WPS 1256

POLICY RESEARCH WORKING PAPER 1256

World Fossil Fuel Subsidies and Global Carbon Emissions in a Model with Interfuel Substitution

World subsidies of fossil fuels are estimated at more than $210 billion. Removing such subsidies would reduce global carbon emissions by 7 percent.

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February 1994

Summary findings

Larsen presents a simple empirical framework for estimating the level of world fossil fuel subsidies and analyzing their implications for carbon dioxide emissions. Larsen extends Larsen and Shah (1992) by applying a simple model with interfuel substitution, using a more detailed sectoral data set that includes energy prices and consumption for an expanded sample of countries.

Larsen concludes that substantial fossil fuel subsidies prevail in a handful of large carbon-emitting countries. The fiscal implications for some countries are significant — as much as 10 percent of GDP in some countries.

World subsidies are estimated to be more than $210 billion, or 20 to 25 percent of the value of world fossil fuel consumption at world prices.

Removing such subsidies, Larsen estimates, would reduce national carbon emissions by more than 20 percent relative to baseline emissions in some countries. It would reduce global carbon emissions by 7 percent.

This paper — a product of the Public Economics Division, Policy Research Department — is an extension of Policy Research Working Paper 1002, "World Fossil Fuel Subsidies and Global Carbon Emissions," by Bjorn Larsen and Anwar Shah October 1992. Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433 Please contact Carlina Jones, room N10-063, extension 37699 (24 pages). February 1994.

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by
Bjorn Larsen

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*This paper is an extension of Larsen and Shah (1992c), "World Fossil Fuel Subsidies and Global Carbon Emissions," Policy Research Working Paper Series No. 1002, the World Bank, Washington, D.C., and explores ideas suggested by Lawrence H. Summers and Andrew Steer. The paper was supervised by Anwar Shah, Principal Economist, PRDPE, World Bank, and financed by a grant from the World Bank Research Committee, RPO 677-28. It has benefitted from discussions with Ramon Lopez and Gordon Hughes, comments by Anthony A. Churchill, Mahan Monasinghe and Robert P. Taylor, and able research assistance from Isidro Soloaga.

WORLD FOSSIL FUEL SUBSIDIES AND GLOBAL CARBON EMISSIONS IN A MODEL WITH INTERFUEL SUBSTITUTION

I. Introduction: The last few years have witnessed a dramatic growth in worldwide concern over global climate change. Increases in atmospheric temperatures are expected to take place as a result of accumulation of so called greenhouse gases. The magnitude of temperature increases and the environmental and economic costs are still highly uncertain and are likely to differ substantially across regions. The main greenhouse gases are carbon dioxide (CO2), methane, CFCs and nitrogen oxides, of which carbon dioxide accounts for as much as 80 percent of the total warming potential on a global scale when adjusting the instantaneous warming potential by the atmospheric lifetime of the gases (Nordhaus 1991)[1].

Most OECD countries have already committed to stabilize CO2 emissions at 1990 levels by year 2000, and some western European countries to further reduce emissions 20% by year 2005[2]. Non-OECD countries are reluctant to reduce emissions on global environmental

[1]The instantaneous warming potential of a gas is defined as the increase in atmospheric concentration of a gas times the instantaneous or current radiative impact of that gas. The total warming potential of a gas is the sum of the instantaneous warming potential over each time period for the life time of the gas. For instance, in terms of instantaneous warming potential, carbon dioxide accounts for about 53% and methane for 17%. But in terms of total warming potential, they account for 80% and 2% respectively because of significantly longer life of carbon dioxide in the atmosphere.

[2]The Framework Convention on Climate Change, signed at the "Earth Summit" in Rio de Janeiro last summer, aims at stabilizing atmospheric concentrations of greenhouse gases in the long term, which would require a reduction in annual global emissions of approximately 50% below current emissions. A shorter term target is a return to 1990 annual emissions levels by year 2000 in industrial countries, while no binding constraints are imposed on developing countries. Although few time specific targets are included in the treaty, mechanisms for deciding on stronger measures in the future, if warranted, were set up (see Steer (1992) for a brief report on the conference in Rio).

considerations because of more urgent development objectives and the fact that the current stock of atmosph nissions is primarily a "responsibility" of the OECD countries[3]. Nevertheless, non-OECDs, and particularly the states of the former Soviet Union and eastern Europe, may achieve substantial reductions relative to "business as usual" over the next 10 to 20 years by policies that make economic and local environmental sense. Such policies include removal of substantial subsidies on fossil fuels and fossil fuel generated electricity, removal of non-price barriers to energy efficiency, a "moderate" tax on fossil fuels based on local environmental considerations, and a reorientation of the fiscal tax structure to reduce disincentives to invest in productive capital and increase incentives to reduce use of inputs and production factors that pollute locally and globally (see Larsen and Shah 1992a, 1992c and Shah and Larsen 1992a, 1992b).

The removal of fossil fuel subsidies has been advocated as the first order of priority in instituting economic policies to protect local and global environments (see Summers, 1991, Churchill and Saunders, 1991, Larsen and Shah, 1992a, 1992b, 1992c and Shah and Larsen, 1992a, 1992b). Elimination of fossil fuel subsidies can be a politically sensitive issue, in particular when prices are only a small fraction of world prices. But many developing countries do price fossil fuel at or above world prices, suggesting that fossil fuel pricing reforms can be done if introduced gradually. In this context, it would be helpful to quantify the magnitude of existing subsidies and potential environmental benefits associated with the elimination of such subsidies. A number of recent studies have reflected upon various aspects of this question. For

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[3]For instance, contribution to atmospheric CO2 concentration increases (1800-1988) from fossil fuel combustion by OECD countries is 65% of world total, while current annual emissions (1988) are "only" 45% (Grubler and Nakicenovic 1992).

example, 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. Burgess (1990) evaluates potential carbon dioxide emission reductions from efficient electricity pricing in a sample of countries including the United States, China and India. Larsen and Shah (1992c) present an estimate of world fossil fuel subsidies and the impact of subsidy removal on global carbon dioxide emissions, but ignore interfuel substitution. This paper attempts to account for interfuel substitution from subsidy removal using a more detailed data set, in most cases from end of 1991, on fuel prices covering a larger country sample.

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 national and global carbon emissions. Estimates of carbon emission reductions are presented in section IV. Section V presents a summary and conclusions.

II. Existing fossil fuel pricing regimes and world subsidies: Getting fossil fuel prices right would prima facie represent first order of priority in any economic policy response to curtail greenhouse gas emissions. This section explores this potential by analyzing fossil fuel pricing practices around the world. It is interesting to note that while a complete inventory of fossil fuel subsidies in the world is a formidable task and beyond the scope of current work, yet it is possible to reach reasonable estimate of the overall level of subsidies by studying only a few countries. For example, 90% of the world coal is consumed by 15 countries; almost 80% of world petroleum products by 28 countries and almost 90% of the world natural gas by 18 countries (Table 1). These few countries emit a total of 85% of global carbon from fossil fuels,

TABLE 1 CARBON DIOXIDE EMISSIONS FROM FOSSIL FUEL COMBUSTION

CO_2 emissions from petroleum products (1989)

	000 tons	% of world emissions	cummulative %
1 UNITED STATES	2075685	23.42%	23.42%
2 USSR	1237842	13.97%	37.39%
3 JAPAN	603157	6.81%	44.19%
4 CHINA	292699	3.30%	47.49%
5 Germany, West	247478	2.79%	50.28%
6 ITALY	241938	2.73%	53.01%
7 MEXICO	234624	2.65%	55.66%
8 FRANCE	214813	2.42%	58.09%
9 CANADA	209383	2.36%	60.45%
10 UNITED KINGDOM	201560	2.27%	62.72%
11 BRAZIL	146816	1.66%	64.38%
12 INDIA	143929	1.62%	66.00%
13 SAUDI ARABIA	110261	1.24%	67.25%
14 IRAN	110191	1.24%	68.49%
15 SPAIN	107231	1.21%	69.70%
16 South KOREA	103468	1.17%	70.87%
17 AUSTRALIA	81748	0.92%	71.79%
18 INDONESIA	81722	0.92%	72.71%
19 ARGENTINA	62834	0.71%	73.42%
20 EGYPT, ARAB REP	59349	0.67%	74.09%
21 TURKEY	58118	0.66%	74.75%
22 ROMANIA	52439	0.59%	75.34%
23 IRAQ	50794	0.57%	75.91%
24 THAILAND	50604	0.57%	76.48%
25 Germany, East	47000	0.53%	77.01%
26 VENEZUELA	46042	0.52%	77.53%
27 CZECHOSLOVAKIA	44979	0.51%	78.04%
28 POLAND	43939	0.50%	78.53%
WORLD	8863216		

CO_2 emissions from coal (1989)

	000 tons	% of world emissions	cummulative %
1 CHINA	1964032	22.41%	22.41%
2 UNITED STATES	1826149	20.84%	43.25%
3 USSR	1328885	15.16%	58.41%
4 INDIA	461803	5.27%	63.68%
5 POLAND	370005	4.22%	67.90%
6 JAPAN	303995	3.47%	71.37%
7 Germany, West	283623	3.24%	74.60%
8 Germany, East	[illegible]65000	3.02%	77.63%
9 UNITED KINGDOM	251277	2.87%	80.49%
10 SOUTH AFRICA	239362	2.73%	83.23%
11 CZECHOSLOVAKIA	156138	1.78%	85.01%
12 AUSTRALIA	141932	1.62%	86.63%
13 North KOREA	136946	1.56%	88.19%
14 CANADA	107352	1.22%	89.41%
15 South KOREA	97037	1.11%	90.52%
WORLD	8764288		

CO_2 emissions from natural gas (1989)

	000 tons	% of world emissions	cummulative %
1 USSR	1129996	32.60%	32.60%
2 UNITED STATES	924735	26.68%	59.28%
3 CANADA	128130	3.70%	62.90%
4 UNITED KINGDOM	104710	3.02%	66.00%
5 Germany, West	96568	2.79%	68.78%
6 JAPAN	92816	2.68%	71.46%
7 ITALY	76926	2.22%	73.68%
8 ROMANIA	66165	1.91%	75.59%
9 NETHERLANDS	64105	1.85%	77.44%
10 FRANCE	55964	1.61%	79.05%
11 SAUDI ARABIA	51270	1.48%	80.53%
12 MEXICO	49255	1.42%	81.95%
13 ARGENTINA	42050	1.24%	83.19%
14 IRAN	42590	1.23%	84.42%
15 VENEZUELA	38945	1.12%	[illegible].54%
16 UNIT. ARAB EMIR	31210	0.90%	[illegible]5.44%
17 AUSTRALIA	30558	0.88%	87.32%
18 CHINA	28317	0.83%	88.16%
WORLD	3466144		

Source: World Resources Institute (1992) of which roughly a half of the coal and natural gas consumers and a third of the petroleum product consumers are OECD countries with relatively insignificant subsidies[4]. We define subsidies on fossil fuels as the difference between domestic fossil fuel prices and their (private) opportunity cost evaluated at end-user prices. When fuels are traded internationally border prices serve as opportunity cost, which is the case for petroleum products for all sample countries. Opportunity cost at end-user level would be 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 to some extent vary across countries. 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 there exist export markets as for the former Soviet Union in the case of natural gas and to a lesser extent coal[5]. In the case of China, an approximation to the opportunity cost of coal is the unit price for the proportion of coal traded in the free domestic market. In the remainder of the paper opportunity cost is referred to as world price for sake of convenience. Official exchange rates reported in IMF's International Financial Statistics have been used to convert domestic prices into dollars. Implicit subsidies stemming from overvalued exchange rates are ignored and subsidies are thus underestimated relative to an

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[4]The Environment Directorate (OECD) is currently undertaking a study on producer and consumer subsidies and other "supports" to the energy sector. There are significant producer coal subsidies in Germany, but end-user prices of coal in Germany are well above border prices due to import restrictions on coal.

[5]It is recognized that border prices plus distribution costs as defined here are not likely to be equivalent to the opportunity cost of energy, but are used in the estimations of subsidies because data on marginal cost of energy and domestic distribution cost are rather scarce. Given that the United States have the lowest pre-tax energy prices of the OECD countries, subsidies as calculated are likely understated rather than overstated.

equilibrium exchange rate. Implicit subsidies are for some countries larger than the subsidies estimated by applying the official exchange rates, and estimated carbon emission reductions may in these cases be significantly understated. Total subsidies S_k for country k evaluated at the official exchange rate is:

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

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[6]. Total subsidies is thus the price differential multplied by quantity consumed at subsidized prices. Price elasticity of demand need not be applied to calculate subsidies. This is apparent from the definition of efficiency cost of subsidies, defined as the difference between increase in consumer surplus and total subsidies. If total subsidies were to be calculated based on consumption at non-subsidized prices, total subsidies would be less than increase in consumer surplus and welfare thus higher with a subsidy.

Total subsidies by fuel and country are presented in Table 2 for 1991. It is important to note that some countries, such as China and Indonesia have increased their energy prices significantly since 1991. Other countries, in particular the states of the former Soviet Union, are attempting to increase prices to international levels but with less success because of high levels of inflation. The former Soviet Union accounted (and still accounts) for more than two-

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

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

	Coal	Gas	Petroleum	Total	Total/ GDP
Former USSR	17000	63000	65000	145000	10-13%[1]
China	3300		4600	7900	1.8%
Poland	6600	130		6730	10.0%
Czechoslovakia	2100	460	380	2940	6.0%
Brazil		50	900	950	0.2%
Venezuela		1750	3600	5350	10.6%
Mexico	90	600	1550	2150	1.0%
India	2550		4250	6800	2.3%
Indonesia			5100	5100	5.0%
Saudi Arabia			5000	5000	4.8%
South Korea	1650		1100	2750	1.2%
South Africa	1550			1550	
Egypt		350	3000	3350	10.7%
Iran		2300	9100	11400	8.0%
Romania	600	800		1400	3.7%
Bulgaria	750		450	1200	6.0%
Total	36190	69440	104030	209660	

Source: Author's calculations.

[1]Assuming per capita income in the range of US $4000-5000.

thirds of the total world subsidies, about US $145 billion. This is not unexpected given the low domestic prices relative to world prices, and the fact that the former Soviet Union consumes approximately 20% of world fossil fuel consumption. Iran follows with the second highest level of energy subsidies, about US $11 billion (in 1993). These subsidies are estimated based on an exchange rate after recent substantial devaluations that were brought about to correct for a significantly overvalued currency. China follows with the third highest level of subsidies of about US $8 billion, although diminishing. Subsidies in China are difficult to estimate because of a multiple pricing system. Coal subsidies in China were significantly higher a few years ago (Bates and Moore 1992) before the two-tier pricing system was introduced that permits a large proportion of coal to be traded at market prices. Subsidies on petroleum products, in total US dollars, were still significant in 1991. Prices of gasoline and diesel to the transport sector have for several years been above world prices, but diesel is subsidized to agriculture and fuel oils in particular to the industrial sector. However, both coal and petroleum product subsidies in China are rapidly being reduced and our estimate of US $8 billion in subsidies could well be significantly lower at this time in 1993. After China follows India, Poland, Venezuela, Indonesia and Saudi Arabia[7] with subsidies in the range of US $5-7 billion, although Indonesia has by now significantly reduced subsidies.

In terms of subsidies by fuel for the world as a whole, petroleum products are heaviest

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[7]In the case of Saudi Arabia, one may argue that the opportunity cost of domestically consumed petroleum products is not world prices if annual exports are constrained (OPEC) and if exports at world prices contain a large rent element. On the other hand, selling petroleum products at lower than world prices may still be considered a subsidy because domestically consumed petroleum products could alternatively be exported at world prices in the future. Thus there are intertemporal inefficiencies unless world prices are to decline significantly in the future.

subsidized accounting for more than 50% of total subsidies, followed by natural gas (33%) and coal (17%). Among petroleum products fuel oils receive the largest subsidies in dollar value. Gasoline is often taxed even in countries with substantial subsidies on other petroleum products. The largest coal subsidizers are the former Soviet Union, Poland, China, India, Czechoslovakia, South Korea and South Africa (Table 3). More than one half of total coal subsidies are to coal to the power sector. The largest natural gas subsidizers are the former Soviet Union, Iran and Venezuela (Table 4). The largest petroleum product subsidizers are the former Soviet Union, Iran, Indonesia, Saudi Arabia, China, India, Venezuela and Egypt (Table 5). All petroleum products (i.e. gasoline, kerosene, diesel, heavy and light fuel oils) are subsidized in the former Soviet Union, Indonesia (not gasoline in 1993), Venezuela, Saudi Arabia, Iran and Egypt, while gasoline prices are siginificantly above world prices in India, Czechoslovakia, Brazil and South Korea. About 60% of petroleum product subsidies in India, about 35% in Indonesia and 33% in Egypt are to kerosene. In total, world fossil fuel subsidies are about US $210 billion, and possibly US $10 billion more from the countries for which no data were obtained. This leaves us with subsidies in the range of US $210-220 billion, which corresponds to 20-25% of the value of world fossil fuel consumption at current world prices. Such large fossil fuel subsidies have significant fiscal implications in many of the larger subsidizing countries and are thus important in a macroeconomic context. Fossil fuel subsidies are higher than 10% of GDP in the former Soviet Union, Egypt, Venezuela and Poland, while "only" 2.3% and 1.8% of GDP in India and China respectively (Table 2).

Estimates of total world subsidies are 5-10% lower than estimated in Larsen and Shah (1992c). This is primarily because estimated subsidies in the former Soviet Union are 15%

Table 3. Subsidies to Coal (billion US $)

Sectors:	Power	Industry	Trans	Agr	Comm	Res	Total	P^d/P^w [1]
Former USSR	6.0	4.0	0.2	0.4	6.4[2]		17.0	0.45
China	0.7	1.6	0.1	0.1		0.8	3.3	0.82
Poland	5.0	1.3	0.1	0.1		0.1	6.6	0.34
Czechoslovakia	1.0	0.3				0.8	2.1	0.25
India	1.9	0.5				0.15	2.55	0.62
South Korea						1.65	1.65	0.40[3]
South Africa	0.9	0.4			0.1	0.15	1.55	0.48
Romania	0.25	0.15				0.2	0.6	0.79
Bulgaria	0.5	0.1				0.15	0.75	0.45
Total	16.25	8.35	0.4	0.6			36.1	

Source: Author's calculations.

1/Ratio of weighted average domestic prices to world prices.

2/Commercial and residential.

3/Residential sector.

Table 4. Subsidies to Natural Gas (billion US $)

Sectors:	Power	Industry	Trans	Agr	Comm	Res	Total	P^d/P^w [1]
Former USSR	20.0	21.0	1.0	1.0	7.0	13.0	63.0	0.12
Czechoslovakia					0.35	0.11	0.46	0.85
Venezuela	0.4	1.0				0.35	1.75	0.15
Mexico		0.3				0.3	0.6	0.85
Egypt	0.35						0.35	0.48
Iran	0.7	0.6				1.0	2.3	0.05
Romania	0.2	0.2				0.4	0.8	0.84
Total	21.65	23.1	1.0	1.0	7.35	15.16	69.26	

Source: Author's calculations.

1/Ratio of weighted average domestic prices to world prices.

Table 5. Subsidies to Petroleum Products (billion US $)[1]

	Gasoline	Kerosene	Diesel	HFO*	LFO*	Total
Former USSR	19.0 (0.54)	1.0 (0.40)	30.0 (0.30)	5.0 (0.68)	10.0 (0.23)	65.0
China			1.5** (0.70)	0.6 (0.70)	2.5 (0.79)	4.6
Czechoslovakia	(2.34)		(1.88)	(1.05)	0.38 (0.74)	0.38
Brazil	(1.95)	0.1 (0.74)	0.4 (0.94)	(1.41)	0.4 (0.71)	0.9
Venezuela	2.3 (0.25)	0.2 (0.47)	0.6 (0.18)	0.1 (0.55)	0.4 (0.19)	3.6
Mexico	(1.06)	0.2 (0.72)	0.85 (0.71)	0.4 (0.84)	0.1 (0.75)	1.55
India	(2.09)	2.55 (0.33)	1.3 (0.79)	(1.60)	0.4 (0.61)	4.25
Indonesia	0.6 (0.65)	1.8 (0.28)	1.3 (0.39)	(1.00)	1.4 (0.36)	5.1
Saudi Arabia	1.1 (0.65)	0.1 (0.22)	0.8 (0.13)	0.5 (0.47)	2.5 (0.12)	5.0
South Korea	(1.84)	0.3 (0.74)	0.3 (0.83)	(1.05)	0.5 (0.68)	1.1
Egypt	0.6 (0.34)	1.0 (0.05)	0.2 (0.05)	0.1 (0.95)	1.1 (0.40)	3.0
Iran	1.7 (0.29)		3.8 (0.05)	1.5 (0.07)	2.1 (0.04)	9.1
Bugaria	(1.29)	0.15 (0.60)	0.1 (0.90)	(1.80)	0.2 (0.75)	0.45
Total	25.3	7.4	41.2	8.3	22.0	104.1

Source: Author's calculations.
* Heavy Fuel Oils and Light Fuel Oils respectively.
** Primarily to agriculture (no diesel subsidies to transport).

1/Figures in parentheses are ratio of domestic prices to world prices.

lower than previously estimated. The main reason is that exchange rate and price data used in this paper on the former Soviet Union is from 1989, rather than 1992, to avoid the problem of high inflation and associated exchange rate uncertainty in recent years. In any case total subsidies in the former Soviet Union are in the range of US $145-172 billion. Estimates of total subsidies are for some countries significantly different than estimated in Larsen and Shah (1992c) primarily due to exchange rate fluctuations, domestic price changes and a more detailed data set used in this paper. Estimates in this study of subsidies on petroleum products in Brazil and Mexico and on coal in Czechoslovakia are significantly lower than the previous estimate. Subsidies in Argentina are now virtually non-existent due to the recent introduction of a new currency. Subsidies on petroleum products are estimated to be significantly higher in Indonesia, Saudi Arabia and Egypt, and on coal and petroleum products in India relative to the previous estimates. Estimates for China, Poland and South Africa are almost identical to previous estimates. Finally, estimates for South Korea, Iran, Romania and Bulgaria are included in this study.

III. Empirical framework:

The approach taken here is in partial equilibrium assuming factor prices, other than energy prices, and level of aggregate output in the economy are constant. This may be an acceptable approximation for small changes in energy prices. For large changes in energy prices however, as is evaluated in this paper, a country specific general equilibrium analysis is of course preferable but beyond the scope of this study given that the analysis extends to 16 countries. At best, estimated emission reductions from fossil fuel subsidy elimination alert to the priority subsidy elimination should take in any strategy to reduce national and global greenhouse gases.

The quantity of energy demanded is considered derived demand, i.e., energy is an input in the production of goods and services. We assume there exists a twice differentiable aggregate production function,

$$Q = f(K, L, E, M, t) \qquad (1)$$

where Q is gross output, K is capital stock, L is labor input, E is energy input, M is material input, and t is technical change. Assuming exogenously given input prices, output level and cost minimizing behavior, the theory of duality implies existence of a unique twice differentiable cost function,

$$C = C(P_K, P_L, P_E, P_M, Q) \qquad (2)$$

where C is total cost and P_i's are the respective input price indices. If the cost function is weakly separable in its aggregate inputs, then an energy function can be written as,

$$E = E(q_C, q_G, q_P) \qquad (3)$$

where q_i's are the primary energies (here fossil fuels) coal, natural gas, and petroleum products respectively. Assuming that E is homothetic with respect to q_i for $i=C, G, P$, we have the energy cost function,

$$P_E = P(P_C, P_G, P_P) \qquad (4)$$

where P_C, P_G, and P_P are prices of coal, natural gas and petroleum products respectively.

Estimation of the impact of subsidy removal on fossil fuel demand is carried out in two stages. First, we hold aggregate energy constant, apply Shephard's lemma to each fossil fuel and differentiate each fuel input with respect to each fuel price. This gives the price elasticities of fuel demand, ϵ_{ij}, for fuel i and fuel price j such that,

$$S_i\epsilon_{ij} = S_j\epsilon_{ji} \qquad \text{for all i, j} \qquad (5)$$

and

$$\Sigma_j \epsilon_{ij} = 0 \qquad \text{for all i} \qquad (6)$$

where $S_{i,j}$ are the fuel cost shares in total energy cost. (5) results from the symmetry of the Hessian matrix of second order derivatives of the energy cost function and (6) from the linear homogeneity of the cost function. Second, we allow aggregate energy E (as well as K, L and M) to adjust to energy price changes while output is still held constant. This gives the price elasticities,

$$\epsilon^*_{ij} = \epsilon_{ij} + \epsilon_{EE}S_j \qquad \text{for all i, j} \qquad (7)$$

where ϵ_{EE} is the own price elasticity of aggregate energy.

In order to estimate the impact of fossil fuel subsidy removal, we will assume values for the own price elasticity of aggregate energy and the own price elasticity for each fuel holding aggregate energy constant. Since we are considering fossil fuels only, of which there are three, the elasticities from (7) is a three-by-three matrix of which three of the entries will be assumed. That leaves six unknowns, which are determined by the system of six equations in six unknowns given by (5) and (6). Thus the off-diagonal entries in the elasticity matrix, i.e. the cross-price elasticities, are uniquely determined from the own price elasticities[8].

We have not assumed any particular technology in (1) and therefore not a specific form for the energy function. We approximate the energy demand function in the relevant region by

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[8]Note that this is not the case if we have more than three fuels.

a Cobb-Douglas function, i.e. the price elasticity of demand for fuel i, ϵ_{ij}, is constant in the relevant region. Taking partial derivatives with respect to energy prices of the Cobb-Douglas function in logaritmic form would give the estimated changes in energy demand from a price change. But the derivative is a linear approximation, while we will estimate changes in energy demand from subsidy removal by a movement along the demand curve. The change in energy demanded from subsidy removal is thus,

$$\Delta q_i = -\sum_j q_i \left(1 - \left(\frac{p_j}{p_j^w}\right)^{-\epsilon_{ij}}\right) \qquad \forall i \qquad (8)$$

where q_i is domestic consumption of fossil fuel i, p_j is the domestic price of fuel j before subsidy removal, p_j^w is the world price of fuel j. The impact on carbon emissions is calculated from (8) by multiplying the change in fuel i by the respective carbon emission coefficients. It should be noted that an implicit assumption is that the energy markets are in equilibirum for the energy prices used in this study, i.e., that energy consumption has fully adjusted to past energy price changes. This may of course not be the case for countries with recent domestic energy price adjustments. In case domestic energy prices have recently been adjusted upwards, reductions in consumption may not yet be realized, as in the case of China, and our estimates understates the new equilibirum energy consumption after subsidy removal.

<u>IV. Implications for greenhouse gas emissions:</u> Removal of fossil fuel subsidies would be expected to induce reductions in fossil fuel consumption and therefore carbon emissions in subsidizing countries. If domestic prices are below world prices because of price ceilings effective for producers as well as consumers, then removal of such price ceilings may have

positive supply effects. In the case of non-traded energy products, in particular electricity, demand may be supply constraint. Removing subsidies, or price ceilings, may therefore increase consumption. We do not take this into account, but recognize the importance of this fact.

Reductions in fossil fuel demand in subsidizing countries may also reduce world prices and thus result in increased consumption in non-subsidizing countries. We will estimate carbon reductions assuming no change in world prices, although this assumption may be unrealistic if all fossil fuel subsidies were removed simultaneously.

The removal of subsidies will not immidiately translate into reductions in fossil fuel consumption. Consumers will respond to higher prices over time, and we have thus estimated reductions as below projected baseline emissions in year 2010, i.e. below projected emissions if subsidies were not removed (table 6). Projected baseline emissions for the world as a whole is estimated to be about 50% higher in 2010 than in 1989. OECD emissions are assumed to be constant given that most OECD countries have committed to stabilize emissions at 1990 levels by year 2000 and some to further reduce emissions to 80% of 1990 emission levels by year 2005. Baseline emission projections in the former Soviet Union and eastern Europe are based on Baron (1992). His estimates incorporate the impacts of restructuring, i.e. compositional changes in aggregate output. Baseline emission projections for all other non-OECD countries are based on GDP projections less 0.5-1.0% annual autonomous energy efficiency improvements that may arise from less energy intensive capital, appliances and transport equipment, and compositional changes in aggregate output.

The magnitude of carbon reductions realized by removal of fossil fuel subsidies clearly depends on the price elasticities of demand. Bohi (1981) presents a comprehensive survey of price elasticities of energy demand. Long run own price 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. Hoeller and Wallin (1991) estimates the long-run price elasticity of carbon demand to -1.04 in a cross sectional study of the OECD countries. These elasticity estimates would be valid for marginal changes in prices only. In cases of high levels of subsidies, as in for example the former Soviet Union, elasticity estimates for marginal price changes can not be applied to arrive at emission reductions but instead much smaller values of elasticities must be considered. Therefore own price elasticities of demand used are in the range of -0.15 to -0.25 in most of these cases and -0.6 in cases of low levels of subsidies. The analysis attempts to include estimation of interfuel substitution and cross price elasticities are determined within the model. Estimates of emission reductions from the removal of subsidies can also be in serious error for countries where supply is completely inelastic with excess demand at low prices as may be the case in particular for natural gas. In Poland, natural gas may be considered supply constrained and therefore an increase in natural gas prices within a certain range may not have any significant effect on natural gas consumption. Excluding emission reductions from Poland on account of natural gas would lead only to a minor revision in the overall estimate for reductions in global carbon emissions. In the case of Soviet Union, the share of natural gas in total energy consumption is as large as that of petroleum products and coal and it is therefore perhaps realistic to assume that price increases of natural gas will lead to reduced natural gas consumption.

Estimates of carbon emission reductions from subsidiy removal are presented by country in Table 6. Removal of subsidies are estimated to result in almost 7% reduction in world carbon

Table 6. CO2 Emissions Reductions

	CO2 emissions 1989 (mill tons) (1)	Baseline CO2 emissons 2010 (mill tons) (2)	CO2 emissions 2010 w/o subsidies (3)	% reduction relative to baseline (4)	CO2 emissions 2010 relative to 1989 (3)/(1)
World	21093	32784	30480	7.0%	1.5
OECD	9717	9717	9717		1.0
Non-OECD	11376	23067	20763	10.0%	1.8
Non-OECD w/o China	9090	16698	14681	12.1%	1.6
Former USSR	3697	5065	3798	25.0%	1.03
China	2286	6369	6082	4.5%	2.7
Poland	433	511	389	24.0%	0.9
India	652	1815	1652	9.0%	2.5
South Africa	274	510	439	14.0%	1.6
Czechoslovakia	221	221	168	24.0%	0.8
Mexico	304	693	669	3.5%	2.2
Brazil	193	439	428	2.5%	2.2
South Korea	206	700	672	4.0%	3.3
Venezuela	86	159	124	22.0%	1.4
Indonesia	106	326	304	7.0%	2.9
Saudi Arabia	162	271	239	12.0%	1.5
Egypt	75	208	175	16.0%	2.3
Iran	157	358	272	24.0%	1.7
Romania	205	246	192	22.0%	0.9
Bulgaria	104	125	111	11.0%	1.1

(2) Projected emissions if fossil fuel subsidies are not removed.
(3) Projected emissions if fossil fuel subsidies are removed.

dioxide emissions from fossil fuel consumption, of which 56% are from coal, 30% from gas and 14% from petroleum products. In terms of potential reductions in national carbon emissions, reductions are estimated to be larger than 20% in the former Soviet Union, Poland, Czechoslovakia, Iran, Romania and Venezuela. Such large reductions may appear unrealistically high, but even after such reductions carbon intensity (tons of carbon to GDP) in these countries would still be significantly higher than in OECD countries or other middle income countries.

Perhaps interesting, total carbon dioxide emission reductions from reductions in consumption of petroleum products are significantly lower than for coal and natural gas, primarily because percentage change in domestic petroleum product end-user prices from subsidy removal is smaller than for coal and gas prices, although total value of subsidies to petroleum products is far higher than to coal and gas. Total value of subsidies to petroleum products is higher in large part because subsidies per unit of carbon content is higher on petroleum products due to higher world prices and non-subsidized end-user prices of petroleum products per unit of carbon content relative to coal and to some extent gas. Emission reductions from gas is also higher than from petroleum products because domestic prices of gas relative to world prices are lower than for petroleum products in the former Soviet Union, from where the largest reductions in emissions from gas are estimated to occur. In terms of total world emission reductions, estimates in this study are lower than the previous emstimates primarily because of lower estimates of reductions from petroleum products in the former Soviet Union. Although estimated emission reductions from petroleum products are as high as 18% of petroleum product emissions, <u>total</u> emission reductions are only 2% because of the large share of coal in total emissions.

In terms of the other countries, estimated emission reductions in Mexico are substantially lower than estimated in Larsen and Shah (1992c) even subsidies, although small in total value, to coal and gas are now included. The reason is that petroleum product subsidies, estimated at official exchange rate, are significantly reduced resulting in an estimated slight increase in petroleum product consumption from interfuel substitution. Emission reductions in Brazil are also substantially lower due to significantly lower estimates of petroleum product subsidies. Estimated reductions in Indonesia are also substantially lower, although estimated total subsidies to petroleum products are now higher. Reductions are lower because estimates suggest relatively large increase in coal and gas consumption from removal of petroleum product subsidies. Estimated reductions in Saudi Arabia and Egypt are significantly higher according to this study because of substantially larger estimated subsidies. Estimated reductions in Czechoslovakia are now larger primarily due to larger estimated reductions in coal conumption and inclusion of subsidies to gas. Estimated reductions in Venezuela are now larger because significant subsidies to gas are included. Estimated total reductions in India, Poland and South Africa are relatively close to previous estimates. Finally, this study includes estimates for South Korea, Iran, Romania and Bulgaria, which were not included in Larsen and Shah (1992c).

V. Summary and conclusions: Substantial energy subsidies prevail in a handful of large carbon emitting countries. Total world subsidies are estimated to be in excess of US $210 billion, or 20-25% of the value of world fossil fuel consumption at world prices. Removal of such subsidies are estimated to reduce national carbon emissions in some countries by more than 20% and reduce global carbon emissions by almost 7% assuming no change in world prices of fossil fuels. If all subsidies are eliminated simultaneously, world prices of fossil fuels may be expected to decline relative to the price path of no subsidy removal. A decline in world prices could stimualate demand in non-subsidizing countries and partially offset estimated reductions in carbon emissions. On the other hand, a decline in world prices would only have a minor effect on most national emission reductions in subsidizing countries estimated in this paper (see Larsen and Shah 1992c).

It should be noted that subsidy removal would not be sufficient to stabilize aggregate carbon emissions at 1989 levels in non-OECD countries. In particular, the share of world emissions from China will increase from about 10% in 1989 to 20% in 2010 even if fossil fuel subsidies are removed. Stronger economic policy responses would be required to achieve stabilization, although emission reductions in some individual countries from subsidy removal would be significant.

The paper does point to the fact that substantial fossil fuel subsidies exist in a handful of large carbon emitting countries, although subsidies are being phased out, or being attempted, in some of these coutries. Further research should include the electricity sector with explicit consideration to supply constraints, a more country specific model, broader energy strategy options for China and India given their current share of global carbon emissions and rapidly increasing share in the future, and the impact of energy subsidy removal on world prices.

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