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Background paper for World Development Report 1992

World Fossil Fuel Subsidies and Global Carbon Emissions

Bjorn Larsen
and
Anwar Shah

Removing world energy subsidies — estimated at US$230 billion — could reduce global carbon emissions by 9 percent.

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This paper — a product of the Office of the Vice President, Development Economics — is one in a series of background papers prepared for the *World Development Report 1992*. The *Report*, on development and the environment, discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Copies of this and other *World Development Report* background papers are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact the *World Development Report* Office, room T7-101, extension 31393 (October 1992, 31 pages).

Larsen and Shah present evidence on the level of fossil fuel subsidies and their implications for carbon dioxide emissions. They conclude that substantial fossil fuel subsidies prevail in a handful of large, carbon-emitting countries. Removing such subsidies could substantially reduce national carbon emissions in some countries. Global carbon emissions could be reduced by 9 percent, assuming no change in world fossil fuel prices, and by 5 percent when accounting for estimated changes in world prices.

Larsen and Shah estimate world energy subsidies to be more than US$230 billion. The welfare costs of these subsidies are more than US$20 billion, not including the cost of greenhouse gas and local pollution from fossil fuel consumption. Net fossil fuel importers in Japan, the United States, and Western Europe are estimated to experience welfare gains of about US$14 billion, while welfare effects would be negative in exporting countries in the event of a dampening effect on world fossil fuel prices associated with the removal of subsidies.

Eliminating these subsidies would translate into an average 21 percent reduction in carbon emissions in the subsidizing countries, or 20 percent of OECD emissions. To achieve an equivalent reduction in tons of emissions in the OECD countries would require imposing a carbon tax of $60-$70 per ton of carbon, even when accounting for estimated changes in world fossil fuel prices.

WORLD FOSSIL FUEL SUBSIDIES AND GLOBAL CARBON EMISSIONS

Bjorn Larsen and Anwar Shah[1]

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The World Development Report 1992, "Development and the Environment," discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Under current practices, the result could be appalling environmental conditions in both urban and rural areas. The World Development Report presents an alternative, albeit more difficult, path - one that, if taken, would allow future generations to witness improved environmental conditions accompanied by rapid economic development and the virtual eradication of widespread poverty. Choosing this path will require that both industrial and developing countries seize the current moment of opportunity to reform policies, institutions, and aid programs. A two-fold strategy is required.

• First, take advantage of the positive links between economic efficiency, income growth, and protection of the environment. This calls for accelerating programs for reducing poverty, removing distortions that encourage the economically inefficient and environmentally damaging use of natural resources, clarifying property rights, expanding programs for education (especially for girls), family planning services, sanitation and clean water, and agricultural extension, credit and research.

• Second, break the negative links between economic activity and the environment. Certain targeted measures, described in the Report, can bring dramatic improvements in environmental quality at modest cost in investment and economic efficiency. To implement them will require overcoming the power of vested interests, building strong institutions, improving knowledge, encouraging participatory decisionmaking, and building a partnership of cooperation between industrial and developing countries.

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Other (unpublished) papers in the series are available direct from the World Development Report Office, room T7-101, extension 31393. For a complete list of titles, consult pages 182-3 of the World Development Report. The World Development Report was prepared by a team led by Andrew Steer; the background papers were edited by Will Wade-Gery.

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WORLD FOSSIL FUEL SUBSIDIES AND GLOBAL CARBON EMISSIONS

I. Introduction

It has been argued that economic policies to protect local and global environments should, first and foremost, remove fossil fuel subsidies (see Summers, 1991, Churchill and Saunders, 1991, Larsen and Shah, 1992a, 1992b and Shah and Larsen, 1992a, 1992b). Unfortunately, the available literature does not document in any meaningful detail the level of worldwide subsidies on fossil fuels, the impact of their removal on world energy markets, global carbon emissions and aggregate welfare in subsidizing and non-subsidizing countries.[2] This paper attempts to correct these deficiencies.

Section II reviews existing fossil fuel pricing regimes and estimates the level of world fossil fuel subsidies. Section III develops a simple framework for estimating the impact of subsidy removal on global carbon emissions. A first estimate of carbon emission reductions is based on the assumption that world prices of fossil fuels do not change in response to the demand reduction in subsidizing countries that results from the removal of subsidies. Subsequently, world price effects and fossil fuel consumption in non-subsidizing countries are estimated using a simple model of global fossil fuel markets. Section IV estimates welfare gains that result from fossil fuel subsidy removal: first, on the assumption that world prices are unchanged for both subsidizing and non-subsidizing countries; second, on the assumption that such prices do change. Section V estimates what level of OECD carbon taxes would be required to achieve world emission reductions equal to those resulting from the removal of subsidies. Section VI presents a summary and conclusions.

II. Existing fossil fuel pricing regimes and world subsidies

Correct fossil fuel prices are a prima facie first order priority in any economic policy to curtail greenhouse gas emissions. This section explores the potential for correct fossil fuel prices by analyzing pricing practices around the world. Although a complete inventory of worldwide fossil fuel subsidies is beyond the scope of this study, it is possible to obtain a reasonable estimate of the overall level of subsidies by studying only a small set of countries. For example, 90% of world coal production is

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[2] A number of recent studies have reflected upon various aspects of this question: Kosmo (1989) estimates the level of subsidies for a large sample of developing countries primarily for petroleum products and electricity; Sterner (1989) presents a time series of domestic petroleum product prices relative to world prices for Latin American countries; and Burgess (1990) evaluates potential carbon dioxide emission reductions from efficient electricity pricing in a sample of countries including the United States, China and India.

consumed by 15 countries; 80% of world petroleum products by 28 countries; and 91% of world natural gas output by 20 countries (see Table 1). These countries are collectively responsible for 85% of fossil fuel carbon emissions. Roughly one half of coal and natural gas consumers, and one fourth of petroleum product consumers, are OECD countries with relatively insignificant subsidies.

We define fossil fuel subsidies as the difference between domestic fossil fuel prices and their opportunity cost evaluated at end-user prices. When fuels are traded internationally, border prices serve as opportunity cost: this is the case for petroleum products for all sample countries. Opportunity costs at end-user level are border prices plus a mark-up for distribution. U.S. pre-tax end-user prices of petroleum products by sector are used as proxies for opportunity cost at end-user level, although unit distribution costs may vary across countries to some extent. Natural gas and coal are traded less frequently than oil/petroleum products and natural gas markets are primarily regional in character. Border prices plus distribution costs are used if these fuels are imported or if there are export markets - as for the former Soviet Union in the case of natural gas, and to a lesser extent coal. Long run marginal costs are used for coal in the cases of China and India and for natural gas in Argentina.[3] For purposes of convenience, opportunity cost is henceforth referred to as world price. Exchange rates reported in the IMF's International Financial Statistics have been used to convert domestic currency figures to dollars.

Thus, total subsidies S_k for country k are given as:

$$S_k = \Sigma_i \Sigma_j (p^w_{ij} - p_{ij}e)q_{ij} \qquad (1)$$

where p_{ij} is domestic end-user price of fossil fuel i in sector j, p^w_{ij} is opportunity cost of fuel i in sector j in US dollars, e is the exchange rate in units of US dollars to domestic currency, and q_{ij} is domestic consumption of fuel i in sector j.[4] According to (1), total subsidies are the product of the price differential and quantity consumed at subsidized prices. Since the efficiency cost of subsidies is defined as the difference between total subsidies and the increase in consumer surplus, there is no need to apply price elasticities of demand in order to calculate subsidies. If total subsidies were calculated on the basis

[3] Although it is possible that China could perhaps increase exports to South Korea, Hong Kong and Japan.

[4] Sectors include electricity generation, industry, transport, households and a residual sector. Subsidies on outputs or complementary inputs to energy in any of these sectors would act as "implicit" subsidies on energy because more energy would be used than at efficient input and output prices. We do not attempt to account for such inefficiencies.

Table 1. Carbon Emissions from Fossil Fuel Combustion

Carbon emissions from petroleum products (1987)

	000 tons	% of world emissions	cumulative %
United States	545300	23.81%	23.81%
USSR	339200	14.81%	38.62%
Japan	139400	6.09%	44.71%
China	83600	3.65%	48.36%
Germany, West	73200	3.20%	51.56%
Italy	63000	2.75%	54.31%
Mexico	57900	2.53%	56.84%
France	56000	2.45%	59.28%
Canada	52400	2.29%	61.57%
United Kingdom	52000	2.27%	63.84%
Brazil	38300	1.67%	65.51%
India	33700	1.47%	66.98%
Saudi Arabia	32000	1.40%	68.38%
Iran	26000	1.14%	69.52%
Spain	25000	1.09%	70.61%
Australia	20800	0.91%	71.52%
Indonesia	20586	0.90%	72.42%
South Korea	20000	0.87%	73.29%
Argentina	17000	0.74%	74.03%
Turkey	16000	0.70%	74.73%
Egypt, Arab Rep.	15966	0.70%	75.43%
Romania	13000	0.57%	76.00%
Belgium	13000	0.57%	76.56%
Germany, East	12800	0.56%	77.12%
Czechoslovakia	12600	0.55%	77.67%
Venezuela	12473	0.54%	78.22%
Bulgaria	12000	0.52%	78.74%
Poland	11600	0.51%	79.25%
World	2290000		

Carbon emissions from coal (1987)

	000 tons	% of world emissions	cumulative %
China	47900	20.71%	20.71%
United States	465800	20.14%	40.85%
USSR	371300	16.05%	56.90%
Poland	108600	4.70%	61.60%
India	108500	4.69%	66.29%
Germany, West	78500	3.39%	69.68%
Japan	75200	3.25%	72.93%
Germany, East	72300	3.13%	76.06%
United Kingdom	71000	3.07%	79.13%
South Africa	66600	2.88%	82.01%
Czechoslovakia	46200	2.00%	84.00%
North Korea	36423	1.57%	85.58%
Australia	35100	1.52%	87.10%
Canada	27100	1.17%	88.27%
South Korea	23700	1.02%	89.29%
World	2313000		

Carbon emissions from natural gas (1987)

	000 tons	% of world emissions	cumulative %
USSR	302400	34.05%	34.05%
United States	235000	26.46%	60.52%
United Kingdom	31000	3.49%	64.01%
Canada	29600	3.33%	67.34%
Germany, West	25600	2.88%	70.23%
Japan	22500	2.53%	72.75%
Romania	22000	2.48%	75.24%
Netherlands	21000	2.36%	77.60%
Italy	19000	2.14%	79.74%
France	14000	1.58%	81.32%
Mexico	13600	1.53%	82.85%
Saudi Arabia	1200	1.35%	84.20%
Venezuela	10731	1.21%	85.41%
Argentina	10000	1.13%	86.54%
Algeria	9000	1.01%	87.55%
Iran	8400	0.95%	88.49%
Australia	7900	0.89%	89.38%
China	7300	0.82%	90.21%
United Arab Emir.	7100	0.80%	91.01%

Source: World Resources Institute (1991) of consumption at non-subsidized prices, they would be less than the increase in consumer surplus, and welfare would therefore be higher with a subsidy.

Total subsidies by fuel and country are presented in Table 2, and ratios of domestic prices to world prices in Chart 1 and the appendix tables. The former Soviet Union accounts for more than two-thirds of total world subsidies. This is to be expected given that domestic prices are low relative to world prices, and the fact that the Soviet Union accounts for approximately 20% of world fossil fuel consumption. Estimates of subsidies in the Soviet Union are highly uncertain. Although there is general agreement that substantial subsidies prevail, it is not clear what exchange rate should be used to convert figures to US dollars for the sake of comparison with world prices. Domestic prices for the former Soviet Union are from January 1992, and the exchange rate used is the commercial rate as of January 1992 - Rb 55 per US dollar. The commercial rate is the rate used for most international trade transactions and is therefore appropriate for this case. It could be argued that the ruble is still overvalued at the commercial rate. However, using an exchange rate of greater than 55 rubles per US dollar will not significantly affect total estimated subsidies.[5]

China follows with the second highest level of energy subsidies. Coal subsidies in China were significantly higher a few years ago (Bates and Moore, 1992) before the introduction of the two-tier pricing system, which permits a large proportion of coal to be traded at market prices. Subsidies on petroleum products are considered larger than those on coal (Haugland and Roland, 1990). Poland follows closely behind with substantial subsidies on coal. However, petroleum products in Poland do not receive any significant subsidies and gasoline is taxed.

Worldwide, petroleum products are the fuel most heavily subsidized, accounting for more than 55% of total world subsidies, followed by coal (23%) and natural gas (21%). Among petroleum products, fuel oils receive the largest subsidies in dollar value. Gasoline is often taxed even in countries where there are substantial subsidies on other petroleum products. For petroleum products, the ratio of domestic to border prices is based on subsidized products only and excludes taxed petroleum products (see Chart 1). Thus the low domestic price to border price ratio for India reflects low domestic prices of kerosene and LPG, although other petroleum products are taxed. In the case of Brazil, gasoline is substantially taxed, but other products are subsidized. Venezuela has

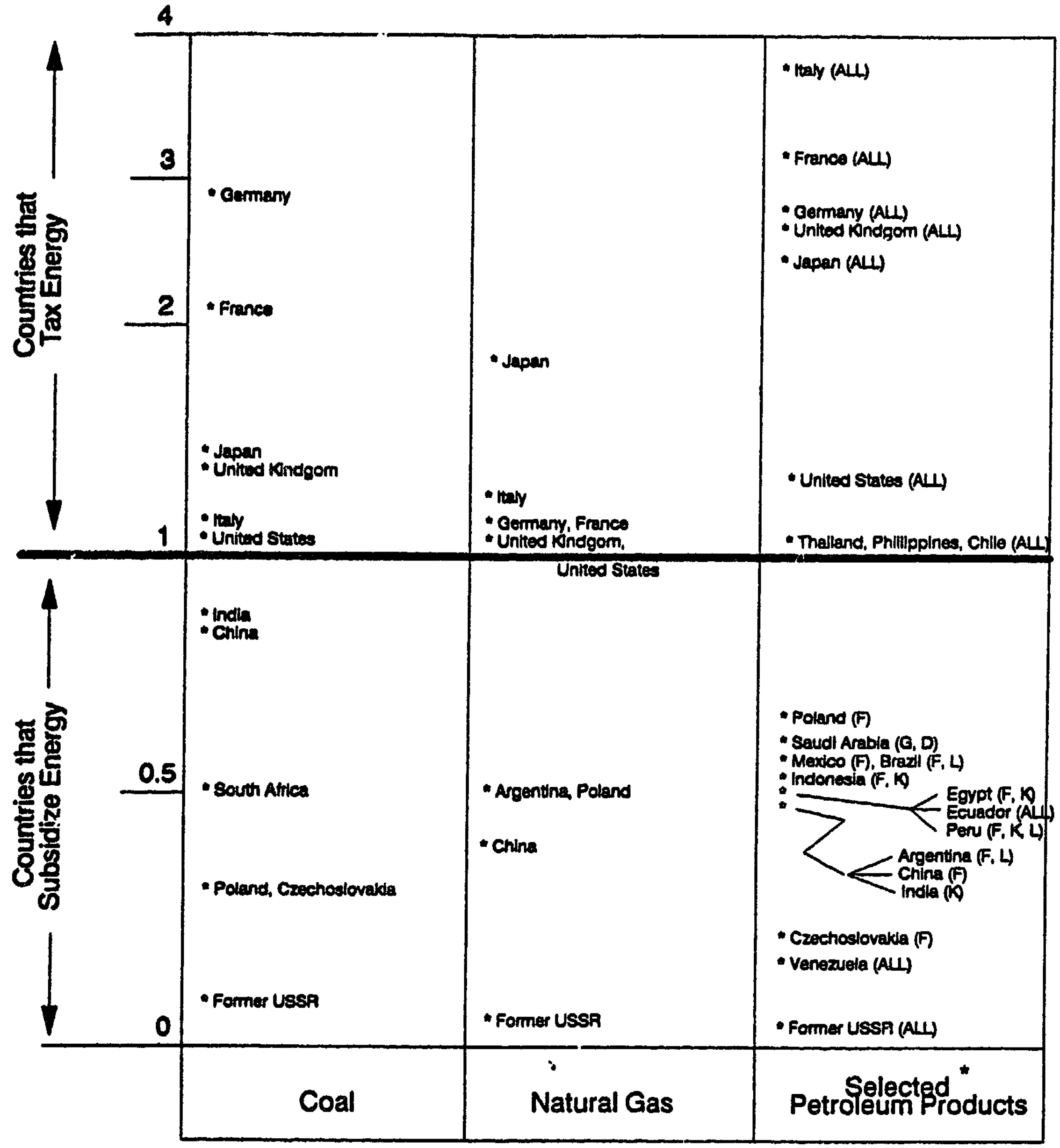
[5] For illustration, suppose world price is \$ 1. At 55 Rb/US\$, price in the former Soviet Union is less than \$ 0.1 and unit subsidy is more than \$ 0.9. At 110 Rb/US\$ price is less than \$ 0.05 and unit subsidy more than \$ 0.95. Thus by doubling the exchange rate total subsidies would only change by 5.5%.

Table 2. Total Subsidies (millions U.S.$)

	No world price effect: Subsidies				World price effect: Subsidies			
	Coal	Gas	Petroleum	Total	Coal	Gas	Petroleum	Total
Former USSR	33415	44783	94250	172449	30312	33310	87902	151523
China	3389	378	10300	14067	1618	378	9033	11029
Poland	7868	980	620	9468	6928	513	496	7937
Czechoslovakia	3500		350	3850	3082		321	3403
Brazil			3700	3700			3196	3196
Venezuela			3500	3500			3227	3227
Mexico			3000	3000			2583	2583
India	906		1675	2581	365		1473	1838
Indonesia			2500	2500			2174	2174
Saudi Arabia			2200	2200			1848	1848
Argentina		400	1600	2000		400	1403	1803
South Africa	1932			1932	1609			1609
Egypt			800	800			698	698
Subtotal	51011	46541	124495	222047	43915	34601	114353	192868
Subsidies - Nonsample countries				8000				8000
Total				230000				201000

Source: Authors' calculations.

Chart 1 **Ratio of Domestic Prices to World Prices**



* For developing countries, selected petroleum products are mainly fuel oils, (gasoline is often taxed and in those cases not included). For industrial countries, however, all petroleum products are included.

Petroleum Products:

ALL - Weighted Avg. of all petroleum products
F - Fuel oils
K - Kerosene
L - Liquified petroleum gas
G - Gasoline
D - Automotive diesel

Source: Authors' calculations.

substantial subsidies on all petroleum products. Gasoline prices in Mexico and Indonesia are close to border prices, but substantial subsidies exist on other petroleum products. Saudi Arabia taxes heavy fuel oil (light fuel oil prices are close to border prices), but has high subsidies on all other petroleum products. Czechoslovakia subsidizes only light fuel oils (besides coal) and gasoline prices are 2.8 times higher than border prices.

Calculations presented in Table 2 place the level of total world fossil fuel subsidies at approximately US $230 billion, which corresponds to 20-25% of world fossil fuel consumption at current world prices.

III. Implications for greenhouse gas emissions

Removal of fossil fuel subsidies will presumably induce reductions in fossil fuel consumption and therefore carbon emissions in subsidizing countries. Conversely, consumption in non-subsidizing countries could increase if reductions in fossil fuel demand in subsidizing countries lower world prices. Furthermore, if domestic prices are below world prices because of price ceilings that are effective for producers as well as consumers, then removing such ceilings may have positive supply effects that could further reduce world prices. On the other hand, because removing producer subsidies will tend to reduce supply, we assume that the combined effect of removing of producer ceilings and subsidies is to leave supply unchanged - as far as subsidies are concerned, we therefore ignore the supply side in subsidizing countries. The extent to which reduced demand in subsidizing countries impacts on world prices and thus on increased demand in non-subsidizing countries can be expected to differ for each fossil fuel.

The first part of this section estimates carbon reductions assuming no change in world prices. The last part estimates world price effects and their impact on demand for each fossil fuel in subsidizing and non-subsidizing countries.

III.1. No world price effects

The magnitude of carbon reductions that result from the removal of fossil fuel subsidies clearly depends on the relevant price elasticities of demand. Bohi (1981) presents a comprehensive survey of price elasticities of energy demand. Long run elasticities are in the range of -0.5 to -1.0 for natural gas, -0.7 to -1.5 for petroleum products, -0.5 to -1.0 for coal, and -0.5 to -1.0 for electricity. In a cross sectional study of OECD countries, Hoeller and Wallin (1991) estimate the long-run price elasticity of carbon demand at -1.04. These elasticity estimates are only valid for marginal price changes. In countries where subsidies are high, such as the former Soviet Union, elasticity estimates for marginal price changes cannot be used to estimate emission reductions. Instead, much smaller elasticities must be considered. The elasticities used in most of the cases considered here range from -0.15 to -0.25, and to -0.6 where subsidy levels are low (see tables in appendix).

The analysis ignores interfuel substitution. For the former Soviet Union, where fossil fuels are subsidized across the board in almost the same proportion, this is an unproblematic assumption. However, in other countries (accounting for some 30% of carbon emissions reductions), to the extent a potential for interfuel substitution exists, the estimates of emission reductions presented here may be too high. Estimates of emission reductions resulting from the removal of subsidies can also be in serious error for countries where supply exceeds demand at low prices and is therefore completely inelastic - as may be the case for natural gas in particular. In Argentina, China, and Poland, demand for natural gas is considered to be constrained by supply. Within a certain range, therefore, an increase in natural gas prices may not have any significant effect on natural gas consumption. Factoring out emission reductions resulting from natural gas price increases in these three countries would have only a minor effect on the overall estimate for global carbon emissions reductions. Since, in the case of the former Soviet Union, the share of natural gas in total energy consumption is as large as that of petroleum products and coal, it is not unrealistic to assume that natural gas price increases will lead to reduced natural gas consumption.

We assume a constant own price elasticity of demand, $-\epsilon$ ($\epsilon > 0$), with an inverse demand function,

$$p(q) = c\, q^{-1/\epsilon} \qquad (2)$$

where q is consumption of fossil fuel, p is the domestic unit price of q, and c is a constant determined by the initial equilibrium.[6] If (p_1, q_1) is the initial equilibrium at subsidized prices, p_1, and (p_w, q_w) is the equilibrium that would prevail if domestic prices were raised to world prices, p_w, the percentage reduction in fossil fuel consumption that results from raising prices from p_1 to p_w is,

$$(q_1 - q_w)/q_1 = 1 - (p_1/p_w)^{\epsilon} \qquad (3)$$

[6] Equation (2) is derived from the differential equation that defines elasticity,

$$(p/q)(\partial q/\partial p) = -\epsilon$$

Estimates of carbon emission reductions resulting from subsidy removal are presented by country in Table 3, and by country and fuel in the appendix. Subsidy removal could result in a 9% reduction in world carbon emissions. In terms of potential national carbon emissions reductions, the former Soviet Union is ranked first with 33% reductions, followed by China and Poland. Although emission reductions of 33% may appear unrealistically high, even after such reductions carbon intensity in the former Soviet Union would still be significantly higher than in other middle income countries or the OECD.[7]

III.2. World price effects

Large reductions in fossil fuel demand in subsidizing countries may have significant effects on world or regional prices and therefore on demand in non-subsidizing countries. We consider only those world price effects that arise from changes in fossil fuel demand caused by removing subsidies. Although changes in the relative prices of other goods may affect consumption patters, this is ignored - even though such changes may to some extent affect fossil fuel consumption since fossil fuels are inputs in their production. We assume world prices, p, are determined by supply and demand in the long run, and define linear world demand and supply functions,

$$q^D = a^D - b^D p$$
$$q^S = a^S + b^S p \qquad (4)$$

where $q^D = q^D_1 + q^D_2$, with q^D_1 and q^D_2 linear demand functions for subsidizing and non-subsidizing countries respectively, and similarly for q^S.

Price equilibrium in the market is,

$$p = (a^D - a^S)/(b^D + b^S) \qquad (5)$$

corresponding to p in Figure 1. Emission reductions resulting from subsidy removal (but estimated without taking account of world price effects) correspond to a movement from a to b in Figure 1. This movement is equivalent to an inward shift in the world demand curve in Figure 2, here noted as a change in a^D.

Thus ∂aD is tons of reduction of carbon or fossil fuel consumption assuming no world price

[7] Carbon intensity is defined as the ratio of tons of carbon emitted per dollar of GDP.

Table 3 Emission Reductions

	No world price effect: emission reductions	No world price effect: % reductions	World price effect: emission reductions	World price effect: % reductions
Former USSR	330688	33%	318062	31%
China	62814	11%	40063	7%
Poland	25111	20%	23171	18%
India	10779	7%	5191	4%
South Africa	10596	14%	9426	12%
Czechoslovakia	10348	16%	9585	15%
Mexico	5538	7%	4701	6%
Brazil	4160	8%	3613	7%
Argentina	3728	13%	3491	12%
Venezuela	3621	15%	3508	14%
Indonesia	3189	12%	2911	11%
Saudi Arabia	2910	7%	2351	5%
Egypt	2032	11%	1809	9%
Total	475515		427982	
	8.7%		7.8%	
Emissions reductions from non-sample countries	22000		22000	
Grand total	497515		449982	
	9.0%		8.2%	
Non-subsidizing countries			-186014	
Net emission reductions			263968	
			4.9%	

Source: Authors' calculations.

Figure 1 **Impact of Subsidy Removal (in subsidizing country)**

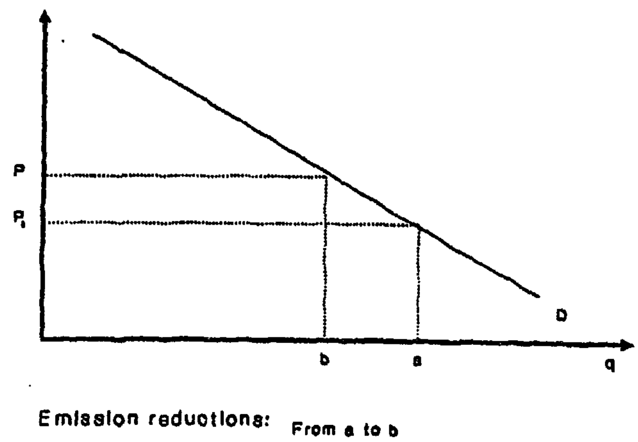
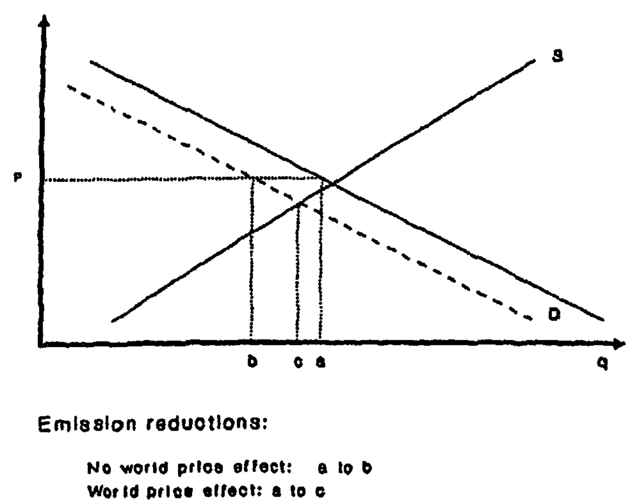


Figure 2 **Impact of Subsidy Removal (world market)**



effects. Differentiating (5) with respect to a^D gives,

$$\partial p/\partial a^D = 1 / (b^S + b^D)$$

which in elasticity form is,

$$(q/p)\partial p/\partial a^D = (q/p) / (b^S + b^D) = 1 / (e^S + e^D) = 1 / (e^S + e_1^D[q_1/q] + e_2^D[q_2/q])$$

or

$$\partial p/p = \{1 / (e^S + e_1^D[q_1/q] + e_2^D[q_2/q])\}\partial a_1^D/q \qquad (6)$$

where e_1^D and e_2^D are absolute values of own price elasticities of demand for subsidizing and non-subsidizing countries respectively, and e^S is weighted average own price supply elasticity for subsidizing and non-subsidizing countries.

The increase in consumption of each fossil fuel resulting from the reduction in world prices is given by,

$$\partial q_i = q_i e_i^D \partial p/p \qquad (7)$$

for country i. The net aggregate effect on consumption (i.e., the decrease in consumption resulting from subsidy removal plus the increase resulting from reduced world prices) is,

$$\partial q = \partial a^D + \Sigma_i \partial q_i \qquad (8)$$

with $\partial a^D < 0$, represented in Figure 2 as the movement from a to c. The following sections apply this framework to the markets for oil/petroleum products, natural gas, and coal.

Oil/petroleum products: Two assumptions are made here: first, that there is a perfectly integrated world market for oil/petroleum products in which prices are determined by supply and demand in the long run; second, that a percentage change in the price of crude oil translates into an equivalent percentage change in the prices for refined products.

Assuming a weighted average supply elasticity of 0.5 and a demand elasticity of 0.8 in non-subsidizing countries, world prices of petroleum products (6) are estimated to fall 6.4%. Demand elasticity in subsidizing countries are as assumed in section 111.1. Increases in petroleum product consumption, and hence carbon emissions, resulting from lower world prices are estimated by equation

(7) and presented in Table 3 for each of the subsidizing countries: estimates for the non-subsidizing countries are given in Table A3, in aggregate terms and by fuel. Net emission reductions in the subsidizing countries make up as much as 95% of total reductions when no world price effects are assumed. Emission increases in non-subsidizing countries amount to more than 50% of reductions in subsidizing countries. Net world emission reductions are 3.3% when world price effects are incorporated, compared to 7.1% when world price effects are ignored.

Natural gas: The natural gas market is more regional in nature than the oil market. For the purposes of this paper, we distinguish the following natural gas markets:

- The United States, Canada and Mexico;
- Western and Eastern Europe, the former Soviet Union and Algeria;
- Rest of the world.

The first two markets account for more than 80% of production, consumption and trade. Furthermore, almost all trade is intra-market. We therefore assume that general equilibrium price effects will not affect prices in other regional markets. World subsidies on natural gas are primarily in the former Soviet Union and therefore our analysis will be confined to relevant European market only. Large reductions in natural gas demand in subsidizing countries may have significant effects on gas prices and consequently on demand in the corresponding regional gas market. We assume that regional prices are determined by supply and demand in the long run. We further assume that a percentage change in the price of natural gas translates into an equivalent percentage change in gas prices in all sectors of consumption.

Assuming a weighted average supply elasticity of 0.5 and a demand elasticity of 0.8 for non-subsidizing countries, regional prices are estimated to fall by almost 24%. Again, demand elasticities for subsidizing countries are the same as in section III.1. Similarly, increases in natural gas consumption, and thus carbon emissions, due to the reduction in regional prices are derived using equation (7) and presented in Table 3 for each of the subsidizing countries, and for the non-subsidizing countries in Table A2, in aggregate terms and by fuel. Net emission reductions in the subsidizing countries are still substantial - as much as 92% of total reductions, assuming no regional price effects. Emission increases in non-subsidizing countries are about 25% of the reductions in subsidizing countries. Net world emission reductions are 7.5%, compared to 11.6% in partial equilibrium.

Coal: World coal markets are not as integrated as world oil markets, in part because of significant domestic protection in the form of producer subsidies and trade barriers. World coal trade is only 10% of world production, but is intercontinental. The United States and Australia are the largest exporters, followed by South Africa, Canada, Poland and the former Soviet Union. The largest import markets are Western Europe and Japan. Subsidy removal can be expected to have some general equilibrium price effects, but the corresponding demand effects, although difficult to quantify, are muted by protectionism. Consequently, although we estimate general equilibrium effects under the assumption of a fully integrated world coal market with no domestic protection, we keep in mind that the increase in world demand that results from a decline in world coal prices may be reduced by domestic protection.

Assuming a weighted average supply elasticity of 0.5 and a demand elasticity of 0.8 in non-subsidizing countries, equation (6) implies a 8.4% fall in coal prices. Again, the demand elasticity in the subsidizing countries is the same as in section III.1. Increases in coal consumption, or carbon emissions, due to the fall in world coal prices are estimated by equation (7) and presented in Table 3 for each of the subsidizing countries, and for the non-subsidizing countries in Table A1, in aggregate terms and by fuel. Net emission reductions in the subsidizing countries are almost 85% of total reductions, assuming no world price effects, and emission increases in non-subsidizing countries are about 36% of reductions in subsidizing countries. Thus, net world emission reductions are 4.3% if world price effects are incorporated, compared to 9.0% if world price effects are ignored.

The aggregate effect of changes in all three markets would be to reduce emissions in subsidizing countries by 8.7%, assuming unchanged world prices. Accounting for reductions in world prices, and thus increased consumption and emissions in non-subsidizing countries, global emission reductions would be 4.5%. Additional emission reductions in non-sample countries accounting for 15% of global carbon emissions, and emission reductions in sample countries for which data were not available, may lead to total emission reductions of around 9%, given unchanged world prices, and 5% of world emissions, accounting for world price changes.

IV. Welfare costs of fossil fuel subsidies.

In the long-run, removing fossil fuel subsidies will improve welfare, assuming no changes in world prices. If subsidies are removed and world prices do fall, the welfare of fossil fuel exporters may decline. The model used here to estimate welfare effects is limited to changes in the fossil fuel markets and ignores effects from potential changes in the relative prices of other goods. Changes in welfare are first estimated on the assumption of constant world prices. (If only a single "small country" eliminated subsidies, this assumption would be realistic). Welfare effects are then estimated for subsidizing and non-subsidizing countries taking into account the impacts on world prices estimated in the previous section. Welfare calculations are based on consumer and producer surpluses of fossil fuel consumption and production, an approach which assumes full employment of resources, and should therefore be considered a long-run approximation. Demand and supply elasticities are as presented earlier.

Case I. No change in world prices:

Welfare measured as the sum of consumer and producer surplus at subsidized fossil fuel prices (p) is,

$$W_p=\int_0^{q_1}D\delta q-\int_0^{x_1}S\delta x+p_w(x_1-q_1) \tag{9}$$

where D is the inverse demand function, S is the inverse supply function, q_i is domestic consumption at subsidized price p, x_1 is domestic production at price p, and p_w is world price. Welfare at non-subsidized world price (p_w) is,

$$W_{p_w}=\int_0^{q_w}D\delta q-\int_0^{x_w}S\delta x+p_w(x_w-q_w) \tag{10}$$

where q_w is domestic consumption and x_w is domestic production at world price p_w. Thus change in welfare from subsidy removal is,

$$\Delta W=W_{p_w}-W_p=-\int_{q_w}^{q_1}D\delta q+p_w(q_1-q_w)-\int_{x_1}^{x_w}S\delta x+p_w(x_w-x_1)>0 \tag{11}$$

This welfare effect is illustrated in Figure 3 for fossil fuel exporters and importers, with the shaded area (+) representing welfare gain. Approximating ΔW by assuming linear demand and supply functions in the relevant range gives,

$$\Delta W = 0.5(q_1 - q_w)(p_w - p) + 0.5(x_w - x_1)(p_w - p)$$

or

$$\Delta W = 0.5\{(q_1 - q_w)/q_1\}\{(p_w - p)q_1\} + 0.5\{(x_w - x_1)/x_1\}\{(p_w - p)x_1\} \quad (12)$$

where the first factor in the first term is percentage change in consumption from subsidy removal, the second factor in the first term is total subsidies, the first factor in the second term is percentage change in production from subsidy removal. The latter is non-zero if domestic prices are below world prices due either to price ceilings and/or to producer subsidies. We assume that the last term is zero - i.e. that subsidy removal engenders no supply response in a subsidizing country.

Total welfare gains in subsidizing countries from removing fossil fuel subsidies are more than US $33 billion (some 15% of world subsidies). Welfare gains are largest for the former Soviet Union at approximately US$ 29 billion (Table 4), a figure which amounts to 17% of its total subsidies and 88% of world welfare gains. China and Poland follow with the second and third largest welfare gains. Welfare gains by fuel are largest for petroleum products (59% of total) as a result of the enormous petroleum subsidies in the former Soviet Union.

Case II. Change in world prices:

We assume that all subsidizing countries remove subsidies in the same time period. Thus welfare at subsidized prices (p) is as given by equation (9) since there is no change in world prices before subsidy removal. When subsidies are removed world prices fall from p_w to $p_{w'}$ and domestic prices are adjusted to $p_{w'}$. Welfare at non-subsidized prices $p_{w'}$ is,

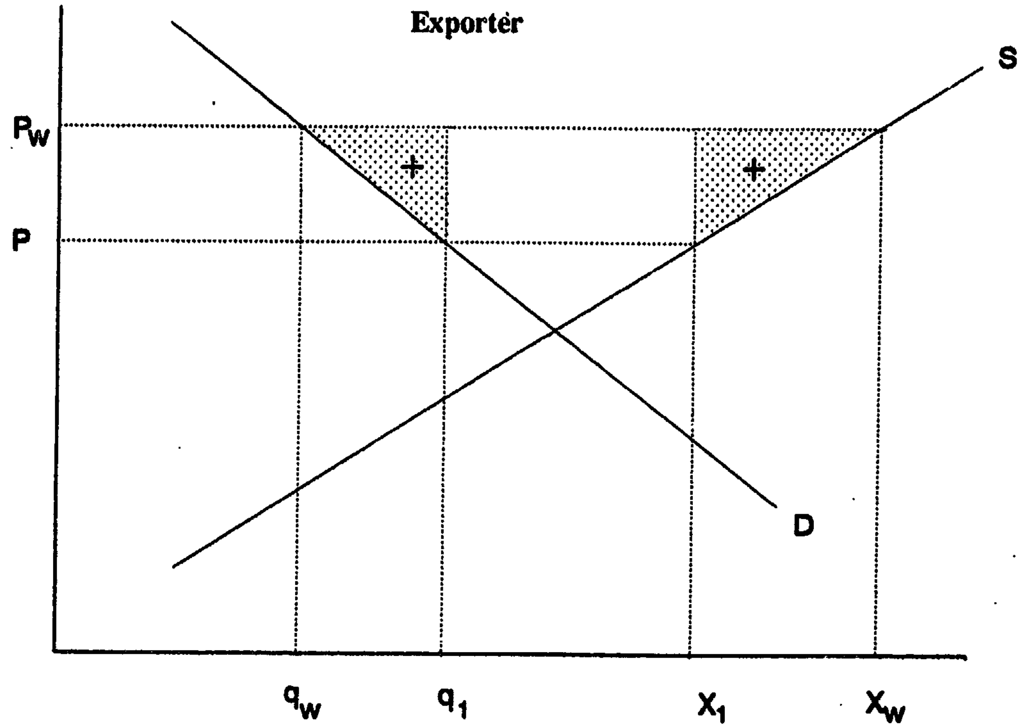
$$W_{p_{w'}} = \int_0^{q_{w'}} D\delta q - \int_0^{x_{w'}} S\delta x + p_{w'}(x_{w'} - q_{w'}) \quad (13)$$

where $q_{w'}$ is domestic consumption and $x_{w'}$ is production at new world prices $p_{w'}$. Change in welfare from subsidy removal is by linear approximation of D and S,

$$\begin{aligned}\Delta W &= W_{pw'} - W_p \\ &= 0.5\{(q_1 - q_{w'})/q_1\}\{(p_{w'} - p)q_1\} + 0.5\{(x_{w'} - x_1)/x_1\}\{(p_{w'} - p)x_1\} + (p_{w'} - p_w)(x_1 - q_1) \quad (14)\end{aligned}$$

Figure 3 **Welfare Gain from Subsidy Removal**

Exporter



Importer

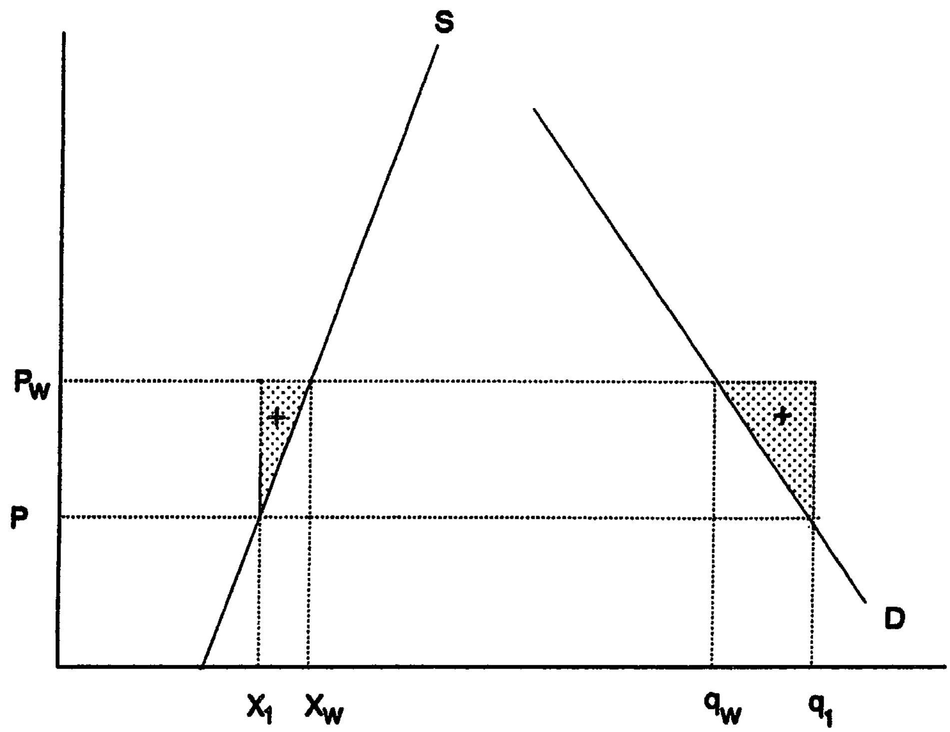


Table 4 Welfare Impacts of Subsidy Removal

	No world price effect:	World price effect:
	Welfare gains	Welfare gains
	(mill US$)	(mill US$)
Former USSR	29302	22195
China	1063	471
Poland	946	891
India	74	206
South Africa	154	6
Czechoslovakia	381	454
Mexico	143	-352
Brazil	201	464
Argentina	132	137
Venezuela	508	-155
Indonesia	194	-223
Saudi Arabia	100	-1446
Egypt	51	-167
Total	33250	22483
Western Europe		7010
United States		3975
Japan		2518

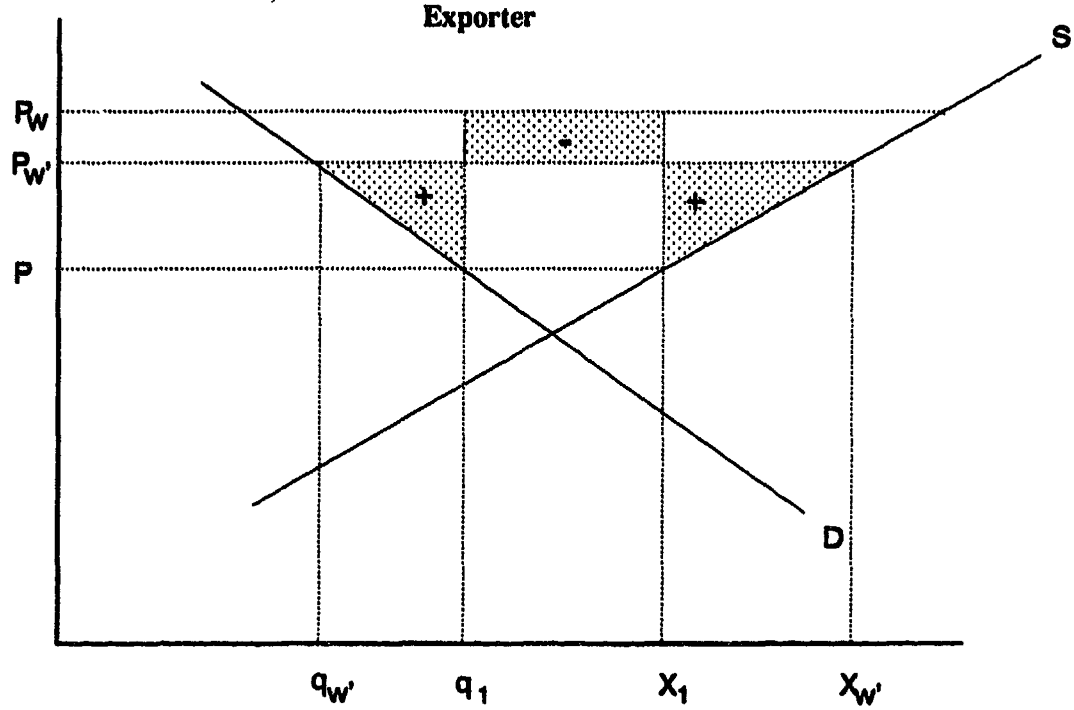
Source: Authors' calculations.

The two first terms are similar to those in case I, but with new world prices and corresponding quantities of consumption and production. The last term represents an exporting country's welfare loss from lower world prices, or an importer's welfare gain from lower prices. Welfare gains (+) and losses (-) are illustrated by shaded area in Figure 4, for both exporters and importers. Welfare gains or losses resulting from the import or export effects of changed world fossil fuel prices are based on border prices for crude oil, natural gas, and coal, and not on end-user prices. If a country produces no fossil fuels, then the second term is zero and $q_1 = 0$.

In this case, welfare gains for the former Soviet Union are reduced to US$22 billion, but are increased for fossil fuel importers such as India, Brazil, and Czechoslovakia. Exporters such as Saudi Arabia, Mexico, Indonesia, Venezuela, and Egypt experience a net welfare loss due to lower export prices. Note, however, that because the fall in world prices is not induced by the subsidy removal in any

Figure 4 Welfare Effect of Subsidy Removal

Exporter



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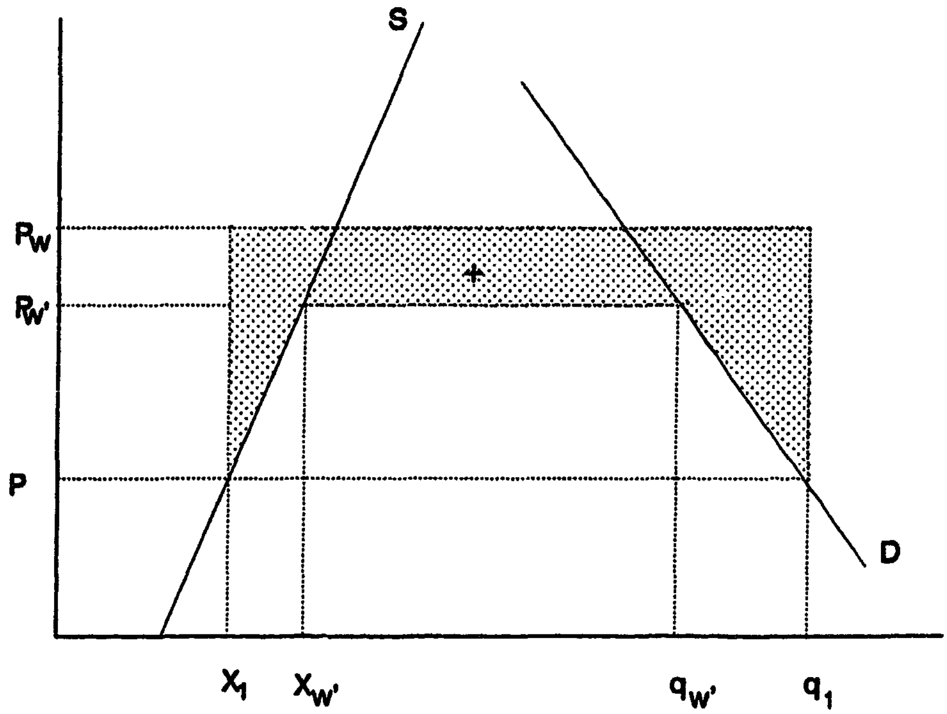

one of these countries alone, welfare losses would be even larger if subsidies were not removed.

Reduced world prices for fossil fuels do not leave welfare in non-subsidizing countries unaffected. Welfare change by linear approximation of D and S is,

$$\Delta W = W_{pw'} - W_{pw} = 0.5(q_{w'} - q_w)(p_w - p_{w'}) + 0.5(x_w - x_{w'})(p_w - p_{w'}) + (p_{w'} - p_w)(x_w - q_w) \quad (15)$$

or

$$\Delta W = W_{pw'} - W_{pw} = 0.5e_D(\partial p_w/p_w)^2 q_w p_w + 0.5e_S(\partial p_w/p_w)^2 x_w p_w + (p_{w'} - p_w)(x_w - q_w) \quad (16)$$

where e's are the absolute values of demand and supply elasticities. Since they all are net importers of fossil fuels, Western Europe, the United States, and Japan would see their welfare increase by more than US$13 billion.

These calculations assume full employment of resources. In fact, subsidy removal may have significant short-run adjustment costs. It may not therefore be politically acceptable over a short time horizon unless some external inducement for subsidy removal is provided to subsidizing countries. This issue is considered in the next section.

V. Potential foreign inducement for removal of subsidies:

Suppose OECD countries decide to reduce carbon emissions from fossil fuel consumption by some percentage below current levels. This may be achieved in several ways, one of which is to impose a carbon tax in the OECD countries. An alternative is to achieve equivalent reductions by paying countries that subsidize fossil fuels to remove such subsidies. While removing such subsidies would improve welfare in the long-run, there might be short run adjustment costs and distributional consequences; without compensation subsidy removal is unlikely to politically acceptable. It is, therefore, of some interest to determine: first, the level of OECD carbon taxes needed to achieve emission reductions equivalent to those achieved by subsidy removal; and second, OECD willingness to "buy" equivalent reductions from subsidizing countries.

Estimated carbon emission reductions from subsidy removal are lowered if world price constancy is not assumed. Similarly, if OECD countries unilaterally reduce carbon emissions we may expect emission increases in non-OECD countries in response to reduced world prices. Furthermore, the effect on carbon emissions per dollar of carbon tax in any one OECD country will be decreased if such a tax is also imposed in *all* OECD countries, since world prices may fall. The net global effect of an

OECD carbon tax on carbon emissions from fuel use is,

$$\partial q = \{e^S / (e^S + e_1^D[q_1/q] + e_2^D[q_2/q])\}\partial a^D \tag{18}$$

derived from (4) and (5), with

$$\partial a^D = \partial q_2 = (1 - (p/p_t)^\epsilon)q_2 \tag{19}$$

where p and p_t are weighted average fossil fuel prices in OECD countries before and after carbon tax respectively, and ϵ is price elasticity of demand (e_2^D) as in equation (3). Table 5 presents a range of three cases in which price elasticity of fossil fuel demand in OECD countries varies from 0.6, through 0.8, to 1.0; supply elasticities for all countries and demand elasticities for all non-OECD countries are the same as in section III. Using equation (8), and thus accounting for world price effects, world emission reductions from subsidy removal are estimated for each of the demand elasticities of non-subsidizing (primarily OECD) countries. Next, a carbon tax is estimated that provides a value for p/p_t in (19) such that the value of ∂q in (18) is equal to world emission reductions resulting from subsidy removal. A range for ∂q is presented in Table 5. The lower bound assumes a demand effect in non-OECD countries from lower world prices, which would be the case if lower world prices were to translate into lower end-user prices. The upper bound assumes no demand effect in non-OECD countries, which would be the case if prices were fixed in subsidizing countries: lower world prices would not translate via the market to lower end-user prices, and there would be no demand effect in those countries. To achieve as substantial a reduction in emissions worldwide as subsidy removal, a carbon tax would need to be in the range of US $50-$90 (see Table 5). Total emission reductions in OECD countries are about 20% assuming no world price effects. Nordhaus (1991), using a survey of cost estimates of carbon reductions in several countries and regions, derives a marginal cost curve according to which a US $60 carbon tax would reduce emissions by 20%. A demand elasticity of 0.8 is therefore quite consistent with Nordhaus' marginal cost curve.

Estimations presented in Table 5 suggest that a substantial carbon tax is necessary to reduce emissions by the same amount as subsidy removal. But, subsidy removal may not be politically acceptable in the short run without some form of external compensation for adjustment costs. OECD countries might therefore consider such compensation a lower cost strategy for reducing emissions than the relatively high carbon tax estimated in this section.

Table 5 Carbon Tax in OECD Countries

	Case 1	Case 2	Case 3
Elasticity of demand in OECD	0.6	0.8	1.0
World emission reduction from subsidy removal	5.5%	5.0%	4.5%
OECD Carbon tax (US$/ton) for equivalent world emission reduction accounting for world price effect	90	65	50
World emission reductions from OECD carbon tax accounting for world price effect	4.4-5.6%	4.2-5.2%	3.9-4.7%
OECD reductions assuming no world price effects	19%	20%	20%

Source: Authors' estimations.

VI. Summary and conclusions

Substantial fossil fuel subsidies prevail in a handful of large carbon emitting countries. Total world subsidies are estimated to be in excess of US $230 billion, or 20-25% of the value of world fossil fuel consumption at world prices. Removing such subsidies would substantially reduce national carbon emissions in some countries and reduce global carbon emissions by 9%, assuming no change in world prices, and by 5%, accounting for changes in world prices. Welfare gains from subsidy removal worldwide would be more than US $33 billion assuming no change in world prices, or 15% of total subsidies, even ignoring the benefits from curtailment of greenhouse gases emissions and abatement of local pollution. Welfare gains when accounting for world price changes would still be some US $22 billion in subsidizing countries. Net fossil fuel importers in Western Europe, United States and Japan would experience a welfare gain of approximately US $14 billion in the event of subsidy removal dampening world energy prices. Equivalent reductions in carbon emissions could be achieved by an OECD carbon tax on the order of US $50-90 per ton. It should be noted that neither the subsidy removal nor an equivalent carbon tax would be sufficient to stabilize global carbon emissions at 1990 levels. To

achieve that objective, stronger economic policy responses would be required.

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APPENDIX A

ALTERNATIVE ENERGY EFFICIENCY SCENARIOS AND REDUCTIONS IN CARBON EMISSIONS

It is instructive to note the potential for reductions in global carbon emissions under three alternative standards of energy efficiency: the Japanese, the German, and the American standards. Table A presents statistics on carbon emissions per dollar of GDP or PENN GDP.[8] Note that the rankings of the three countries remain unchanged under the different measures of GDP, but the U.S. fairs poorly compared to the world average in terms of energy efficiency on account of the GDP measure adjusted for purchasing power parity. If the world were to adopt Japanese or German standards of energy efficiency, remarkably large reductions in global carbon emissions could be achieved.

However, given the significance of the composition of fossil fuel use, a note of caution is in order. For example, if Japan, the USA and Germany are below the world average in terms of (i) the ratio of coal emissions to total emissions, and (ii) the ratio of petroleum emissions to total emissions, global carbon emission reductions will not be as high as stated in Table A. This is because coal and petroleum products have a higher carbon content per unit of energy than natural gas. This concern may not be relevant in the case of West Germany and the USA because their fossil fuel composition is about the same as the world average. However, in the case of Japan, which has a lower coal use than the world average, the potential for emission reductions is to some extent overstated. It is also worth noting that to achieve German or Japanese standards of energy efficiency, developing countries would have to raise the relative prices of fossil fuels to similar levels - possibly through energy or carbon taxation. Such a change in relative prices would have to be carefully evaluated on a country by country basis.

[8]PENN GDP is GDP adjusted to purchasing power parity (Summers and Heston 1991).

Table A

Global Carbon Emission Reductions from Fossil Fuel Combustion
Under Alternate Energy Efficiency Scenarios
1987

	Carbon Efficiency:	
	CO_2/GDP * (kg/US$)	CO_2/Penn GDP ** (Kg/US$)
Japan	0.10	0.16
West Germany	0.16	0.17
United States	0.28	0.28
World (weighted average)	0.31	0.27

	Global carbon emission reductions if all countries in the world had carbon emissions per dollar of GDP similar to:		
	Japan	West Germany	United States
Under UN National Accounts GDP	68%	48%	10%
Under PENN (PPP adjusted) GDP	41%	37%	0.4% ***

Notes:

* UN National Accounts GDP
** UN National Accounts GDP adjusted for Purchasing Power Parity
*** Increase

Source: Authors' Calculations

APPENDIX B

DATA SOURCES AND STATISTICAL TABLES

<u>Data sources:</u>

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Table A1. Carbon Emission Reductions from Removing Subsidies on Fossil Fuels The Case of Coal

	domestic consumption 1987 million metric tons	domestic price to border price	own price elasticity	No world price effect: emission reductions (000 mt)	No world price effect: emission reductions to total emissions	World price effect: emission increase from fall in world price	World price effect: net emission reductions (000 mt)	emission reductions to total emissions
China	1112	0.84 (1989)*	0.60	47577	10%	21638	25939	5%
Former USSR	884	0.10 (1992)	0.15	108440	29%	3296	105144	28%
Poland	281	0.30 (1990)	0.20	23240	21%	1427	21813	20%
India	232	0.86 (1991)*	0.60	9387	9%	4971	4416	4%
Germany, East				n.a.	n.a.			
South Africa	161	0.50 (1991)	0.25	10596	16%	1170	9426	14%
Czechoslovakia	150	0.30 (1990)	0.20	9887	21%	607	9280	20%
North Korea	66	n.a.		n.a.	n.a.			
Total	2886			209127		33110	176017	
Non-subsidizers	2699		0.8			75755	-75755	
World	5585			209127		108865	100262	
Reductions as % of world emissions				9.0%			4.3%	

Source: Authors' calculations.

Table A2. Carbon Emission Reductions from Removing Subsidies on Fossil Fuels: The Case of Natural Gas

				No regional price effect:		Regional price effect:		
	domestic consumption 1987 (billion cu m)	domestic price to border price	own price elasticity	emission reductions (000 mt)	emission reductions to total emissions	emission increase from fall in regional price	net emission reductions (000 mt)	emission reductions to total emissions
Former USSR	636	0.07 (1992)	0.15	99470	33%	7253	92217	30%
Romania	39	n.a.		n.a.	n.a.			
Mexico	24	n.a.		n.a.	n.a.			
Saudi Arabia	26	n.a.		n.a.	n.a.			
Venezuela	18	n.a.		n.a.	n.a.			
Argentina	17	0.50 (1989)	0.25	1591	16		1591	16%
Algeria	17							
Iran	15	n.a.		n.a.	n.a.			
China	14	0.40 (1986)	0.20	1222	17%		1222	17%
United Arab Emirates	14							
Poland	13	0.50 (1990)	0.25	875	16%	276	600	11%
Total	833			103158		7528	95630	
Non-subsidizers	317		0.8			28917	-28917	
World	1867			103158		36446	66713	
Reductions as % of world emissions				11.6%			7.5%	

Source: Authors' calculations.

Table A3. Carbon Emission Reductions from Removing Subsidies on Fossil Fuels: The Case of Petroleum Products (subsidized products only)

				No world price effect:		World price effect:		
	domestic consumption 1987 (million tons)	domestic price to border price	own price elasticity	emission reductions (000 mt)	emission reductions to total emissions	emission increase from fall in world price	net emission reductions (000 mt)	emission reductions to total emissions
Former USSR	448	0.05 (1992)	0.15	122778	36%	2077	120701	35%
China	103	0.48 (1985)	0.25	14015	17%	1113	12902	15%
Mexico	76	0.54 (1990)	0.25	5538	10%	838	4701	8%
Brazil	63	0.53 (1990)	0.25	4160	11%	546	3613	9%
India	49	0.47 (1990)	0.25	1391	4%	517	874	2%
Saudi Arabia	44	0.60 (1990)	0.30	2910	9%	558	2351	7%
Iran	43	n.a.		n.a.	n.a.			
Indonesia	25	0.51 (1990)	0.25	3189	15%	278	2911	14%
Argentina	24	0.48 (1990)	0.25	2137	13%	238	1900	11%
Egypt	22	0.50 (1992)	0.25	2032	13%	223	1809	11%
Romania	17	n.a.		n.a.	n.a.			
Germany, East	17	n.a.		n.a.	n.a.			
Czechoslovakia	16	0.22 (1990)	0.20	461	4%	155	306	2%
Venezuela	20	0.18 (1990)	0.20	3621	29%	113	3508	28%
Bulgaria	14	n.a.		n.a.	n.a.			
Poland	17	0.68 (1990)	0.35	996	9%	237	759	6%
Total	998			163229		6894	156335	
Non-subsidizers	2142		0.8			81341		
World	3140			163229		88236	74994	
Reductions as % of world emissions				7.1%			3.27%	

Source: Authors' calculations.

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