollution dispersion, height of the smokestack, etc. Second, the human health effects of these pollution concentrations need to be modeled, accounting for local population exposure (or, more precisely, the number of seniors, people with pre-existing conditions, and others who are most vulnerable to health effects) and “dose-response” relationships based on epidemiological evidence. Ideally, other physical effects (e.g., morbidity, building corrosion, crop damage, impaired visibility) would also be assessed, although, for the pollutants discussed here, they tend to be small in magnitude relative to health effects. Finally, physical effects need to be monetized using evidence, for example, about people’s willingness to pay for mortality risk reductions.

All three steps involve considerable uncertainties. For example, modeling secondary pollution formation through atmospheric chemistry is especially difficult (National Research Council, 2009). The last step is perhaps the most disputed, as there remains disagreement among an appropriate number for the VSL. For example, the U.S. Department of Transportation used a VSL of \$3.5 million to value road deaths in 2004 but has since increased this value to \$6 million; Muller and Mendelsohn (2009) used VSLs of \$2-4 million; National Research Council (2009) used \$6 million (in year 2000 dollars), while the U.S. Environmental Protection Agency used a VSL of \$9.1 million for new clean air rules in 2010.

In addition, however, damages vary across space with local population exposure and natural factors affecting pollution dispersion. In principle, firms could be charged different taxes according to their location, or according to where their emissions are transported (e.g., Baumol and Oates, 1988; and Montgomery, 1972). However, this could be administratively complex, and in any case welfare gains from imposing a (second-best) uniform price on emissions (equal to average damages across the country) appear to be considerably larger than the additional welfare gains from optimally differentiating emissions prices by region (Muller and Mendelsohn, 2009). Hence our discussion focuses on uniform taxes.

Tax adjustment

Corrective taxes should be adjusted over time in line with growth in marginal environmental damages. For example, the value of pollution-health effects should be adjusted for the VSL, which rises with growth in income (depending on the income elasticity of the VSL). For climate change, marginal damages from CO₂ emissions rise over time, for example with growth in the size of (world) GDP potentially at risk (e.g., U.S. Interagency Working Group on Social Cost of Carbon, 2010).

Tax Base

The (flatter) marginal cost curve in Figure 2 reflects the horizontal summation of a set of (steeper) marginal cost schedules reflecting the costs of specific behavioral responses to reduce emissions. A tax levied on a ‘proxy’ for emissions would exploit a narrower range of these reduction opportunities than would a direct tax on the externality (e.g., Sandmo, 1976). The corresponding marginal cost schedule under a proxy tax would therefore be steeper (see Figure 2). Under constant marginal benefits, the optimal (implicit) tax would be unaffected. But the emissions reduction, and welfare gain from the proxy tax, is smaller than under the emissions tax, perhaps dramatically so. With linear marginal costs, if the proxy tax induces a fraction z of the emissions reductions that would be forthcoming under the emissions tax (in either case with taxes set to internalize environmental damages), welfare gains would also be that fraction z of those under the emissions tax.

For example, suppose (based on Krupnick and others, 2010, Figure 6.2a) that under a comprehensive carbon tax, 25 percent of the energy-related CO₂ reductions would come from reduced electricity demand and 75 percent from other sources (e.g., by switching towards cleaner generation fuels and reducing demand for transportation fuels). Excise taxes on electricity consumption might then sacrifice around three-quarters of the welfare gains from carbon taxes.⁸

Another important example of efficiency losses due to proxies is vehicle ownership taxes (e.g., excise taxes, registration fees, annual road taxes). These taxes are a weak proxy for

⁸ Taxes on electricity use, especially at the household level, are prevalent among developed countries. For example, the European Union Energy Directive 2003/96/EC sets minimum excise tax rates on electricity.

taxing CO₂ emissions from motor fuels (leave aside, for a moment, the possibility that they vary with engine size or CO₂ per mile). Suppose (on the basis of Fischer and others, 2007) that 20 percent of the CO₂ emissions reduction from a fuel tax came from a reduction in the demand for vehicles and the other 80 percent from reductions in miles driven per vehicle and longer-run, fuel economy improvements. Then vehicle ownership taxes would reduce emissions by only 20 percent of the reductions induced by (equivalently scaled) fuel taxes.

In the ideal Pigouvian framework, all emissions would be directly priced at marginal damages and there would be no proxy taxes (on electricity, vehicle ownership, etc.).⁹

A related issue: pricing all emissions at the same rate. Not only should all emissions sources be priced, but they should also be priced at the same rate—that is, pollution content should be charged at the same rate across fuels and across end users.

In this regard, using multiple pricing instruments, for example, an emission trading system for some sources and a tax for others, is inefficient, unless policies are harmonized. Similarly, if, for example, a country in the EU Emissions Trading System (ETS) adopted a national, comprehensive carbon tax, refunds should be provided for ETS allowance purchases to avoid double charging for ETS emissions. Taxes should also vary continuously in proportion to emissions, avoiding “notches”, like those for vehicles related to CO₂ per km (see Box 2).

Administrative complications

Administrative costs raise important policy design issues. First, if marginal administration costs rise as more diffuse emissions sources are brought under the tax, there is a trade-off between emissions coverage and administrative feasibility (Metcalf and Weisbach, 2009). Take the example of taxing non-CO₂ GHGs and CO₂ emissions beyond the energy sector (fossil fuel emissions are relatively straightforward to administer—see below). Some sources of non-CO₂ GHGs (e.g., vented methane from underground coalmines) can be monitored and taxed. But other sources may be better incorporated through domestic offset provisions whereby the onus is on the individual entity to demonstrate valid reductions (e.g., capture of methane from livestock waste in airtight tanks or covered lagoons). In principle, forest carbon sequestration projects can be integrated into domestic tax regimes through domestic offsets, but only in cases in which carbon benefits can be reasonably measured through some combination of satellite imagery, aerial photography, and ground-level tree sampling (e.g., Macauley and Sedjo, 2011).

⁹ In this setting, proxy taxes are welfare-reducing. Although they would further reduce emissions, this would not produce an efficiency gain with the externality already fully-internalized.

Box 2. The Problems with Tax ‘Notches’

A prominent example of tax notches is the trend to assign new vehicles to different brackets according to their engine size or, more recently, CO₂ per mile, and to levy different taxes according to the bracket.¹⁰ These tax systems are not cost effective because they do not provide the same reward for reducing CO₂ across various behavioral responses—therefore, such systems do not strike the right balance between, for example, reducing CO₂ per mile in small vehicles, reducing CO₂ per mile in large vehicles, and shifting demand from large to small vehicles. Instead, such tax systems place too much of the burden on shifting people into small vehicles and on reducing CO₂ for vehicles that are currently slightly above lower tax brackets (Sallee and Slemrod, 2010). The notches in the tax system also distort vehicle choice by causing a bunching of demand for vehicles with CO₂ per mile just sufficient to be in a lower tax bracket. Moreover, there is a tension between revenue needs and reducing emissions—as sales shares for low-tax, low-CO₂-per-mile vehicles rise, revenues fall.

If new vehicle taxes are to be retained (in a second-best world), a better approach is to combine a simple, proportional tax on new vehicle prices with a revenue-neutral ‘feebate’. The former is easily set to meet a revenue objective without distorting choices among different vehicles. The latter involves fees on fuel-inefficient vehicles in proportion to the difference between their CO₂ per mile and a pivot point of CO₂ per mile, whereas corresponding rebates are paid for relatively fuel-efficient vehicles. The feebate provides a cost-effective way to reduce emissions per mile, as the same reward per ton is provided, regardless of how the emissions reduction comes about (e.g., Small, 2010). And the feebate component can be kept (approximately) revenue-neutral by setting the pivot point equal to average CO₂ per mile of the previous year’s vehicle fleet.

In another example of tax notches, firms pay tax only if their emissions exceed a threshold level. Besides limiting emissions coverage, these exemptions can create other distortions like discouraging mergers or firm growth.

A third example is fuel taxes that vary discretely with embodied pollution per unit. These tax systems provide no incentives for refiners to further remove impurities once they have achieved a lower tax notch.

Second, administrative considerations can imply that environmental taxes should be levied upstream at the point where fuels enter the economy to limit the number of collection points and to maximize emissions coverage. For instance, in the United States levying a carbon tax upstream on petroleum refineries, natural gas operators, and coal mines would involve monitoring about 2,000 companies, whereas if the tax involved a downstream element—charging from the smokestack at power generators and major industrial facilities—the number of covered firms would rise to about 13,000 (e.g., Metcalf and Weisbach, 2009). Moreover, downstream systems tend to be less comprehensive due to administrative reasons (i.e., small-scale emitters are often exempt) and perhaps political pressure for exemptions. The case for upstream charging is especially strong when there are many small-scale stationary emitters (e.g., in countries with large informal sectors) while in other cases with limited numbers of emitters (e.g., the U.S. sulfur trading program) pricing downstream can be entirely reasonable.

Upstream tax systems can be complemented with rebates to promote behavioral responses at downstream firms to further reduce emissions, for example, through adoption of flue gas

¹⁰ Basing the tax on CO₂ per mile promotes a broader range of responses for reducing emissions beyond smaller engine size, such as use of lighter materials or reduced cabin size.

‘scrubbing technologies; coal washing; and adjusting the design, temperature, oxygen and moisture content of the combustion chamber to reduce NO_x emissions. That is, a power plant or manufacturing firm that demonstrated (through installing continuous emissions monitoring technologies) that its emissions out of the smokestack are less than the embodied emissions in its fuel inputs could claim a credit equal to the difference in emissions times the (upstream) emissions price (e.g., on SO₂ content). Placing the onus on firms to demonstrate valid emissions reductions (in order to obtain the refund) provides them with ongoing incentives to improve emissions monitoring technologies.

Another example is vehicle tailpipe emissions, for which individual sources of local pollution are far too numerous to be taxed directly. In this case, an upstream fuel tax (to encourage better fuel economy and reduce vehicle miles traveled) coupled with emissions regulations on vehicles (to encourage installation of abatement technologies) may approximately mimic the effects of a direct tax on emissions (e.g., Eskeland, 1994).

B. Multiple-Externality Situations

Multiple-externality problems are endemic. For example, in the power sector, fuel combustion causes a variety of local pollutants, in addition to CO₂, and legislative proposals are often designed to deal with multiple pollutants at the same time. But these pollutants are, to a large extent, additive, and can be dealt with through a combination of charges on fuel use. The most important exception is the transportation sector, in which some externalities vary with fuel consumption—which depends on vehicle mileage and fuel economy—whereas other externalities vary only with vehicle mileage. Here we first discuss the appropriate level of motor fuel taxes, assuming that they are the only available fiscal instrument, and then briefly note the ideal system of more precisely targeted taxes.

Motor fuel taxes (for passenger vehicles)

We focus on fuel taxes for passenger vehicles, where there are four main relevant externalities.¹¹

First is CO₂ emissions, which are proportional to fuel combustion (leaving aside blending from biofuels). Here the appropriate fuel tax would equal the CO₂ produced per unit of fuel combustion times the marginal damage from CO₂ emissions.

Second, fuel taxes reduce local pollution emissions, but by less than in proportion to the fuel reduction. Emissions fall as people drive less in response to higher fuel prices. However, at least in countries enforcing emissions-per-mile regulations, roughly speaking emissions are

¹¹ Other possible externalities are ignored here either because they are difficult to define (e.g., energy security implications of oil dependence) or because they appear to be relatively small for passenger vehicles (e.g., noise, road wear and tear). Also, we do not discuss corrective taxes for fuels used by heavy trucks, although at least for the United States, corrective fuel taxes for passenger vehicles and trucks seem to be in the same ballpark (e.g., Parry 2011). For more discussion of motor vehicle externalities see, for example, de Borger and Proost (2001), Delucchi (2000), FHWA (1997), Quinet (2004), Maibach and others (2008).

not affected by long run, fuel economy improvements—in response to higher fuel economy, manufacturers can cut back on abatement technologies and still meet the same emissions-per-mile standards (e.g., Fischer and others, 2007). In assessing corrective fuel taxes, pollution damage estimates therefore need to be multiplied by the fraction of the fuel reduction that comes from reduced driving (as opposed to from better fuel economy).

Third, tax-induced reductions in vehicle miles driven will also reduce traffic congestion (here the externality arises because drivers do not account for their impact on adding to congestion and slowing travel times for other motorists). And fourth, tax-induced reductions of driving also lower the incidence of traffic accidents (externalities in this case encompass, for example, injury risk to pedestrians or third-party property damage). In computing corrective taxes, congestion, and accident externalities obtained on a per-mile basis need to be expressed per unit of fuel (i.e., multiplied by fuel economy) and then (as for local pollution) scaled back by the fraction of the incremental, tax-induced fuel reduction that comes from reduced driving (Parry and Small, 2005).

Better Instruments (than Fuel Taxes) for Vehicle Externalities. But there are much better fiscal instruments for addressing motor vehicle externalities than fuel taxes (e.g., Transportation Research Board of the National Academies, 2006; and Parry and others, 2007). Besides complementary policies (like road upgrades to improve traffic flow and to reduce collision risk), traffic congestion would ideally be reduced through (electronically-collected) per-mile tolls on congested roads; such tolls would rise and fall during the course of the rush hour, to flatten the distribution of departure times within the peak period and promote other responses to deter people from driving on busy roads. Accident externalities are also best addressed through mileage tolls, ideally adjusted for driver and vehicle crash risk. These broader tax instruments are beyond our scope, but we note that the corrective fuel tax would be reduced considerably with their introduction.

C. Other Pre-Existing Distortions

This subsection discusses implications of market power, energy subsidies, pre-existing regulations, and broader fiscal distortions. Distortions in technology markets and appropriate treatment of energy under the value-added tax (VAT) are discussed in Boxes 3 and 4 respectively, but are not considered in our country evaluation (the former calls for supplementary instruments whereas there are no glaring problems with VAT systems in regard to energy).

Institutional distortions

In principle, the optimal tax on emissions differs from marginal environmental damages when there is a second source of market failure from distortions in the output market and the tax leads to a reduction in output.

Box 3. Distortions in Technology Markets

The processes of (clean) technology *development* and *deployment* are potentially characterized by additional market failures. At the development stage, the problem is that innovators may not be able to capture the spillover benefits of new technologies to other firms that (legally) imitate them or use them in their own research programs. At the deployment level, possibilities include, for example, lack of consumer awareness about the future saving from more energy-efficient technologies, and network externalities (e.g., reluctance of one firm to invest in clean energy infrastructure if other firms benefit from these investments).

In general, these additional market failures are more efficiently addressed through complementary technology instruments, rather than by setting the environmental tax above marginal environmental damages (e.g., Goulder and Schneider, 1999; Fischer and Newell, 2008; and Jaffe and others, 2003), though the efficient scale of these instruments can be difficult to assess. Moreover, in general the corrective environmental tax itself generates the largest source of welfare gain—addressing technology-related market failures yields further, though more modest, welfare gains (e.g., Goulder and Mathai, 2000; Nordhaus, 2002; Parry and others, 2003; and Popp, 2004). In any case, the use of supplementary technology policies does not generally affect the basic recommendation that environmental taxes should be set to cover marginal environmental damages.

Box 4. Coverage of Energy under the Value-Added Tax System

If we ignore environmental considerations, all consumption goods should ideally be included under the coverage of a broader value-added tax (VAT) (or other consumption tax) system to raise revenues in a way that avoids distorting consumer choices. Inputs into the production of goods should be exempt from such taxes to avoid distorting production efficiency. Thus, power generation fuels, electricity used by industry, truck purchases, etc. by firms should be VAT exempt, while residential electricity and fuel use, consumer purchases of cars and gasoline, etc. should be included in the tax base. However, this occurs automatically under an appropriately designed VAT tax—there is no need for any adjustment to this tax system when taxes are applied to fuels to account for their external costs.

One possibility is that output is already sub-optimal because of market power. The implied downward adjustment in the optimal environmental tax may often be of little practical relevance, however (Oates and Strassmann, 1984). One reason is that, at least for some countries studied below, energy markets exhibit a fair, or growing, degree of competition. Another is that the distortions created by market power (expressed relative to marginal supply costs) are not always large. Furthermore, if most of the behavioral response from emissions pricing comes from reducing emissions intensity through substituting cleaner inputs or adoption of end-of-pipe abatement technologies rather than from reducing the overall level of output (which tends to be true of the power sector), then the compounding of market power distortions will again be limited.

Another distortion is pre-existing price controls, or other subsidies, that may exacerbate excessive production in polluting industries.¹² Although removing the subsidy and then internalizing environmental externalities through tax instruments are the most efficient responses, if the subsidy is likely to be durable, then setting a higher environmental tax to partly offset it might be warranted on second-best grounds.

Pre-existing regulations

Preexisting regulations do not always affect efficient tax design. For example, if regulations on emissions per kilowatt hour, or automobile fuel economy, remain binding, this eliminates some of the potential behavioral responses from emissions or fuel taxes, but it does not affect the optimal level of these taxes (e.g., Parry and others, 2010).¹³

Broader tax distortions

The broader fiscal system causes important sources of distortion elsewhere in the economy which can have implications for environmental tax design.

Taxes on labor income and consumption (e.g., personal income and payroll taxes, VATs) drive a wedge between the value marginal product of labor and the marginal opportunity cost of labor supply (i.e., the value of time forgone in the household sector). Therefore, environmental taxes will lead to efficiency changes in the labor market to the extent that they affect labor force participation rates and hours worked and effort on the job. Similarly, taxes on firm income from investment and household income from savings drive a wedge between the value marginal product of capital and the marginal cost of capital in terms of forgone current consumption. Environmental taxes interact with these sources of distortion in two opposing ways (e.g., Goulder and others, 1999).

First, using environmental tax revenues to reduce broader tax distortions (either directly, or indirectly through deficit reduction, if such reduction obviates the need to raise income taxes) produces gains in economic efficiency, which can be large, relative to those from reducing the externality itself. Second, however, as environmental taxes are passed forward into the prices of fuels, electricity, and so on, the general price level is increased. In turn, real household wages and the real return on capital are reduced, which lowers labor supply and capital accumulation over the longer term in the same way that a direct tax on wages and savings/investment income does.

The general finding in the theoretical literature is that—with some qualifications—the net impact from shifting taxes off income and onto emissions is to increase the costs of pre-

¹² Even in developed countries, energy subsidies are still substantial, amounting to approximately \$60 billion a year (e.g., OECD, 2011).

¹³ In terms of Figure 1, these regulations steepen the marginal abatement cost curve, but do not affect the marginal benefit curve and hence the corrective tax.

existing taxes, that is, the gains from recycling revenues are more than offset by efficiency losses in factor markets from higher energy prices. Consequently, the optimal tax is below the marginal external damage, but only moderately so, implying that the Pigouvian tax is still a reasonable, rough approximation.¹⁴ There are some exceptions to this finding—for example, net employment effects can be positive if taxes are shifted onto a product that is a relatively weak substitute for leisure, or if externality mitigation raises the marginal value of work time relative to leisure time, though these special exceptions do not seem applicable for the cases studied below.¹⁵ In general therefore, taxes on fuels and energy products need to be justified on environmental grounds.

The most important point here, however, is the importance of revenue recycling. If emissions tax revenues are not used to increase economic efficiency through cutting distortionary taxes (or through funding socially desirable spending), the net benefits from emissions taxes are greatly reduced (e.g., Fullerton and Metcalf, 2001; Goulder and others, 1999; Crampton and Kerr, 2002; and Hepburn and others, 2006). In fact, the case for using environmental taxes on cost effectiveness grounds over regulatory approaches (e.g., emissions standards) can then be substantially undermined (e.g., Goulder and others, 1999). Environmental taxes tend to have a bigger impact on energy prices than regulatory policies (because the former involve the pass through of tax revenue into prices) and the revenue-recycling benefit is needed to offset the effect of these greater energy price increases on exacerbating factor tax distortions.

Earmarking

One important implication from the above discussion is a potential red flag for schemes to earmark environmental tax revenues, for example, on environmentally-related public projects. Ideally, earmarking would be limited to cases in which spending generates efficiency gains comparable to those from using the revenues for cutting distortionary taxes (e.g., Bird and Jun, 2005). Furthermore, with earmarked revenues, there has been an observed tendency to set tax levels to meet revenue needs, which may imply tax rates well below levels needed to correct for externalities (e.g., Opschoor and Vos, 1989).¹⁶

One possible exception is when (a minor portion of) revenues are earmarked in the form of production subsidies for firms affected by the environmental tax (see below). The usual idea here is to improve acceptability by limiting the overall impacts on product prices. This

¹⁴ In fact, Jacobs and De Mooij (2011) find that (under certain circumstances) the Pigouvian tax is the optimal tax, even in a distorted tax system, if the government optimally trades off its efficiency and distributional effects.

¹⁵ For further discussion of these issues, see, for example, Bovenberg and De Mooij (1994); Bovenberg and Goulder (1996, 2002); and Parry (1998). The above discussion assumes long-run, competitive equilibrium in the labor market. In the shorter term, employment effects may be more opaque with temporary disequilibria (e.g., Bosquest, 2000).

¹⁶ A practical caveat here, however, is that earmarking may create political pressure for sustaining the environmental tax and improving its initial credibility (Brett and Keen, 2000).

approach need not sacrifice too much in the way of effectiveness and cost effectiveness, at least if the bulk of low-cost emissions reductions are from reducing emissions intensity rather than reducing the scale of output (e.g., Bernard and others, 2007).

Revisiting the case for vehicle and electricity taxes

Finally, although we have critiqued the use of taxes on electricity consumption and vehicle ownership on environmental grounds, these taxes can make sense on fiscal grounds in countries where revenues from the broader tax system are limited by exemptions, lack of coverage, and easy evasion. In this case, some taxation of widely consumed products can be efficient as part of the overall tax system, although ideally these taxes target bases that are inelastic, which can be at odds with targeting taxes on emissions to maximize environmental impacts (e.g., IMF, 2011a).

D. Some Practical Concerns: Distribution and Competitiveness

In some specific cases, environmental taxes could undermine distributional objectives—particularly in developed countries where lower-income households tend to have disproportionately large budget shares for energy goods (e.g., Metcalf, 2009)—though this is not always the case (Stern, 2012).

Distributional effects might be taken into account by assessing the impacts of environmental taxes from models distinguishing different income groups, with social welfare weights applied to those groups (e.g., Cremer and others, 1998, 2003; and Mayeres and Proost, 2001). However, the choice of weights is arbitrary.¹⁷

Another possibility is to scale back other energy taxes at the time new environmental taxes are introduced, to limit the overall impacts on energy prices. As noted above, with adequate taxation of fuels and emissions, excise taxes on electricity use and vehicle ownership become redundant and can be reduced to limit overall burdens on consumers and motorists. Another possibility is to make offsetting (progressive) adjustments to the broader fiscal system—for example, in Australia’s prospective carbon pricing system, revenues obtained from allowance auctions are used to finance an increase in the personal income tax threshold to ameliorate effects on low-income households. Yet another possibility is to subsidize household adoption of clean alternative technologies (e.g., solar water heaters, heat insulation) to compensate for higher fuel prices.

Environmental taxes also raise concerns about competitiveness through the impacts of higher energy prices on energy-intensive firms competing in global markets for, say, aluminum, cement, and steel. These issues are less of a concern if environmental taxes are harmonized

¹⁷ Some studies infer these weights from observed distributional/efficiency trade-offs in the setting of broader income tax rates (e.g., Gruber and Saez 2002; and United Kingdom, Her Majesty’s Treasury, 2011). However, these estimates may provide an unreliable indicator of society’s true preferences to the extent that tax rates are driven by interest group competition and political ideology rather than benevolent government optimization.

across countries, which make sense for a global pollutant like CO₂, but not when pollution is localized and marginal damages vary by country (e.g., Oates, 2002). The first step should be to remove any redundant taxes (e.g., on electricity) to neutralize effects on energy prices. Alternatively, concerns might be addressed through (temporary) production subsidies for exposed industries or for adoption of energy-efficient technologies (to the extent that the subsidy is just sufficient to neutralize the burden of higher prices for energy inputs). Another possibility is border tax adjustments, although these are complex to design, and their compatibility with free-trade treaties is uncertain.¹⁸ The first two compensation schemes would also be the better way to pacify politically powerful downstream firms, rather than imposing environmental taxes downstream and exempting them.

E. Summary

On the basis of the above discussion, our policy recommendations would include:

- Taxes on fossil fuels for stationary sources to charge for CO₂ and local pollutants with tax refunds for downstream emissions capture and no exceptions or preferential rates for specific fuels or end users. To avoid double pricing, a tax refund should also be granted for allowance purchases by entities covered by the EU ETS.
- Taxes on motor fuels to account for a broader range of externalities (although with a planned transition to per-mile charges as the capability for their implementation is developed).
- Given the above, scaling back taxes/subsidies for hydro and other renewables, electricity, and vehicle ownership on environmental grounds. Taxation of nuclear seems appropriate, but the efficient level appears beyond quantification.

III. ENVIRONMENTAL TAX SYSTEMS AND REFORMS: THE CASE OF GERMANY, SWEDEN, TURKEY, AND VIETNAM

After some brief comments on the diverse energy systems across the countries, this section discusses our assessment of externalities for Germany, Sweden, Turkey, and Vietnam, and then evaluates actual tax systems in light of the above recommendations. Box 5 describes recent environmental tax reforms in these countries.¹⁹ All monetary figures are updated to year 2010 and expressed in U.S. dollars using IMF (2011).

¹⁸ In principle, a different tax needs to be applied to all goods from all countries that sell products to the domestic economy, where the tax varies with the emissions intensity of the exporting country. For some discussion of how legal and other challenges might be overcome, see, for example, Hilbert and Berg (2009).

¹⁹ A spreadsheet with complete data documentation is available upon request. We present only a snapshot at a point in time—failure to update taxes annually in line with inflation (or growth in income) is actually a common problem in practice.

Box 5. Environmental Tax Reforms in Sweden, Germany, Turkey, and Vietnam

Sweden. Together with other Nordic countries, Sweden took the lead in environmental tax reform during the early 1990s, followed by further reforms in the early 2000s (see Millock and Sterner, 2004; TemaNord, 2011; Agell and others, 1999; Johansson, 2006; and Swedish Agencies for Environment and Energy, 2007). These reforms represented a key component in a broader tax-shifting operation that strengthened indirect taxes, particularly the VAT, and environmental taxes, and that reduced taxes on labor. The aim here was to stimulate employment, although as noted above, the literature is far from settled on this possibility.

The Swedish reform added several new taxes between 1991 and 1992. These included taxes on oil and natural gas to charge for CO₂ and (for oil) SO₂ and downstream taxes on coal-related SO₂ and industrial sources of NO_x. These increases were partly compensated by a reduction in ‘traditional’ energy excises—mainly on motor fuels and other oil products. Due to worries about reduced competitiveness, a tax change in 1993 made manufacturing completely exempt from traditional energy taxes and made it pay only 21 percent of CO₂ tax rates from 2004 onwards (Johansson, 2006, p.1). Meanwhile, the CO₂ tax on fuels used in manufacturing plants covered by the EU ETS was gradually reduced to 15 percent of the statutory rate (TemaNord, 2009, p.81). Electricity generators have been fully exempt from all corrective taxes but the one on SO₂ (Speck and Jilkova, 2009, p.45).

Germany. A comprehensive environmental tax reform was introduced in Germany in 1999, involving (a) a gradual increase in taxes on transport fuels, and (b) new taxes on natural gas, heating fuels, heavy fuel oil, and (primarily) residential electricity consumption. The reform was broadly revenue-neutral, with about 85 percent of revenue recycled via equal reductions in employers’ and employees’ payroll taxes (about 13 percent was used for budget consolidation, and 1 percent was earmarked for renewable energy deployment). However, the reform was subject to considerable public dissatisfaction, which presumably helps to explain why, subsequently, tax rates were allowed to fall in real terms (BMU, 2004). The reform was viewed as regressive, and not helping with competitiveness, despite evidence to the contrary (e.g., Knigge and Görlach, 2005; Kohlhaas, 2005; and Salmons and Miltner, 2009, p.98), and public surveys suggest the recycling of revenues was poorly understood (e.g., BMU, 2004; and Ludewig and others, 2010).

As part of the tax changes, a comprehensive set of tax expenditures on energy products (other than transportation fuels) was also granted to the manufacturing and power generation sectors, with the justification of protecting their international competitiveness: Tax expenditures were initially 80 percent, but later reduced to 40 percent (Speck and Jilkova, 2009). Manufacturing firms were also eligible (with restrictions) for direct refunds if the extra tax burden was larger than the tax relief from reduced payroll taxes; in some cases reducing the effective tax rate to close to nil. There are no downstream rebates for scrubbing technologies; instead, these technologies are mandated.

Turkey. Turkey is an ‘outlier’ in environmental tax terms in that, although its per capita GDP is almost at the bottom of that among OECD countries, it has the highest gasoline tax among OECD countries (\$0.98 per liter)—a rate that, furthermore, has been steadily increased in recent years. This high tax rate goes a long way in explaining why Turkey is at the very top of OECD countries in terms of revenue raising from environmentally-related taxes (Figure 1).

The main reason for Turkey’s high fuel tax was purely fiscal: Revenues were needed for fiscal consolidation in the early 2000s, and fuel taxes are relatively difficult to evade compared with Turkey’s personal income tax system. Nonetheless, better still from a revenue-raising (although not an environmental) perspective would be to tax vehicle ownership (which is more inelastic) than fuel.

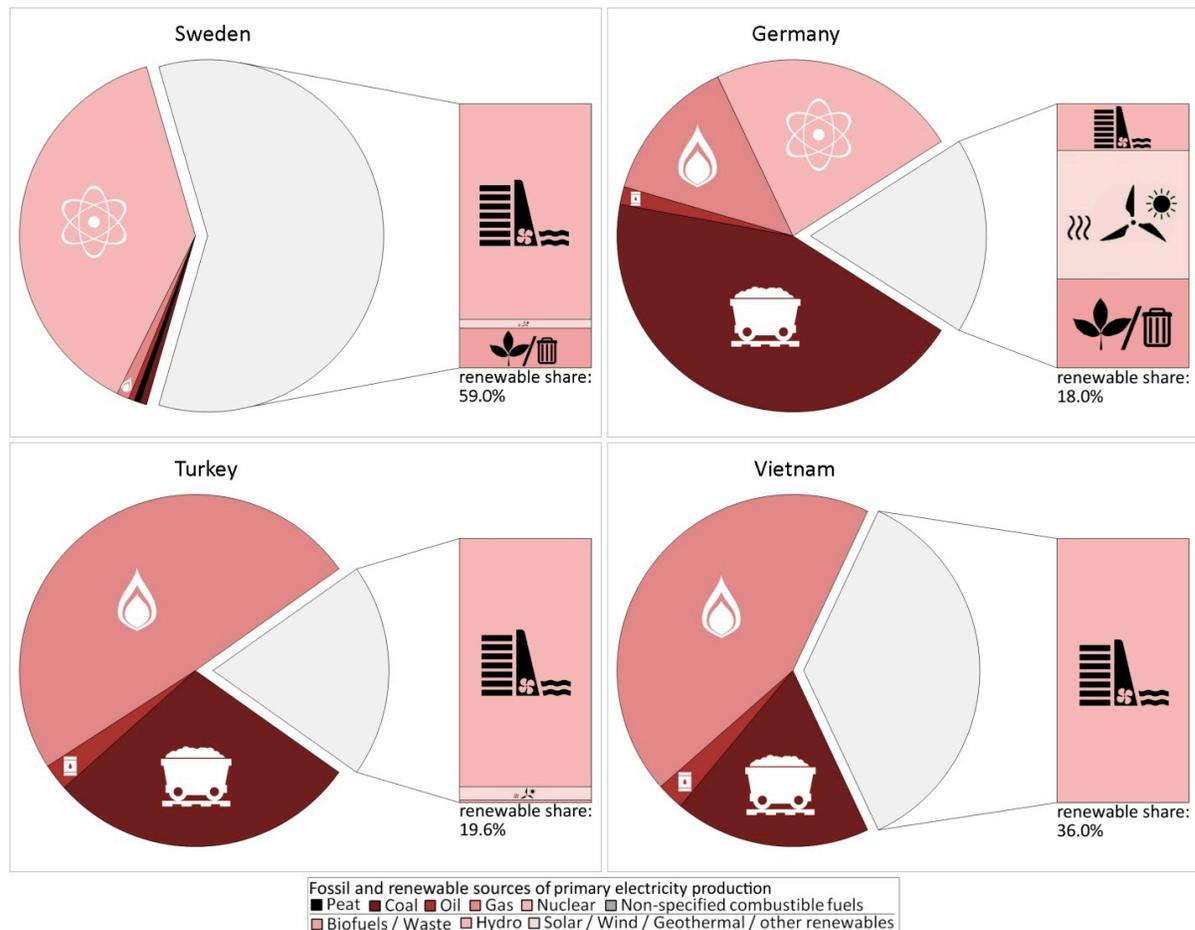
Vietnam. The government of Vietnam decided in 2004 that a comprehensive environmental tax reform was required. This decision was in part prompted by increasing public awareness of pollution levels. Although the 2008–10 financial crisis may have delayed the initiative somewhat, the government is now committed to environmental tax reform.

Currently, coal and gasoline are taxed in Vietnam, but at very low levels relative to those in other countries (\$0.52 per ton and about 20 cents per gallon, respectively), whereas natural gas is not taxed at all. This picture does not change in any significant manner when also taking into account a system of so-called ‘Environmental Protection Charges’ that Vietnam levies on resource extraction, due to the minuscule size of these charges. Vietnam is furthermore grants significant fuel subsidies to consumers (IEA 2011). For electricity, these subsidies are progressively scaled so as to favor poor households (though targeted transfers would be more efficient).

A. Comparing Energy Systems in Sweden, Germany, Turkey, and Vietnam

As regards power generation (see Figure 3), Sweden stands out as it does not rely on fossil fuels—almost half of electricity is produced by hydro, almost 40 percent by nuclear, and 9 percent from biofuels (oil generation has been phased out and although new nuclear plants were banned in 1980 this was lifted in 2011).

Figure 3. Fuel Mix in Electricity Generation



Source: IEA (2010).

Germany currently relies on coal for about 45 percent of power generation, with the remainder split between natural gas (14 percent), nuclear (23 percent), and renewables (18 percent). About half of the coal is lignite, produced domestically, and the remainder is hard coal, two-thirds of which is imported. Domestic hard coal production has long been subsidized though subsidies are set to phase out by 2018 (BFM, 2011). However, these subsidies may have little impact on lowering coal prices at least if Germany is approximately a price taker in the world coal markets.²⁰ With plans to phase out nuclear by 2022

²⁰ Lignite is also subsidized (e.g., Lechtenböhmer and others, 2004) and the subsidies are not being phased out. Due to its weight, lignite is not internationally traded, and is therefore an infra-marginal coal source, so again (continued...)

(AtG 2011), the fuel mix in Germany is set to change significantly, with much of the generation gap made up by further expansion of renewables, both from domestic and imported sources (e.g., hydro from Sweden), besides a transitory expansion of natural gas.

Given their large upfront costs, nuclear plants have not been constructed in Turkey and Vietnam, hence their reliance on fossil fuels—primarily natural gas, then coal, and small amounts of oil. Hydro power is also important however, accounting for 36 percent of generation in Vietnam and 19 percent in Turkey.

As indicated in Figure 4, about 35–45 percent of overall energy consumption comes from oil in Germany, Sweden, and Turkey, though somewhat less (28 percent) in Vietnam, where car ownership rates are low. In Vietnam, there were 13 passenger vehicles per 1000 people in 2010, compared with 131 in Turkey, 523 in Sweden, and 623 in Germany. Coal accounts for 13–23 percent of final energy consumption in Germany, Turkey and Vietnam, reflecting usage in power generation and steel production. Natural gas accounts for a large share of final energy consumption in Germany and Turkey (31 and 26 percent, respectively) given its widespread use both in power generation and home heating. In Sweden, heating is mainly from electricity and biomass (mostly wood fiber which caters for long-distance, district heating). The share of natural gas in final energy consumption in Vietnam is ‘only’ 6 percent, given that electricity is just 12 percent of energy consumption and there is little usage of natural gas in other sectors.

Renewables account for 45 percent of final energy consumption in Sweden, given the intensive use of hydro in power generation and biomass in heating. In Vietnam, the renewable share is even higher (47 percent) with a large contribution from biomass—mostly direct (rather than processed) fuel wood and agricultural residue—used for heating and cooking.

B. Externality Assessment

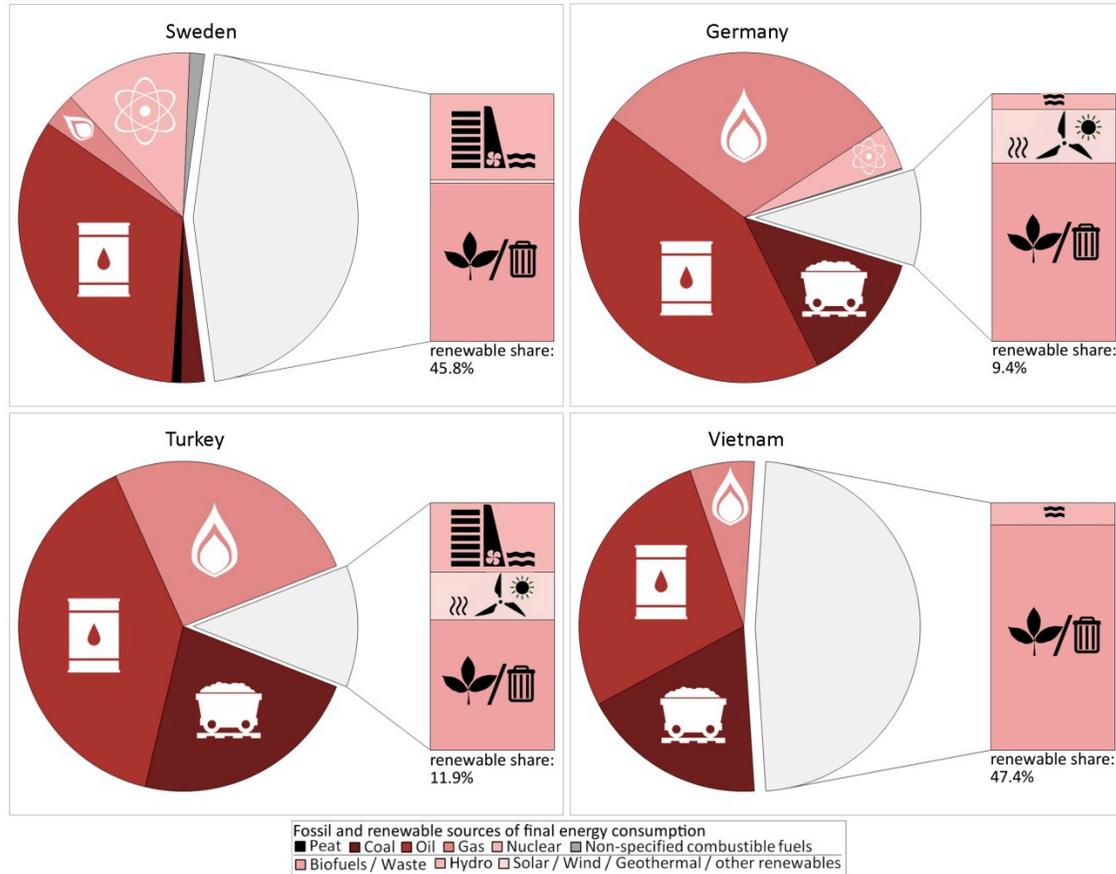
Our externality values are “illustrative,” given data limitations and methodological controversies (e.g., over discounting climate damages). They are meant to provide a broad-brush sense of efficient taxes, without getting into detailed parameter assessments which could be endlessly debated. We do not value externalities from nuclear power.²¹ Nor do we differentiate taxes within fuel groups—such differentiation would be potentially important in

these subsidies should have little impact on the domestic price (which is driven by the price of hard coal, the marginal fuel source).

²¹ In principle, corrective taxes are warranted to address risks from nuclear accidents (so long as liability is limited by legislation), nuclear proliferation, and long-term storage, but these risks are extremely difficult to quantify. And externalities from routine releases would generally justify only minimal taxes. See, for example, National Resources Council (2009); and Rothwell (2010).

cases with significant heterogeneity in embodied pollution content (most notably differences in sulfur content between hard coal and lignite).²²

Figure 4. Fuel Mix in Total Energy Consumption



Source: IEA (2010).

CO₂

We use two illustrative values for CO₂ damages: US\$23 per ton from the U.S. Interagency Working Group on Social Cost of Carbon (2010, p. 1), updated to 2010 dollars, based on their assessment of environmental damages, and US\$85 per ton, from the U.K. Department of Energy and Climate Change (2010), which corresponds to a shadow price for rapid stabilization of atmospheric concentrations. Given that (global) damages are uniform, regardless of where emissions are released, the same values are applied to different countries (although on equity grounds, lower values might be appropriate for low-income countries in

²² We used data on fuel emissions factors from EIA (2007) (which are very similar to average emission coefficients in EU Commission data). We then used localized energy densities of fuel (from IEA 2010) to obtain emissions in terms of energy units for the different fuels, to account for important variations in cross-country efficiency.

the absence of compensation payments). Coal is approximately 77 percent more carbon intensive per terajoule than natural gas, and 27 percent more intensive than oil.

SO₂, NO_x, and (primary) particulates for stationary sources

National Research Council (2009) provides a state-of-the-art assessment of local pollution damages for the United States. Damages per ton for SO₂ and NO_x include their effects on forming particulates, especially fine particulates (PM 2.5), which permeate the lungs—SO₂ has an especially high propensity to form such particulates through chemical reactions. Averaged across fuels and regions, the National Research Council (2009) central case damage estimates are approximately \$10,000 per ton for SO₂, \$2,000 per ton for NO_x, and \$22,000 per ton for primary (fine) particulates (i.e., those produced at the time of fuel combustion rather than from subsequent chemical reactions), in year 2010. Again, coal is the most emissions-intensive fuel and natural gas the least intensive fuel—natural gas does not produce SO₂, and its NO_x intensity is one-fifth of that for coal—although these damages are prior to any downstream scrubbing (which can capture around 90 percent of SO₂).

To adjust for the VSL, we multiply by a country's real per capita income (in purchasing power parity equivalent to account for the real spending power of local income) relative to that in the United States, raised to the income/VSL elasticity (Cifuentes and others, 2005). Real income in Sweden is 82 percent of that for the United States, 77 percent for Germany, 29 percent for Turkey, and 7 percent for Vietnam. For the VSL/income elasticity we use a value of 0.75.²³ These adjustments lead to damage values per ton that are just under half as large in Turkey relative to Germany and Sweden and about one-sixth as large in Vietnam.²⁴

Making further adjustments for, e.g., local population exposure, climate, geographical factors, and green preferences is beyond our scope. We simply note that damages for Vietnam and Turkey may be understated if their populations are less healthy (and therefore more vulnerable to pollution-related illness) than those in rich countries, whereas, in contrast, damages for Sweden and Vietnam may be overstated, given the relatively close coastal location of many emissions sources, which favors pollution dispersion.

Motor vehicle externalities

We begin with marginal pollution, congestion, and accident externalities for gasoline-powered vehicles in Germany from Mailbach and others (2008, table 48) and update them to year 2010 for inflation. These estimates are transferred (very crudely!) to other countries, making an adjustment only for per capita income. If anything, this approach likely provides

²³ Income data is from IMF (2011). Our elasticity assumption is based on a personal communication with Alan Krupnick and a meta-analysis of VSL studies in OECD (2012).

²⁴ Our damage estimates for SO₂ are nearly double those (after updating to 2010) in another study by ExternE (2005). The most important reason for the difference appears to be their use of disability-adjusted life years, which leads to a significantly smaller value for mortality than does the use of VSLs.

conservative damage estimates for Turkey and Vietnam to the extent, for example, that they might have a higher incidence of pedestrian fatalities or their roads are more congested.²⁵

In each case, externalities are scaled back by 50 percent on the assumption that reduced driving accounts for half of any tax-induced reduction in fuel use (Parry, 2011). External costs per mile are expressed per gallon of fuel, assuming on-road fuel economy of 30 miles per gallon. Combined with our lower carbon value, this yields our illustrative corrective taxes: \$3.69 per gallon for Germany, \$4.14 per gallon for Sweden, \$2.35 per gallon for Turkey, and \$0.78 per gallon for Vietnam (congestion is easily the most dominant component in each case). We caution against taking these figures too literally—for example (outside of Germany), they obviously need to be refined with local data sources on congestion, accident risks, etc.

Tax rates

Motor fuel taxes are based on statutory rates collected by IEA (2010). Prices on CO₂, SO₂ and NO_x from any domestic emissions taxes, and from the EU ETS, are converted to their fuel tax equivalents (i.e., they are divided by emissions factors), and added to other fuel charges. Where relevant, tax rates are scaled back taking into account preferential rates, and the portion of end-users exempt from charges (e.g., typically only about 40–60 percent of industries are covered by the ETS). We lacked the data to gauge how much optimal fuel taxes might be affected by non-marginal cost pricing of fuels (supplied by state-run enterprises), which might be significant for Vietnam.

C. Evaluating Environmental Tax Systems

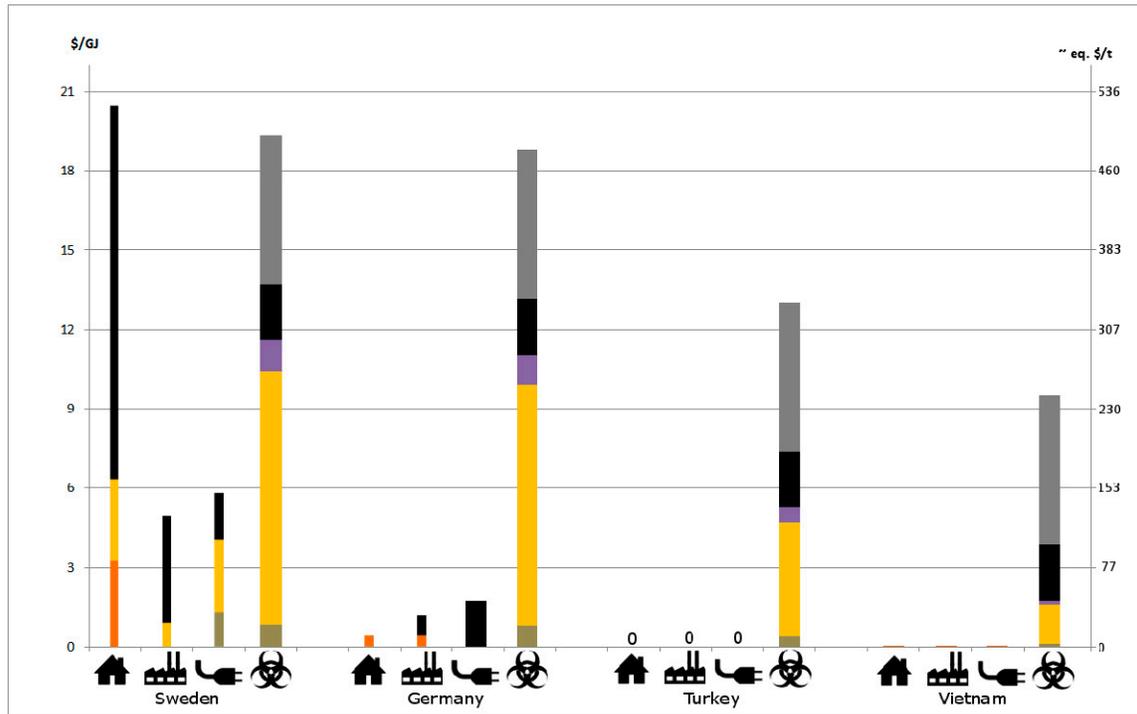
Coal

In Figure 5, the right-hand columns for each country indicate external costs (in dollars per gigajoule and dollars per ton): The yellow bars indicate damages from SO₂, the green bars damages from NO_x, the purple bars damages from (primary) particulates, the black bars the value for carbon damages recommended by the U.S. government, and the grey bars the difference between this value and that recommended by the U.K. government.

SO₂ is the dominant component of local pollution damages, though this case is prior to any scrubbing, and local pollution damages are substantially lower for Turkey and Vietnam, given the assumed smaller VSL for these countries.

²⁵ Mailbach and others (2008) provide separate externality estimates for urban and interurban road categories, which we assume correspond to large urban areas (population in metropolitan areas of at least 2 million) and all other (rural and intermediate urban areas) respectively. We weight these by regional population shares in these respective areas, using data on metropolitan areas and national populations from the Geopolis and WDI databases of 2011 respectively.

Figure 5. Coal Externalities and Taxes



Legend

Tax base / Source of damage:

- CO2 tax, CO2 damage (if adopting lower [US Inter-Agency] estimate)
- Additional CO2 damage if incorporating higher [UK DECC] estimate
- SO2 tax, SO2 damage estimate
- NOx tax, NOx damage estimate
- Energy tax
- Particulate Matter (PM2.5, PM10) damage estimate
- ⊕ Total damage estimate

Source. See text.

Use - dependent tax differentiation

- 🏠 Taxes applicable to households
- 🏭 Industry
- ⚡ Generators

Notes. Tax rates are less than statutory levels to the extent some sources pay lower, or zero taxes.

The other set of boxes for each country indicates existing tax rates by end-users—households, industries, and power generators, respectively (these are average tax rates across users within an end-use category). Here, a black box indicates CO₂ charges (from the ETS and/or carbon taxes), a yellow box indicates an explicit SO₂ tax, and an orange box indicates an excise tax. Furthermore, thin boxes indicate cases where fuel consumption by an end user is small (less than 15 percent of energy consumption by that user), and where hence (absent large behavioral responses), there is less urgency for tax reforms in these cases.

In Sweden, taxes on coal use vary dramatically across end users. However, welfare gains from tax reform will be very limited, given that end-use consumption is very small in all cases.²⁶ In Germany, coal use by power generators is substantial, and the coal tax equivalent

²⁶ See Box 5 for relevant data sources. Adjustment of emissions tax rates over time in Sweden is also problematic. The SO₂ and NO_x taxes have been fixed in nominal terms since 1991, reducing their real values by (continued...)

from the EU ETS is not sufficient to cover even the U.S. value for carbon damages, let alone the (larger) local pollution damages. In Turkey coal is not taxed, and in Vietnam coal is taxed very lightly, despite significant local and global pollution damages, and rising coal use in the latter case.

Natural gas

Figure 6 displays analogous information for natural gas. In this case, total environmental damages per gigajoule are about one-third to one-half as large as for coal. This reflects lower carbon intensity and, in particular, very low SO₂ damages—in fact, local pollution damages overall are smaller than carbon damages for natural gas (whereas the converse generally applies for coal). Again, tax rates vary considerably across end-users in Sweden, but natural gas consumption is minor in all cases. For Germany, there is a substantial tax on residential natural gas consumption (larger than local pollution damages plus the U.S. government carbon damage), although again power sector gas use is undercharged. We would recommend levelizing the natural gas tax across end users and setting it somewhere between current rates for households and generators. For Turkey and Vietnam, we would also recommend modest taxation of natural gas, mainly to cover carbon damages.

Light fuel oil

Estimated damages for light fuel oil (mainly used for heating), shown in Figure 7, are an intermediate case between those for coal and natural gas. For example, light fuel oil has a higher carbon and NO_x intensity than does natural gas. In nearly all cases, light fuel oil is undercharged for externalities—the exception is residential consumption in Turkey and Sweden, where tax rates are excessively high (although consumption is significant only in the Turkish case).

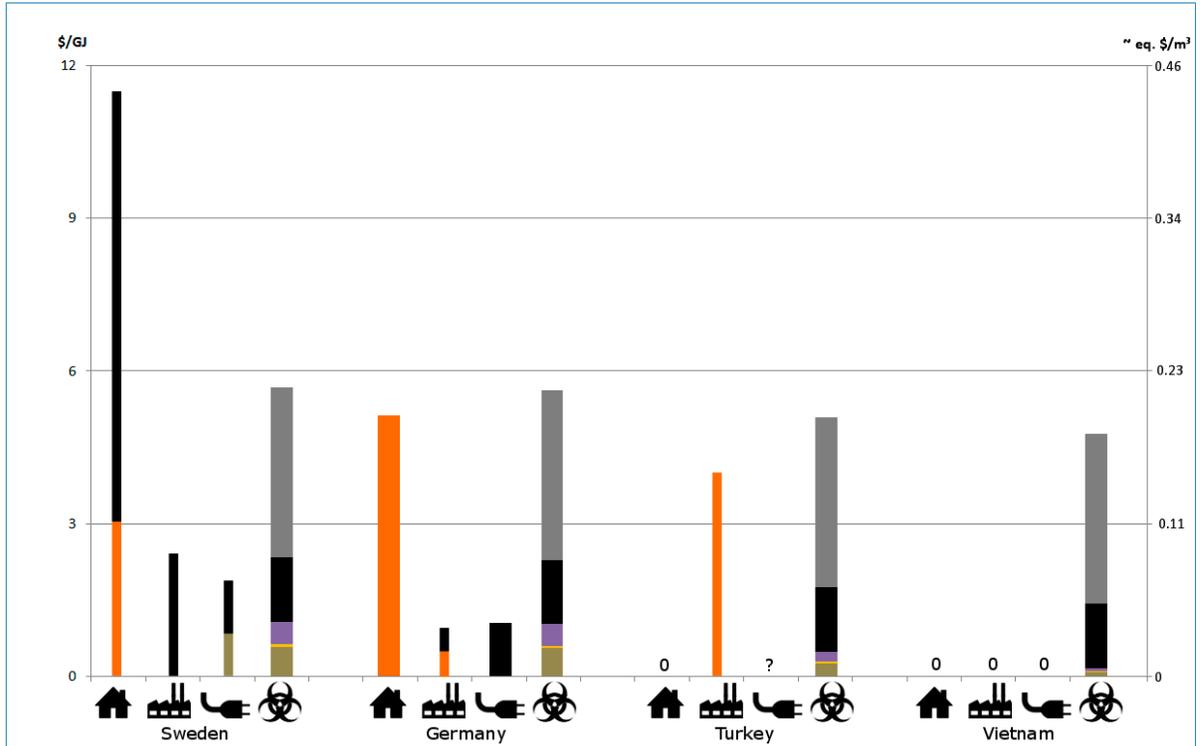
Motor fuel taxes.

Motor fuel taxes in Sweden, Germany, Turkey, and Vietnam are currently about \$2.90, \$3.30, \$3.70, and \$0.20 per gallon respectively. For Germany and Sweden, our calculations of corrective fuel taxes are somewhat above these current tax rates, although given the highly rudimentary nature of our calculations, we would not necessarily recommend raising tax rates. And in any case, the more important policy reform is to partially transition away from fuel taxes to time-varying mileage tolls. The case for higher fuel taxes may be more solid for Vietnam, where our (conservative) corrective tax estimate is four times the current tax. In contrast, it may be a stretch to justify current fuel taxes in Turkey on externality grounds.²⁷

about 35 percent, and while the CO₂ tax has been updated for inflation this has occurred sporadically, rather than annually.

²⁷ Parry and Strand (2011) put the corrective gasoline tax in Chile (which is similar to Turkey in terms of per capita income and a large portion of its population residing in large cities) at 2.35 per gallon (in 2006 \$).

Figure 6. Natural Gas Externalities and Taxes



Source. See text.

Legend

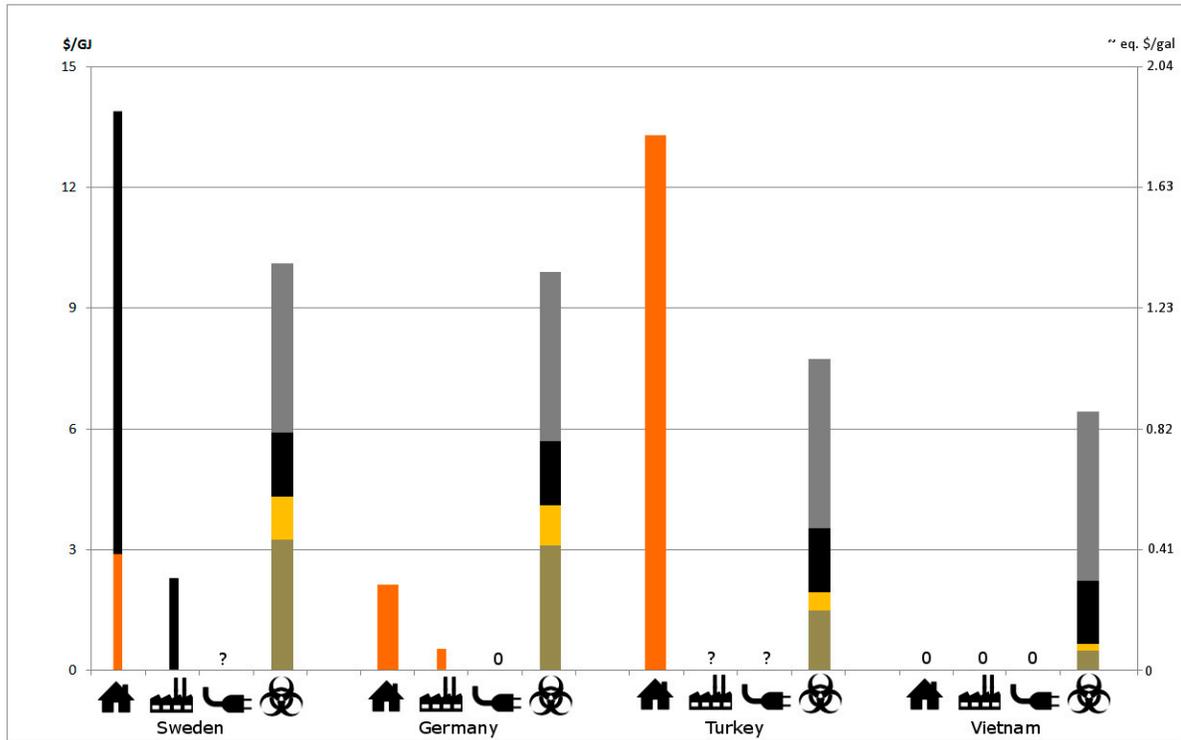
Tax base / Source of damage

- CO2 tax, CO2 damage (if adopting lower [US Inter-Agency] estimate)
- Additional CO2 damage if incorporating higher [UK DECC] estimate
- SO2 tax, SO2 damage estimate
- NOx tax, NOx damage estimate
- Particulate Matter (PM2.5, PM10) damage estimate
- Energy Tax
- ☠ Total damage estimate

Use-dependent tax differentiation

- 🏠 Taxes applicable to households
- 🏭 Industry
- ⚡ Generators

Figure 7. Light Fuel Oil Externalities and Taxes



Source. See text.

Legend

<p>Tax base / Source of damage</p> <ul style="list-style-type: none"> ■ CO2 tax, CO2 damage (if adopting lower [US Inter-Agency] estimate) ■ Additional CO2 damage if incorporating higher [UK DECC] estimate ■ SO2 tax, SO2 damage estimate ■ NOx tax, NOx damage estimate ■ Particulate Matter (PM2.5, PM10) damage estimate ■ Energy Tax ☠ Total damage estimate 	<p>Use-dependent tax differentiation</p> <ul style="list-style-type: none"> 🏠 Taxes applicable to households 🏭 Industry ⚡ Generators
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Redundant taxes

In most cases, there are significant (excise) taxes on electricity use (particularly at the household level) and on vehicle ownership—as noted above, any *environmental* rationale for these taxes disappears as fuel taxes are brought up to their corrective levels. Excise taxes on residential electricity consumption are 3.7 cents tax per kWh in Sweden, 2.7 cents in Germany, and 1.2 cents per kWh in Turkey (IEA, 2010). And vehicle excise taxes in Sweden, Germany, and Turkey raise revenues equivalent to fuel charges of 33 to 66 cents per gallon (IMF, 2011b), Table 3. Ironically, Vietnam subsidizes electricity use (IEA, 2011), even though the *fiscal* case for electricity taxes makes most sense there, given the difficulty

of raising revenues from broader fiscal instruments (the system of vehicle taxation in Vietnam is opaque).

Revenue use

Revenue use appears to have been efficient in most cases, at least in terms of revenue accruing to the Treasury. Even better, in some cases (e.g., Sweden, Germany) environmental tax revenues were used specifically to fund reductions in labor taxes (Box 6). A slight caveat is that NO_x tax revenues in Sweden funded a production subsidy in trade-exposed industries, resulting in some (probably very modest) loss of efficiency (Stern and Isaksson, 2006).

D. Conclusion

Well-designed fiscal policies (emissions taxes or their cap-and-trade equivalents with allowance auctions) should form the centerpiece of efforts to promote greener economies. We have a reasonable sense of where, ideally, environmental taxes should be levied, and where they should not; of how revenues should best be used; and of pitfalls to avoid in tax design, like notches and differentiated treatment of the same emissions across different fuels or end users. There are a variety of options for compensating adversely affected (low-income) households and (trade-exposed) firms for higher energy prices, which are preferable to setting environmental taxes below Pigouvian levels, or exempting sectors from environmental taxes. Administrative and coverage considerations suggest a preference for levying taxes upstream in the fossil fuel supply chain, with a system of refunds or credits for downstream emissions capture.

Specifically, a set of set of charges for coal, oil products, and natural gas should be imposed for potential releases of CO₂ and local emissions, grounded roughly to respective damage estimates. Other taxes in energy and transport systems would then become almost redundant, at least on environmental grounds. For motor vehicles, the problem is that some important externalities are related to vehicle use, which calls for a longer term shift away from heavy taxation of fuels and vehicles towards more innovative charges varying with miles driven on busy roads.

A quick look at existing environmental tax systems in selected countries suggests that there is much scope for policy reforms, in terms of leveling taxes across emissions sources causing the same damage, better aligning taxes with external damages, and scaling back redundant energy taxes. As regards research, we hope our cursory discussion of externality estimates might whet the appetite for more sophisticated work, especially on the measurement of pollution and congestion externalities for different countries.

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