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Policy Research

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World Development Report

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Background paper for World Development Report 1992

Carbon Taxes, the Greenhouse Effect, and Developing Countries

Anwar Shah
and
Bjorn Larsen

A universal case cannot be made for national carbon taxes. Nevertheless, such taxes make eminent sense for many developing countries — on the grounds of equity, efficiency, ease of tax administration, and an improved local environment, even ignoring the potential benefits from controlling global carbon emissions.

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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 (August 1992, 68 pages).

Shah and Larsen evaluate the case for carbon taxes in terms of national interests. They reach the following conclusions:

• A global carbon tax involves issues of international resource transfers and would be difficult to administer and enforce. It is thus unlikely to be implemented in the near future.

• National carbon taxes can raise significant revenues cost-effectively in developing countries and are not likely to be as regressive in their impact as commonly perceived. Such taxes can also enhance economic efficiency if introduced as a revenue-neutral partial replacement for corporate income taxes or in cases where subsidies are prevalent. The welfare costs of carbon taxes generally vary directly with the existing level of energy taxes, so a carbon tax should be an instrument of choice for countries such as India and Indonesia, which have few or no energy taxes.

• A carbon tax can significantly reduce local pollution and carbon dioxide emissions. Cost-benefit analysis shows countries with few or no energy taxes substantially gaining from carbon taxes in terms of an improved local environment.

• A carbon tax of $10 a ton produces very small output losses for Pakistani industries analyzed in this paper, and the output losses are fully offset by health benefits from reduced emissions of local pollutants — even ignoring the global implications of a reduced greenhouse effect.

• Tradable permits are preferable to carbon taxes where the critical threshold of the stock of carbon emission beyond which temperatures would rise exponentially is known. Given our current ignorance on the costs of reducing carbon emissions and the threshold effect, a carbon tax appears to be a better and more flexible instrument for avoiding large unexpected costs.

Carbon Taxes, The Greenhouse Effect and Developing Countries

Anwar Shah* and **Bjorn Larsen***
World Bank, Washington, D.C.

Prepared as a Background Report for the
World Development Report 1992

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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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1.0 Introduction

The last few years have witnessed a dramatic growth in worldwide concern over global climate change and a proliferation of proposals to limit or reverse global environmental damage. Carbon taxes and tradeable permits figure prominently in proposed economic policy responses. Despite this policy interest, empirical work relevant to developing countries is almost completely lacking. Even for developed countries, research on carbon taxes is of recent origin (see e.g. Jorgenson and Wilcoxen 1990, Poterba 1991, Pearce 1991 and Goulder 1991) and still largely in progress. A careful analysis of carbon taxes in terms of their impacts on efficiency, equity, economic growth, government revenues and environmental protection, is needed for an informed debate on policy development (see Summers 1991). This paper takes a first step in this direction by quantifying the efficiency and equity implications of carbon taxes for a few selected developing countries.

The paper is organized into seven sections. The remainder of Section 1 outlines the global warming issue and suggested policy responses. Section 2 briefly outlines the potentials and perils of global carbon tax regimes. Section 3 deals with the economics of a national carbon tax. Calculations on the revenue potential and differential incidence of carbon taxes are presented for India, Indonesia, Pakistan, USA and Japan. For Pakistan, detailed calculations on the distributional implications are also presented. Section 4 provides estimates of the impact of carbon taxes on greenhouse gases and local pollutants for the sample countries. Impacts of carbon taxes on industrial performance for selected industries in Pakistan are traced in Section 5, using dynamic production structure empirical models. Section 6 evaluates the use of tradeable permits as an alternative to carbon taxes. A final section presents a summary of the conclusions. The paper concludes that whereas a global carbon tax may be a more distant policy option, national carbon taxes -- if introduced in revenue-neutral fashion by reducing corporate income taxes -- offer significant potential in combatting global change and local pollution as well as reforming the tax system. Further, a conservative evaluation of the benefits of reducing local externalities overwhelms the negative output effects of carbon taxes. Thus, even ignoring global externalities, a case for carbon taxes for some countries can be made purely on own national interest considerations.

The Problem and the Status of Current Policy Discussions

In recent years, worldwide concern about the atmospheric accumulation of so-called "greenhouse" trace gases - carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), tropospheric ozone (O_3), and chlorofluorocarbons (CFCs) - has been mounting. By trapping some of the sun's heat in the atmosphere, these gases permit the existence of life on earth. Their rapid accumulation, however, can contribute to a rise in the earth's temperature (commonly termed the "greenhouse effect" or "global warming"). CO_2 is estimated to contribute 80.3% of total warming potential (Nordhaus 1991). Scientists fear that if the current pace of accumulation continues unchecked into the 21st century, a point might be reached when the absorptive capacity of the earth's atmosphere would become exhausted and a natural disaster of unprecedented proportions would consequently ensue. Even without this point being reached, significant warming of the earth's surface is expected to have major economic consequences (see

Churchill and Saunders, 1991, for an overview of the scientific and economic issues of relevance to developing countries). Developing countries with agrarian economies and/or coastlines would be particularly vulnerable to natural calamities associated with global warming. It must be emphasized that there is considerable uncertainty at the present time regarding global climate change, its magnitude, its regional manifestations and its consequences. Much scientific work remains to be done. The uncertain state of our present knowledge of global warming coupled with the potentially large and irreversible damages that might result, call for public policy responses that are both flexible and reversible. The possible use of carbon taxes and tradeable permits to deal with global climate change has initiated a controversial debate.

These debates reflect a wide spectrum of views on this issue. Some argue that in view of the uncertainties regarding climate change, inaction would be the best policy (Eckaus, 1991). At the other extreme, some environmentalists argue that we may have already missed the boat and immediate economic policy responses that may forsake growth are needed (see Postel and Flavin, 1991). A majority, however, take a middle view. Energy economists argue that energy policy options consistent with restraining the greenhouse effect also make good economic sense. Churchill and Saunders (1991), for example, exhort developing countries to seize the initiative and "increase incentives for sustainable energy use, shift to cleaner alternative fuels and technologies, and improve efficiency in energy production, distribution and end use" (p.28). Some public finance economists espouse the same middle-of-the-road view by presenting a somewhat different perspective that emphasizes reliance on flexible and less distortionary tools to deal with an uncertain but potentially serious problem. Summers (1991) has argued that corrective taxes, e.g. taxes on carbon contents of fossil fuels can raise significant amounts of revenue at a relatively small deadweight loss while furthering global and local environmental protection and discouraging "bads", and therefore represent "what we pay to preserve civilization". It has also been argued that in developing countries, carbon taxes offer a potential for enhancing the environment as well as financing developmental expenditures, and could therefore serve as a means to enrich civilization.

It is interesting to note the large energy subsidies that prevail in a handful of large carbon-emitting countries. Getting energy prices right would prima facie represent a first order priority in any economic policy response designed to curtail greenhouse gas emissions. Larsen and Shah (1992a) examine energy pricing practices around the world. In determining the level of subsidy, they use border prices of fossil fuels as reference prices (as proxies for marginal opportunity costs of production). Total world energy subsidies in 1990 are estimated to be in excess of US $230 billion and, in revenue terms, equivalent to a negative carbon tax of US $40 per ton of carbon. The removal of such subsidies could reduce global carbon emissions by 9.5%, and would translate into a 21% reduction in carbon emissions in the subsidizing countries. To achieve an equivalent reduction in tons of emissions in the OECD countries, a carbon tax of US $60 per ton would need to be imposed in the OECD countries. This would result in a total annual cost (in terms of foregone output, adjustment costs, etc.) of US $15.5 billion. This amount would then represent the upper bound for OECD compensatory transfers to the subsidizing countries. It is also worth noting that very large (37-68%) reductions in global carbon emissions could be achieved, were Japanese or German standards of energy efficiency to be universally adopted.

While this debate continues to rage, some countries have already moved to adopt tax policies that, intentionally or otherwise, bear on the issue of global warming. In late 1989 and in response to ozone depletion, the USA introduced a tax on the sale of CFCs at an initial rate of $3.02 per kg, representing a 200% tax on the sale price. This tax is scheduled to rise to $6.83/kg by 1995 and to $10.80/kg by 1999. Total revenue intake during the first five years is estimated to total $4.3 billion. The USA has not yet imposed a carbon tax but legislation is currently pending in the U.S. Congress for the phased introduction of a carbon tax to start at $5 per ton of carbon in 1991, rise to $25 per ton in 1995. Proposals to increase excises on gasoline and introducing a Federal BTU tax are also under discussion. Note that the U.S. Government remains uncommitted to a targeted policy response to climate change other than advocating economic policies which make good economic sense independently (the so-called "no regrets" policies). Among European countries, Finland took the lead in introducing the world's first carbon tax at a rate of $6.10 per ton of carbon on all fossil fuels in January 1990. Netherlands and Sweden ($45/ton tax) have followed suit in February 1990 and January 1991 respectively. The European Community is currently debating a proposal to introduce in a revenue-neutral manner a community-wide carbon-cum-energy tax at US $3 per barrel. The tax would increase by $1 a barrel each year in real terms until it reached $10 per barrel (roughly equivalent to a carbon tax of $70 per ton) in the year 2000.

At the international level, momentum has steadily built behind the proposition that global warming and other aspects of climate change are of major consequence and require a concerted global policy response. In 1990, the UN General Assembly formally launched international negotiations on a "Framework Convention on Climate Change" and assigned this task to an "Intergovernmental Negotiating Committee"(INC). The INC has held conferences in Geneva (1990, 1991) and Washington (1991). These conferences have debated international protocols to limit emissions of "greenhouse gases. A global climate change "framework convention" is likely to be ratified at the June 1992 UN Conference on the Environment and Development to be held in Brazil. The discussion in these international fora has centered on both domestic and global policy options to combat global climate change. These have included: immediate term options such as a global carbon tax or permits (tradeable or otherwise) and emission limits; intermediate term measures such as increased energy efficiency, afforestation, biomass, nuclear energy and population control; and long term measures such as backstop technologies that use solar, solar-hydrogen and other environmentally safe sources. Developing countries are fully involved in the debate on these issues. One argument often advanced is that the greenhouse effect results from the accumulation over a long period of trace gases contributed primarily by industrial activity in developed countries, and consequently that developing countries should not be asked to sacrifice their current developmental goals in order to address a problem created by past policies of developed countries. In fact, if one were to construct an index of "global warming debt" by level of development, this particular argument would have some empirical validity (see Smith, 1991). It is also frequently asserted that any global attempt to limit environmentally harmful emissions would ultimately slow the economic development of LDCs. Attempts to develop energy intensive manufacturing capability in the early to mid stages of development would be more costly, and hence more difficult. Also as importers of energy intensive manufactures (primarily capital goods), developing countries would end up bearing the burden of the policy response applied to emission generating activities. In general, it is commonly perceived that, unless accompanied by compensatory transfers, the relative costs of action are likely to be higher for developing countries, given that their relative contribution to the accumulation of these gases is expected to grow faster than that of the OECD countries over the next century. The available literature offers little guidance in determining the validity of these arguments. The following section provides preliminary and tentative guidance on these questions.

2.0 Global Carbon Taxes: Potentials and Perils

Taxes on the carbon content of fossil fuels have been advocated in recent years as part of a proposed concerted international effort to combat global climate change. While both the need for and the mechanics of such taxes remain unsettled issues, a general consensus is emerging that, if adopted globally, such taxes would represent a flexible, reversible and lower cost alternative to regulatory responses, including the widely-discussed notion of equal percentage reductions in greenhouse emissions by all countries. The latter measure is unlikely to lead to the equalization of marginal emission reduction costs from all sources and would not, therefore, result in a cost efficient outcome for the world as a whole (see Hoel, 1991). Tietenberg (1985) reports that cost savings associated with moving from equal percentage reductions to a market based instrument such as a carbon tax, could be substantial (exceeding 40% of total costs). Maler (1989) also reports that a uniform percentage reduction strategy for greenhouse gas emissions would capture only one third of the total potential gains from optimal allocation. A uniform level carbon tax (i.e., tax per unit of carbon emissions equal for all gases and all countries), if imposed by a global agreement, *would* equalize the marginal costs of emission reductions (by fossil fuel and by location), and would therefore be cost-efficient. Several alternative designs for such an agreement are possible, with each presenting its own particular shortcomings. Consider the case of a domestic carbon tax that is imposed by an international agreement. Since perspectives on global warming vary among countries, national commitment to impose such taxes will also vary. If a country has signed such agreement under international pressure, that country can make the carbon tax an ineffective instrument by reducing existing energy taxes, by taxing close substitutes of fossil fuels (e.g. hydroelectricity), and providing subsidies to complements or products that are fossil fuel energy intensive, and by lax enforcement of the agreed-upon carbon tax (see Hoel 1991). Thus by following a suitable strategy, a free ride becomes possible. A global carbon tax imposed by an international agency, on the other hand, would impinge on national sovereignty and therefore would not likely be accepted internationally. A third alternative would have globally imposed but nationally administered and collected carbon taxes; countries would make a positive or negative net transfer to an international agency based upon an agreed revenue disposition scheme. Basic criteria for such redistribution would be population and GDP, or a combination of these factors. Additionally, a small fraction of the revenue pool could be distributed on the basis of special considerations, e.g. to provide an inducement to countries which might view global warming as beneficial (such as Russia, Canada and Nepal) to join an international agreement. Tables 2.1 and 2.2 provide illustrations of net transfers involved based on the three revenue redistribution schemes outlined above, using either standard GDP or GDP adjusted by purchasing power parity -- so-called Penn GDP. From these tables, it is apparent that a revenue redistribution alternative

Table 2.1 Net transfers by country under alternate carbon tax regimes (Using UN National Accounts GDP)

Tax Regimes 1-3

		GDP per capita (US$) 1987	% of world emissions	Carbon emissions to GDP (kg/$)	Carbon emissions per capita (kg)	Tax Revenues (Tax: $10/ton) mill US$	Tax revenues to GDP (%)	1: World tax revenues distributed by population (mill US$)	1: Net revenues per capita (US$)	1: Net revenues % of GDP	2: World tax revenues distributed by GDP (mill US$)	2: Net revenues per capita (US$)	2: Net revenues % of GDP	3: World tax revenues distributed half and half by population and [illegible] (mill [illegible])	3: Net revenues per capita (US$)	3: Net revenues % of GDP
BANGLADESH	•	166	0.06%	0.179	30	32	0.18%	1180	10.82	6.50%	54	0.21	0.13%	617	5.52	3.31%
NIGERIA	•	229	0.16%	0.366	84	90	0.37%	1185	10.28	4.48%	75	-0.14	-0.06%	630	5.07	2.21%
CHINA	•	286	10.38%	1.868	533	5699	1.87%	11882	5.79	2.03%	934	-4.46	-1.56%	6408	0.66	0.23%
INDIA	•	322	2.65%	0.567	182	1454	0.57%	8868	9.30	2.89%	785	-0.84	-0.26%	4827	4.23	1.32%
PAKISTAN	•	325	0.24%	0.394	128	132	0.39%	1140	9.84	3.02%	102	-0.29	-0.09%	621	4.77	1.47%
INDONESIA	•	463	0.48%	0.346	155	263	0.35%	1906	9.59	2.16%	232	-0.18	-0.04%	1069	4.71	1.06%
ZIMBABWE	•	598	0.08%	0.774	463	42	0.77%	100	6.49	1.09%	16	-2.80	-0.47%	58	1.85	0.31%
EGYPT, ARAB REPUBLIC	•	709	0.35%	0.536	380	190	0.54%	558	7.32	1.03%	109	-1.63	-0.23%	333	2.85	0.40%
KOREA, DEM PEOPLE'S R		889	0.71%	2.063	1834	392	2.06%	238	-7.22	-0.81%	58	-15.62	-1.76%	148	-11.42	-1.28%
Total			15.10%			8292	1.07%		7.78	2.45%		-2.30	-0.72%		2.74	0.86%
Average		318		1.073	341											
Ave w/o China, Kor				0.491												
MEXICO	•	1715	1.41%	0.550	943	772	0.55%	910	1.69	0.10%	430	-4.18	-0.24%	670	-1.25	-0.07%
BRAZIL	•	2165	0.92%	0.166	356	503	0.17%	1573	7.56	0.35%	928	3.01	0.14%	1251	5.29	0.25%
SOUTH AFRICA	•	2493	1.38%	0.919	2292	759	0.92%	368	-11.80	-0.47%	253	-15.29	-0.61%	310	-13.55	-0.54%
VENEZUELA	•	2629	0.42%	0.485	1276	233	0.49%	203	-1.64	-0.06%	167	-4.71	-0.18%	175	-3.17	-0.12%
KOREA, REPUBLIC OF	•	3121	0.82%	0.342	1067	449	0.34%	468	0.45	0.01%	402	-1.12	-0.04%	435	-0.33	-0.01%
Total			4.95%			2716	0.38%		2.55	0.11%		-1.76	-0.08%		0.39	0.02%
Average		2228		0.385	857											
Ave w/o S. Africa				0.314												
POLAND	•	1697	2.29%	1.967	3338	1257	1.97%	419	-22.26	-1.31%	196	-28.18	-1.66%	307	-25.22	-1.49%
YUGOSLAVIA	•	2848	0.60%	0.492	1403	328	0.49%	260	-2.91	-0.10%	204	-5.31	-0.19%	232	-4.11	-0.14%
USSR	•	8325	18.45%	0.430	3578	10129	0.43%	3148	-24.66	-0.30%	7213	-10.30	-0.12%	5180	-17.48	-0.21%
CZECHOSLOVAKIA	•	9242	1.17%	0.44[illegible]	4110	640	0.44%	173	-29.98	-0.32%	440	-12.82	-0.14%	307	-21.40	-0.23%
Germany, East	•	11261	1.63%	0.477	5369	894	0.48%	185	-42.57	-0.38%	574	-19.23	-0.17%	379	-30.90	-0.27%
Total			24.13%			13248	0.47%		-24.08	-0.32%		-12.28	-0.16%		-18.18	-0.24%
Average		7489		0.470	3520											
Ave w/o Poland				0.435												
AUSTRALIA	•	11364	1.16%	0.346	3926	638	0.35%	181	-28.14	-0.25%	565	-4.48	-0.04%	373	-16.31	-0.14%
CANADA	•	16056	1.99%	0.263	4221	1091	0.26%	287	-31.09	-0.19%	1270	6.93	0.04%	779	-12.08	-0.08%
Germany, West	•	18249	3.23%	0.159	2898	1773	0.16%	680	-17.86	-0.10%	3416	26.87	0.15%	2048	4.50	0.02%
UNITED STATES	•	18434	22.69%	0.277	5112	12461	0.28%	2711	-40.00	-0.22%	13753	5.30	0.03%	8232	-17.35	-0.09%
JAPAN	•	19437	4.32%	0.100	1942	2371	0.10%	1358	-8.30	-0.04%	7263	40.07	0.21%	4310	15.88	0.08%
Total		18295	33.39%			18334	0.21%		-27.96	-0.15%		16.91	0.09%		-5.53	-0.03%
Average				0.216	3908											
Sample total			77.56%													
AFRICA		645	2.80%	0.405	261	1540	0.40%	6561	8.51	1.32%	1164	-0.64	-0.10%	3862	3.94	0.61%
SOUTH AMERICA		1951	2.46%	0.249	486	1350	0.25%	3091	6.26	0.32%	1660	1.12	0.06%	2376	3.69	0.19%
EUROPE		11136	21.13%	0.210	2343	11600	0.21%	5506	-12.31	-0.11%	16870	10.65	0.10%	11187	-0.83	-0.01%
NORTH & CENTRAL AMERI		12897	26.04%	0.281	3620	14300	0.28%	4392	-25.08	-0.19%	15591	3.27	0.03%	9992	-10.91	-0.08%
OCEANIA		9372	1.31%	0.319	2992	718	0.32%	267	-18.80	-0.20%	688	-1.23	-0.01%	478	-10.02	-0.11%
ASIA		1333	24.40%	0.350	466	13400	0.35%	31947	6.46	0.48%	11723	-0.58	-0.04%	21835	2.94	0.22%
USSR		8328	18.39%	0.429	3569	10100	0.43%	3147	-24.57	-0.30%	7213	-10.20	-0.12%	5180	-17.39	-0.21%
WORLD		3633	100.00%	0.306	1112	54910	0.31%	54910	0.00	0.00%	54910	0.00	0.00%	54910	0.00	0.00%

Note: carbon emissions are from fossil fuel combustion only.
Emissions from deforestation are not included.

Table [illegible].2 Net transfers by country under global carbon tax regimes (Using PENN GDP)

	Penn GDP per capita (US$) 1987	% of world emission	Carbon emissions to Penn GDP (kg/$)	Carbon emissions per capita (kg)	Tax Revenues (Tax: $10/ton) mill US$	Tax revenues to Penn GDP (%)	Tax Regimes 1-3 1: World tax revenues distributed by populatio (mill US$)	1: Net revenues per capita (US$)	1: Net revenues % of Penn GDP	2: World tax revenues distributed by Penn GDP (mill US$)	2: Net revenues per capita (US$)	2: Net revenues % of Penn GDP	3: World tax revenues distributed half and half by Penn GDP and population (mill US$)	3: Net revenues per capita (US$)	3: Net revenues % of Penn GDP
NIGERIA	• 248	0.16%	0.339	84	90	0.34%	1185	10.28	4.14%	71	-0.18	-0.07%	628	5.05	2.03%
BANGLADESH	• 831	0.06%	0.036	30	32	0.04%	1180	10.82	1.30%	235	1.92	0.23%	708	6.3?	0.77%
INDIA	• 947	2.65%	0.193	182	1454	0.19%	8868	9.30	0.98%	2014	0.70	0.07%	5441	5.00	0.53%
ZIMBABWE	• 1047	0.08%	0.442	463	42	0.44%	100	6.49	0.62%	25	-1.84	-0.18%	63	2.33	0.22%
INDONESIA	• 1269	0.48%	0.121	153	263	0.12%	1906	9.59	0.76%	580	1.85	0.15%	1243	5.72	0.45%
PAKISTAN	• 1391	0.24%	0.092	128	132	0.09%	1140	9.84	0.71%	380	2.43	0.17%	760	6.13	0.44%
EGYPT, ARAB REPUBLIC	• 1654	0.35%	0.261	380	190	0.26%	558	7.32	0.50%	195	0.08	0.01%	376	3.70	0.25%
CHINA	• 2235	10.38%	0.239	533	5699	0.24%	11882	5.79	0.26%	6370	0.63	0.03%	9126	3.21	0.14%
Total		14.39%			7900										
Average	1534		0.213	328		0.21%		7.84	0.51%		0.82	0.05%		4.33	0.28%
VENEZUELA	• 3422	0.42%	0.373	1276	233	0.37%	203	-1.64	-0.05%	167	-3.63	-0.11%	185	-2.63	-0.08%
MEXICO	• 3780	1.41%	0.249	943	772	0.25%	910	1.69	0.04%	823	0.65	0.02%	868	1.17	0.03%
KOREA, REPUBLIC OF	• 42?6	0.82%	0.252	1067	449	0.25%	468	0.45	0.01%	474	0.60	0.01%	471	0.53	0.01%
BRAZIL	• 4613	0.92%	0.077	356	503	0.08%	1573	7.56	0.16%	1740	8.75	0.19%	1657	8.16	0.18%
SOUTH AFRICA	• 5921	1.38%	0.387	2292	759	0.39%	368	-11.80	-0.20%	523	-7.13	-0.12%	446	-9.47	-0.16%
Total		4.95%			2714										
Average	4416		0.194	857		0.19%		2.55	0.06%		3.20	0.07%		2.87	0.07%
YUGOSLAVIA	• 5000	0.60%	0.281	1403	528	0.28%	260	-2.91	-0.06%	312	-0.69	-0.01%	286	-1.80	-0.04%
POLAND	• 5579	2.29%	0.598	3338	1257	0.60%	419	-22.26	-0.40%	560	-18.50	-0.33%	490	-20.38	-0.37%
USSR	• 6791	18.45%	0.527	3578	10129	0.53%	3148	-24.66	-0.36%	5128	-17.66	-0.26%	4138	-21.16	-0.31%
CZECHOSLOVAKIA	• 8521	1.17%	0.482	4110	640	0.48%	173	-29.98	-0.35%	354	-18.38	-0.22%	264	-24.18	-0.28%
Germany, East	• 8767	1.63%	0.612	5369	894	0.61%	185	-42.57	-0.49%	389	-30.31	-0.35%	287	-36.44	-0.42%
Total		24.13%			13248										
Average	6717		0.524	3520		0.52%		-24.08	-0.36%		-17.28	-0.26%		-20.68	-0.31%
AUSTRALIA	• 11782	1.16%	0.333	3926	638	0.33%	181	-28.14	-0.24%	511	-7.83	-0.07%	346	-17.99	-0.15%
JAPAN	• 12506	4.32%	0.155	1942	2371	0.16%	1358	-8.30	-0.07%	4073	13.94	0.11%	2715	2.82	?.02%
CANADA	• 15730	1.99%	0.268	4221	1091	0.27%	287	-31.09	-0.20%	1085	-0.25	0.00%	686	-15.67	-0.10%
Germany, West	• 16893	3.23%	0.172	2898	1773	0.17%	680	-17.86	-0.11%	2756	16.08	0.10%	1718	-0.89	-0.01%
UNITED STATES	• 17505	22.69%	0.292	5112	12461	0.29%	2711	-40.00	-0.23%	11383	-4.42	-0.03%	7047	-22.21	-0.13%
Total		33.39%			18334										
Average	15828		0.247	3908		0.25%		-27.96	-0.18%		3.14	0.02%		-12.41	-0.08%
Sample total		76.85%													
% of world total															
AFRICA	1065	2.80%	0.245	261	1540	0.25%	6561	8.51	0.80%	1677	0.23	0.02%	4119	4.37	0.41%
SOUTH AMERICA	3976	2.46%	0.122	486	1350	0.12%	3091	6.26	0.16%	2949	5.75	0.14%	3020	6.01	0.15%
EUROPE	11146	21.13%	0.210	2343	11600	0.21%	5504	-12.31	-0.11%	14718	6.30	0.06%	10111	-3.01	-0.03%
NORTH & CENTRAL AMERI	12828	26.04%	0.282	3620	14300	0.28%	4392	-25.08	-0.20%	13516	-1.98	-0.02%	8954	-13.53	-0.11%
OCEANIA	9824	1.31%	0.305	2992	718	0.30%	267	-18.80	-0.19%	629	-3.71	-0.04%	448	-11.25	-0.11%
ASIA	2126	24.40%	0.219	466	13400	0.22%	31947	6.46	0.30%	16294	1.01	0.05%	24120	3.73	0.18%
USSR	6793	18.39%	0.525	3569	10100	0.53%	3147	-24.57	-0.36%	5128	-17.57	-0.26%	4138	-21.07	-0.31%
WORLD	4169	100.00%	0.267	1112	54910	0.27%	54910	0.00	0.00%	54910	0.00	0.00%	54910	0.00	0.00%

Note: Carbon emissions are from fossil fuel combustion only.
Emissions from deforestation are not included.

based on population alone would be unacceptable to most industrialized countries, whereas one based solely on GDP would not be agreeable to developing countries. Note that under the formula that uses population as the sole factor, net transfers to developing countries would dwarf current official development assistance. It is possible that a formula that uses a combination of both factors and therefore redistributes only a very small fraction of total carbon tax revenues, might find acceptance by a majority of countries.

A recent proposal by Norway would have mandatory greenhouse reduction targets imposed on industrial countries; such targets could be exceeded only by financing the transfer and/or adoption of green technology in developing countries. If such a proposal is received well in OECD countries, some of these countries might well choose to adopt carbon taxes to achieve the agreed-upon targets, then partly use the proceeds from carbon taxes to finance technology transfer to developing countries. In general, the prognosis for the acceptance of a global carbon tax regime is quite pessimistic. The degree of scientific uncertainty that surrounds global warming makes it unlikely that a majority of countries would agree to an international convention that is seen to forsake their current growth. The critical question then is that if one ignores the important yet uncertain phenomenon of global warming, is there a case for the adoption of national carbon taxes on other grounds, such as tax reform or a reduction in environmental externalities? The following sub-sections present a benefit-cost calculus of carbon taxes based on these latter considerations.

3. Economics of a National Carbon Tax

As discussed earlier, taxes on the carbon content of fossil fuels to combat global climate change have been widely advocated and also recently implemented in selected countries. In the following section, the case for carbon taxes is examined in terms of their revenue potential, efficiency and distributional implications, and impacts on global and local externalities. For the purpose of these calculations, a small fossil fuel carbon tax of the order of $10/ton of carbon contents is selected. Such a tax results in 2% and 8.6% increases in the aggregate price of fossil fuels, and 1.0% and 5.6% reductions in consumption of fossil fuels, in Japan and India, respectively (Table 3.1). Partial equilibrium calculations presented in this paper, offer reasonable and defensible approximation of the impact of small carbon taxes; the same confidence could not be asserted for those taxes of $100/ton or higher which are frequently discussed in global models.

3.1 Revenue Potential of Carbon Taxes

The revenue potential of carbon taxes is extremely large. For example, a $10/ton carbon tax, individually imposed by all nations of the world could raise $55 billion in the very first year of its operation (see Table 3.1). For some countries, like China and Poland, such revenues would amount to about 2% of GDP and would be sufficient to wipe out central government's budgetary deficit. On the average, countries having a 1987 per capita GDP of less than US$900 could raise revenues exceeding one percent of GDP and 5.7% of government revenue. For the OECD countries, comparable figures would be 0.21% of GDP and 1.0% of government revenue. Carbon taxes in general are easier to administer than personal and corporate taxes and thereby less prone to tax avoidance and evasion. Due to tax evasion, the latter taxes raise revenues that are considerably less than their potential yield. Carbon taxes therefore present an attractive alternative to income taxes in developing countries. But how do such taxes fare in terms of equity and efficiency?

3.2 Distributional Implications of Carbon Taxes

The existing literature on industrialized countries typically portrays carbon taxes as regressive charges. This is because expenditures on fossil fuel consumption as a proportion of current annual income, falls with income. Poterba (1991) relates carbon taxes to annual consumption expenditures -- a proxy for permanent income -- and still finds a regressive incidence, although one considerably less pronounced than with respect to annual income. These results nevertheless cannot be generalized to developing countries, where the incidence of carbon taxes would be affected by institutional factors. Some important factors that may have a bearing on the tax-shifting are: market power, price controls, import quotas, rationed foreign exchange, the presence of black markets, tax evasion and urban-rural migration.

Case (a): Full Forward Shifting. The degree of tax-shifting depends upon the relative elasticities of supply and demand for the taxed commodity. For example, carbon taxes on production or use of fossil fuels can be fully forward-shifted in the short run if the firms in the industry have full market power, or the demand for the taxed commodity is perfectly inelastic, or the supply is perfectly elastic. In Table 3.2, columns (a) and (b) present carbon tax ($10/ton) incidence calculations for Pakistan using data from the 1984/85 Household Income and Expenditure Survey and employing two alternative concepts of household income. Column (a) relates carbon tax payments to household current income by income class and column (b) to household expenditure by income class. In either case, the carbon tax burden falls with income, thereby yielding a regressive pattern of incidence. Such regressivity is nevertheless less pronounced with respect to household expenditures, thereby confirming the same conclusions reached by Poterba (1991) for the US.

Table 3.1 Revenue Potential of a US $10/ton domestic carbon tax (Using UN National Accounts GDP)

	Population (mill) 1987	GDP per capita (US$) 1987	Carbon emissions to GDP (kg/$)	Carbon emissions per capita (kg)	Tax Revenues (Tax:$10/ton) mill US$	Tax revenues to GDP (%)	Gov't rev to GDP %	Carbon tax revenues to total gov't revenues %	Carbon tax revenues to gov't deficit %
BANGLADESH	* 106.1	166	0.179	30	32	0.18%	9.12%	1.96%	
NIGERIA	* 106.6	229	0.366	84	90	0.37%	15.71%	2.33%	4.18%
CHINA	*1068.5	286	1.868	533	5699	1.87%	21.19%	8.81%	262.31%
INDIA	*797.53	322	0.567	182	1454	0.57%	14.73%	3.85%	6.65%
PAKISTAN	*102.48	325	0.394	128	132	0.39%	17.29%	2.28%	4.63%
INDONESIA	*171.44	443	0.346	153	263	0.35%	21.33%	1.62%	21.97%
ZIMBABWE	* 8.99	598	0.774	463	42	0.77%	33.10%	2.34%	7.03%
EGYPT, ARAB REPUBLIC	* 50.14	709	0.536	380	190	0.54%	38.07%	1.41%	9.03%
KOREA, DEM PEOPLE'S R	21.37	889	2.063	1834	392	2.06%			
Total					8292				
Averages						1.07%	18.78%	5.71%	25.20%
MEXICO	* 81.86	1715	0.550	943	772	0.55%	17.41%	3.16%	4.06%
BRAZIL	*141.43	2145	0.166	356	503	0.17%	33.29%	0.50%	1.42%
SOUTH AFRICA	* 33.11	2493	0.919	2292	759	0.92%	23.02%	3.99%	16.11%
VENEZUELA	* 18.27	2629	0.485	1276	233	0.49%	21.61%	2.25%	27.25%
KOREA, REPUBLIC OF	* 42.08	3121	0.342	1067	449	0.34%	17.27%	1.98%	-77.26%
Total					2716				
Averages						0.38%	25.16%	1.53%	4.56%
POLAND	* 37.66	1697	1.967	3338	1257	1.97%	38.78%	5.07%	137.92%
YUGOSLAVIA	* 23.41	2848	0.492	1403	328	0.49%	6.86%	7.18%	-1288.78%
USSR	* 283.1	8325	0.430	3578	10129	0.43%			
CZECHOSLOVAKIA	* 15.57	9242	0.445	4110	640	0.44%	48.35%	0.92%	527.11%
Germany, East	* 16.65	11261	0.477	5369	894	0.48%			
Total					13248				
Averages						0.47%			
AUSTRALIA	* 16.25	11364	0.346	3926	638	0.35%	26.50%	1.30%	28.73%
CANADA	* 25.85	16056	0.263	4221	1091	0.26%	20.29%	1.30%	-10.32%
Germany, West	* 61.17	18249	0.159	2898	1773	0.16%	29.34%	0.54%	15.01%
UNITED STATES	*243.77	18434	0.277	5112	12461	0.28%	20.23%	1.37%	8.45%
JAPAN	*122.09	19437	0.100	1942	2371	0.10%	13.77%	0.73%	2.82%
Total					18334				
Averages						0.21%	19.77%	1.08%	7.81%

Note: Carbon emissions are from fossil fuel combustion only.
Emissions from deforestation are not included.

Table 3.2 Carbon Tax ($10/Ton) Incidence - Pakistan 1984/85

(carbon taxes (TAX) as percent of monthly income (Y) or expenditure (EXP))

Monthly Income (Rupees)	Full Forward Shifting		Capital Owners		Capital Owners (0.69)	Consumption (0.31)
	TAX/Y (a)	TAX/EXP (b)	TAX/Y (c)	TAX/EXP (d)	TAX/Y (e)	TAX/EXP (f)
–600	1.49	1.19	0.66	0.53	0.92	0.74
601-700	0.89	0.83	0.62	0.58	0.71	0.66
701-800	0.91	0.86	0.64	0.60	0.72	0.68
801-1000	0.80	0.77	0.68	0.66	0.72	0.69
1001-1500	0.81	0.81	0.72	0.72	0.75	0.75
1501-2000	0.81	0.85	0.76	0.79	0.78	0.81
2001-2500	0.82	0.87	0.74	0.79	0.77	0.82
2501-3000	0.74	0.80	0.77	0.83	0.76	0.82
3001-3500	0.76	0.83	0.75	0.81	0.75	0.82
3501-4000	0.78	0.83	0.77	0.83	0.77	0.83
4001-4500	0.68	0.78	0.78	0.90	0.75	0.86
4500+	0.51	0.67	0.80	1.06	0.71	0.94
	Regressive	Regressive	Progressive	Progressive	Proportional	Progressive

Case (b): Complete Absence of Forward Shifting. Under a variety of circumstances, the burden of carbon taxes can fall entirely on capital owners. This can happen if price controls apply and legal pass-forward of the tax is disallowed, or if supply is completely price inelastic. The carbon tax will then be fully borne by fixed factors of production. With binding import quotas or rationed foreign exchange, carbon taxes will reduce rents received by quota recipients, rather than affect prices paid by consumers. Under the assumption of zero forward shifting, the burden of a carbon tax is attributed to capital income alone. The allocation of tax by capital income is then related to household income and household expenditures. Both these calculations yield a progressive distribution of the carbon tax burden (see Table 3.2: columns (c) and (d)).

Case (c): Partial Forward Shifting. Clearly, (a) and (b) above are polar cases and are unlikely to be fully satisfied for energy products in any country. There are only a handful of empirical studies which examine shifting assumptions for developing countries. One such study was carried out for excise taxes in Pakistan by Jeetun (1978). He finds 31% forward shifting of excises in Pakistan. Given than a tax on the carbon content of fossil fuels at their production stage is by its very nature an excise tax, it would be reasonable to use this assumption for assessing the distribution of the carbon tax burden. In Table 3.2, columns (e) and (f), 31% of the carbon tax is attributed to final consumption and 69% to general capital income; these series are then related to household incomes and expenditures by income class. This results in a roughly proportional incidence of carbon taxes under the former series and a progressive incidence pattern under the latter series.

Comparison with the Incidence of Personal and Corporate Income Taxes: The above analysis suggests that the regressivity of carbon taxes should be less of a concern in developing countries than in developed countries. This conclusion is further reinforced when one examines the incidence of personal income tax in a typical developing country. Personal income tax may not necessarily turn out to be a progressive element in the overall tax system, given both tax evasion and urban-rural migration effects, and their significance in lower to middle income countries. With respect to tax evasion, Shah and Whalley (1991) argue that, if the bribe rate is high and tax compliance low, the redistributive impact of the bribe system is likely to dominate the direct redistributive effects of income taxes. The relevant issue then is who receives the bribes. If public service is dominated by a seniority system, then high officials with higher income and wealth receive a large portion (or the majority) of the bribe, along with professionals (accountants) who often act as "middlemen" in this process. Increasing income tax can thus trigger a reverse distributional process from middle class businessmen and others to wealthy elites, an entirely opposite conclusion to that commonly reached. Thus tax evasion either reduces or offsets the progressivity of the tax system. The perceived progressivity of personal income tax is further clouded by the operation of the Harris-Todaro effect. In developing countries, personal income tax is imposed on urban sector incomes only. Under such circumstances, if expected wages are equalized across modern and traditional sectors through rural-urban migration effects, some of the burden of the (urban) tax is shifted to the rural sector through intersectoral wage effects. Thus, rural workers, although they face no legal liability to pay the tax, bear part of the burden of the tax through reduced wages. The potential importance of this effect is illustrated by Shah and Whalley (1991) using 1984-85 data for Pakistan. They find that incorporation of the Harris-Todaro effect in incidence calculations clouds the progressivity of the personal income tax in Pakistan (see Table 3.3). Shah and Whalley (1991) also present calculations establishing the progressivity of corporate income taxes that take into account complications introduced by foreign and public ownership of the corporate sector in Pakistan.

The above analysis suggests that concerns over the regressivity of carbon taxes may be over-stated. If the lowest income group is protected from the regressive impact of carbon taxes by direct subsidies or alternate measures, then the regressivity of carbon taxes may not pose a serious policy concern. Further, if carbon taxes are used to reduce personal income taxes, traditional concerns that such a tax change would represent a move to a less progressive tax structure are not fully justified. Thus, a commonly perceived and widely accepted case against carbon taxes, based on equity grounds, does not hold up under a closer scrutiny.

3.3 Efficiency Costs of Carbon Taxes

By design, carbon taxes distort production, investment and consumption decisions and thereby internalize the social costs of global and local externalities. For every dollar of carbon tax revenues raised, consumers lose more than a dollar in direct and indirect costs. It is the indirect or hidden costs of carbon taxes relative to other forms of taxation that are of interest to policy makers. The literature commonly refers to these costs as marginal welfare costs of taxation. In evaluating the potential of carbon taxes, one needs to determine what will be the impact on economic efficiency if the same revenues were to be raised by carbon taxes rather than by existing (and distortionary) taxes on income. The empirical literature on this question is regrettably sparse. Poterba (1991), for example, provides estimates of average and marginal deadweight loss associated with carbon taxes relative to a no-tax scenario. Such calculations are interesting, yet, as the following analysis demonstrates, pre-existing taxes have a major bearing on welfare costs. Further, it is the differential (relative to other taxes), rather than the absolute incidence of carbon taxes, that offers useful policy insights. Goulder (in progress) is pursuing this line of inquiry for the U.S. using a computable general equilibrium model. Browning (1987) has argued that a properly specified partial equilibrium model of taxation's welfare costs offers superior insights on the measurement of welfare costs since, in such an analysis, the contribution made by key parameters to the final estimate remains transparent, whereas it is obscured in CGE models. He further demonstrates that almost all the differences in welfare costs of taxation for the US can be traced to different assumptions regarding key parameters, rather than differences in the nature of models (i.e. partial vs general equilibrium). In the following, two measures for the differential costs of carbon taxation and a measure for the absolute burden of carbon taxes are presented. All these measures explicitly recognize existing taxes. Derivations of these expressions are laid out more fully in Appendix A.

Case (a): Welfare Costs Under a Revenue Neutral Change That displaces Equal yield Personal Income Taxes by a $10/ton Carbon Tax. An evaluation of the welfare costs of carbon taxation is carried out here by using a frequently employed concept of applied welfare economics known as the Hicksian compensating variations. According to this measure, welfare loss is defined as the additional income required to maintain the consumer's original utility level, given

Table 3.3 Incidence of Personal and Corporate Income Taxes in Pakistan Under Alternative Approaches

(a) Incidence of Personal Income Taxes in Pakistan under Alternative Approaches (tax as a percentage of total income)

Annual household income (rupees)	*No personal income tax in rural sector*			*Form of income tax shift to rural sector: Reduced wages for low-income rural households*			*Form of income tax shift to rural sector: Reduced rural wages overall*		
	Urban	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*
Under 7,200	0	0	0	0	0.74	0.58	0	0.54	0.42
7,200–8,400	0	0	0	0	0.83	0.63	0	0.60	0.45
8,400–9,600	0	0	0	0	0.88	0.63	0	0.64	0.46
9,600–12,000	0	0	0	0	0.73	0.46	0	0.52	0.34
12,000–18,000	0.02	0	0.01	0.01	0.57	0.35	0.01	0.41	0.25
18,000–24,000	0.04	0	0.02	0.02	0.70	0.38	0.02	0.32	0.18
24,000–30,000	0.02	0	0.02	0.01	0.01	0.01	0.01	0.29	0.13
30,000–36,000	0.20	0	0.13	0.09	0.02	0.06	0.09	0.26	0.16
36,000–42,000	0.22	0	0.16	0.10	0.02	0.07	0.10	0.31	0.17
42,000–48,000	0.40	0	0.29	0.18	0.03	0.13	0.18	0.19	0.18
48,000–54,000	0.77	0	0.50	0.35	0.01	0.23	0.35	0.18	0.29
Above 54,000	1.33	0	1.04	0.61	0.11	0.47	0.61	0.13	0.48

Note: Calculations under "no personal income tax in rural sector" are based on actual tax collections by income class as reported in Pakistan, Government of (1985). All figures from this survey are adjusted to bring the total in line with data from Pakistan, Government of (1988). Income tax collections on household income derived from urban sources or from graduated surcharges on land revenue are effectively zero.

(b) Incidence of Corporate Taxes in Pakistan under Alternative Approaches (tax as a percentage of total income)

Annual household income (rupees)	*Income category subject to the tax burden: Capital*	*Capital and consumption*	*Capital and labor*	*Tax incidence excluding taxes paid by state and foreign enterprises*
Under 7,200	1.18	1.71	1.56	0.85
7,200–8,400	1.06	1.55	1.64	0.77
8,400–9,600	1.04	1.53	1.70	0.76
9,600–12,000	1.26	1.62	1.69	0.91
12,000–18,000	1.46	1.70	1.69	1.06
18,000–24,000	1.70	1.79	1.68	1.24
24,000–30,000	1.68	1.76	1.69	1.22
30,000–36,000	1.75	1.78	1.68	1.28
36,000–42,000	1.77	1.78	1.66	1.29
42,000–48,000	1.81	1.79	1.65	1.32
48,000–54,000	1.89	1.76	1.63	1.34
Above 54,000	2.01	1.74	1.64	1.46

Source: Shah and Whalley (1991)

the vector of new consumer and producer prices resulting from the policy change. Thus it is the additional income that would make the consumer indifferent to the new vector of consumer prices. A Taylor-series approximation of the expenditure function, yields the following expression for the welfare cost of the tax system under the equal yield scenario mentioned above.

$$L^N = L - L' = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2 - (T_1^x + T_2^x)^2}{p_1^2}\right]p_1 x_1$$
$$-\frac{1}{2}\epsilon_{xw}\left[\frac{T_1^x T_1^H - (T_1^x + T_2^x)(T_1^H + T_2^H)}{P_1 W_1}\right]p_1 x_1 \cdot \theta$$
$$+\frac{1}{2}\epsilon_{Hp}\left[\frac{T_1^x T_1^H - (T_1^x + T_2^x)(T_1^H + T_2^H)}{P_1 W_1}\right]W_1 H_1 \cdot \theta \qquad (1)$$
$$+\frac{1}{2}\epsilon_{HW}\left[\frac{(T_1^H)^2 - (T_1^H + T_2^H)^2}{W_1^2}\right]W_1 H_1 .$$

where

ϵ_{xp} = own price elasticity of fossil fuel demand
ϵ_{xw} = cross price elasticity of fossil fuel demand with respect to after tax wages.
ϵ_{Hp} = elasticity of labor supply with respect to prices of fossil fuels.
ϵ_{HW} = elasticity of labor supply with respect to after tax wages.
p_1 = composite price of fossil fuels before carbon tax.
X_1 = quantity of annual consumption of fossil fuels before carbon tax.
W_1 = after tax hourly wages before revenue neutral labor income tax change.
H_1 = manhours of labor per year.
θ = share of fossil fuel expenditures to total expenditures.
T_1^x = pre-existing unit taxes on fossil fuels.
T_2^x = unit carbon tax (US$10/ton).
T_1^H = pre-existing labor income taxes per manhour.
T_2^H = reduction in per manhour labor income taxes.

The first term in the expression above captures the direct effect of higher fossil fuel prices on fossil fuel consumption. The two middle terms are the indirect effects (cross effects) of higher after tax wages on fossil fuel consumption and higher fossil fuel prices (lower real wages) on labor supply. The fourth term captures the direct effect of higher after tax wages on labor supply. The key parameters needed for the evaluation of this expression are: hours worked per year; current labor income tax rate; prices of energy products; quantity of energy consumption; current tax rate on energy; carbon tax rate (per unit of energy); elasticity of labor supply; and elasticity of energy demand. The data required to calculate these parameters for India, Indonesia, Pakistan, USA and Japan were collected from a variety of sources. Table 3.4 presents data on carbon emissions, carbon prices and energy taxes for the sample countries and Table 3.5 reports a summary of results on welfare effects based on the above model. These calculations suggests that replacement of personal income tax by an equal yield $10/ton carbon tax represents a welfare deteriorating proposition in the sample countries. Estimates of the welfare loss (compensating variations) range from a low of 1.5 cents per dollar of carbon tax revenues in Indonesia to a high of 17.5 cents per dollar in Pakistan. On economic efficiency considerations alone, therefore, carbon taxes cannot be supported as a replacement for personal income taxes. The difference in the welfare costs of a US$10 carbon tax arise primarily from variations in elasticity values (quite similar for our sample countries), pre-existing fossil fuel taxes, labor income taxes, carbon prices (i.e., market value of total fossil fuel consumption divided by carbon emissions) and energy price changes from the carbon tax. The price of carbon, a key parameter in the welfare cost calculations, is a function not just of fossil fuel prices, but also of the types and mix of fossil fuels consumed. A country that is a large consumer of coal will have a low price of carbon relative to a country that is a large consumer of natural gas or oil, even if the latter has the same level of fossil fuel prices. The relatively low welfare loss indicated for Indonesia is primarily attributable to lower levels of energy taxation in Indonesia, and the relatively large loss for Pakistan is due to high pre-existing energy taxes. In the case of Japan, the welfare loss is substantially lower than for Pakistan despite high pre-existing energy taxes. This results from the high price of carbon in Japan, which implies the percentage increase in energy prices due to the US$10 carbon tax will be low. The welfare loss for India compares well with that for the U.S., even though pre-existing taxes in India are much lower (see Tables 3.4 and 3.5). This is because the price of carbon in India is only half of the price in the U.S -- the result of India's high consumption of coal.

The welfare gain associated with the direct effect of lower labor income tax on labor supply is very small for India, Indonesia and Pakistan (at most 0.5% of the total welfare loss), because labor income taxes are low relative to wage income in these countries. Higher labor income taxes make the equivalent effect substantially larger in the U.S and Japan (20% and 15% respectively). For the first three countries, the indirect effects are small but positive, which indicates that the positive effect of higher real wages on energy consumption that results from the lowering of labor income taxes, dominates the negative effect of higher energy prices on labor supply. Again this is caused by low initial labor income taxes. In absolute terms, the indirect effects are negative and larger for the U.S. and Japan. This is because the negative effect of higher energy prices on labor supply dominates the positive effects on energy consumption of higher real wages associated with income tax reductions, and because the initial effective taxation of labor income is higher in the U.S. and Japan than in developing countries. These results imply that analyses which ignore pre-existing taxes will be in error, and could consequently result in possibly quite misleading policy advice. The difference in measured

Table 3.4 Carbon Emissions, Carbon Prices and Energy Taxes in Selected Countries, 1987

Country	Carbon Emissions (Million tons)	Carbon Price ($/ton)	Energy Taxes ($/ton)
India	148.2	117	10.69
Indonesia	26.6	200	0.00
Pakistan	13.2	253	65.13
USA	1246.1	198	26.64
Japan	237.1	538	104.80

Sources:

Carbon emissions - World Resources Institute (1990)

Carbon price - Authors' calculations based on data from Asia Development Bank and Energy Information Administration

Energy taxes - Authors' calculations based on data from International Energy Agency.

Table 3.5 Summary of Welfare Effects of a $10/ton Carbon Tax, 1987

	Carbon Tax Revenues	Welfare Loss (-) or Gain (+)			
	Million US$	Million US$	% of Carbon Tax Revenues	% of Total Revenues	% GDP
A. Revenue Neutral Change by Equal Yield Reduction in Personal Income Tax					
India	1482	-129	-8.7	-0.39	-0.06
Indonesia	266	-4	-1.5	-0.03	-0.005
Pakistan	132	-23	-17.5	-0.39	-0.07
USA	12461	-1049	-8.4	-0.11	-0.02
Japan	2371	-269	-11.4	-0.07	-0.008
B. Revenue Neutral Change by Equal Yield Reductions in Corporate Income Tax					
India	1482	+250	+16.9	+0.8	+0.11
Indonesia	266	+23	+8.7	+0.2	+0.03
Pakistan	132	+12	+9.0	+0.2	+0.04
USA	12461	-773	-6.2	-0.08	-0.017
Japan	2371	+213	+9.0	+0.06	+0.007
C. Raising Additional Revenues with NO Change in Existing Taxes					
India	1482	-130	-8.8	-0.40	-0.06
Indonesia	266	-4	-1.5	-0.03	-0.005
Pakistan	132	-23	-17.7	-0.40	-0.07
USA	12461	-1269	-10.2	-0.14	-0.03
Japan	2371	-291	-12.3	-0.08	-0.009
D. Raising Additional Revenues with NO Change in Existing Taxes but Accounting for Subsidies					
India	1482	0	0	0	0
Indonesia	266	+1	+0.4	+0.01	+0.005
Pakistan	132	-23	-17.7	-0.40	-0.07
USA	12461	-1269	-10.2	-0.14	-0.03
Japan	2371	-291	-12.3	-0.08	-0.009

Source: Calculations based on the models presented in Appendix A.

welfare costs can be substantial if pre-existing taxes are high, as is the case for Pakistan. If these pre-existing taxes were to be ignored, one would obtain for Pakistan fairly low estimates for the welfare costs of carbon taxes, similar to those for Indonesia. For India, the welfare costs of carbon taxes in a no tax case scenario, would then be twice the level of Pakistan and Indonesia (since, due to the Indian use of inexpensive coal, carbon prices in India are nearly half of those in Pakistan and Indonesia.)

Case B: Revenue Neutral Introduction of a $10/Ton Carbon tax by Equal Yield Reductions in the Corporate Income Tax. Feldstein's (1978) model is adapted to derive the following expression for the welfare costs of taxation (see Appendix A, Case B for details):

$$L^N = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2-(T_1^x+T_2^x)^2}{(p_1)^2}\right]p_1X_1$$

$$-(\eta_{sr}/r_1T+1-\sigma)\left[\frac{T_1^xT_1^R-(T_1^x+T_2^x)(T_1^R+T_2^R)}{p_1p_1^R}\right]p_1^RR_1\theta \qquad (2)$$

$$+\frac{1}{2}(\eta_{sr}/r_1T+1-\sigma)\left[\frac{(T_1^R)^2-(T_1^R+T_2^R)}{(p_1^R)^2}\right]p_1^RR_1$$

where

η_{sr} = elasticity of corporate savings with respect to after tax rate of return.

r_1 = after corporate tax rate of return on corporate savings.

T = number of years from time of savings to dis-saving.

σ = marginal propensity to save.

T_1^R = pre-existing unit tax on consumption in the period of dis-saving; i.e. unit tax on return on corporate savings.

T_2^R = reduction in unit tax on return on corporate savings.

p_1^R = after corporate tax discounted price of consumption in period of dissaving, i.e. after tax price of savings.

R_1 = savings in real terms such that $p_1^RR_1$ = nominal after tax value of savings.

The first term portrays welfare loss associated with a $10/ton carbon tax, and is equivalent to the corresponding term in Case A. The second term captures the interaction of reductions in corporate income taxes and a simultaneous increase in carbon taxes. An increase in the after tax price of energy products is likely to affect the consumption of energy products, and a reduction in after tax return on savings is likely to affect savings decisions. This term could be either positive or negative. The third term represents the welfare gain associated with a reduction in corporate income taxes. Corporate income may be considered as a return on savings, i.e. on a firm's total assets or shareholders' equity. Thus the third term captures the welfare effects of changes in after tax rate of return on savings in the corporate sector. Corporate income taxes induce intertemporal inefficiencies by reducing savings and increasing current consumption. Key parameters needed for the evaluation of this expression include: energy and retirement (future) consumption expenditures and prices, taxes on energy and retirement consumption, savings, marginal propensity to save out of exogenous income, uncompensated elasticity of savings with respect to after tax rate of return, and price elasticity of energy demand. These parameter values are obtained from a variety of sources. The model's results, presented in Table 3.5, suggest that, with the major exception of the U.S., an equal yield introduction of carbon taxes in part replacement of corporate income tax would uniformly represent a welfare-improving proposition for the sample countries. The estimated net welfare gain varies from a high of 0.11% of GDP for India, to a low of 0.007% of GDP for Japan. These positive net welfare effects lend support to the widely-supported view that corporate income taxes are far more distortionary than labor income taxes.

For the U.S., the revenue-neutral introduction of a $10/ton carbon tax to replace corporate tax revenues is, in contrast to the above, a welfare-deteriorating proposition. The welfare loss is estimated to equal 6.2% of carbon tax revenues or 0.017% of GDP. The effect is due to lower marginal taxation of corporate income in the USA in comparison with other sample countries.

Case C: Raising Additional Revenues From Carbon Taxes With No Change in Existing Taxes. The following expression for the evaluation of net welfare captures the direct effect of carbon taxes on energy demand through price increases, and also their indirect effect through reduced real wages -- the latter being associated with an increase in consumption taxation.[1]

$$L^N = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2-(T_1^x+T_2^x)^2}{(p_1)^2}\right]p_1X_1 - \epsilon_{HW}\left[\frac{-T_2^xT_1^H}{p_1W_1}\right]W_1H_1\theta \qquad (3)$$

The key elasticity parameters required for the evaluation of the above expression are the demand elasticities for fossil fuels and supply elasticity for labor. The results presented in Table 3.5 suggest that although the welfare costs of carbon taxes are significant, they represent only a small fraction of carbon tax revenues. Estimates for the sample countries range from a low of 1.5 cents per dollar for Indonesia (0.005% of GDP), to a high of 17.7 cents per dollar for Pakistan (0.07% of GDP). The welfare losses for India, Indonesia and Pakistan are only slightly higher than those obtained in case A. This is because, given very ineffective pre-existing labor

[1] For a formal derivation, see Appendix A, Case C.

income taxes and substantial tax evasion, the direct welfare effect of labor income tax reductions is very small for these countries. The difference in the two cases is larger for the U.S and Japan because of higher pre-existing labor income taxes and levels of tax compliance. Poterba (1991) finds a much lower welfare loss for the US (average welfare costs of 3 cents per dollar of carbon tax revenues, or about 0.01% of GDP) in the revenue increase scenario by assuming no pre-existing taxes and no wage effects from carbon taxes. Thus levels of pre-existing taxes (on energy, income etc.) are critical in the estimation of the overall welfare effects associated with tax changes. Calculations that ignore these effects will understate the welfare cost of tax policy changes.

Case D: Raising Additional Revenues From Carbon Taxes With No Change in Existing Taxes but Accounting for Subsidies. The efficiency costs of carbon taxes will be over-stated if, as in Cases A through C, subsidies are ignored. An efficient energy pricing policy calls for price to equal long run marginal cost (in the case of no externalities). Thus it is interesting to re-evaluate this welfare calculation by recognizing *existing* subsidies (Larsen and Shah 1992). For the sake of simplicity, only the welfare cost of the carbon tax's direct effect on fossil fuel consumption is calculated, and the indirect effect on labor supply of higher fossil fuel prices is ignored. This is justified because the indirect effect on labor supply is less than 1% of total welfare costs. In order to calculate the welfare cost, petroleum products, natural gas and coal are considered separately and the same own price elasticity of demand is applied to all product groups. Furthermore, the welfare calculation ignores the substitution effect between coal and petroleum products in cases A-C, thus overstating true welfare costs.

Significant fossil fuel subsidies exist in India and Indonesia. The price of coal in India was only 85% of long run marginal cost in 1990 (Bates and Moore, 1991), implying a 15% subsidy. By (conservatively) assuming a similar level of subsidy in 1987, the year used here for welfare calculations, a US$10 carbon tax leads to an approximately 26% increase in the price of coal at 1987 prices. Thus a large proportion of the tax acts to remove the subsidy and should be considered a welfare gain. The welfare cost of the carbon tax on petroleum products and natural gas is estimated to be equal to the welfare gain of the subsidy removal on coal. The overall welfare effect of a US$10 carbon tax is therefore approximately zero, rather than the -8.8% of carbon tax revenues in Case C. Similarly, petroleum products in Indonesia are priced significantly below world prices -- approximately 35% lower in 1987. Following the same approach as for India, the carbon tax on petroleum products in Indonesia represents a welfare gain, although it is too small to eliminate the subsidies completely. The welfare gain is larger than the welfare costs of the carbon tax on coal and natural gas. Thus, in comparison with Case C's welfare loss of -1.5%, the net effect is a small welfare gain of 0.4% of carbon tax revenues. This section illustrates not only that are pre-existing taxes critical in estimating the welfare effects of carbon taxes, but that many subsidies are also. Calculations that ignore subsidies will over-state the welfare costs of tax policy changes.

In conclusion, the case for carbon taxes on efficiency considerations alone depends on whether they are introduced in a revenue-neutral manner, whether they replace corporate income taxes, and whether fossil fuel subsidies exist. According to the calculations presented here, such taxes do not fare so well against personal income taxes, at least for countries with pre-existing energy taxes and no subsidies. Clearly, however, an overall assessment of carbon taxes must therefore consider their impact on greenhouse gases and local pollutants, as well as on industrial performance and economic growth. These issues are taken up next.

4.0 The Impact of Carbon Taxes on Greenhouse Gases and Local Pollutants

Through their impact on aggregate use and composition of fossil fuel consumption, carbon taxes may reduce the emissions of local and regional pollutants such as nitrous oxides (NOx), carbon monoxides (CO), particulates (PM) and sulphur dioxides (SO_2) as well as carbon emissions. This section deals with the impact of carbon taxes on NOx, SO_2 and PM emissions. These extent of these latter three emission types depend on technology, combustion processes and sulphur content of fossil fuels; emission coefficients therefore vary greatly across sectors and countries. The data on emissions are derived here from available sectoral emission coefficients and sectoral fossil fuel consumption (OECD 1989, and Radian Corporation 1990). Table 4.1 illustrates the impact of a US$ 10 carbon tax on fossil fuel prices, and on CO_2, SO_2, NOx and PM emissions for selected countries.

The impact of the carbon tax on CO_2, SO_2, NOx and PM depends on the percentage increase in the end-user price of each fuel, in addition to the price elasticity of demand and emission coefficients. It is calculated as follows:

$$Z = \Sigma_{ij} e^{Z}_{ij} \delta Q_{ij} = \Sigma_{ij} e^{Z}_{ij} Q_{ij} \epsilon_{ij} \delta p_{ij}/p_{ij} \qquad (4)$$

where: Z is tons of reductions in CO_2, SO_2 or NOx; i are sectors; j are fuels (coal, natural gas and petroleum products); e^{Z}_{ij} is the emission coefficient of Z for fuel j in sector i; Q_{ij} is consumption of fuel j in sector i; ϵ_{ij} is the own price elasticity for fuel j in sector i; and $\delta p_{ij}/p_{ij}$ is the percentage increase in price of fuel j in sector i from the carbon tax. Interfuel substitutions are ignored.

The elasticity of energy demand, being fairly similar across all the sample countries, does not contribute to the cross country differences in emission reductions. The price of coal shows the largest increases primarily because of the low price of coal per ton. The increases for petroleum products and natural gas are only marginal in comparison because of their much higher current prices per ton. India shows the highest estimated emission reductions principally because coal is the predominant fossil fuel in consumption; it experiences relatively large reductions due to the high price increase induced by the carbon tax. Reductions are lowest in Japan because of high pre-existing energy prices that induce very low price increases from the carbon tax and thus low reductions in fossil fuel consumption. SO_2 emission reductions are highest in Pakistan because most such emissions are from high sulphur (5-6%) coal. SO_2 emission reductions are also quite high in the United States because of the large share of coal in consumption. Because of low coal use, Indonesia experiences relatively modest emission reductions. In all sample countries, percentage PM reductions tend to follow percentage reductions in the other pollutants.

A benefit-cost analysis of a US$10 carbon tax can now be made by comparing the welfare losses (Table 3.5) of a revenue-increasing carbon tax (with no reductions in either labor

Table 4.1 Costs and Benefits of Carbon Taxes for Selected Countries, 1987

		Pakistan	Indonesia	India	United States	Japan
Fossil fuel consumption (million local currency)		58209	8793837	222744	246502	15759000
Carbon (C) emissions (million tons)		13.2	26.6	148.2	1246.1	237.1
Price of carbon (per ton): Local Currency		4409	330595	1503	198	66465
US$		253	200	117	198	538
Energy Taxes (US$/ton of carbon)		65.13	0.0	10.69	26.64	104.80
Carbon tax (US$/ton)		10	10	10	10	10
Carbon tax (local currency/ton)		174	16500	129	10	1235
Elasticity of energy demand		-0.64	-0.6	-0.651	-0.6	-0.55
Price increase (from carbon tax) of						
coal		37.8%	17.5%	26.2%	18.3%	8.7%
petroleum products		3.2%	5.8%	2.3%	3.4%	0.15%
natural gas		2.6%	4.4%	3.0%	4.3%	1.4%
Emissions of (000 tons)						
PM		44	87	1192	6478	463
SO2		321	337	2207	17900	1600
NOX		203	434	2090	17400	1400
Emission reductions (%)						
C		-4.5%	-3.9%	-13.3%	-5.3%	-1.6%
PM		-11.6%	-5.0%	-15.3%	-7.8%	-0.6%
SO2		-19.1%	-4.6%	-15.9%	-10.0%	-2.3%
NOX		-3.8%	-3.8%	-11.9%	-5.6%	-1.2%
(1) Welfare cost of a US$ 10 per ton carbon tax (revenue increasing tax) million US$ (Table 3.5)		-23	-4	-130	-1270	-292
(2) Cost of carbon (C) reductions (US$/ton) (1) divided by tons of C reductions		38.7	3.9	6.6	13.8	78.9
(3) Price level (GDP/Penn GDP 1987)		0.23	0.35	0.34	1	1.55
(4) Benefit-cost ratio*	High (SO2+NOX+PM)	1.8	17.9	9.5	11.2	1.3
	Medium (SO2+NOX+PM)	1.6	12.9	7.5	8.7	1.0
	Low (SO2+NOX+PM)	0.5	2.2	1.9	2.1	0.2

* "High" is based on Glomsrod et al (1990); "Medium" is based on Bernow and Marron (1990); "Low" is based on EPA/Energy and Resource Consultants, Inc. referenced in Repetto (1990).

Source: Authors' calculations

Table 4.2 Marginal Benefits of NOx, SO_2 and PM Reductions (US $/ton)

	NOx	SO2	PM
Glomsrod et al. * ("High")	10300	1400	3300
Bernow and Marron ("Medium")	6500	1500	4000
EPA/Energy and Resource Consultants ("Low")	230	637	2550

* The first study is for Norway and the two last for the United States.

Source: Glomsrod et al (1990), Bernow and Marron (1990), Repetto (1990).

income taxes or corporate income tax) with the benefits of emission reductions. Welfare cost calculations are for the case which does not account for subsidies. Thus welfare costs are substantially overstated for both India and Indonesia. Benefits are estimated given only SO2, NOx and PM emission reductions; no attempt is made to estimate the benefits of reductions in emissions of CO_2, CO, lead and ground level ozone. The monetary value of emission reductions for any of these gases will be highly uncertain, in part because the damage emissions cause depends on: the aggregate level of emissions, climatic and topographic conditions, population density around emission sources and on concentration levels of the pollutant. The main monetary benefits per reduced ton of SO2, NOx and PM emissions, come from improvements in health and reduced corrosion (see Table 4.2, for results from three independent studies). Glomsrod et al (1990) and Bernow and Marron (1990) report the highest estimates based on their studies for Norway and the United States, respectively. EPA/Energy and Resource Consultants Inc. report (for the United States) significantly lower benefits, in particular for NOx. This low benefit estimate for NOx may result from excluding chronic health effects. Benefit figures are adjusted by Penn GDP relative Purchasing Power Parity indices (Summers and Heston, 1991) for each sample country, thereby allowing more meaningful cross-country comparisons. Note that this procedure assumes a degree of transferability for different countries' externality measures that is unlikely to be satisfied in practice; estimates of such measures are therefore likely to be crude at best.

Notwithstanding the above caveat, the comparison of costs and benefits (Table 4.1) suggests that, on local environmental grounds alone, Indonesia, India and the United States can benefit substantially from a carbon tax. Benefits exceed costs by a ratio of more than 7 in two cases, and approximately 2 in the case of the lowest benefit estimates. In the case of Pakistan and Japan, because of high pre-existing energy taxes and thus high a welfare cost for carbon taxes, the benefit-cost ratio is significantly lower, although still greater than one.

It is important to note that, although the monetary benefits of emission reductions are uncertain, there emission reductions have additional benefits that are not accounted for here as already mentioned. Furthermore, welfare losses are based on the worst-case scenario of a revenue-increasing carbon tax not compensated for by a reduction in other taxes. Last, but not least, significant energy subsidies in India and Indonesia are not incorporated in the welfare calculations, which consequently overstate welfare losses.

Note also that these benefit-cost ratios do not depend on the price elasticity of demand for fossil fuels, which is assumed identical for each fuel. Both the welfare costs of carbon taxes and the quantity of emission reductions are proportional to that elasticity parameter, which is therefore canceled out in the ratio of benefits and costs. The latter depends primarily on pre-existing taxes on fossil fuels (which affects welfare costs) and on the valuation of emission reductions of SO_2 and NOx in both relative and absolute terms. Furthermore, the calculations presented here do not attempt to identify least-cost policies for local pollutant reduction. They merely quantify various additional benefits from carbon taxes that are frequently ignored in the literature.

One means of accounting for the non-uniformity of emission externality costs across countries is to adjust the benefits of emission reductions for variations in population density and rural/urban population ratio. Here, an equal weight is applied to population density and urbanization. In consequence, benefits are larger by an average factor of two for Pakistan, Indonesia and India. Thus the benefit-cost ratio is larger than one for Pakistan even when lowest benefit estimates are used. For Japan, benefits are as much as twelve times higher. This is the result of a very high population density, which brings the ratio to 2.4 in the case of lowest benefit estimates and to as much as 14 in the case of highest benefit estimates. In this circumstance, Japan would benefit even more from a carbon tax than the United States.

A cost analysis of carbon reductions is also illustrated in Table 4.1. The cost of carbon reductions is stated in terms of the welfare costs of a revenue-increasing US $10/ton carbon tax, divided by tons of carbon reductions. The large cost differences across countries are caused mostly by differences in pre-existing energy taxes (high pre-existing energy taxes implying high welfare costs) and percentage carbon emission reductions. To illustrate this point, the cost of carbon reductions may be stated as follows:

$$C = (W/R)(R/E) = (W/R)(t^*C_e/E) = W/E \qquad (5)$$

where: C is the cost per ton of carbon reductions; W is the total welfare cost of the carbon tax; R is total carbon tax revenues; E is tons of carbon emission reductions; t is the carbon tax rate (US $10/ton); and C_e is the total tons of carbon emissions (thus C_e/E is the reciprocal of percentage carbon emission reductions). Equation (5) reveals that C is high if welfare cost per tax revenue dollar (W/R) is high (Table 3.5, C), and/or if percentage carbon emission reduction is low (Table 2.2). The cost per ton of carbon emission reduction is lowest for Indonesia, even though percentage emission reduction is low. This is because of virtually non-existent energy taxes, which imply very low welfare costs per tax revenue dollar. Cost per ton is highest in Japan because of the combination of high welfare costs per tax revenue dollar and very low percentage emission reductions. The results in Table 4.1 also suggest that optimal carbon taxes are not uniform across countries because of different levels of pre-existing energy taxes and impact on local pollutants.

The preceding analyses of fossil fuel consumption and emission reductions considers only aggregate fuel reductions and not interfuel substitution. But since a carbon tax may induce significant interfuel substitutions, it is to be expected that the estimated emission reductions in Table 4.1 are overstated, given own-price elasticities. However, allowing for interfuel substitution would reduce the welfare costs of the carbon tax, such that the overall ratio of benefits to costs would most probably be only marginally affected.

In conclusion, the above analysis suggests that a carbon tax has significant benefits in terms of both local pollutant and CO_2 reductions. A monetary benefit-cost analysis indicates that, for countries with low or non-existent energy taxes, a carbon tax can be justified on local environmental grounds alone, even ignoring its benefits from a public finance viewpoint.

5.0 Carbon Taxes, Industrial Performance and Economic Growth

Carbon taxes by changing the relative prices of inputs can impact on the production, financing and investment decisions of firms. In this section, the Bernstein-Shah dynamic model of production structure (forthcoming) is used to examine the impact of carbon taxes on the economic performance of Pakistan's apparel and leather products industries (1966-84). Several features of this dynamic model are noteworthy.

The costs of adjustment are treated as internal to the firm and are explicitly modelled. These capital adjustment costs imply that capital input does not necessarily attain its long-run desired level within any one contemporaneous period. The model formulation allows for estimation of this speed of adjustment. Investment in capital results in some foregone output in the short run. The model distinguishes short run, intermediate run and long run effects of tax policy initiatives. These effects are influenced by the varying degree of capital adjustment. The model also treats the determination of output supplies, variable and quasi-fixed input demands simultaneously. Thus both the direct and indirect effects of tax policy changes are captured in the model. Moreover, the dynamic nature of the model allows for direct and indirect effects to be estimated in all three runs of production. In addition to the explicit modelling of adjustment costs, the Bernstein-Shah model incorporates several features of producer behavior which are absent from the Jorgenson-Wilcoxen framework. Output supply is endogenous and not solely a function of factor demand or of investment. Furthermore, product markets are not assumed purely competitive and the nature of firm interdependence, as measured by the conjectural elasticity parameter, governs the structure of product markets. Finally, the model recognizes financial capital market imperfections as firms are constrained by the rate of return that can be earned on their financial capital. Rates of return on equity and debt capital are treated as exogenous to firm's behavior, and cannot therefore be influenced by shareholders. Under such circumstances, the interest of owners is best served by maximizing the expected present value of the flow of funds to shareholders and bondholders. In other words, the firm's objective function is to maximize the expected present value of financial capital. The above mentioned product and financial market imperfections are germane to most developing countries.

Table 5.1 Impact of Carbon Taxes on Pakistan's Industries Application of Bernstein-Shah Dynamic Variable Profits Model and Shah-Baffes Dynamic Flexible Accelerator Model

		Own Price Elasticities			Carbon Tax Elasticities		Impact of a US$10/ton			Carbon Emissions reductions	
		Apparel	Leather	Aggregate manufacturing	Apparel	Leather	Apparel	Leather	Aggregate manufacturing	Apparel & Leather	Aggregate manufacturing
	Y				-0.00081	-0.00098	-0.032%	-0.039%	-0.205%		
	L				-0.00086	-0.00090	-0.034%	-0.036%	-0.137%		
Short Run	M	-1.521	-0.979	-0.514	-0.00193	-0.00133	-0.076%	-0.053%	-0.482%	-4.8%	-7.6%
	K				-0.00052	-0.00072	-0.021%	-0.028%	0.499%		
	Y				-0.00111	-0.00145	-0.044%	-0.057%			
	L				-0.00108	-0.00147	-0.043%	-0.058%			
Intermediate Run	M	-1.402	-1.135	-	-0.00178	-0.00154	-0.070%	-0.061%		-4.9%	-
	K				0.00085	-0.00121	-0.034%	-0.048%			
	Y				-0.00220	-0.00272	-0.087%	-0.107%			
	L				-0.00198	-0.00307	-0.079%	-0.121%			
Long Run	M	-2.461	-2.879	-	-0.00313	-0.00392	-0.124%	-0.155%		-10.4%	-
	K				0.00201	-0.00255	-0.079%	-0.101%			

Notations: Y = Output
L = Man Years worked
M = Intermediate Inputs
K = Capital stock

Source: Model Results

Table 5.2 Impact of a US $10 Carbon Tax on Manufacturing Value Added and Local Externalities

PAKISTAN

	Pakistani Apparel & Leather Industries			Pakistani Aggregate Manufacturing Industries
	Short run	Intermediate run	Long run	Short run
Output effect (%)	-0.035%	-0.051%	-0.098%	-0.205%
Output effect (in 000 US$)	-102	-148	-284	-20900
Value added effect (in 000 US$)	-19.1	-27.3	-52.3	-6650
Emission Reductions (%)*				
NOX	-4.9%	-5.0%	-10.5%	-7.4%
SO2	-4.7%	-4.8%	-10.2%	-18.4%
PM	-4.8%	-4.9%	-10.3%	-12.9%
CO2	-4.8%	-4.9%	-10.4%	-7.6%
Cost of CO2 reductions - US$/ton (loss of value added divided by tons of CO2 reductions)	44.2	61.9	55.9	14.5
Benefit-Cost Ratios associated with the impact of a US $10 carbon tax on value added and local pollutants **				
High	2.5	1.8	1.9	3.9
Medium	1.6	1.1	1.2	3.5
Low	0.09	0.06	0.07	1.1

* Emission reductions are percentage of emissions from the Apparal and Leather industries or from total manufacturaing industries.

** Includes sulfur dioxides (SO2), nitrous oxides (NOx) and particulate matters (PM). "High" is based on Glomsrod et al (1990); "Medium" is based on Bernow and Marron (1990); "Low" is based on EPA/Energy and Resource Consultants, Inc. The last study does not include chronic health effects of NOx emissions.

Source: Model based calculations

Accounting for them, thus adds a sense of realism to the analysis of producer responses in these countries.

The estimation model is characterized by an after tax normalized shadow variable profit function, output supply and input demand and capital input demand equations. The model fits the data quite well. Furthermore, estimated parameters satisfy the conditions that the after tax shadow variable profit function be concave in capital and net investment and convex in prices.

Table 5.1 provides estimates of carbon tax elasticities with respect to input demands and output supply in the short, intermediate and long runs. These tax elasticities are then used to calculate carbon tax effects at mean sample values. A \$10/ton carbon tax on the apparel and leather industries leads to reductions in output and input demands in all periods, with the leather industry experiencing slightly higher reductions in output than the apparel industry. This difference is primarily attributable to the slightly higher energy intensity of the leather industry. Long run output impacts are (-)0.09% for apparel and (-)0.11% for leather goods, both of which are higher than intermediate and short run impacts. Higher adverse effects in the long run arise because the model estimation suggests energy inputs serve as complements to both labor and capital in the two industries.

To examine the same effects for manufacturing industries in Pakistan overall, a flexible accelerator type dynamic factor demand model developed by Shah and Baffes is implemented using time series data for the period 1956 to 1985. This model employs a flexible and non-restrictive technology and captures the short run divergence of fixed factors from their equilibrium values as well as the speed of such adjustment. Parameter estimates from the model suggest some pairwise substitutability among energy (materials) inputs and capital and labor. The model results suggest that the imposition of a \$10 per ton carbon tax on Pakistani manufacturing industry will result in an output loss of 0.21% in the short run (see Table 5.1).[2] The primary reason for larger output losses in aggregate manufacturing than in the apparel and leather industries is the substantial impact of the carbon tax on the price of coal. Coal is used primarily in industries other than apparel and leather. Thus energy prices for aggregate manufacturing increase substantially more than for the apparel and leather industries.

A comparison of value added losses with the health benefits of reductions in local externalities throws some (albeit limited) light on the cost-benefit calculus of carbon taxes. Table 5.2 reports estimates of costs associated with carbon taxes, as well as benefits arising from a reduction in local externalities. Data limitations restrict the analysis to NOx, SO_2 and particulate matter (PM) only. The dollar values on local externalities are based on the same three studies used in Section 4.0, adjusted for purchasing power parity. Benefit to cost ratios are higher for aggregate manufacturing than for the apparel and leather industries because relatively large emission reductions from reduced consumption of high sulfur coal more than offsets the higher loss of value added. Ratios are larger than one except in the case with the lowest benefit estimates for the apparel and leather industries. These tentative calculations suggest that losses of value added are offset by health benefits associated with NOx, SO_2 and PM emission reductions, even if the reduction in global externalities associated with curtailing CO_2 emissions is completely ignored. Table 5.2 also reports estimates for the average cost of

[2] Jorgenson-Wilcoxen (1990) obtain -0.5% long run output effect for the U.S. for a \$15.45/ton carbon tax

carbon reductions associated with a US $10/ton carbon tax in terms of US$/ton of carbon reductions, ignoring the benefits of reductions in local externalities. Calculations suggest that such costs are higher in the apparel and leather industries. The is primarily because total carbon emissions relative to value added in these two industries are much lower than in the overall manufacturing sector, while model results suggest that the elasticity of output or value added with respect to energy prices is only slightly lower. Thus losses of value added relative to carbon emission reductions are higher in the apparel and leather industries.

6.0 Tradeable Permits

Tradeable emissions permits represent an alternative instrument that can ensure marginal costs of emission reductions are equalized across domestic sources and across countries. Given both perfectly competitive markets and certainty, permits are equivalent to emissions taxes (see Hoel 1990). Tradeable permits afford direct control over quantities of emissions as opposed to a carbon tax regime's indirect influence through prices. They are also easier to implement as an initial allocation of such permits reduces the resistance of existing emitters. Furthermore, tradeable permits in terms of their regulatory effects are more transparent to policy makers and administrators (see Oates and Portney, 1991). Tradeable permits have also been cited for their potential as a hedging instrument against risk and a vehicle for international technology transfer.

Epstein and Gupta (1990) have argued that tradeable permits could serve as an instrument to reduce the risk of investing in backstop technology R&D. They argue that agents or nations that invest in R&D are exposed to a high probability of failure, although also to high profits in the event of success. If R&D investments turn out a successful technology that significantly reduces the costs of carbon emission reductions, the price of emissions permits will fall. If the investments yield no return the price of permits is expected to rise. This means that risk averse investors can purchase futures on emission permits[3] as a hedging against risk. In this case, total investments in R&D can be expected to be higher than if a market for emission permits did not exist. One could further argue that carbon taxes would also induce higher levels of investment if tax revenues were pooled (fully, or in part) in an R&D fund or used to subsidize R&D. A closer analysis of the effectiveness of these alternatives seems appropriate given potential gains from the development of backstop technology.

Emissions permits will induce international technology transfers if initial emissions allocations are such that industrialized countries will purchase emissions permits from developing countries. If this is the case, developing countries may purchase more energy efficient technology from industrialized countries until the marginal benefit is equal to the permit price. This transfer could potentially be quite substantial and significant for developing countries. Its magnitude depends on the costs of emission reductions and initial permit allocations (Larsen and Shah 1992b). If costs of emission reductions are high (after some smaller initial reductions) in industrialized countries, then developing countries will want to purchase more emissions permits from developing countries than if costs are low. This would imply larger revenue accumulations

[3] According to the New York Times, the Chicago Board of Trade will create a private market for trading in sulfur dioxide emission permits and forward contracts, and a futures market is also considered.

in developing countries which could be used to purchase more energy efficient technology. Technology transfers may turn out to be significant for developing countries because, in addition to reducing energy dependency, new capital embodies technological progress and thus contributes to increased total factor productivity. Total factor productivity gains are considered an important component for economic growth and improved international competitiveness.

In practice, tradeable permits are subject to important limitations. These include: the "thinness" of permit markets, the presence of large buyers and sellers, and lack of any mechanism to deal with overshooting the mark. In the U.S., it is observed that the main reason the permit markets are not as well-functioning as envisioned is the "thinness" of the market, especially on the supply side, that is largely due to trading restrictions and unclear definitions of property rights. When permits are infrequently traded, clear price signals are absent, thereby impairing the functioning of the permit system. On the other hand, a carbon tax is in itself a clear measure of the cost of emissions.

To avoid ill-functioning permit markets, the number of potential traders should be sufficiently large. In the case of carbon emission permits, an insufficient number of traders may be avoided by integrating international (inter-country) and domestic markets. Market power is then eliminated and sufficient liquidity provided, especially if the market is open to outside parties as well as "emitters". In this case, any agent -- a producer or consumer -- obtains emission permits at a price quoted at trading boards, in much the same way as foreign exchange is traded and rates are quoted in international markets.

There are alternative market arrangements, although an international (inter-country) market seems a minimum requirement because the costs of emission reduction can be expected to differ substantially across countries. Emission permits, traded internationally, allow marginal costs of reduction to be equalized across nations. Permits may be traded independently within nations so that marginal costs are equalized across domestic sources. It is also possible that permits will only be traded internationally and that carbon taxes will be used domestically. Alternatively, some countries may use emissions permits to reduce domestic emissions while other countries use taxes. In the latter case, there may be separate international and domestic permit markets. Any market arrangement that reduces the number of traders below that in a globally integrated market is exposed to the danger of market inefficiencies (market power, illiquidity). However, the transactions costs of such markets may be too high to justify the establishment of a market that involves all "emitters" of carbon gases, from large industrial firms through to the individual household using fossil fuels. A carbon tax avoids these transactions costs. In global trading of permits, large countries can influence prices. For a large seller, it is optimal to have higher emissions than the level indicated by the marginal cost of reductions (the market price for quota); and the opposite holds true for a large buyer (see Hoel, 1990).

A potential problem with permit markets is that the supply of permits is by no means guaranteed to be intertemporally fixed. New information about the costs of emission reductions and of global warming will induce policy makers to change the total supply. Furthermore, such changes cannot be preannounced at the initial time period since the changes are a function of the new information in future periods. New information is therefore similar to random shocks. This exposes permit holders to the risk of permit price changes that cannot be ignored. Two ways of getting around this problem are to establish a futures market, or to let permits expire at the end of each time period in order to issue the new supply at market determined prices.

Clearly, additional transactions costs will be unavoidable, thereby making tradeable permits less of an attractive instrument.

It is not clear whether or not there will be a regional or global policy response to the greenhouse effect. In the event of such a response, the most talked about scenario is to set a target of a certain percentage global emissions reduction below their current (or some future) level, or to stabilize the current (or some future) global stock of emissions. The most frequently discussed target is a 20% reduction below current levels by a specific year, although a 50% reduction is considered necessary to stabilize the stock of global emissions at current levels (World Resources Institute 1990). What is the optimal policy instrument to achieve this objective? A carbon tax will result in some uncertainty about the magnitude of reductions but less uncertainty about the cost of reductions. Under a regime with tradeable permits the magnitude of emission reductions will be known, but there may be great uncertainty about the total cost of reductions. This is an important distinction between the two instruments in the case of global warming. Oates and Portney (1991) make this distinction when comparing a carbon tax with tradeable permits. If there is great uncertainty regarding the costs of emission reductions, a tax is preferred in order to avoid potentially large unexpected costs. (This is particularly important if the marginal costs of reduction are rising steeply after some initial reductions have been achieved.) However, if the costs of global warming are believed to be unacceptably high or there is a threshold effect, it becomes very important to limit total emissions to an upper bound. In this case, tradeable permits are preferred to a tax even though there will be great uncertainty regarding the costs of emission reductions. At this point in time, we do not know whether there is a threshold with respect to the stock of carbon emissions beyond which temperatures would rise exponentially. Furthermore, we know little about the economic costs and environmental consequences of global warming. Given present ignorance regarding the global warming phenomenon, one might currently argue for a carbon tax in order to limit unexpected costs of emission reductions. When, or if, future research reveals more about possible threshold effects and the costs of warming, tradeable permits may become the appropriate instrument.

A global tradeable permit (or carbon tax) regime poses an additional problem in terms of initial permit allocations (or redistribution of tax revenues). Larsen and Shah (1992b) evaluate alternative allocations, such as allocations relative to GDP or population, and conclude that neither of the two are likely to induce participation from significant groups of countries. They propose an alternative allocation, based on willingness to pay for carbon reductions, that may induce broader participation in an international treaty.

7.0 Summary and Conclusions

This paper has evaluated the case for carbon taxes on national interest grounds. As a background to this discussion, it has also reviewed current energy pricing regimes in developing countries and their implications for greenhouse gas emissions (Larsen and Shah, 1992). The following conclusions emerge from the analysis:

• A global carbon tax raises difficult issues of tax administration, compliance and international resource transfer, and is therefore unlikely to be implemented in the near future.

• National carbon taxes can raise significant amounts of revenue in a cost effective manner and, in developing countries, are not likely to have as regressive an impact as commonly perceived. Such a tax also fares quite well in efficiency terms if introduced in a revenue-neutral manner as a partial replacement for corporate income taxes. In general, the welfare costs of carbon taxes vary directly with the existing level of energy taxes and therefore a carbon tax should be the instrument of choice for countries with no or low levels of energy taxation, such as Indonesia and India.

• A carbon tax also has significant benefits in terms of local pollutant reductions in addition to CO_2 reductions. The cost-benefit analysis for selected countries presented in this paper suggests that countries with low or non-existent energy taxes can receive substantial net gains from a carbon tax, not just in efficiency terms, but on grounds of local environmental considerations alone.

• A carbon tax of US $10/ton results in very small output losses for the Pakistani industries analyzed in this paper. The estimated effects are somewhat lower than comparable estimates for the U.S. obtained by Jorgenson-Wilcoxen (1990). The value added losses are, however, offset by the health benefits associated with reductions in NOx, SO_2 and particulate matter (PM) emissions, even if reductions of global externalities associated with the curtailment of CO_2 emissions are ignored.

• Tradeable permits represent a preferred alternative to carbon taxes should there be a known critical threshold in the stock of carbon emissions beyond which temperatures would rise exponentially. Given our current lack of knowledge about the costs of carbon emission reductions and the threshold effect, a carbon tax appears to be a superior and more flexible instrument that avoids potentially large and unexpected costs.

Thus, while a universal case for national carbon taxes cannot be made, even ignoring global externalities, such taxes make eminent sense for a large number of developing countries in terms of efficiency, equity and local environmental externality considerations.

APPENDIX: Measurement of Differential Welfare Costs of Carbon Taxes

Welfare costs L of a tax system $T_1 = (T_1^1, T_1^2, \ldots T_1^n)$ introduced at a non-distorted equilibrium with prices $p_0 = (p_0^1, p_0^2, \ldots p_0^n)$ is defined as the difference in the expenditure level E necessary to maintain a utility level $\bar{U}$ in the presence of T and the expenditure level required to sustain $\bar{U}$ in the absence of T, minus the tax revenues R:

$$L(p_1,p_0,\bar{U}) = E(p_1,\bar{U}) - E(p_0,\bar{U}) - R(p_1,p_0,\bar{U}) \qquad (1)$$

with $p_1 = p_0 + T_1$.

The expenditure functions can be approximated by a second order Taylor expansion in prices. Thus in general the welfare costs of taxes introduced at a non-distorted initial equilibrium is

$$L = -\tfrac{1}{2} \Sigma \Sigma S_1^{ij} T_1^i T_1^j \qquad (2)$$

where $S_1^{ij} = \delta X_1^i / \delta p_1^j$, the cross-derivative of the compensated demand function and T_i is the unit tax of good i.

In the presence of existing taxes, welfare costs of changes in the tax system is not simply L. An intermediate step becomes necessary (Feldstein 1978). Consider a revenue neutral tax policy change such that $p_2 = p_1 + T_2$, with T_2 a vector of additional taxes. The total welfare costs of the tax system $T_1 + T_2$ is

$$L'(p_2,p_0,\bar{U}) = E(p_2,\bar{U}) - E(p_0,\bar{U}) - R(p_2,p_0,\bar{U}) \qquad (3)$$

or in general

$$L' = -\tfrac{1}{2} \Sigma \Sigma S_2^{ij} (T_1^i+T_2^i)(T_1^j+T_2^j) \qquad (4)$$

The additional welfare costs of the revenue neutral tax change is

$$L^N = L - L' = E(p_1,\bar{U}) - E(p_2,\bar{U}) \qquad (5)$$

since $R(p_2,p_0,\bar{U}) = R(p_1,p_0,\bar{U})$ because of revenue neutrality.

Case A: Welfare Costs of Carbon Taxes That Displace Equal Yield Personal Income taxes.

Consider the case of two goods (x, 1-H), where x is fossil fuels and 1-H is leisure (H is supply of labor). Prices of fossil fuels and leisure is (P_0, W_0) in an initial non-distorted equilibrium. The welfare cost of pre-existing taxes on fossil fuels and labor income (T_1^x, T_1^H), before introducing a carbon tax, is given by (2):

$$L = -\frac{1}{2}\frac{\partial x}{\partial p}T_1^x T_1^x - \frac{1}{2}\frac{\partial x}{\partial w}T_1^x T_1^H - \frac{1}{2}\frac{\partial(1-H)}{\partial p}T_1^x T_1^H - \frac{1}{2}\frac{\partial(1-H)}{\partial w}T_1^H T_1^H \tag{6}$$

with $T_1^H = W_1 - W_0 < 0$, $T_1^x = p_1 - p_0 > 0$. Writing L with compensated elasticities, (5) becomes

$$L = -\frac{1}{2}\epsilon_{xp}\left(\frac{T_1^x}{p_1}\right)^2 p_1 x_1 - \frac{1}{2}\epsilon_{xw}\left(\frac{T_1^x}{p_1}\right)\left(\frac{T_1^H}{W_1}\right)p_1 x_1 + \frac{1}{2}\epsilon_{Hp}\left(\frac{T_1^x}{p_1}\right)\left(\frac{T_1^H}{W_1}\right)^2 W_1 H_1 + \frac{1}{2}\epsilon_{HW}\left(\frac{T_1^H}{W_1}\right)^2 W_1 H_1 \tag{7}$$

with the elasticities evaluated at (p_1, x_1) and (w_1, H_1).

Suppose that carbon taxes are levied on fossil fuels $T_2^x = p_2 - p_1 > 0$, in addition to existing taxes T_1^x, and that labor income taxes are reduced in a revenue neutral manner $T_2^H = W_2 - W_1 > 0$. The welfare cost of the tax system ($T_1^x + T_2^x$, $T_1^H + T_2^H$) is given by (4):

$$L' = -\frac{1}{2}\epsilon'_{xp}\left(\frac{T_1^x+T_1^x}{p_2}\right)^2 p_2x_2 - \frac{1}{2}\epsilon'_{xw}\left(\frac{T_1^x+T_2^x}{p_2}\right)\left(\frac{T_1^H+T_2^H}{W_2}\right)p_2x_2$$

$$+\frac{1}{2}\epsilon'_{Hp}\left(\frac{T_1^x+T_2^x}{p_2}\right)\left(\frac{T_1^H+T_2^H}{W_2}\right)W_2H_2 + \frac{1}{2}\epsilon'_{HW}\left(\frac{T_1^H+T_2^H}{W_2}\right)^2 W_2H_2 \qquad (7')$$

with the elasticities now evaluated at (P_2, X_2) and (W_2, H_2).

The change in welfare costs of the revenue neutral tax change is

$$L^N = L - L' = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2-(T_1^x+T_2^x)^2}{P_1^2}\right]p_1x_1$$

$$-\frac{1}{2}\epsilon_{xw}\left[\frac{T_1^xT_1^H-(T_1^x+T_2^x)(T_1^H+T_2^H)}{P_1W_1}\right]p_1x_1\cdot\theta$$

$$+\frac{1}{2}\epsilon_{Hp}\left[\frac{T_1^xT_1^H-(T_1^x+T_2^x)(T_1^H+T_2^H)}{P_1W_1}\right]W_1H_1\cdot\theta \qquad (8)$$

$$+\frac{1}{2}\epsilon_{HW}\left[\frac{(T_1^H)^2-(T_1^H+T_2^H)^2}{W_1^2}\right]W_1H_1$$

where θ = share of energy in total consumption and by noting that

$$\epsilon'_{xp}\left(\frac{T_1^x+T_2^x}{p_2}\right)^2 p_2x_2 = \epsilon_{xp}\left(\frac{T_1^x+T_2^x}{p_1}\right)^2 p_1x_1$$

and similarly for the other elasticities. The indirect terms are multiplied by the expenditure share of fossil fuels, θ, to account for the fact that in reality there are more goods than leisure and fossil fuels.

The first term in (8) is the direct effect on consumption of fossil fuels of higher fossil fuel prices. The last term is the direct effect on labor supply of higher after tax wages. The two middle terms are the indirect effects (cross effects) on fossil fuel consumption of higher after tax wages and on labor supply of higher fossil fuel prices (lower real wages).

$L^N > 0$ would imply a welfare gain from the revenue neutral tax change.

We would like to express the two indirect effects in terms of ϵ_{HW} which can be accomplished in two steps. The first step is to express the third term in (8) in terms of ϵ_{xw} by noting that

$$\frac{\partial^2 E}{\partial p \partial w} = -\frac{\partial^2 E}{\partial w \partial p} \qquad (9)$$

from the symmetry in the two-by-two matrix in the second order Taylor expansion of the expenditure function. The negative sign in (9) comes from the use of leisure as 1 - H. Given that

$$\frac{\partial E}{\partial p} = x \quad and \quad \frac{\partial E}{\partial w} = H$$

are the compensated demand functions, it follows that

$$\frac{\partial x}{\partial w} = -\frac{\partial H}{\partial p}$$

which is (9), and therefore

$$\epsilon_{xw} \frac{x_1}{w_1} = -\epsilon_{Hp} \frac{H_1}{p_1} \qquad (10)$$

Thus, the two indirect terms can be expressed as

$$- \epsilon_{xW} \left[\frac{T_1^x T_1^H - (T_1^x + T_2^x)(T_1^H + T_2^H)}{P_1 W_1}\right] p_1 W_1 \cdot \theta \qquad (11)$$

The second step is to express the compensated elasticity ϵ_{xW} in terms of ϵ_{HW}. Let

$$U = f(x, 1 - H) \qquad (12)$$

The total differential of (12) (letting $\partial u = 0$ is

$$\frac{\partial f}{\partial x}\partial x + \frac{\partial f}{\partial (1-H)} \partial(1-H) = 0 \qquad (13)$$

From the first order conditions of utility maximization

$$\frac{\partial f/\partial x}{\partial f/\partial(1-H)} = \frac{p}{W} \qquad (14)$$

By (13) and (14) and dividing through by ∂W:

$$p\frac{\partial x}{\partial w} - w\frac{\partial H}{\partial W} = 0 \qquad (15)$$

This gives

$$px\epsilon_{xW} = WH\epsilon_{HW} \qquad (16)$$

To quantify L^N, T_2^H is derived from the revenue neutrality condition

$$\partial R = T_1{}^x X_1 - T_2{}^H H_1 = 0 \qquad (17)$$

for small changes in the tax system. From (17) we get

$$T_2^H = T_2^x \frac{X_1}{H_1} \qquad (18)$$

With (11), (16) and (18) we have

$$L^N = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2 - (T_1^x + T_2^x)^2}{p_1^2}\right]p_1x_1$$

$$-\epsilon_{HW}\left[\frac{(T_1^xT_1^H - (T_1^x + T_2^x)(T_1^H + T_2^x\frac{X_1}{H_1})}{p_1W_1}\right]W_1H_1 \cdot \theta \qquad (19)$$

$$+\frac{1}{2}\epsilon_{HW}\left[\frac{(T_1^H)^2 - (T_1^H + T_2^x\frac{X_1}{H_1})^2}{W_1^2}\right]W_1H_1$$

Note that the elasticity values applied to (19) are uncompensated elasticities rather than the theoretically correct compensated elasticities. The difference in terms of welfare cost is quite small (Willig 1976), approximately 10% with an income elasticity of 1 and $\theta = 0.05$ given our uncompensated elasticity values. This result may be derived from the Slutsky decompositions of the substitution and income effect. Thus welfare costs are slightly overstated here.

Case B: Welfare Costs of Carbon Taxes That Displace Equal Yield Corporate Income Taxes.

Corporate income may be regarded as return on savings (Feldstein, 1978), i.e. on assets or shareholders equity. Consider the case of two goods (x,R) in a two period model where x is fossil fuel consumption in the first period and R is second period consumption of first period savings, both in real terms.

Prices of fossil fuels (x) and second period consumption (R) are (p_o,p_o^R) in an initial non-distorted equilibrium. In the presence of existing unit taxes on fossil fuels and second period consumption (T_1^x,T_1^R), welfare costs are given by (20):

$$L = -\frac{1}{2}\frac{\partial x}{\partial p}T_1^x T_1^x - \frac{1}{2}\frac{\partial x}{\partial p^R}T_1^x T_1^R - \frac{1}{2}\frac{\partial R}{\partial p}T_1^x T_1^R - \frac{1}{2}\frac{\partial R}{\partial p^R}T_1^R T_1^R \tag{20}$$

with $T_1^R = p_1^R - p_0^R > 0$, $T_1^x = p_1^x - p_0^x > 0$.

If r_0 is the rate of return on savings in the corporate sector, then $p_o^R = e^{-r_o t}$ is the discounted (current) price of consumption in period T+1 in the case of no tax on corporate income. Similarly, $p_1^R = e^{-r_1 t}$ is the after tax discounted price, with $r_1 = (1 - t)\, r_o$ and t is the corporate income tax rate. Thus corporate income taxes reduces the real value of period one savings since $p_1^R - p_o^R > 0$.

Writing L with compensated elasticities, (20) becomes

$$L = -\frac{1}{2}\,\epsilon_{xp}\left(\frac{T_1^x}{p_1}\right)^2 p_1 X_1 - \frac{1}{2}\,\epsilon_{xp}{}^R\left(\frac{T_1^x}{p_1}\right)\left(\frac{T_1^R}{p_1^R}\right) p_1 X_1 - \frac{1}{2}\,\epsilon_{Rp}\left(\frac{T_1^x}{p_1}\right)\left(\frac{T_1^R}{p_1^R}\right) p_1^R R_1 - \frac{1}{2}\epsilon_{Rp}{}^R\left(\frac{T_1^R}{p_1^R}\right)^2 p_1^R R_1 \tag{21}$$

with the elasticities evaluated at (p_1,x_1) and (p_1^R,R_1)

Suppose that carbon taxes are levied on fossil fuels $T_2^x = p_2 - p_1 > 0$ in addition to existing taxes T_1^x, and that corporate income taxes are reduced in a revenue neutral manner $T_2^R = p_2^R - p_1^R < 0$. The welfare costs of the tax system $(T_1^x + T_2^x, T_1^R + T_2^R)$ is

$$L' = -\frac{1}{2}\epsilon'_{xp}\left(\frac{T_1^x+T_2^x}{p_2}\right)^2 p_2X_2 - \frac{1}{2}\epsilon'_{xp}{}^R\left(\frac{T_1^x+T_2^x}{p_2}\right)\left(\frac{T_1^R+T_2^R}{p_2^R}\right)p_2X_2$$

$$-\frac{1}{2}\epsilon'_{Rp}\left(\frac{T_1^x+T_2^x}{p_2}\right)\left(\frac{T_1^R+T_2^R}{p_2^R}\right)p_2^RR_2 - \frac{1}{2}\epsilon'_{RP}{}^R\left(\frac{T_1^R+T_2^R}{p_2^R}\right)^2 p_2^RR_2 \qquad (22)$$

with the elasticities now evaluated at (p_2,X_2). The change in welfare costs of the revenue neutral tax is

$$L^N = L - L' = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2 - (T_1^x + T_2^x)^2}{(p_1)^2}\right]p_1X_1$$

$$-\frac{1}{2}\epsilon_{xp}{}^R\left[\frac{T_1^xT_1^R - (T_1^x + T_2^x)(T_1^R + T_2^R)}{p_1p_1^R}\right]p_1X_1 \cdot \theta$$

$$-\frac{1}{2}\epsilon_{Rp}\left[\frac{T_1^xT_1^R - (T_1^x + T_2^x)(T_1^R + T_2^R)}{p_1p_1^R}\right]p_1^RR_1 \cdot \theta \qquad (23)$$

$$-\frac{1}{2}\epsilon_{Rp}{}^R\left[\frac{(T_1^R)^2 - (T_1^R + T_2^R)^2}{(p_1^R)^2}\right]p_1^RR_1$$

where θ = expenditure share of fossil fuels in total consumption and by noting that

$$\epsilon'_{xp}\left(\frac{T_1^x + T_2^x}{p_2}\right)^2 p_2X_2 = \epsilon_{xp}\left(\frac{T_1^x + T_2^x}{p_1}\right)^2 p_1X_1$$

and similarly for the other elasticities.

The first term in (23) is the direct effect of higher fossil fuel prices on consumption of fossil fuels. The last term is the direct effect of lower prices on second period consumption. The lower tax on corporate savings reduces the inter temporal inefficiency. The two middle terms are the indirect effects (cross effects) on fossil fuel consumption of lower prices on second period consumption and on savings from higher prices on fossil fuels.

$L^N > 0$ would imply a welfare gain from the revenue neutral tax change.

We would like to express the two indirect effects in terms of ϵ_{Rp^R} which can be accomplished in two steps. The first step is to express the third term in (23) in terms of ϵ_{Rp^R} by noting that

$$\frac{\partial^2 E}{\partial p^R \partial p} = \frac{\partial^2 E}{\partial p \partial p^R} \qquad (24)$$

from the symmetry in the two-by-two matrix in the second order Taylor expansion of the expenditure function. Given that

$$\frac{\partial E}{\partial p} = X \quad and \quad \frac{\partial E}{\partial p^R} = R$$

are the compensated demand functions, it follows that

$$\frac{\partial x}{\partial p^R} = \frac{\partial R}{\partial p}$$

which is (24), and therefore

$$\epsilon_{xp} \frac{R}{p} = \epsilon_{xp^R} \frac{X}{p^R} \qquad (25)$$

Thus, the two indirect terms can be expressed as

$$- \epsilon_{xp}{}^{R} \left[\frac{T_1^x T_1^R - (T_1^x + T_2^x)(T_1^R + T_2^R)}{P_1 p_1^R} \right] p_1 X_1 \cdot \theta \qquad (26)$$

The second step is to express the compensated elasticity ϵ_{xp^R} in terms of ϵ_{Rp^R}. Let

$$U = f(x, R) \qquad (27)$$

The total differential of (27) (letting $\partial U=0$) is

$$\frac{\partial f}{\partial x}\partial x + \frac{\partial f}{\partial R}\partial R = 0 \qquad (28)$$

From the first order conditions of utility maximization

$$\frac{\partial f/\partial x}{\partial f/\partial R} = \frac{p}{p^R} \qquad (29)$$

By (28) and (29) and dividing through by ∂p^R:

$$p\frac{\partial x}{\partial p^R} + p^R \frac{\partial R}{\partial P^R} = 0 \qquad (30)$$

This gives

$$p\, X\, \epsilon_{xp}{}^{R} = -\, p^R\, R\, \epsilon_{Rp}{}^{R} \qquad (31)$$

By substituting (26) and (31) into (23):

$$L^N = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2 - (T_1^x + T_2^x)^2}{(p_1)^2}\right]p_1 x_1$$

$$+ \epsilon_{Rp}{}^R\left[\frac{(T_1^x T_1^R - (T_1^x + T_2^x)(T_1^R + T_2^R)}{p_1 p_1^R}\right]p_1^R R_1 \cdot \theta \qquad (32)$$

$$- \frac{1}{2}\epsilon_{Rp}{}^R\left[\frac{(T_1^R)^2 - (T_1^R + T_2^R)^2}{(p_1^R)^2}\right]p_1^R R_1$$

It remains to express $\epsilon_{Rp}{}^R$ in terms of the elasticity of savings with respect to the after tax rate of return for which elasticity alternatives are available.

Note that

$$\epsilon_{Rp}{}^R = \eta_{Rp}{}^R + \sigma \qquad (33)$$

where η is the uncompensated elasticity and σ is the marginal propensity to save out of exogenous income (Feldstein, 1978). Given that savings is $S = p^R R$, we have

$$\eta_{sp}{}^R = \frac{\partial S}{\partial p^R} \cdot \frac{p^R}{S} = \frac{\partial (p^R R)}{\partial p^R} \cdot \frac{p^R}{S}$$

$$= \frac{Rp^R}{S} + \frac{\partial R}{\partial p^R}\frac{(p^R)^2}{S} \qquad (34)$$

$$= 1 + \eta_{Rp}{}^R$$

By (33) and (34),

$$\epsilon_{Rp}{}^R = \eta_{sp}{}^R - (1-\sigma) \qquad (35)$$

Recall that the discounted price of period T + 1 consumption is $p^R = e^{-rT}$ with r the after tax rate of return on period 1 savings. Thus,

$$\eta_{sp}{}^{R} = \frac{\partial S}{\partial p^{R}} \frac{p^{R}}{S} = \frac{\partial S}{\partial r} \frac{p^{R}}{S} \frac{1}{-Te^{-rT}} = \frac{\partial S}{\partial r} \frac{p^{R}}{S} \frac{1}{-Tp^{R}}$$
$$= \frac{\partial S}{\partial r} \frac{r}{S} \frac{1}{-rT} = -\eta_{sr}/rT \qquad (36)$$

because $\partial p^R = -Te^{-rT}\,\partial r$.

It follows that

$$\epsilon_{Rp}{}^{R} = -(\eta_{sr}/rT + 1 - \sigma) \qquad (37)$$

To quantify L^N, T_2^R is derived from the revenue neutrality condition. With I being total tax revenues,

$$\partial I = T_2^x X_1 + T_2^R R_1 = 0 \qquad (38)$$

for small changes in the tax system. Thus,

$$T_2^R = -T_2^x \cdot \frac{X_1}{R_1} \qquad (39)$$

With (32), (37) and (39), we have

$$L^N = -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2-(T_1^x+T_2^x)^2}{(p_1)^2}\right]p_1X_1$$
$$-(\eta_{sr}/r_1T+1-\sigma)\left[\frac{T_1^xT_1^R-(T_1^x+T_2^x)(T_1^R-T_2^x\frac{X_1}{R_1})}{p_1p_1^R}\right]p_1^RR_1\theta \qquad (40)$$
$$+\frac{1}{2}(\eta_{sr}/r_1T+1-\sigma)\left[\frac{(T_1^R)^2-(T_1^R-T_2^x\frac{X_1}{R_1})}{(p_1^R)^2}\right]p_1^RR_1$$

Case C: Welfare Costs of a Revenue Enhancing Carbon Tax with No Change in Existing Taxes

Consider the case of two goods (x, 1-H) as in Case A. The welfare cost L^N may be derived directly from (19) by noting that with no other changes in the tax system than the carbon tax on fossil fuels,

$$T_2^H = 0 \quad (i.e.\ T_2^x \frac{X_1}{H_1} = 0 \ in\ (19))$$

Thus,

$$\begin{aligned} L^N = & -\frac{1}{2}\epsilon_{xp}\left[\frac{(T_1^x)^2 - (T_1^x + T_2^x)^2}{(p_1)^2}\right] p_1 X_1 \\ & - \epsilon_{HW}\left[\frac{-T_2^x T_1^H}{p_1 W_1}\right] W_1 H_1 \theta \end{aligned} \tag{41}$$

as the last term vanishes.

The case of a revenue increasing carbon tax may alternatively be considered by recognizing the indirect effect on corporate savings instead of the indirect effect on labor supply. In this case L^N can be derived for (40) instead of (19). The first term will remain the same and the last term will vanish, but the indirect effect will in this case be unambiguously positive since $T_1^R > 0$. This is because higher prices on current period consumption induces a substitution to second period consumption, i.e. savings will increase. Thus the welfare loss will be slightly smaller than the direct effect on fossil fuel consumption, contrary to the case previously considered with indirect effect on labor supply.

Case D: Welfare Effects of a Revenue Enhancing Carbon Tax with No Change in Exisitng taxes but Accounting for Subsidies

The calculation will only include the direct effect on fossil fuel consumption from a carbon tax, i.e. the first term in (19) or (40). Fossil fuels are disaggregated as petroleum products/natural gas (x) and coal (y). Notation is the same as before. Interfuel substitution effects are ignored in order to be consistent with calculations in Case A-c.

The expression for welfare cost becomes

$$L^N = -\frac{1}{2}\epsilon_{xp}{}^x\left[\frac{(T_1^x)^2 - (T_1^x + T_2^x)^2}{(p_1^x)^2}\right]p_1^x X_1 + \frac{1}{2}\epsilon_{yp}{}^y\left[\frac{(T_1^y)^2 - (T_1^y + T_2^y)^2}{(p_1^y)^2}\right]p_1^y Y_1 \qquad (42)$$

Note that the second term is positive (welfare gain) if $T_2^y < 2 \mid T_1^y \mid$. This is because $T_1^y < 0$ is a subsidy.

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