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Using A Border Adjustment To Take The Lead On Climate Change Without Encouraging Runaway Shops

By Frank Muller and Andrew Hoerner

Negotiations are currently underway through the Framework Convention on Climate Change (FCCC) for a new binding agreement by industrialized countries to reduce their emissions of greenhouse gases over the next few decades. The agreement is due to be signed in Kyoto, Japan, this December. It implements a key principle of the convention that was signed by President Bush in 1992 and ratified by the U.S. Senate: that developed countries should take the lead in combating climate change. Nevertheless, on July 25, in what has become known as the Byrd Resolution (after its chief sponsor), the Senate resolved that the United States should not sign the agreement unless it includes "new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period." Underlying this resolution are concerns that the Kyoto agreement will cause a loss of American jobs to China and other developing countries. Are these concerns justified? If so, does the Byrd resolution solve the problem? Is there a better solution?

Will the Kyoto agreement cause widespread loss of American jobs to developing countries?

No. An effective agreement will lead over time to lower employment in some industries, such as coal mining and higher employment in others, such as natural gas, energy efficiency and renewable energy technologies. But it will not cause widespread loss of American jobs to developing countries. Two-thirds of US carbon dioxide emissions come from energy used in transportation and buildings -- activities that by their nature cannot be exported. The remaining one third comes from manufacturing. In most of manufacturing, except for a few energy-intensive industries, energy is too small a cost factor for emissions limits to provide any real incentive for relocating overseas. Furthermore, American coal miners will not lose their jobs to China because emissions limits will apply equally to all coal consumed in the United States regardless of its origin.

Is there a risk of runaway shops in energy-intensive manufacturing?

Yes. It is widely recognized that to achieve long-term reductions in US carbon dioxide emissions at least cost will require an economy-wide incentive as well as incentives and other measures targeted to individual sectors. The two main options are a carbon tax or a system of tradable carbon emission permits. Either would raise the cost of energy from fossil fuels. Energy is a significant cost factor in a small number of industries including aluminum, pulp and paper, iron and steel, and basic chemicals (see attached table). Energy costs have always influenced where investments are made in these industries. Following the fuel price increases of the 1970s, for example, aluminum production was relocated from Japan and (to some extent) Europe to countries with cheaper electricity, such as Australia. Similarly, future investments might be redirected from countries where energy costs are expected to rise due to carbon dioxide emissions limits to countries with lower emissions constraints or no limits at all. In total, the industries facing this risk account at most for about 1 percent of US employment. In other words, critics have vastly exaggerated the magnitude of the runaway shop problem. Nevertheless, these industries provide good jobs that form an important part of the economic base of some regions of the country.

Does relocation overseas of energy-intensive production help protect the climate?

No. Carbon dioxide has the same impact on the global climate system wherever emitted. In some cases, a marginal reduction in global emissions may be achieved, if efficient new greenfield plants overseas displace aging US production capacity. But, in other cases, displacement may involve greater utilization of existing inefficient power plants or manufacturing capacity in a developing or transition country, resulting in a net increase in global emissions. More importantly, though, the relocation option greatly weakens the economic incentive for developing more efficient production technologies and substitute low-emission products. The climate change convention's goal of stabilizing atmospheric greenhouse gas concentrations can only be achieved through a transition to sustainable production and consumption patterns. Simply shifting emissions around the world puts off the task of undertaking this transition. And from a political perspective, the threat of job displacement is used by special interests to undermine climate protection efforts, not only in the United States but also in every other developed country.

Does the Byrd resolution solve the runaway shop problem?

No. Even if developing countries agree at Kyoto to accept specific scheduled commitments on the same timetable as developed countries, this would not greatly diminish the risk of runaway shops. Senator Byrd himself has accepted that commitments will need to vary among countries according to level of development. Whereas industrial countries will be required to reduce emissions below current levels, developing countries at most will face limits to future growth. An American steel corporation, for example, could still move production and emissions to Mexico or Indonesia and export steel back to the United States without either country breaching its treaty commitments. Countries like China, India, and Indonesia with relatively low per-capita emissions (one-tenth of US levels or lower) would likely have considerable room within their emissions "budgets" to accommodate expansion in energy-intensive manufacturing for export to industrial countries. The Byrd resolution fails to address this problem, yet threatens to undermine the negotiations by reneging on earlier agreements by the United States.

Do joint implementation and international emissions trading solve the runaway shop problem?

No. US negotiators have proposed that the Kyoto agreement allow joint implementation (JI) between industrial and developing countries and emissions trading among industrial countries. Some proponents of JI and international trading have argued that these schemes address jobs concerns by promoting emissions reductions in developing countries and enabling affected US firms to reduce their compliance costs. Under JI, a firm could invest in a low-cost emission reduction project in a developing country and gain a credit for a share of the reductions against its own domestic emissions. Under international trading, a firm would purchase emission rights (directly or indirectly) from another industrial country with lower emission reduction costs that is able to do better than its treaty commitments. Whatever the merits of JI and international trading in enhancing flexibility and lowering costs, though, they do not necessarily solve the runaway shop problem.

At best, JI and international trading would reduce, but not eliminate, the cost disadvantage imposed on US-based energy-intensive manufacturers by an effective emission-reduction agreement. Under such an agreement and a JI regime that provides real and verifiable emission reductions in developing countries, not just paper reductions, emission credits would be unlikely to cost less than around $20 per ton of carbon. The purchase of such credits would still impose a significant cost disadvantage on energy-intensive plants selling into highly competitive global markets.

At worst, the expansive JI and trading schemes advanced by some proponents within the Administration and environmental community could actually promote footloose corporate behavior. For example, in the JI case, a US steel firm could invest in improving the efficiency of a steel plant in Brazil (or alternatively Mexico or Indonesia) as part of a joint venture deal that also included construction of a new steel plant. The firm could use the emission reduction at the upgraded plant to gain a credit under JI against its US emissions while also importing steel from the new plant to displace its highest-cost US capacity. Similarly, in the case of tradable permits, an aluminum major facing high electricity costs for its eastern US plants (or the coal-based utility which supplies it) might invest in Russia's inefficient and underutilized power supply and aluminum industries and close its oldest US plants. As Russia is expected to easily meet its treaty commitments, the deal could be partly financed through the sale of internationally tradable emission rights to the US utility. In these cases, JI and international trading form an integral element of the financing of deals that shift American jobs overseas.

Why not simply exempt energy-intensive industries from emission limits?

The manufacturing sector or particular energy-intensive industries could be exempted from a carbon tax or permit scheme. However, this would increase the cost to the economy as a whole by requiring a greater emission reduction effort in other sectors. It also would greatly diminish the incentive to improve production technologies in the exempted industries, develop substitute low-emission products and generally shift to more sustainable consumption patterns. Moreover, as the BTU tax debate demonstrated, exempting heavy industry would undermine broader support for the tax or permit scheme.

What is a border tax adjustment?

Under the "destination system" of border tax adjustments (BTAs), traded goods are subject to the taxes of the importing ("destination") country and exempted from the taxes of the exporting ("origin") country. For instance, gasoline trucked from Toronto to Buffalo is exempted from paying gasoline tax in Canada and subject to gasoline tax in New York, at the combined New York/federal tax rate. BTAs are a necessary part of a tax on national or in-state consumption, and are a nearly universal feature of sales, excise, value added and other taxes. Because BTAs are required for consistent treatment of a consumption tax base they are regarded as a normal part of the tax and not as a form of local favoritism.

How can a border tax adjustment solve the runaway shop problem?

BTAs are the most straightforward way to prevent firms in low-tax jurisdictions from preying on energy-intensive industries in high tax jurisdictions. A BTA system would rebate the tax on fuels used to produce energy-intensive exports (such as metal ingot and certain bulk chemicals), thus maintaining the competitiveness of exports. A comparable tax would be imposed on imports of energy-intensive basic materials to put foreign firms on a level playing field in the home market. This BTA system is a natural part of a tax on fuels used to produce goods consumed domestically.

BTAs should be distinguished from tariffs and other forms of industry protection. Energy-intensive manufacturers (e.g. basic chemicals, aluminum) already undertake large investments in developing countries that sometimes displace American production and jobs. Various factors make such investments attractive including lower resource costs and the prospect of winning large new markets. A BTA ensures that job displacement is not accelerated by the FCCC, but does not favor domestic over foreign production or otherwise alter underlying market conditions. Aluminum or ethylene production that already would have been shifted overseas, for example, will still be shifted. But it won't be shifted because of climate protection policies.

Why are border tax adjustments controversial?

Some advocates of unbridled free trade argue that BTAs for taxes on carbon embodied in energy-intensive traded goods are or should be barred by the General Agreement on Tariffs and Trade (GATT). (BTAs on the fuels themselves are universally accepted.) There are three major arguments for this position:

The basic policy argument. Many GATT experts take seriously the conclusion of the never-adopted Tuna-Dolphin decision that trade measures can be based only on taxes on *products*, and not on taxes on *processes*.

The practicality argument. Some administrators have argued that such BTAs would be *hard to enforce* or *easy to abuse*.

The technical legal argument. Some legal scholars argue that the rebate of taxes on embodied fuels is barred by the GATT Subsidies Code's ban on rebating *prior stage cumulative indirect taxes*.

Does the GATT forbid border tax adjustments on "process" taxes?

No. The GATT allows BTAs on taxes that fall "directly or indirectly" on like products. It was the intent of the original GATT negotiators that process as well as product charges be border adjustable. This language was first introduced in 1946 by U.S. negotiator Oscar B. Ryder at the London Preparatory Committee as part of the process of drafting the Havana Charter, the precursor to GATT. The Brazilian delegate, Mr. Rodrigues, demanded to know what was meant by the addition of the term "or indirectly." Mr. Ryder replied that the language was to allow border adjustments on "a tax, not a tax on a product as such, but on the processing of a product, which are covered by the word 'indirectly' here." The process/product distinction proposed by the Tuna-Dolphin Panel, like the Tuna-Dolphin decision itself has never been adopted by the GATT contracting parties or by the World Trade Organization (WTO).

Can border tax adjustments be administered effectively?

Yes. A BTA system for carbon taxes would be no more complicated than the BTA systems already in place for many other taxes. For instance, the U.S. administers border tax adjustments on hundreds of chemicals under the Superfund toxic chemical excise tax. BTAs apply to all taxed chemicals, and to all products manufactured primarily from a taxed chemical. If the producer documents the amount of taxed chemical used in the manufacture, the tax is based on the documented amount. Otherwise, it is taxed at a rate set by Treasury regulation, based on the amount of the taxed chemical that is used to manufacture the same product in the U.S. under the predominant method of production. This tax was held by the GATT to be consistent with international trade rules. The Ozone-Depleting Chemicals (ODC) Tax has similar BTA provisions, except that it is a "process" tax, in that it applies to products manufactured with taxed substances but not physically incorporating them, such as electronic parts cleaned with ODCs.

BTAs on the embodied carbon in energy-intensive goods would be administratively identical to the BTAs on these existing taxes. For plausible carbon tax rates, only a handful of energy-intensive basic materials -- fewer than are covered under the existing Superfund chemical excise -- would have price increases great enough to justify border adjustment.

Are border tax adjustments on taxes on embodied carbon barred as "prior stage cumulative indirect" (PSCI) taxes.

No. Border adjustment of carbon taxes is clearly not barred by the ban on PSCI taxes, for two reasons. First, the Uruguay Round Amendments to the GATT specifically excluded taxes on fossil fuels from the scope of the PSCI tax ban. Second, energy taxes are not PSCI taxes because they are not "cumulative." Although energy is used in every phase of the manufacturing process, each unit of fuel is taxed only once. This contrasts with the standard example of a PSCI tax, the cascade tax. A cascade tax is a tax on the value of all products sold, including goods used as materials in the manufacture of other goods. Cascade taxes cumulate, because the tax on, for example, sheet steel used to make an automobile, becomes part of the cost of manufacturing the automobile and the tax is *itself taxed again* when the automobile is sold. Cascade taxes were once common in Europe, but are now extinct in all but a few developing nations, having been replaced by VATs (which, like energy taxes, are not cumulative).

If the United States chooses a domestic emission trading scheme rather than a carbon/energy tax, could such a scheme include a border adjustment?

The Clinton Administration has not proposed specific domestic policies to implement the proposed Kyoto agreement. Current thinking within the Administration, however, favors a domestic tradable permit scheme over a carbon/energy tax. Such permits either would be auctioned by the government (most likely to coal, oil and gas companies at the point where carbon fuels enter the economy) or given away under "grandfathering" rules (most likely to utilities and other major industrial emitters). In principle, a border adjustment (at the current market price of permits) could be levied on imports and rebated on exports of energy-intensive products as part of such a scheme. Doing so, however, would raise different and more difficult international legal and policy issues than in the case of a tax.

Whereas border adjustments on consumption taxes have long been used and accepted under international trade rules, this is not true for environmental requirements like emissions permits. In implementing a border-adjusted permit scheme, the United States could not rely on the above mentioned BTA provisions of Article III of the GATT, except by analogy, and therefore probably would have to claim an environmental exemption under Article XX from GATT trade rules otherwise prohibiting import charges and export subsidies. Such a scheme, therefore, would be more vulnerable than a BTA to a challenge through the WTO by a country seeking to exploit the climate change convention for competitive advantage. GATT and WTO dispute panels have not looked favorably on claims for environmental exemptions. Indeed, to date, no country has successfully defended the use of Article XX to justify an environmental policy measure that runs foul of GATT provisions. Given this history, the availability of border adjustments for tradable permits cannot be guaranteed without a multilateral agreement specifically allowing them as part of the Kyoto accord.

Although elements of the trade community might object to including such provisions in the Kyoto accord, there are precedents for including even stronger trade provisions in multilateral environmental agreements (e.g., Montreal Protocol, Convention on International Trade in Endangered Species). Article 5.3 of the FCCC states "Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade." The earlier discussion makes clear that BTAs do not constitute "arbitrary or unjustifiable discrimination" within the meaning of this article. Although legally different, the trade policy arguments for allowing border adjustments for auctioned emission permits are virtually identical. However, in the case of grandfathered permits, the trade community might legitimately argue that border adjustments at the market price of the permit unjustifiably discriminate in favor of domestic producers by overcompensating them for the actual costs imposed by the emission permit scheme. In summary, the runaway shop problem can be avoided with a border-adjusted carbon tax but achieving the same goal with tradable permits may require a specific provision in the Kyoto agreement overriding GATT trade rules.

Frank Muller is Director and Andrew Hoerner is Research Director of the Environmental Tax Program. *For a more detailed discussion of border tax adjustments, see J. Andrew Hoerner and Frank Muller, "Carbon Taxes for Climate Protection in a Competitive World," Center for Global Change, University of Maryland, June 1996 (available from the authors, and also published in an abbreviated form by the Swiss Federal Office for Foreign Economic Affairs in E. Staehelin-Witt and H. Blöchliger, "Ökologisch orientierte Steuerreformen," Verlag Paul Haupt, Bern, Switzerland, 1997.)*

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Direct Cost Impact of a $50 per ton Carbon/Energy Tax for the 24 Most-Affected Manufacturing Industries				
Industry Groups and Industries	Energy Tax (% of Shipments)	Employment (1,000s)	Cumulative Employment (% of manufacturing)	Cumulative Value of Shipments (% of manufacturing)
Lime	23.9%	4	0%	0%
Primary Aluminum	15.0%	20	0%	0%
Cement Hydraulic	13.7%	16	0%	0%
Alkalies and Chlorine	9.9%	8	0%	0%
Industrial Gases	8.4%	9	0%	1%
Nitrogenous Fertilizers	8.0%	7	0%	1%
Paper Mills	7.4%	130	1%	1%
Electrometalurgical Products	7.2%	5	1%	1%
Paperboard Mills	6.2%	51	1%	2%
Blast Furnaces and Steel Mills	3.9%	177	3%	3%
Industrial Inorganic Chemicals nec	3.9%	79	3%	4%
Beet Sugar	3.7%	8	3%	4%
Synthetic Rubber	3.7%	12	3%	4%
Cellulosic Manmade Fibers	3.7%	11	3%	4%
Pulp Mills	3.5%	17	3%	4%
Wet Corn Milling	2.8%	10	3%	4%
Flat Glass	2.7%	13	3%	4%
Industrial Organic Chemicals nec	2.4%	101	4%	6%
Glass Containers	2.3%	35	4%	6%
Primary Nonferrous Metals nec	2.3%	11	4%	7%
Mineral Wool	2.2%	18	4%	7%
Gray and Ductile Iron Foundries	2.1%	76	5%	7%
Petroleum Refining	2.0%	74	5%	12%
Pressed and Blown Glass nec.	2.0%	33	5%	12%

Source: Analysis by J. Andrew Hoerner using energy consumption estimates from the U.S. Department of Energy's Manufacturing Energy Consumption Survey. Employment and value of shipment data is from the National Bureau of Economic Research's Productivity Database. Manufacturing industries are defined at the four digit SIC level. All data is for 1991.

Notes: The tax would apply to all fossil fuels at a rate of $50 per ton of carbon and to large-scale hydro and nuclear electricity at the national average rate for utility fossil-fired generation. Such a tax is at the high end of proposals by advocates of stronger climate change policy, and ideally would be phased in over 5-10 years. It translates into 13 cents per gallon on gasoline, and measured in terms of its impact on electricity is about three times President Clinton's 1993 Btu tax proposal. Due to high transportation costs and other factors, some of the above industries (e.g., cement) face limited international competition, and therefore little risk of job exports. All manufacturing accounted for 15.3 percent of U.S. non-farm employment in 1996.

Climate change background paper on environmental measures and economic competitiveness: August 9, 1997

There exist concerns that attempts to reduce carbon emissions will cause a marked deterioration in U.S. competitiveness. The "competitiveness" argument has at least two versions:

- Without specific developing country targets, U.S. industry will relocate abroad.
- Without specific developing country targets, the demand for U.S. energy-intensive goods will decline and the trade balance will deteriorate.

Before summarizing the literature, it is important to recognize factors that tend to militate against significant location or trade effects:

- Non-tradeable sectors account for a substantial share of carbon emissions. Transportation and buildings, for example, account for roughly two-thirds of U.S. emissions. For these sectors, the "competitiveness" argument seems largely irrelevant.
- In most manufacturing sectors, energy costs are a small percentage of total costs. According to the 1995 Annual Census of Manufactures, energy costs for manufacturing industries averaged just 2.2 percent of total costs. In electronic equipment (SIC code 36), for example, energy accounts for 1.2 percent of total costs. In instruments and related products (SIC code 38), energy also accounts for 1.2 percent of total costs. Given the small share of energy in total costs in most industries, differential shifts in the relative price of energy across countries are unlikely to have substantial effects on location decisions and trade flows. Another form of this argument notes that significant differentials in existing energy prices across countries do not seem to cause substantial movements in industries. The price of a barrel of heavy fuel oil in 1994, for example, was $13.65 in the United States and $5.06 in Venezuela.[1] Yet firms have not generally fled the United States for Venezuela.
- The burden of meeting an emission reduction target will be partially borne by non-participating countries because of changes mediated through international trade. For example, Annex I nations can be expected to demand less oil, shifting the terms of trade against oil-producing countries, and thereby forcing them to bear some of the costs of reducing greenhouse gases -- even if they do not formally participate in the international emissions reduction agreement.

The rest of this memorandum briefly summarizes the available literature on both forms of the competitiveness argument. The paucity of studies on climate change policies *per se*, especially on the subject of relocation, necessitates reliance on studies of environmental regulations more generally. Caution may therefore be warranted in applying these results to the climate change

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[1] *Statistical Abstract 1996*, Table 1359, Page 848.

issue.

Firm location decisions

The first type of competitiveness argument is a form of the "pollution havens" hypothesis,[2] in which firms are tempted to relocate to (or to build new plants in) countries with lax environmental standards. The evidence, however, suggests that the pollution havens effect does not show up strongly: the costs of complying with environmental regulations are too small relative to other factors (labor costs, tax rates, infrastructure, etc.) to have much effect on firms' location decisions.

- The literature review conducted by Jaffe, Peterson, Portney, and Stavins concludes that "We assess the evidence and find that there is little to document the view that environmental regulations have had a measurably adverse effect on competitiveness. Although the long-run social costs of environmental regulation may be significant, including adverse effects on productivity, studies attempting to measure the effect of environmental regulation on net exports, overall trade flows, and plant-location decisions have produced estimates that are small, statistically insignificant, or not robust to tests of model specification."[3]

- Palmer, Oates, and Portney point out that (1) except for the biggest polluting industries, the costs of complying with environmental regulation is a small fraction of total cost, and are swamped by international differences in labor costs, capital costs, material costs, and exchange rate changes; (2) the differences between US environmental regulations and those of most major trading partners are not that big; and (3) US firms often build state-of-the art facilities abroad regardless of the host nation's environmental regulations (this behavior makes sense if firms believe that tighter standards in developing countries are inevitable, and that better technology reduces the risks of major accidents like Bhopal).[4]

- Esty notes that "empirical studies have shown little propensity of pollution-intensive industries to move to 'pollution havens'...Even in industries with high pollution control costs, companies often face other deterrents to relocations, including high fixed costs and

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[2] The term was coined in Walter and Ugelow, "Environmental policies in developing countries," *Ambio*, 8 (1979), 102-109.

[3] Adam Jaffe, Steven Peterson, Paul Portney, and Robert Stavins, "Environmental Regulation and International Competitiveness: What Does the Evidence Tell Us?" Resources for the Future, Discussion Paper 94-08.

[4] Karen Palmer, Wallace Oates, and Paul Portney, "Tightening Environmental Standards: The Benefit-Cost of the No-Cost Paradigm?" *Journal of Economic Perspectives* 9 (1995), 119-132.

sensitivity to transportation expenses."[5]

- Dean writes that "More stringent regulations in one country are thought to result in loss of competitiveness, and perhaps industrial flight and the development of pollution havens. The many empirical studies which have attempted to test these hypotheses have shown no evidence to support them."[6]

- Summers reaches the same conclusion: "costs of compliance with environmental regulations are generally not a sufficiently high fraction of total cost to be a crucial determinant of location...there is very little evidence of footloose polluting industries."[7]

Studies of plant location decisions at the state level similarly conclude that "there is little direct evidence of a relationship between stringency of environmental regulations and plant location choices."[8] For example, separate studies by Bartik and Levinson both conclude that plant location is not significantly affected by state-level environmental regulations.[9]

Some have taken the argument even further, arguing that more rigorous environmental standards make domestic firms *more* competitive because the regulations spur innovation.[10] Many who find this extreme position unconvincing are nevertheless willing to accept that environmental regulations seem to have little effect on firm location decisions.[11]

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[5] Daniel Esty, *Greening the GATT*, Institute for International Economics, 1994, p. 159.

[6] Judith Dean, "Trade and the Environment: A Survey of the Literature," in Patrick Low, editor, *International Trade and the Environment* World Bank Discussion Paper No. 159, 1992.

[7] Larry Summers, "Foreword," in Patrick Low, editor, *International Trade and the Environment*, World Bank Discussion Paper No. 159, 1992.

[8] Adam Jaffe, Steven Peterson, Paul Portney, and Robert Stavins, "Environmental Regulation and International Competitiveness: What Does the Evidence Tell Us?" op. cit., page 23.

[9] Timothy Bartik, "The Effects of Environmental Regulation on Business Location in the United States," *Growth and Change*, 19 (1988), 22-44; Arik Levinson, *Environmental Regulations and Manufacturers' Location Choices: Evidence from the Census of Manufactures* (Columbia University, 1992).

[10] Michael Porter, "America's Green Strategy," *Scientific American*, August 1991.

[11] "When green is good," *Economist*, November 20, 1993; Adam Jaffe et al., op. cit.; Palmer et al., op cit.

Trade flows

Even if firms do not move or build plants abroad, trade flows could still shift in response to environmental policies. But existing studies have generally concluded that the effects on trade of environmental regulations are not large. For example, Grossman and Krueger conclude that pollution abatement costs in the United States have had little effect on imports from Mexico or activity in the maquiladora sector.[12] Consistent with the lack of a significant negative relationship at the national level, states with higher-than-average pollution abatement spending apparently do not export less than other states.[13]

Trade balance effects

Standard trade theory suggests that an increase in the relative price of energy should have some adverse impact on exports of energy-intensive manufactures from the U.S., as from other Annex I countries. But this decline in energy-intensive manufactured exports may not expand the *trade deficit* for several reasons:

- There would likely be a fall in oil imports that would offset the decline in energy-intensive exports. Reduced dependence on foreign oil has both economic and political advantages.

- Trade theory suggests a *positive* effect on U.S. exports of goods that are *not* intensive in energy. Resources would be expected to flow from energy-intensive to other sectors.

- Technical reasons also suggest it may not be useful to look at the effect on the trade balance. An appendix discusses these issues.

In short, to assess competitiveness concerns, it is probably more meaningful to talk about adverse effects on specific, individual energy-intensive export sectors than to look at the impact on the trade balance or current account balance.

Climate change studies

Few studies have examined the specific impact on competitiveness of climate change policies per se. One study by McKibbin and Wilcoxen examined how a carbon tax of $15 per ton applied in the United States alone, and in the United States and the OECD together, affected trade flows. They conclude that "our results suggest that a carbon tax would produce little

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[12] Gene Grossman and Alan Krueger, "Environmental Impacts of a North American Free Trade Agreement," in Peter Garber, ed., *The US-Mexico Free Trade Agreement* (MIT Press, 1992).

[13] J. David Richardson, *Sizing Up U.S. Export Disincentives* (Institute for International Economics, 1993), pages 114-115.

redistribution of trade in either the short or long run."[14]

A seemingly related literature has studied the magnitude of "leakage effects" -- that is, to what extent cuts in domestic emissions would be offset by shifts in production and therefore increases in emissions abroad. But the relationship between carbon leakage and competitiveness is complicated: a large carbon leakage figure may not imply a large decline in competitiveness, and a small carbon leakage figure need not imply the opposite. In any case, the carbon leakage literature has not reached any firm conclusions: Repetto and Austin report that studies of unilateral emissions reduction policies in OECD countries predict leakage rates of between 3.5 and 70 percent.[15] Based on a review of the recent modeling efforts that produced dramatically different results, Thomas Rutherford's (University of Colorado) best guess is that carbon leakage is probably larger than 10 percent and less than 50 percent.[16]

Caveat

In sum, the related literatures suggest that carbon policies are unlikely to effect a massive shift of energy-intensive production abroad. At the same time, the empirical literature on the specific impact of carbon policies is sparse. And an important caveat to the general findings above is that for several industries, energy costs are a significant share of total costs. These industries are vulnerable, and there may be substantial adjustment costs. For example, in primary aluminum production (SIC 3334), energy accounts for 21.4 percent of total costs. In hydraulic cement (SIC 3241), energy accounts for 20.5 percent of total costs, while in inorganic chemicals (SIC 281), the share is 13.7 percent. And in other industries -- including the pulp and paper industry, and the steel industry -- energy is a significant input. In these industries, which account for perhaps 2 to 3 percent of total industrial output, the effects are expected to be more significant than those outlined above.

The Department of Energy commissioned a study by the Argonne National Laboratory to study the potential impact of possible carbon emission restrictions on energy-intensive industries.[17] The study focused on six sectors: chemicals, petroleum refining, paper and allied products, iron and steel, aluminum, and cement. The general conclusion of the study was that "the policy

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[14] Warwick McKibbin and Peter Wilcoxen, "Environmental Policy and International Trade," Brookings Discussion Papers in International Economics, October 1995, page 2.

[15] Robert Repetto and Duncan Austin, *The Costs of Climate Protection: A Guide for the Perplexed*, World Resources Institute, 1997, page 31.

[16] Thomas Rutherford, "International Competitiveness and National Plans," University of Colorado, 1995.

[17] Ronald J. Sutherland, "The Impact of Potential Climate Change Commitments on Energy Intensive Industries: A Delphi Analysis," Argonne National Laboratory, 5 February 1997.

constraints placed on these six large industries in developed countries, but not on their less developed trading partners, would result in significant adverse impacts on the affected industries."

The precise impact of climate stabilization policies on the most energy-intensive industries, however, is sensitive to how the policies are implemented. If an emissions permit trading system is created, for example, and the permits are auctioned, the funds from the auctions could be used to boost national saving. The increase in national saving would reduce real interest rates. That reduction in real interest rates would stimulate demand for consumer durables, new construction and business investment -- which would, in turn, boost demand for energy-intensive products such as cement, aluminum, and steel. A study using the DRI/McGraw Hill Inter-Industry Model thus suggests that depending on how the carbon emission reductions are achieved, the results of the Argonne study could be exaggerated.

Implications for the importance of LDC participation

It is important to note that even if competitiveness problems are not likely to prove as substantial in practice as some have asserted, the serious participation of developing countries in a global program to address climate change remains essential. The importance of developing country participation has more to do with the objective of reducing emissions than with competitiveness. Despite possible adverse competitiveness effects on a few energy-intensive industries, the economic costs for the United States associated with the absence of developing countries would overall be expected to be relatively small. But the environmental costs could be large: without the participation of the developing countries, whose emissions are expected to exceed the developed countries by the middle of the 21st century, little progress is possible in attenuating the impact of carbon emission on global climate change.

Conclusion

In sum, the related literatures suggest that carbon policies are unlikely to effect a massive shift of energy-intensive production abroad. At the same time, the empirical literature on the specific impact of carbon policies is sparse. And an important caveat to the general findings is that for several industries, energy costs are a significant share of total costs and therefore the effects may be more significant. Finally, the involvement of the developing economies is crucial to carbon reduction efforts not for economic reasons, but rather for environmental ones.

Appendix: Carbon emissions programs and the balance of payments

The impact of carbon emissions programs on the country's international accounts depends on the precise definition of the balance of payments: the current account balance or overall balance of payments could well move in the opposite direction of the merchandise balance or the balance on goods and services. The merchandise trade balance could very well improve in a system with international permit trading. This is a likely outcome if the U.S. and other industrialized countries buy emission permits from Russia, Ukraine, and other economically depressed countries. (If the U.S. turns out to be a net seller of permits, as is possible in the medium run if the Russian economy recovers, the effects would be reversed.)

Why might the trade balance be expected to improve? Imports of permits from Russia would likely not be counted as imports of merchandise, but would likely be counted on the broader measures of the balance of payments.[18] Economists often term such transactions "international transfers." Such transfers, all else equal, reduce disposable income in the United States or other permit-buying countries, and raises disposable income in the recipient country. The first effect leads to a fall in imports into the U.S., and the second effect leads to a rise in exports to the recipient country. Thus both effects clearly work to narrow the trade deficit of the United States, and to expand the trade deficit (or narrow the trade surplus) of the recipient country. This illustrates the general principle that the trade balance is a highly misleading indicator of the effect on U.S. income or economic welfare.

Public attention tends to be more focussed on the trade balance, as it is the measure associated with output and employment. But the trade balance leaves out the outward transfers themselves. The effect on the overall current account, which adds in the transfers along with the balance on goods and services, would be more likely to be negative (as compared to the effect on the trade balance). But even the current account might improve, if carbon emissions programs were used to raise public saving, or if there were a flow of capital from the United States to developing countries.

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[18] The precise treatment within the balance of payments of emissions permits is currently being studied by the relevant officials at the Department of Commerce. This appendix is predicated on preliminary analysis by the Council of Economic Advisers, and is subject to revision following determinations by the Department of Commerce.

Appendix: Other examples of environmental regulations and competitiveness

U.S. Investment in Mexico. Some detractors of NAFTA feared that U.S. industries would move to Mexico, attracted by looser environmental standards. But the facts suggest that such fears were unfounded. Overall, U.S. direct investment in Mexico from 1993 to 1996 grew about 14.5 percent. The share in Mexico peaked in 1994 at about 2.7 percent, but then the actual level of U.S. direct investment into Mexico fell in 1995.[19]

Mexico's share of U.S. FDI, pre- and post-NAFTA

1993	1996
2.7%	2.4%

The data show growth in U.S. direct investment into Mexico over the post NAFTA period, particularly in manufacturing (where growth has been about 22 percent). But this growth has not differed dramatically from the world as a whole -- where manufacturing FDI grew 23 percent over the same period. Even if the Mexico numbers are understated because of the peso devaluation, a generous upward adjustment doesn't change much.

Not only is Mexico's share changing little, but it has only a small share of total U.S. direct investment to begin with. The share of U.S. investment in Europe has remained relatively constant (about half) in the post-NAFTA period, and the share of U.S. investment in Asia and the Pacific has remained stable at about 18 percent. The top destination for U.S. FDI is still the United Kingdom, and its share remains at about 18 percent (the same as the whole of Latin America and Asia and the Pacific), while Canada has maintained 11 to 12 percent.

Japanese direct investment. Japan is one case where environmental regulation is thought to have had a noticeable relocation effect. Some polluting firms and activities have moved to Southeast Asia and Australia. Even in this case, however, environmental considerations appear to have been less important than other factors as causes of these investment flows -- rising prices in Japan for labor and land, other countries' barriers to Japanese exports, and general economic and political conditions in host countries.[20]

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[19] This decline suggests that the measurement method may not have sufficiently adjusted U.S. assets denominated in pesos. But even adjusting the 1996 historical cost data for FDI in Mexico upward by 30 percent (roughly the value of the real depreciation) only raises Mexico's share to 3 percent compared to 2.7 percent pre-NAFTA.

[20] Pages 26-29 in Jeffrey Frankel and Shang-Jin Wei, "ASEAN in a Regional Perspective," Pacific Basin Working Paper Series NO. PB96-02, Federal Reserve Bank of San Francisco, August.

Prices vs. Quantities Revisited: The Case of Climate Change

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Prices vs. Quantities Revisited: The Case of Climate Change

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Abstract

Uncertainty about compliance costs causes otherwise equivalent price and quantity controls to behave differently. Price controls – in the form of taxes – fix the marginal cost of compliance, leading to uncertain levels of compliance. Meanwhile quantity controls – e.g., tradeable permits or quotas – fix the level of compliance, leading to uncertain marginal costs. This fundamental difference in the face of cost uncertainty leads to different welfare outcomes for the two policy instruments. Seminal work by Weitzman (1974) clarified this point and derived conditions under which one policy is preferred to the other.

Such a situation – where tax and permit policies have been proposed and cost uncertainty is pervasive – accurately describes the current debate concerning policies to reduce greenhouse gas emissions, specifically carbon dioxide generated by fossil fuel combustion. Despite the considerable attention given to the political, welfare and revenue differences between taxes permits, only anecdotal evidence has addressed the efficiency difference due to uncertainty about costs.

This paper simulates uncertainty in an integrated climate economy model in order to compare the efficiency of taxes and permits. The results indicate that an optimal tax policy generates gains which are *five times higher* than the optimal permit policy – a $337 billion dollar gain versus $69 billion. This result follows from the basic Weitzman intuition that relatively flat marginal benefits/damages favor taxes, a feature that drops out of standard assumptions about likely climate damages.

An alternative policy which uses an initial distribution of tradeable permits to set a target emission level, but then allows additional permits to be purchased at a fixed price, leads to an even higher welfare gain. Such a system would preserve the political benefits of a permit system – namely preferential distribution to large emitters – and the efficiency benefits of a tax system – e.g., a hedge against unexpectedly high costs. This combined permit-fee system may provide a more credible domestic alternative to a pure permit system which could prove too costly or a pure tax system which has little political support.

Key words:

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Prices vs. Quantities Revisited: The Case of Climate Change

William A. Pizer[1]

1 Introduction

Seminal work by Weitzman (1974) drew attention to the fact that uncertainty about costs leads to a potentially important efficiency distinction between otherwise equivalent price and quantity controls. Despite this well-known observation and its relevance in the climate change policy context, most of the debate concerning carbon taxes versus permits has centered on political, legal and revenue concerns. This paper attempts to fill this gap by examining the efficiency properties of permits and taxes in the climate change arena.

The basic distinction among instruments arises because taxes in a competive, profit-maximizing world will tend to fix the marginal cost of abatement at the specified tax level. In a world where costs are uncertain, this will lead to a range of possible abatement levels and emission outcomes. In constrast, a permit system will precisely limit emissions but lead to a range of potential cost outcomes. This difference in emission and cost outcomes leads to a difference in social welfare when coupled with a model of reduction benefits.

In the case of climate change, much of the cost uncertainty arises due to uncertainty about the level of future emissions. The Intergovernmental Panel on Climate Change (1992) gives a range of CO_2 emission levels in 2025 of between 8.8 and 15.1 GtC. The cost of attaining a particular target, say the 1990 emission level of 7.4 GtC, will obvious fluctuate widely depending on the level of future uncontrolled emissions.

In addition to the baseline, however, there is considerable uncertainty about the cost of reducing emissions below the baseline. A study by Nordhaus (1993) reports that a $30/tC tax might reduce emissions anywhere from 10 to 40%. While some models predict that a $300/tC would virtually eliminate emissions, other models require $430/tc. This wide range of reduction estimates only compounds the uncertainty about baseline to generate extreme uncertainty about the cost of a

[1]Fellow, Quality of the Environment Division, Resources for the Future.

particular emission target.

With such motivation in mind, this paper adapts a popular integrated assessment model (Nordhaus 1994b) for analyzing alternative policies under uncertainty. In particular, the simulations are sped up using a technique developed in Pizer (1996) and uncertainty about a wide range of model parameters is introduced based on both Nordhaus (1994b) and Pizer (1996). Key modeling assumptions are discussed in the next section while specifics are covered in the appendix.

Before presenting the dynamic policy results in Section 4, Section 3 gives a simpler static analysis. This analysis, following Weitzman (1974), uses marginal cost and benefit estimates derived from the full dynamic model to examine optimal policy in a single year (2010). This simple static analysis provides the intuition for the full dynamic policy analysis and closely replicates the dynamic results in that year.

These results indicate that an optimal permit policy would begin with a 13 GtC target in 2010 and would rise gradually over time to accomodate some growth. This policy generates $69 billion in expected net benefits (e.g., benefits–costs). Importantly, this gain is sensitive to correctly setting the target. Slightly lower targets lead to dramatic welfare losses. Meanwhile, the optimal tax policy starts at $7.34/tC in 2010 and rises gradually over time. In contrast, this policy generates $337 billion in net benefits and the gain is much less sensitive to miss-setting the tax level.

As an alternative to the pure tax and permit policies, a combined permit-fee policy is proposed (Roberts and Spence 1976; Weitzman 1978; McKibbin and Wilcoxen 1997). Such a mechanism would involve an initial distribution of tradeable permits with additional permits available at a specified price. This system turns out to be only slightly more efficient than a pure tax system but provides the political advantages of a permit system. Namely, permits can be distributed to existing emission sources to reduce the tax liability they would face under a pure tax system.

2 Model Overview

2.1 Description

The integrated climate economy model used in this analysis is based on a stylized representation of economic activity and climate behavior. This stylized approach, based on Nordhaus (1994b), is appropriate given this paper's focus on *uncertainty*. While additional detail might improve the results for a given set of assumptions, it is unlikely that such embellishments would affect the range of predicted outcomes or the insight concerning optimal policy choice.

The economic model is based on one-sector model of global economic activity. Global capital and labor are combined to produce a single output each year which is either consumed or invested in additional capital. A representative agent chooses an allocation of consumption across time which maximizes her utility.

Climate change enters the model through the emission of greenhouse gases caused by economic activity. These emissions accumulate in the atmosphere and lead to a higher equilibrium temperature. This higher temperature then causes damages by reducing output according to a simple quadratic damage function.

The opportunity to reduce the effect of climate change arises from the potential to reduce emissions of greenhouse gases by using a more expensive production technology. In particular, there is a cost function describing the reduction in output required to reduce emissions by a given fraction. This cost is born in the current period, while the consequences of reduced emissions persist far into the future due to the longevity of greenhouse gases in the atmosphere.

Appendix A describes the model in more detail.

2.2 Key Modeling Assumptions

While the previous section gave a broad picture of the model and the appendix provides a detailed picture, it useful to summarize key assumptions in the model. These assumptions tend to drive the results in spite of the range of uncertainty considered. Table 1 compares this model with other commonly referenced economy-climate models and is followed by a discussion of the major issues.

2.2.1 Trends

An important issue for modeling long-term phenomena is the treatment of trends. In particular, assumptions about exogenous population growth, productivity improvements and changes in energy efficiency/carbon content will determine the baseline of uncontrolled greenhouse gas emissions. This model borrows from the work of Nordhaus and Yohe (1983), Nordhaus (1994b) and Nordhaus and Popp (1997) to characterize the range of global population and carbon content trends. Those same sources provide estimates of a future productivity growth slowdown. The initial rate of productivity growth is based on econometric estimates using U.S. data (Pizer 1996).

CHECK WORLD BANK/UN DOCUMENTATION ON FORECASTS; REFERENCE NORDHAUS AND YOHE CITES; SUMMARIZE NORDHAUS/IPCC SECTION ON EMISSION TRENDS.

2.2.2 Damages

Damages are perhaps the least understood aspect of climate change and at the same time one of the most important. In this model, damages are modeled as a quadratic function of temperature change, in turn determined by GHG concentrations. The model is calibrated so that a three degree temperature change is equally likely to reduce GDP by 0, 0.4, 1.3, 1.6, or 3.2 percent. The warming due to a doubling of greenhouse gas concentrations (due to occur by the end of the next century) is similarly calibrated to be either 1.5, 2.2, 2.9, 3.7 or 4.4 degrees with equal probability.

Among these assumptions, there are two that tend to drive the final results – in particular by suggesting a relatively flat marginal benefit schedule. The first is that climate damages are a gradual phenomena (represented by a quadratic function). The fact that damages from increased GHG concentrations rise smoothly and gradually contributes to a relatively flat marginal benefit schedule (e.g., marginal damages from increased emissions). In contrast, a damage function that involved critical phenomena – such as the breaching of a concentration threshold generating dramatically higher damages – would lead to a much steeper or stepwise damage function (though uncertainty

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Table 1: Comparison of Assumptions Across Models

Model	Population	Productivity	Emissions	Abatement Costs	Climate Change	Damages
This Paper	1995 growth rate of 1.24% declining geometrically 0.25% to 3.3% annually	1995 growth rate of % declining geometrically 0.2% to 2.5% annually	1995 growth rate (emissions/output) of -0.15 to -2.3% declining at the same rate as productivity growth	20% emission reductions from BAU baseline cost between 0.03% and 0.13% of GDP; 50% reductions cost 0.36–1.8%	50–80% of emitted CO_2 remains in the atmosphere; CO_2 doubling causes 1.5–4.4° rise in temperature	3° rise in temperature causes 0–3.2% loss of GDP
IPCC 1992						
Edmonds						
Manne & Richels						
Dowlatabadi						

about the threshold level would tend to smooth the expected damage function).

The second assumption – which is less controversial – is that damages are related to the *stock* of GHGs in the atmosphere and not the annual *flow*. This contrasts with traditional pollutants, such as particulates, SOx, NOx, etc., whose damages are related to annual flows.[2] Stock pollutants by their nature will have relatively flat benefit curves associated with reductions since the reductions in any period have a relatively small effect on the total stock. If the total stock does not change much, the marginal benefit cannot change much.

As an example of this stock pollutant phenomena, imagine a pollutant, like carbon dioxide, whose atmospheric stock decays naturally at a rate of less than 1% per year. At an equilibrium, it can be shown that the emissions in any year will equal to 1% of the total stock.[3] If marginal benefits decline linearly from some initial level – say $10 ton – to zero over the entire balance of the stock, the decline in marginal benefits over a 100% reduction in emissions in a single year will be only $0.10 (1% of $10).

In the absence of a compelling argument that climate damages exhibit sudden, catastrophic increases over a gradual increase in GHG concentrations, this fact that GHGs are a stock pollutant turns out to provide a strong rationale for emission taxes via the flatness of the marginal benefit schedule.

2.2.3 Costs

Reductions in GHG emissions from any given baseline are assumed to reduce global GDP according to a simple power rule,

$$\text{fractional reduction in global GDP} = b_1(\text{fractional reduction in GHGs})^{2.887}$$

where the parameter b_1 takes on the values 0.027, 0.034, 0.069, 0.080, 0.133 with equal probability. That is, complete elimination of GHG emissions is forecast to cost between 2.7% and 13.3% of

[2]To some extent this is an arbitrary distinction. Any pollutant can be viewed as a stock pollutant when viewed on a suitably small time-scale. For conventional pollutants, this might be a period of a day or a single hour.

[3]E.g., annual emissions will exactly equal the annual decline of the stock – 1%.

global GDP.[4]

More important than the particular numbers entering the cost function are the assumptions that (1) marginal cost rises more and more steeply as additonal reductions are undertaken and (2) that the choice of emission level is an annual decision involving an annual cost function. Both of these points are crucial because they affect the relative slope of marginal costs (in turn affecting the difference in expected welfare between taxes and permits). If, for example, we believe that substantial reductions of GHGs will involve the development of new carbon-free technologies, it seems reasonable that the marginal cost of reducing emissions will eventually flatten. This will diminish the argument that marginal benefits are relatively flat compared to costs. Alternatively, many decisions to reduce emissions – such as those reductions resulting from investment in innovative research or in new capital – are made over horizons of decades rather than annually. In such cases, costs and benefits should be viewed over equally long intervals, again weakening the argument that marginal benefits are relatively constant.

3 Single Period Policy Simulations

Given the long-term nature of climate change, a policy to reduce GHG emissions inevitably involves decisions over periods of years or decades. However, understanding the differences between GHG tax and permit mechanisms under uncertainty is complicated when policies are viewed as paths for tax and permit levels, rather than single-period, single-value choices. With that in mind, this section presents results for a single-period policy analysis – reductions in GHG emissions in the year 2010. Since a single dimension captures the range of policies in this context, graphs can be used to view policy consequence. The next section will discuss the dynamic policy results.

3.1 Weitzman's Result

The analysis presented in Weitzman (1974) concerns the choice of policy instrument used to regulate a market where either political considerations or market failure requires government interven-

[4] See Nordhaus (1993) for further details.

tion. A price (tax) or quantity (permit) instrument is at the government's disposal and the question posed by Weitzman is which leads to the best welfare outcome, measured as net social surplus.[5]

With complete certainty concerning costs, price and quantity controls can be used to achieve the same outcomes. For every price, there is a profit-maximizing level of production where price equals marginal cost and for every level of production there is an associated marginal cost. Note that while uncertainty solely about *benefits* leads to uncertain welfare outcomes, it does not lead to uncertainty about the level or marginal cost of production – these are determined by the structure of costs. Therefore, the two instruments (which affect production) can be used to obtain exactly the same set of potential welfare outcomes when costs are known, though the welfare outcomes may be uncertain due to unknown benefits.

The interesting case arises when *costs* are not certain. In this case, fixing the marginal cost through a price instrument leads to an uncertain level of production. Correspondingly, fixing the level of production with a quantity instrument leads to an uncertain marginal cost.

Weitzman's basic result was that price instruments would be favored when the marginal benefits were relatively flat and quantity instruments would be favored when the marginal costs were relatively flat. In particular, he derived an expression for the difference in expected welfare between the price and quantity instruments:

$$\Delta = \frac{\sigma^2}{2C''^2}(B'' + C'') \quad (1)$$

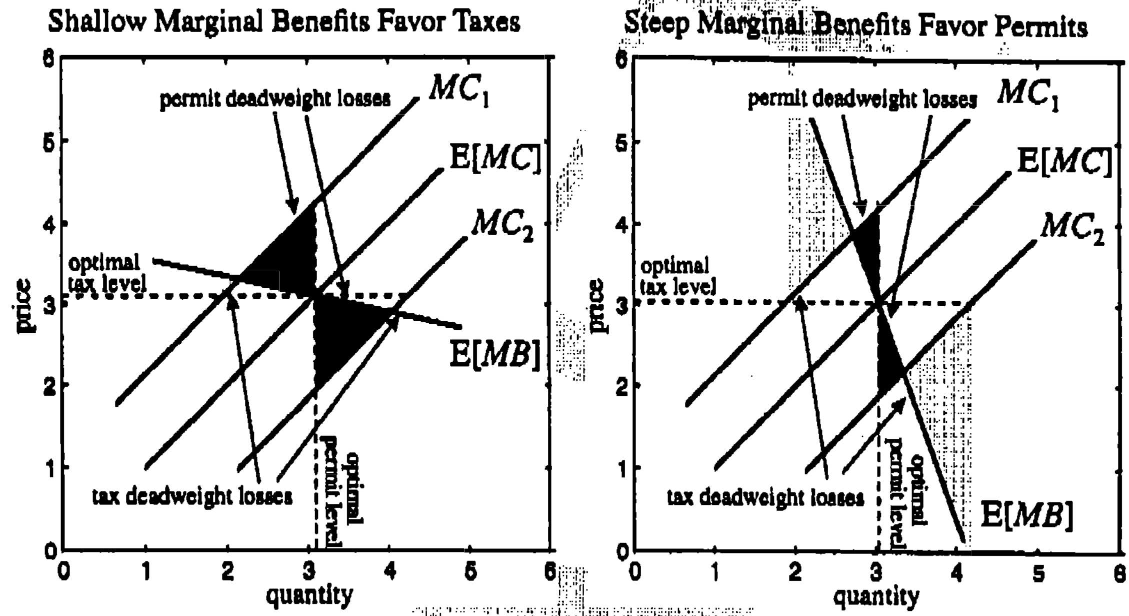
where σ^2 is the variance of the shocks to the marginal cost schedule, C'' is the slope of the (linear) marginal cost schedule and B'' is the slope of the (linear) marginal benefit schedule.[6] Since the marginal benefit schedule is assumed to be downward sloping ($B'' < 0$), the price instrument is preferred when $|B''| < |C''|$ and the quantity instrument is preferred when $|B''| > |C''|$.

The intuition behind this result is that when marginal benefits are relatively flat ($|B''| < |C''|$), the ex post (after cost uncertainty is resolved) optimal price is relatively constant. In contrast,

[5]Here and throughout it is assumed that the quantity instrument is an *efficient* quantity instrument; e.g. a tradeable permit system with negligible transaction costs.

[6]This result is derived for the case of linear marginal costs and benefits, where uncertainty enters as small shifts to each curve. The uncertainty about costs is assumed to be independent of the uncertainty about benefits.

Figure 1: Deadweight Loss of Taxes Versus Permits

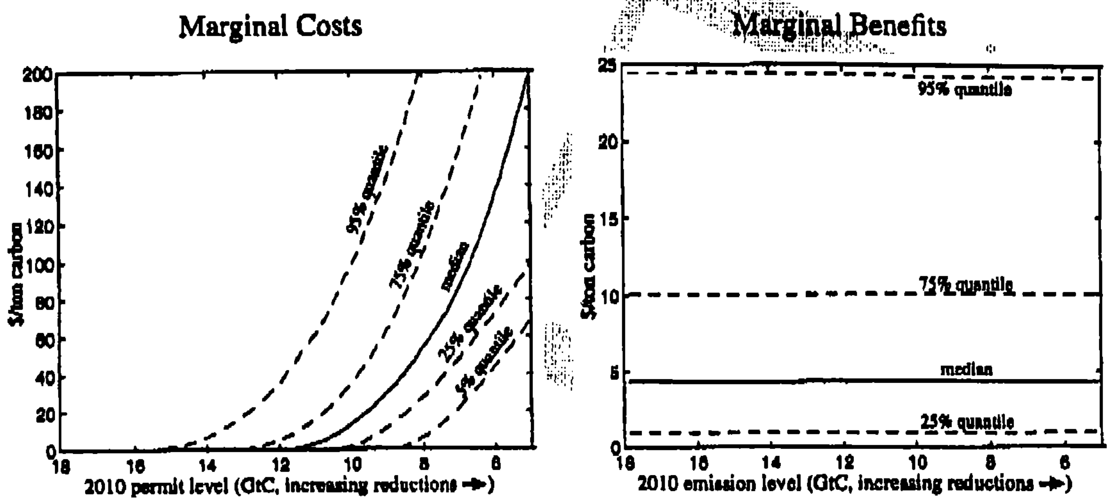


when marginal benefits are relatively steep ($|B''| > |C''|$), the ex post optimal quantity is relatively constant. Therefore, fixing the ex ante price when the optimal ex post price is fairly constant and fixing the ex ante quantity when the optimal ex post quantity is fairly constant leads to smaller deadweight losses. This is shown visually in Figure 1.

3.2 Marginal Costs and Benefits

While there are a number of strong assumptions in the Weitzman analysis which are inappropriate for examining climate change policy, it remains a sensable starting point. How do the marginal costs and benefits of GHG emission reductions in the year 2010 compare in terms of relative slopes? In order to answer this question, the integrated assessment model of uncertainty outlined in Section 2 and described in detail in Appendix A is used to compute two quantities. First, the welfare associated with different levels of emissions in 2010 is computed in net present (2010) value terms for several thousand randomized trials. Marginal benefits are computed by numerically differentiating the derived schedule of benefits. Second, the cost associated achieving different levels of emissions in 2010 is computed based on the model's cost function for the same set of

Figure 2: Distribution of Marginal Costs and Benefits in 2010[a]



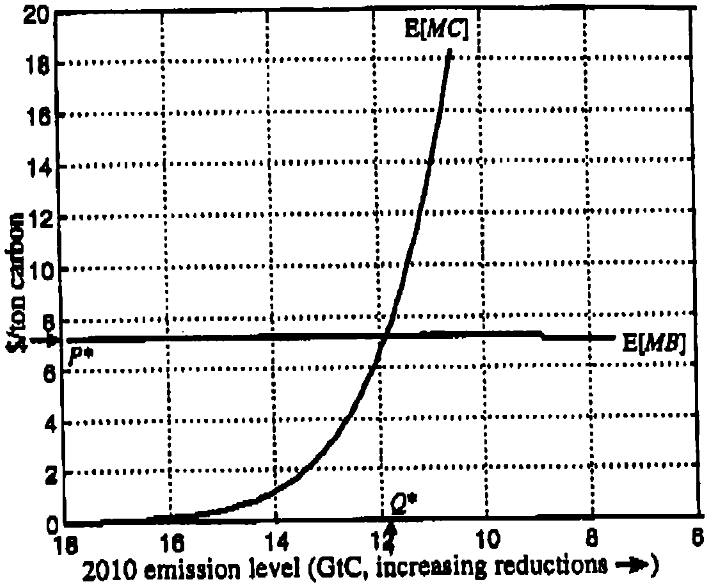
[a]Marginal costs are based on dollar value ($2010) of lost global GDP in order to reduce emissions at or below the indicated level. In those cases where uncontrolled emissions are below the indicated level, the marginal cost is zero. Marginal benefits are based on the dollar value ($2010) of the net present value of forgone damages at the given emission levels. These foregone damages hold constant all future emissions at their baseline level. Values are expressed in $2010 and, due to different discount rates across states of nature, will not be weighted equally when balancing costs and benefits.

randomized trials. This cost is similarly numerically differentiated to obtain marginal costs in the year 2010. In some trials and for some levels of emissions, the cost is zero since the given emission level may be higher than actual uncontrolled emissions.

These two calculations result in a distribution of marginal benefits and marginal costs at different levels of emission. Figure 2 attempts to summarize these distributions by showing how different quantiles of marginal costs and benefits vary over the range of emissions considered. Keeping in mind that 1990 GHG emissions were around 8.5 GtC, the left-hand panel indicates that achieving 1990 emission levels in 2010 would involve a marginal cost of between zero and $180/ton – a very wide range. This large variation occurs for two reasons: (1) marginal costs are assumed to rise steeply given the specified cost function, and (2) the baseline emissions in 2010 are not known with certainty. This panel essentially depicts a distribution of fairly steep curves whose horizontal intercept is unknown.

The right panel, in contrast, indicates rather constant but unknown benefits. As suggested earlier, the fact that damages due to GHGs depend on their *stock* in the atmosphere rather than

Figure 3: Expected Marginal Costs and Benefits in 2010[a]

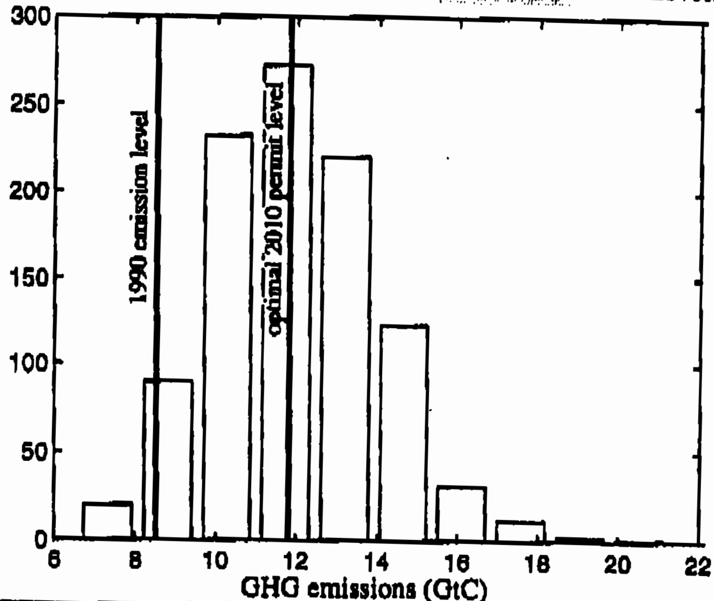


emissions in any one year – and the fact that GHGs remain in the atmosphere for a very long time – makes marginal benefits insensitive to the level of annual emissions. For example, in 1995 the concentrations of GHGs in the atmosphere was 760 GtC and annual emissions were around 10 GtC. Therefore the difference in concentrations between no reductions and 100% reductions in any one year is small – making it unlikely that the marginal benefit of the first ton of reductions is much different than the marginal benefit of the last ton.

Taking expectations across these marginal costs and benefits yields the schedules shown in Figure 3. Under the assumptions made by Weitzman, the optimal permit level is simply emission level where expected marginal benefits equal expected marginal costs and the optimal tax level is similarly the marginal benefit at that intersection. Thus P^* and Q^* indicate the optimal tax and permit policies in 2010 for controlling GHG emissions.

Visually, it is apparent that expected marginal benefits are flatter than expected marginal costs. Calculating the slopes at the intersection, $B'' = -0.0012$ and $C'' = 5.4$. Further, setting $\sigma^2 = \text{var}(MC_{\text{emission}=11, 2010})$ yields $\sigma^2 = 270$. This allows a rough calculation of the welfare gain of taxes over permits using (1): $\Delta = \frac{270}{2 \cdot 5.4^2}(-0.0012 + 5.4) \approx \$25$ billion. Discounting this to 1995 (the base year of the model) with a 6% discount rate generates an estimated gain of \$10 billion

Figure 4: Histogram of Uncontrolled 2010 Emissions Levels



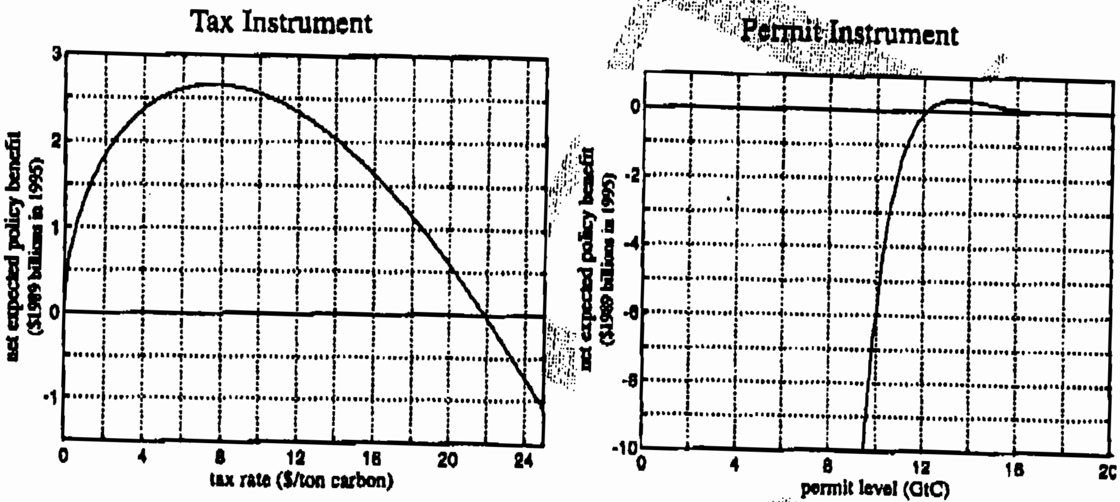
[a]GHG emissions include CO_2 and CFCs. 1990 emissions are based on 7.4 GtC of CO_2 and 1.1 GtC of CFCs (p. 71, Nordhaus 1994b). The 1990 emissions also correspond to data from IPCC(1992), p. 12, using a factor of 1300 to convert tons of CFCs into tons of carbon equivalent global warming potential (GWP) (Lashof and Ahuja 1990). The optimal 2010 permit level is discussed in the text.

from using taxes instead of permits – just in the year 2010.

In addition to the welfare difference, it is interesting to compare the optimal quota in 2010 to the range of actual emissions. Figure 4 shows 1990 emissions (a target under consideration), the optimal 2010 permit level, and the distribution of uncontrolled emissions in 2010. Roughly half of the emission scenarios involve uncontrolled emissions *below* the optimal permit level (versus around 3% below the 1990 level). That is, implementing the optimal permit policy would result in non-binding targets half the time.

Why is the optimal permit policy so loose? Intuitively, uncertainty about baseline emissions is large relative to reductions and a large amount of reductions is costly. Therefore committing to an emission target which is almost surely below all forecasts (such as 1990 emissions levels) will involve extremely high costs in the event of high growth and high baseline emissions. These high costs, based even on the highest estimated benefits, lead one to prefer a less stringent (higher) target.

Figure 5: Welfare Consequences of Pure Tax and Permit Instruments in 2010



3.3 Welfare Consequences of Pure Tax and Permit Mechanisms

While the previous analysis based on Figure 3 provides important intuition and a rough approximation of the welfare consequences of taxes and permits, it fails to capture several important failures of the Weitzman assumptions. While the intuition behind these failures and their individual consequences is discussed in Appendix C, in this section their net effect is summarized. In particular, the net welfare gains of alternative tax and permit policies are shown in Figure 5

These results simply confirm the intuition in Figure 3. Namely the welfare gain from the optimal tax instrument, around \$2.5 billion, is much larger than the gain from the optimal permit instrument, around \$0.3 billion. Although the rough calculation using Weitzman's formula suggested a difference of \$10 billion, there are many reasons why Weitzman's result is not exactly right in this context (as discussed in Appenidix C).

Figure 5 also indicates a large risk associated with setting an emission target incorrectly – specifically setting a target too low. While the net benefits of a tax are positive for a wide range of values, from zero to \$20/ton C, the net benefits of a permit system rapidly become negative as the target falls below 11 GtC. At the proposed 1990 emission level, 8.5 GtC, the welfare gain is below –\$10 billion. This result is a consequence of reductions becoming extremely expensive in the high-emission states of the world. Thus, an important conclusion from this graph is that low targets could be prohibitively costly. While adopting a more optimistic view about the cost of reductions might weaken this conclusion, it seems unlikely that the uncertainty surrounding even such optimism would allow a complete reversal.

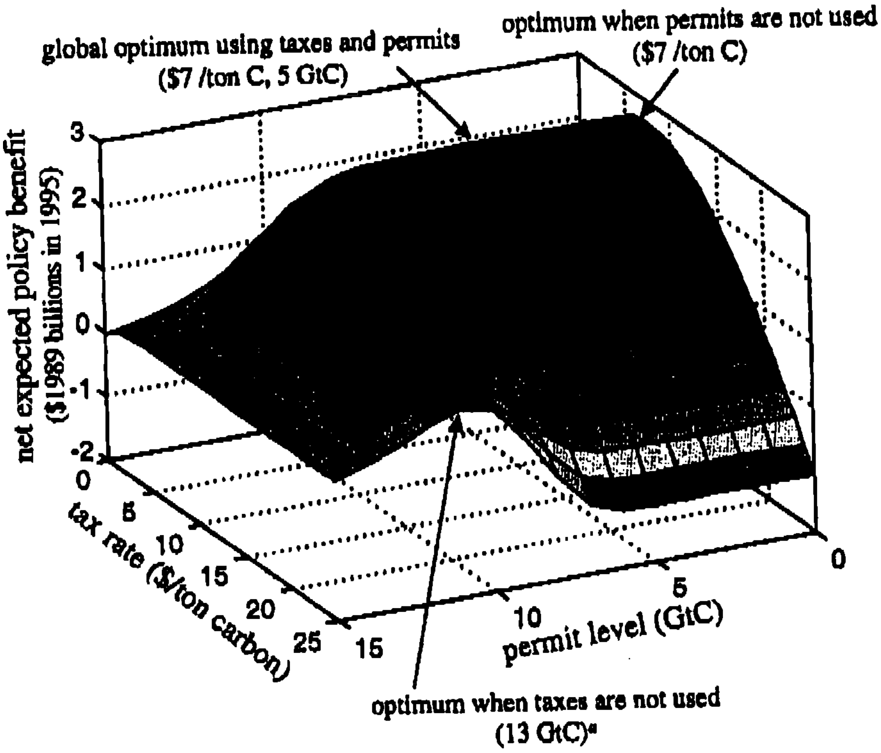
3.4 Combining Taxes and Permits

Not long after Weitzman's original article, several authors suggested using a combined fee and permit policy (Weitzman 1978; Roberts and Spence 1976) to regulate a market. That is, a producers have a choice of either obtaining a permit or paying a tax-like fee. Such a system works like a permit system by fixing emissions as long as the marginal cost (e.g., the price of the permit) lies below the fee level and works like a tax system by fixing marginal cost when marginal cost rises to the level of the fee. When the fee is set high, such a combined mechanism functions like a pure permit system (since the fee is never paid) and when the number of permits is set low, it functions like pure tax mechanism (since permits are never used).

Even ignoring efficiency concerns, such a mechanism has considerable appeal in the climate change context as pointed out by McKibbin and Wilcoxen (1997). Relative to a pure carbon tax, it effectively exempts payment of taxes on the volume of emissions in 1990. This would lower the cost to industry by over $10 billion in the U.S. alone.[7] While it would not necessarily stabilize emissions, the policy would reduce emissions below their baseline and quite possibly be more effective than an aggressive policy which is later abandoned as too costly. The fact that governments would receive some revenue also provides an incentive mechanism for monitoring which is absent in a pure permit system. Finally, as McKibbin and Wilcoxen highlight, it would be relatively easy to add new countries to an international agreement involving such a mechanism. In contrast to a pure permit system involving complex international trades, a permit and fee system could be adopted domestically by non-participating countries without international negotiations. Countries such as India and China, which are unlikely to participate initially in a climate change agreement, would have the additional incentive of fee revenue to enact such a policy in the future.

[7] As pointed out in other work, losing the revenue from such taxes could also have important welfare consequences (Goulder, Parry, and Burtraw 1996).

Figure 6: Net Expected Policy Benefits of Alternative Tax/Permit Policies in 2010



[a]The optimal permit level when taxes are not used (13 GtC) does not become apparent until the tax rate is set roughly twice as high as shown in the figure (around $50/ton carbon), otherwise the tax is still used in some states of nature. From the figure, it is evident that the optimal permit level as a function of the tax is increasing. At $25/ton carbon, however, the optimal permit level is only 11 GtC. The net expected benefit when the tax is no longer used and the permit level is 13 GtC is $0.3 billion, roughly one-tenth of the benefit from a straight tax or combination tax/permit policy.

Importantly, the efficiency gains of such a combined mechanism are large relative to a pure permit scheme. As shown in Figure 6, the gains from a combined permit-fee mechanism are roughly the same as a pure tax mechanism, but roughly ten times the gain from a pure permit mechanism. It is interesting that the global optimum – a 5 GtC permit volume and $7/ton C tax – is quite close to the proposal suggested by McKibbin and Wilcoxen.[8]

4 Dynamic Policy Under Uncertainty

Up to this point the analysis has focused on the costs and benefits of different policies *in a single year*. The problem of climate change, however, is spread out over decades if not centuries. Policies to combat climate change are therefore likely to be in place for many years. It is not immediately obvious whether the results comparing different instruments in a single year are immediately applicable to a multiperiod policy.

In this section, optimal paths for taxes, permits and combined permit-fee mechanisms are explored. In addition to considering the net welfare consequences of these policies, results concerning the range of climate outcomes and compliance costs (ignoring climate benefits) are presented.

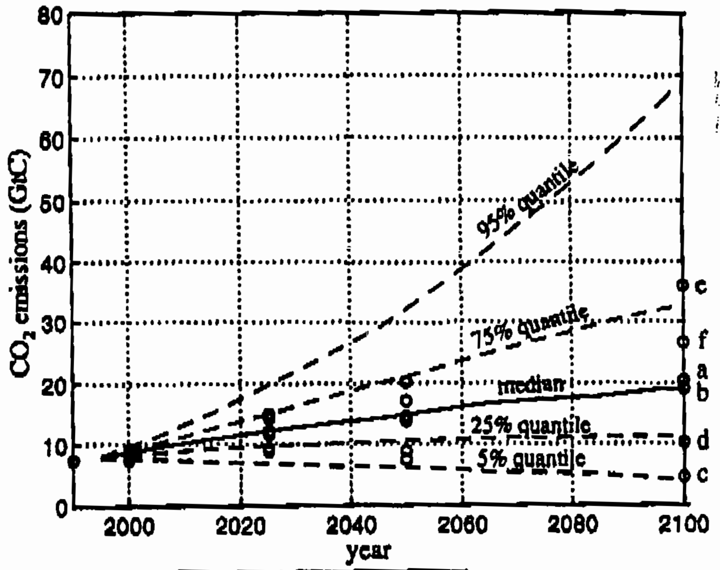
4.1 Baseline Emissions

Before exploring different dynamic policies, it is useful to report on the model's ability to replicate the results of other models under business-as-usual assumptions. In particular, the IPCC (1992) gives six forecasts of future emission scenarios for the major greenhouse gases based on a range of assumptions concerning global population and productivity growth. Figure 7 shows the IPCC forecasts against the range produced by the model presented in this paper for the most important greenhouse gas, carbon dioxide.

The IPCC forecasts tend to fall between the 25th and 75th percentile in 2025 and between the 5th and 75th in 2050 and 2100. The median of the IPCC forecasts remains quite close to the 50th

[8] They advocated 1990 emission levels as the permit volume coupled with a $10/ton C tax. 1990 global controllable GHG emissions were 8.5 GtC.

Figure 7: Simulated CO_2 Emission Distribution vs IPCC Scenarios



[a]Lines indicate the distribution of CO_2 emission paths generated by the model. These reflect controllable carbon equivalent GHG emissions, scaled by the fraction due to CO_2 (e.g., 86.6%; see p. 71, Nordhaus 1994b). Circles (o) indicate 1992 IPCC CO_2 emission scenarios (p. 12, IPCC 1992; pp. 101–112, Pepper et al. 1992); letters in right margin refer to individual scenarios.

percentile of the simulated emission levels. This suggests that, relative to the IPCC forecasts, the model in this paper predicts a similar central tendency but with a larger spread. In particular, this paper suggests that future uncontrolled emissions could be much higher than all six of the IPCC forecasts. Is this unreasonable?

First, it is important to recognize that the IPCC scenarios do not have a probabilistic interpretation. They are subjectively developed scenarios combining a large number of alternative assumptions in six particular combinations. Their high emission scenarios, for example, alternatively combine high population growth with lower per capita productivity growth, and vice versa. Further, the underlying growth forecasts themselves have no probabilistic interpretation.[9]

Second, even analyses that are well-grounded in probability often underestimate the probability of extreme events. This phenomena has been documented in everything from the measurement of

[9]See Pepper et al. (1992) for further details. Note that early Census population forecasts using similar non-probabilistic techniques often grossly misforecast population. For example, the forecast range given in 1966 (#381, Table 1) lies completely above the actual population reported in 1989 (#1045, U.S. Department of Commerce, Bureau of the Census).

physical constants to the forecast of future energy demand (Shlyakhter and Kammen 1992). Such results suggest that forecasts with "thicker tails" are likely to be a more realistic description of likely outcomes.

Finally, the time horizon under consideration – over one hundred years – makes any forecast based on historical data somewhat dubious. It is implicitly assumed that historical trends will continue with no structural change. When in the history of the world have such periods of stability existed? For all these reasons, the wider range of uncontrolled emission forecasts produced in this paper is likely a more accurate description of emission outcomes than the range of IPCC scenarios.

4.2 Optimal Permit Policy

To compute optimal policies, the paths of alternative permit, tax and combined permit-fee systems were parameterized with six parameters describing stringency in 2010 (the first year of implementation), 2020, 2040, 2070, 2110 and 2160. Policies in intervening years are taken smooth interpolations,[10] except the stringency in 2160 which is allowed to be discontinous and is held fixed through the end of the simulation (2245). The length of the simulation as well as the spacing of the policy parameters was subjectively chosen to make the policy evaluation in the 2000-2100 interval as accurate as possible, especially the early 2000-2050 period.

The resulting optimized permit policy, which limits global greenhouse gas emission to a specified level, is shown in Figure 8. The policy is not known with certainty due to sampling error – only 8,000 states of nature were used to estimate the policy (this could be reduced with additional computing power).[11] Interestingly, the optimal permit level of 13 GtC in 2010 is roughly the same as the optimal permit level determined in the static analysis. This is not so surprising given the fact that initial emission reductions will not substantially affect GHG concentrations for many years, at which point the discounted benefits in 2010 will be small.[12]

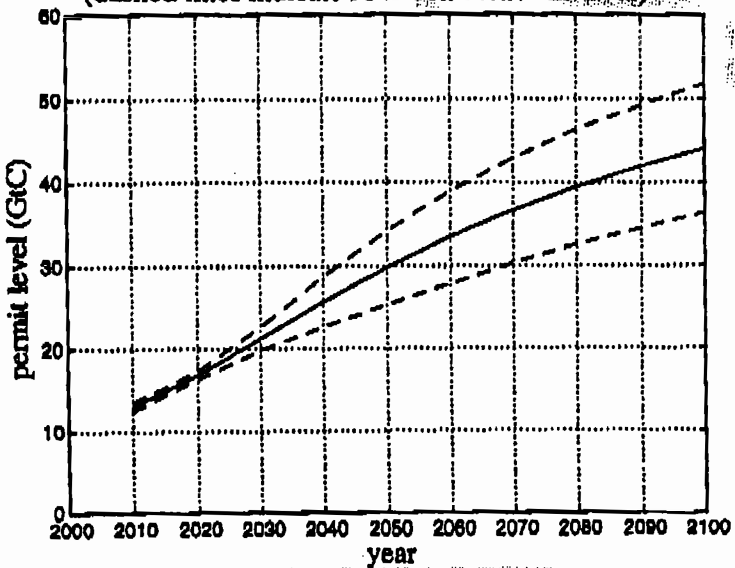
[10] Policies are interpolated to ten-year intervals using a cubic spline; annual policies are linearly interpolated from the ten-year values. The combined permit-fee system is always interpolated linearly due to sampling error.

[11] The stringency was optimized over eight sets of 1,000 states of nature, taking on average 30 minutes to converge. These eight sets were then averaged and the standard deviation among the eight estimates was used to compute a standard error for the average.

[12] An important assumption in the underlying DICE model is that damages are continuous and have been occuring

Figure 8: Optimized Permit Level -- Dynamic Policy

(dashed lines indicate 95% confidence interval)



An important observation is that the proposal to reduce emissions to their 1990 levels (roughly 8.5 GtC) is far below the optimal permit level in these simulations. Further, the optimal permit level rises in the future to accomodate growth in population and per capita productivity. While this kind of policy might appear to ignore the possibility that a carbon-free technology becomes not only commerically available but dominant in the next century, it conversely accomodates the possibility that such a technology never gets off the ground.

When the optimal policy is implemented it improves welfare on average by $69 billion ($1989).[13]

4.3 Optimal Tax Policy

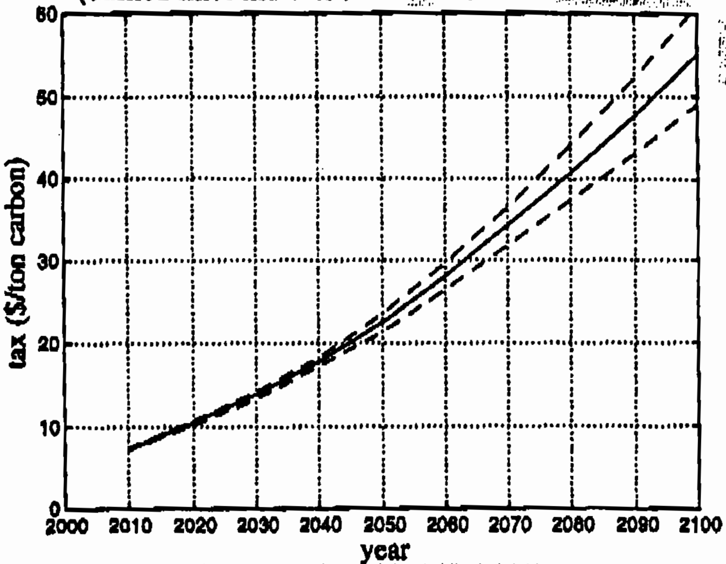
While the permit policy requires that emissions in every state of nature be at or below the specified level, a tax policy effectively fixes the marginal cost of emission reductions. Consumers and producers facing a tax on greenhouse gas emissions will reduce emissions until the cost of reducing emissions further equals the cost of paying the tax instead. If costs are particularly low, emissions

since the beginning of industrialization. Thus we are already experiencing the consequences of global warming and current emission reductions are prodominately concerned with reducing damages for roughly the next 30 years.

[13]This is the net present value of benefits minus costs and has an associated sampling error of $16 billion. This can be compared to annual global output in 1995 which was $24 trillion.

Figure 9: Optimized Tax Level – Dynamic Policy

(dashed lines indicate 95% confidence interval)

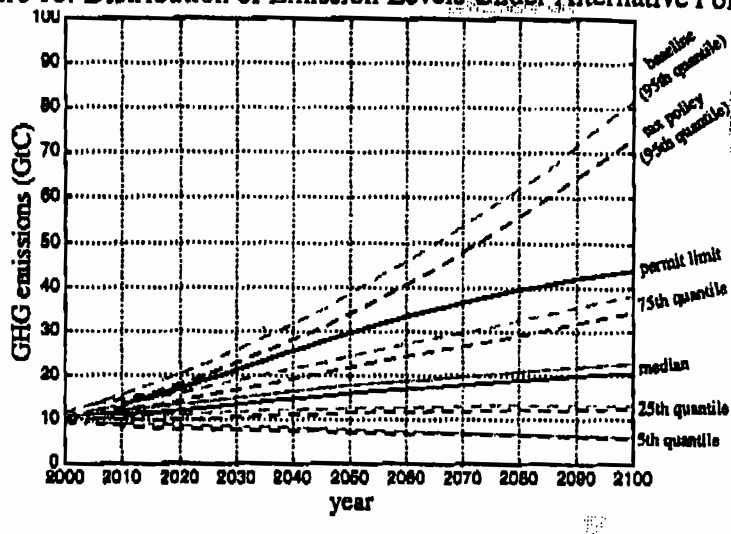


may be completely eliminated and the marginal cost of the last ton of reductions will lie below the specified tax rate.

Figure 9 shows the tax policy which maximizes expected welfare. The initial tax of $7.35 is close to, but slightly lower than, the tax computed in the static analysis. Unlike the optimal permit policy, which rises and relaxes in stringency in order to accomodate growth, the optimal tax policy becomes *more stringent* in the future. This occurs because, unlike a constant permit level, a constant tax automatically leads to proportionally higher emissions as the economy grows. While some increase in emissions is desirable as the economy grows, a proportional increase is not – therefore the tax must increase in stringency while the permit system must be relaxed.

An important difference between tax and permit policies is that taxes do not provide a strict limit on emissions. This, however, should not be viewed strictly as a weakness: relaxing the level of emissions when costs turn out to be particularly high is desirable if the benefits of reduction are fairly constant. Figure 10 shows the distribution of resulting emissions with and without the tax policy. Note that the optimal permit policy is *not* binding over 75% of the time (it lies above the 75th quantile of baseline emissions). Meanwhile the optimal tax policy leads to emissions above

Figure 10: Distribution of Emission Levels Under Alternative Policies



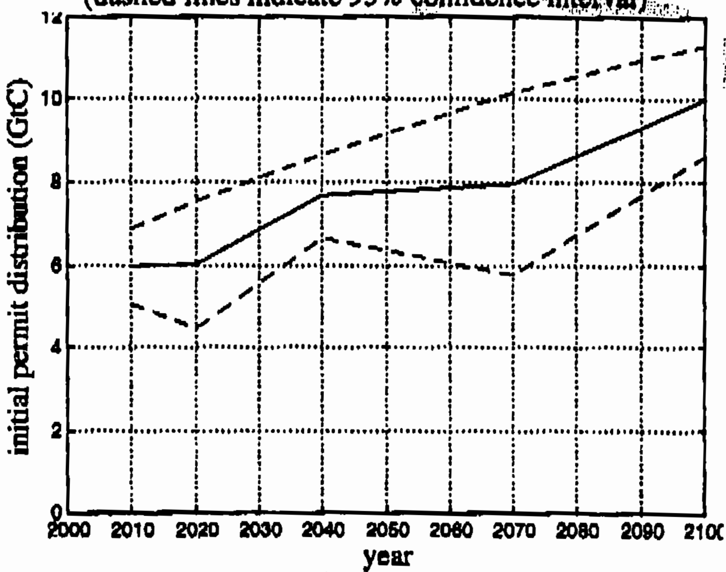
the optimal permit level between 5 and 25% of the time.

Finally, if welfare improvements are averaged across states of nature, the typical welfare improvement amounts to $338 billion – compared to $69 for the permit instrument (the standard error in this case is $21 billion). This represents an improvement five times higher than that obtained with the permit system – a smaller ratio than the factor of eight determined in the static analysis.

Why might permits appear slightly better when viewed over a longer horizon? As pointed out by Weitzman (1974) and discussed later by Stavins (1996), negative correlation between marginal costs and benefits leads to a preference for quantity instruments (e.g., permits). In the case of a stock pollutant which is regulated by a emissions target, such correlation is likely over long periods of time due to uncertainty about baseline emissions. When baseline emissions are consistently low, the pollutant stock is lower in the future making marginal damages lower. At the same time, lower emissions make any single period target cheaper to obtain. This assumes that baseline emissions in one period are correlated with baseline emissions in other periods – a likely consequence when uncertainty about future growth is modeled as "low growth" versus "high growth" scenarios.

Figure 11: Optimal Initial Permit Distribution in a Combined Permit-Fee System

(dashed lines indicate 95% confidence interval)



4.4 Combined Permit-Fee Mechanism

An alternative to the pure tax and permit systems discussed so far is a combined system of permits and fees. Such a system involves an initial allocation of permits coupled with a price at which additional permits are sold by the government. The initial distribution involves a quantity mechanism while the subsequent permit sales involve a price mechanism. Since the initial distribution can be set to an arbitrarily small number of permits and the subsequent sale price can be set arbitrarily high, the combined permit-fee system can be made to resemble either the pure tax or permit policy.

To explore this possibility, the subsequent sale price was set to the optimized tax level and welfare was then re-optimized over alternative levels for the initial permit distribution.[14] The resulting optimal permit level is shown in Figure 11. There is a much higher degree of sampling error in the estimation of the optimal permit level. This occurs because the marginal effect of the policy is derived only from those states of nature where baseline emissions are above the permit level but marginal costs are below the tax – this turns out to be a relatively small fraction of

[14]A direct optimization over all the policy parameters turned out to be troublesome due to the sample size. By using the optimized tax policy, the combined policy is guaranteed to both raise welfare and involve lower costs.

the sample and results in a large estimation error.[15] Interestingly, the optimal initial permit level remains close to the 1990 emission level (8.5 GtC) for almost the entire forecast period. Setting the intitial distribution to 8.5 GtC, in fact, has a negligible effect on the welfare (as was true in the static case). The gain in welfare is $339 billion for the optimized permit-fee policy and $340 billion for a policy with an initial permit distribution of 8.5 GtC in every period, both with a standard error of $20 billion.

4.5 Costs Only Comparison

The purpose of this paper has been to compare alternative climate change policy instruments under a metric of *welfare maximization*. The main conclusion of this study is that the current view of climate damages leads to a relatively flat marginal benefit curve. In the presence of uncertainty, this generates a preference for tax rather than quantity instruments – or even better, a combined permit-fee system.

However, in order to perform this analysis, it has been necessary to lean on rather speculative assessments of climate damages. Even while allowing for considerable uncertainty, the underlying structure of damages – a quadratic function depending on temperature change – has not been questioned in this paper. This may tend to cast some doubt on the welfare calculations presented in support of the alternative policies.

For that reason, Table 2 presents a "cost-only" comparison of the policies derived in the previous sections. That is, the climate portion of the model (specifically, the damages due to global warming) is ignored and only the *cost* of the different reduction strategies is computed. As highlighted in Figure 10, however, it is important to keep in mind that the alternative policies have different emission consequences as well. The interpretation of this measure is that it reflects the expected cost of each policy in the event that there are, in fact, no consequences to global warming.

The permit policy, which has the lowest net benefits, also has the lowest gross cost. Intuitively, the policy simply fails to affect many states of nature since it is only binding 25% of the time. The

[15] This sampling error could be reduced with additional simulations. This increased uncertainty can also be observed in Figure 6 as a relatively flat ridge for a wide range of permit levels near the optimal tax.

Table 2: "Cost-only" Comparison of Alternative Policies
(measured in $1989 billions; standard errors in parentheses)

	optimal[a] permit system	optimal[a] tax system	optimal[a] permit-fee system
benefit-cost[b]	69	338	339
	(16)	(21)	(20)
cost-only[c]	−151	−187	−170
	(5.5)	(2.7)	(2.7)

[a]Policies are optimal in that they maximize the benefit-cost measure. Large standard errors arise due to the variability of benefits (note that the variation is much smaller in the cost-only measures). Additional simulations can be used to reduce the sampling error further.

[b]Benefit-cost measures the change in expected net present value of welfare when damages due to global warming are included in the simulation.

[c]Cost-only measures the change in expected net present value of welfare when damages are ignored (both in the baseline welfare simulations as well as for the given policies).

tax policy, which has much higher net benefits has 20% higher gross costs. These higher costs arise inevitably in the other 75% of the states of nature, relative to the permit policy, where the tax policy has some effect. Finally, the combined permit-fee system is only marginally better in benefit-cost terms than the pure tax policy, but cuts the gross cost difference in half. This cost savings arises because in those states of nature where permit level is either not binding or marginally binding, less aggressive reductions are undertaken. The fact that the net benefits remain virtually unchanged indicates that this slackness in the policy is occuring in states where marginal benefits are roughly equal to marginal costs.

Perhaps the most important obervation from Table 2 is that while the benefit-cost comparison shows taxes and permit-fee systems to be much more efficient than a pure permit mechanism (a factor of five-to-one) the difference in costs is much smaller – at most 25%. This suggests that concern about a tax system turning out to be much more expensive than a quota or permit system is misplaced.[16]

[16]This statement, of course, is in reference to the cost difference among efficiently implemented policies in a first-best world. Issues related to cost-effectiveness and second-best distortions are not considered.

5 Conclusion

Discussions of alternative tax and permit mechanisms for combating climate change have generally ignored the fact that the costs and benefits of future reductions are highly uncertainty. Such uncertainty can lead to large efficiency differences between the two policies (Weitzman 1974). This paper has explored this question in the context of an integrated climate-economy model capable of simulating thousands of uncertain states of nature.

The resulting welfare analysis indicates that taxes perform much more efficiently than permits – by a factor of *five to one* ($337 billion versus $69 billion). This derives from the relatively flat marginal benefit curve associated with emission reductions. This flatness is partially a product of the assumption of quadratic damages, even allowing for the fact that the level of damages due to three degrees of warming is anywhere from zero to a three percent loss of GDP. It also arises naturally because greenhouse gases are stock pollutants so reductions in any period inevitably have little effect on the level of marginal benefits.

An important observation in the static analysis was the risk involved in setting the permit level *too low*. Not only does the optimal permit involve much lower welfare gains, but setting the permit level incorrectly can lead to massive losses. The tax instrument, in contrast, leads to welfare gains over a much wider range of values.

In addition to pure tax and permit systems, a combined permit-fee system was considered. Such a system involves an initial allocation of permits followed by the subsequent sale of additional permits at fixed price. The initial distribution function like a quota while the subsequent permit sales function like a price instrument. By making the initial distribution small or the subsequent sale price high, this combined system can be made to mimic either the pure tax or permit system.

The combined permit-fee system improves on the welfare outcome using taxes but only slightly ($339 billion vs. $337 billion). Interestingly, the optimal distribution of initial permits turns out to insignificantly different than the proposed 1990 emission level target of 8.5 GtC. This mechanism thus combines the benefits of a tax system, namely efficiency, with the benefits of a permit system, e.g., flexible distribution of rents.

A Model Specification

A.1 Economic Behavior

Economic behavior within each state is derived from a representative agent model where consumption must be optimally allocated across time. In a typical model with constant exogenous productivity growth, agent preferences define a steady state to which the economy converges over time. In the presence of random shocks and slowly changing trends, the economy instead converges to a distribution of states (due to the random shocks) which is itself slowly evolving (due to the slowly changing trends). For the moment we ignore these changing trends and focus on a standard stochastic growth model.

The representative consumer in this model exhibits constant relative risk aversion τ with respect to consumption per capita. Utility is separable across time, discounted at rate ρ and weighted each period by population. With the further assumption that preferences satisfy the von Neuman-Morgenstern axioms, the consumer's optimization problem can be written as

$$\max_{\substack{C_t \\ t\in\{0,1,\ldots\}}} \mathrm{E}\left[\sum_{t=0}^{\infty}(1+\rho)^{-t} N_t \frac{(C_t/N_t)^{1-\tau}}{1-\tau}\right] \tag{A.1}$$

where C_t is consumption in period t and N_t is population. That is, the consumer maximizes expected discounted utility where each period's utility is population weighted. This consumption program $\{C_0, C_1, \ldots\}$ is subject to the resource constraints describing production

$$Y_t = (A_t^* N_t)^{1-\theta} K_t^{\theta} \tag{A.2}$$

and capital accumulation

$$K_{t+1} = K_t(1-\delta_k) + Y_t - C_t \tag{A.3}$$

where Y_t is aggregate output, $A_t^* N_t$ is effective labor input and K_t is the capital stock. A_t^* is a measure of productivity distinct from capital but not completely exogenous, as discussed later. The parameter θ summarizes the Cobb-Douglas production technology given in Equation (A.2) and δ_k reflects the rate of capital depreciation in the capital accumulation equation (A.3). Finally, there is a transversality condition for a balanced growth steady state,

$$\rho > (1-\tau) \times (\text{asymptotic growth rate of } A_t^*) \tag{A.4}$$

This is always satisfied by assuming zero growth asymptotically.

Even with exogenous constant growth models for N_t and A_t^*, the dynamic optimization problem given by Equations (A.1–A.3) is difficult if not impossible to solve analytically.[17] However, choosing

$$\Delta \ln(K_{t+1}/N_{t+1}) = \alpha_1 + \alpha_2(\ln(K_t/N_t) - \ln(A_t^*)) \tag{A.5}$$

and

$$C_t = K_t(1-\delta_k) + Y_t - K_{t+1} \tag{A.6}$$

– where α_1 and α_2 are functions of the parameters $(\rho, \tau, \theta, \delta_k)$ – yields a close approximation of optimal consumer behavior around the balanced growth steady state. This technique of approximating optimal dynamic behavior has its origins in the real business cycle literature beginning with Kydland and Prescott (1982). It is also related to the technique of feature extraction discussed by Bertsekas (1995).[18]

Intuitively, Equation (A.5) approximates behavior around a balanced growth steady state. At such a steady state, $\ln(K_t/N_t) - \ln(A_t^*)$ is constant and $\Delta\ln(K_{t+1}/N_{t+1})$ = (growth rate of A_t^*) $= \alpha_1 + \alpha_2(\ln(K_t/N_t) - \ln(A_t^*)) =$ constant. If some unforseen shock moves the economy away from the equilibrium value of $K_t/(A_t^* N_t)$ and α_2 is negative, e.g., the steady state is stable, then the economy will move back toward the steady state. In particular, when $K_t/(A_t^* N_t)$ is too high, capital accumulation will slow. If $K_t/(A_t^* N_t)$ is too low, capital accumulation will increase. Importantly, even if the growth rate of A_t^* is not constant, this approximation performs well as long as expected productivity growth changes gradually.

[17] Long and Plosser (1983) derive an analytic solution for the case of $\delta_k = 1$ and $\lim \tau \to 1$ (log utility).

[18] See Appendix A of Pizer (1997) for a simple derivation of expressions for α_1 and α_2.

A.2 Long-term Growth, Climate Behavior and Damages

This section explains the remainder of the state-contingent model – specifically the evolution of A_t^* and N_t. This includes exogenous growth projections, climate behavior and damages from global warming (based primarily on the DICE model, Nordhaus 1994b). Exogenous labor productivity A_t is modeled as a random walk in logarithms with an exponentially decaying drift. That is,

$$\log(A_t) = \log(A_{t-1}) + \gamma_a \exp(-\delta_a t) + \sigma_a \epsilon_t \tag{A.7}$$

where γ_a is the initial growth rate, δ_a is the annual decline in the growth rate, σ_a is the standard deviation of the random growth shocks and ϵ_t is a standard NIID random shock. This means that productivity growth begins with a mean growth rate of γ_a (around 1.3%) in the first period and eventually declines to zero. In addition, random and permanent shocks change the level of productivity every period. The standard error of these shocks is σ_a.

Net labor productivity A_t^* is distinguished from this exogenous measure A_t by the fact that A_t^* describes the amount of output available for consumption and investment – after output has been reduced by control costs and climate damages. To that end, A_t^* is expressed as A_t multiplied by a factors describing these two phenomena:

$$A_t^* = \left(\frac{\overbrace{1 - b_1 \mu_t^{b_2}}^{\text{control costs}}}{\underbrace{1 + (D_0/9) \cdot T_t^2}_{\text{damages}}} \right)^{\frac{1}{1-\theta}} A_t \tag{A.8}$$

μ_t is the fractional reduction in greenhouse gas emissions at time t (the "control rate") versus a business as usual/no government policy baseline, while b_1 and b_2 parameterize the cost of attaining these reductions. Since b_1 and b_2 are both positive, additional rates of control involve reductions in net productivity. T_t is the average surface temperature relative to pre-industrialization in degrees Celsius and D_0 is the fractional loss in aggregate GDP from a 3° temperature increase. For temperature changes less than 10°, this is essentially a quadratic damage function.[19] Additional details about the control cost and damage functions can be found in Nordhaus (1993) and Nordhaus (1994a), respectively.

[19]Over larger ranges, the damage function becomes S-shaped.

Population is modeled in the same way as exogenous productivity but without the stochastic element:

$$\log(N_t) = \log(N_{t-1}) + \gamma_n \exp(-\delta_n t) \qquad \text{(A.9)}$$

where γ_n is the initial growth rate and δ_n is the annual decline in the growth rate. Note that these models predict zero growth asymptotically, though this may occur centuries in the future.[20]

The remaining portion of the model explains the link between economic activity (measured as aggregate output Y_t) and warming (measured as the average surface temperature T_t). The first step is linking output to emissions:

$$E_t = \sigma_t(1 - \mu_t)Y_t \left(\frac{A_t}{A_t^*}\right)^{1-\theta} \qquad \text{(A.10)}$$

where E_t is emission of controllable greenhouse gases,[21] σ_t is an exogenous trend in emissions/output, and μ_t is the rate of emissions reductions induced by the policymaker. The expression $Y_t \left(\frac{A_t}{A_t^*}\right)^{1-\theta}$ reflects raw output prior to the effects of climate damages and control costs. The model of σ_t is, as with labor productivity and population, based on exponentially decaying growth:

$$\log(\sigma_t) = \log(\sigma_{t-1}) + \gamma_\sigma \exp(-\delta_a t) \qquad \text{(A.11)}$$

where γ_σ is the initial growth rate of emissions/output (a negative number) and δ_a is the annual decline in the growth rate. Note that the annual decline in the emissions/output growth rate is the same as the annual decline in labor productivity growth (δ_a).

Emissions of greenhouse gases accumulate in the atmosphere according to:

$$M_t - 590 = \beta E_{t-1} + (1 - \delta_m)(M_{t-1} - 590) \qquad \text{(A.12)}$$

where M_t is the atmospheric concentration of greenhouse gases in billions of tons of carbon equivalent. β is a measure of the retention rate of emissions. Low values of β indicate that emissions do

[20] For example, the range of parameters used in the simulations (with $\delta_{a/n} \in (0.25\%, 2.5\%)$) leads to a halving of the growth rates every 20 to 200 years.

[21] See discussion of controllable versus uncontrollable greenhouse gases in Nordhaus (1994b), page 74. For the most part, controllable greenhouse gases are CO_2 and CFCs and uncontrollable greenhouse gases are everything else.

not, in fact, accumulate while a value of unity would mean that every ton of emitted greenhouse gases remains in the atmosphere. The parameter δ_m plays the role of a depreciation rate: it is assumed that greenhouse gases in the atmosphere above the pre-industrialization level of 590 billion tons slowly decays. This decay reflects absorption of greenhouse gases into the oceans which are assumed to be an infinite sink.

Above average concentrations of greenhouse gases in the atmosphere lead to increased radiative forcings, a measure of the rate of transfer between solar energy produced by the sun and thermal energy stored in the atmosphere. This is modeled according to

$$F_t = 4.1 \times \log(M_t/590)/\log(2) + O_t \tag{A.13}$$

where F_t measures radiative forcings in units of watts per meter squared. The specification is such that a doubling of greenhouse gas concentrations leads to a roughly four fold increase in forcings (since 590 is the concentration before industrialization). O_t in this relation represents radiative forcings due to other uncontrollable greenhouse gases and is assumed exogenous to the model:

$$O_t = \begin{cases} 0.2604 + 0.0125t - 0.000034t^2 & \text{if } t < 150 \\ 1.42 & \text{otherwise} \end{cases} \tag{A.14}$$

Increased forcings lead to temperature changes according to

$$T_t = T_{t-1} + (1/R_1)\left[F_t - \lambda T_{t-1} - (R_2/\tau_{12})(T_{t-1} - T^*_{t-1})\right] \tag{A.15}$$

$$T^*_t = T^*_{t-1} + (1/R_2)(R_2/\tau_{12})(T_{t-1} - T^*_{t-1}) \tag{A.16}$$

where T_t is the surface temperature and T^*_t is the deep ocean temperature, both expressed in changes relative to pre-industrialization levels in degrees Celsius. Note that if $M_t = 590$ and $O_t = 0$ (e.g., pre-industrialization), T_t and T^*_t will equilibriate to zero. The parameter λ describes the equilibrium change in surface temperature for a given change in radiative forcings. In particular, based on (A.13) and (A.15), a doubling of the concentration of greenhouse gases in the atmosphere will lead to a $4.1/\lambda$ rise in surface temperature in the long run. This parameter $4.1/\lambda$ is a measure of the temperature sensitivity of the atmosphere.[22]

[22] λ by itself is referred to as the climate feedback parameter.

The parameters R_1, R_2 and τ_{12} describe the thermal capacity of the surface atmosphere and deep oceans and the rate of energy transfer between them, respectively.

A.3 Social Welfare

A distinguishing feature of this analysis is the use of an econometrically estimated parameter distribution describing uncertainty in the economic model. However, the consumer's objective function given by Equation (A.1) makes no allowance for uncertainty about the preference parameters ρ and τ which are fixed from his or her perspective. In order to encompass uncertainty about preferences, it is necessary to step back and imagine a social planner who would like to maximize the objective given in (A.1) but is unsure of the parameters. Since a policy change which raises the expected utility for one set of parameters may lower the expected utility for another set, the social planner will need to specify a social welfare function to compare gains and losses across states of nature. This social welfare function provides a single objective specifying how changes in utility measured with different preferences are aggregated.[23] It is important to recognize that although parameter values in the representative agent model can be inferred from observed consumer behavior, there is no information available to estimates parameters in a social welfare function. Such information would be revealed only by observing the behavior of an actual social planner. Instead, we must rely on social choice theory and our own sense of fairness to specify the relation.

It is useful to note that the common approach in the climate change literature skirts this issue of preference aggregation by reporting a range of policy prescriptions based on a range of possible preferences and states of nature. For example, Cline (1992) presents benefit-cost analyses for 92 different cases (Tables 7.3 and 7.4). Dowlatabadi and Morgan (1993) integrate out much of the uncertainty in their analysis, but still present results for 48 scenarios. Chapter 8 of Nordhaus (1994b) gives one of the few examples where even preference uncertainty is integrated out, yielding a single welfare metric and a single policy recommendation. In a similar analysis, however, Nordhaus and Popp (1997) choose to fix preferences because of the difficulties with preference aggregation.

[23] E.g., providing a negative loss function across states of nature for the social planner.

Regardless, these authors ubiquitously observe that uncertainty about time preference has large consequences for optimal policy choice.[24] Moreso, in fact, than uncertainty about climate sensitivity and damages. It therefore behooves us to seriously consider how to aggregate over uncertain preferences in the most reasonable way.

In this analysis social welfare is specified as an average of utility measured in each state of nature by Equation (A.1), *rescaled.* The rescaling serves to equate the marginal social welfare of one additional dollar of current consumption in all states of nature. While arbitrary, some adjustment is necessary to prevent the resulting policy prescription from being sensitive to the choice of units in the model.[25] Social welfare can then be written as

$$SW(x) = I^{-1} \sum_{i=1}^{I} u(x,i) \qquad \text{(A.17)}$$

where $u(x,i)$ is rescaled utility in state i with outcome x and $SW(x)$ is the social welfare associated with x. The rescaling is such that

$$u(+\$1 \text{ in initial period}, i) - u(\emptyset, i) = u(+\$1 \text{ in initial period}, j) - u(\emptyset, j) \qquad \forall i, j$$

That is, a policy corresponding to an extra dollar of consumption in the initial period is assumed to have the same utility gain in every state relative to a no policy ($\emptyset$) baseline.

This social welfare function has its origins in the literature on social choice. Harsanyi (1977) shows that in defining social welfare over lotteries, if individual preferences satisfy the von Neumann Morgenstern axioms then social welfare must have this weighted average form. Otherwise, social preferences will fail to mimic individual preferences over lotteries involving only that individual. This functional form can also be derived from the assumption of cardinal unit comparibility, as discussed by Roberts (1980). More flexible forms require additional assumptions about level or scale comparibility. Our choice of welfare functions is therefore less arbitrary than it might have originally appeared: a more flexible form requires both integrating out uncertainty from the representative agent's perspective (to satisfy Harsanyi's point) and more stringent assumptions about

[24]See discussion in Arrow, Cline, Maler, Munasinghe, and Stiglitz (1996).
[25]An explanation of this point is given in Appendix C of Pizer (1997).

the level of comparibility (to satisfy Robert's point)[26]

B Measuring Uncertainty

Estimates of uncertainty in the model come from two sources: econometric analysis and subjective assessment. The model involves nineteen different parameters. Six are parameters describing observable economic activity:

- pure time preference ρ,
- risk aversion τ,
- output-capital elasticity θ,
- productivity growth γ_a,
- variation in productivity growth σ_a^2, and
- depreciation δ_k.

A joint distribution for these parameters is estimated with historical data. The remaining thirteen describe emissions:

- emissions rate growth γ_σ,

climate change:

- CO_2 retention rate β,
- temperature sensitivity $4.1/\lambda$,
- CO_2 decay rate δ_m,
- thermal capacities and conductivities R_1, R_2 and τ_{12},

control costs and damages:

- cost function parameters b_1 and b_2,
- fractional loss of GDP for 3° temperature rise D_0,

and long-term growth trends

- population growth γ_n,
- productivity slowdown and slowdown in the growth rate of emissions/output δ_a,
- population slowdown δ_n.

Uncertainty about these parameters is based on subjective analysis.

The econometric analysis of the six economic parameters is based on post-war U.S. data.[27]

[26] Additional levels of comparability are especially difficult with the the constant coefficient of relative aversion (CRRA) form in Equation (A.1) where the parameter $\tau \gtrless 1$. Under these assumptions, utility is alternatively bounded from above or below.

[27] See Chapter II of Pizer (1996).

Series describing aggregate investment, capital services, output and prices are fit to the model described by Equations (A.2),(A.3) and (A.5). The posterior parameter distribution which arises from this analysis is summarized in Table B.1.

Nordhaus (1994b)[28] develops a distribution for the remaining parameters based on a two-step subjective analysis. The first step involves testing his model's sensitivity to each parameter being changed, one at a time, to a more extreme value. Those parameters which produce the largest variance in model output are then further scrutinized. A discrete, five-value distribution is developed for seven of these thirteen variables. The other six are fixed at their best guess values. The distribution of the seven uncertain parameters is summarized in Table B.2. Values of the six fixed parameters as well as initial conditions for the model are given in Table B.3.

C Factors Which Complicate the Weitzman Analysis

In this section the factors which complicate Weitzman's (1974) original analysis are discussed. While these factors do not affect the basic intuition behind his result – that a flatter marginal benefit curve favors taxes – they do qualify it. In particular, the intersection of the expected marginal benefit and expected marginal cost curve can no longer be used to determine the optimal tax policy when there are non-linear marginal costs and non-additive shocks. As noted by Weitzman and others (Stavins 1996), correlation also changes the optimality result, with positive correlation among costs and benefits favoring permits and negative correlation favoring taxes. Other factors such as truncation and discounting further complicate the simple graphical analysis in Section 3.

C.1 Non-linearities and Non-additive Shocks

A simple graphical comparison of expected marginal benefits and expected marginal costs allows one to quickly derive the optimal quantity control. This works because these marginal measures are with respect to the quantity measure *and* expectations are taken holding the quantity fixed.

[28]Chapters 6 and 7.

Table B.1: Marginal distributions of uncertain economic parameters
(narrow bars indicate values used in simulations without uncertainty)

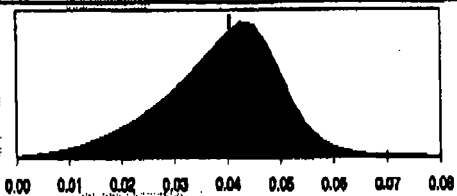
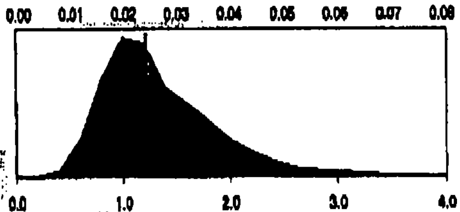
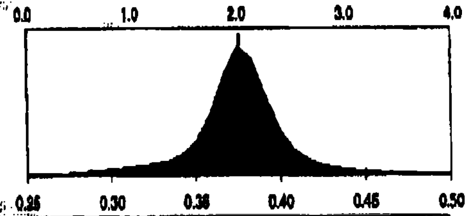
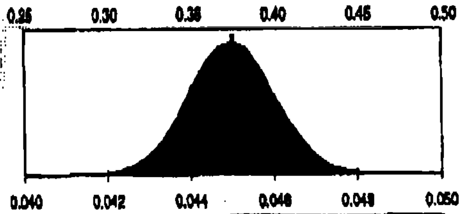
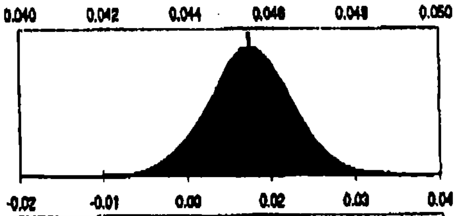
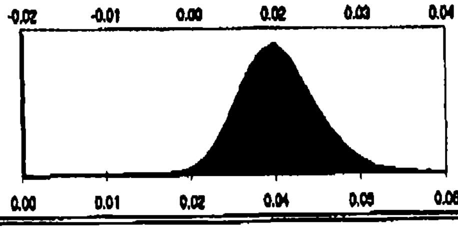
description	symbol	equation	distribution
pure rate of time preference	ρ	(A.1)	
coefficient of risk aversion	τ	(A.1)	
output-capital elasticity	θ	(A.2)	
rate of capital depreciation	δ_k	(A.3)	
initial productivity growth rate	γ_a	(A.7)	
standard error of productivity shocks	σ_a	(A.7)	

Table B.2: Discrete distributions of uncertain climate/trend parameters
(narrow bars indicate values used in simulations without uncertainty)

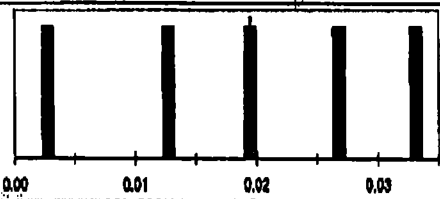
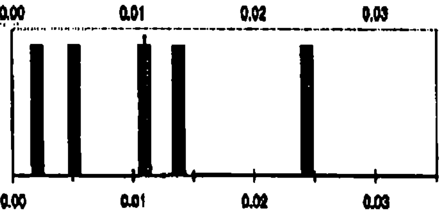
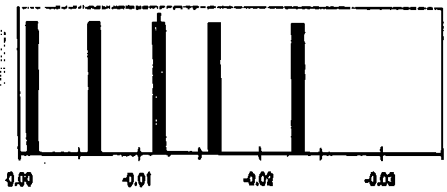
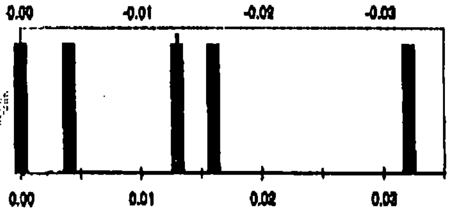
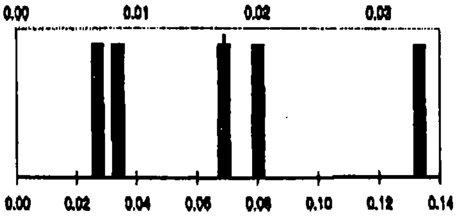
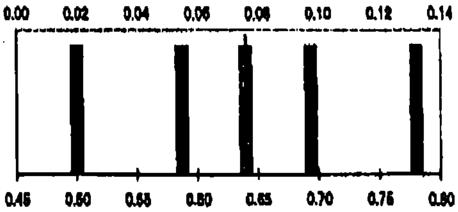
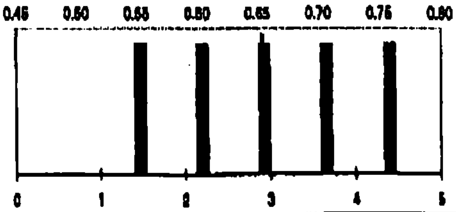
description	symbol	equation	distribution
annual decline of population growth rate	δ_n	(A.9)	
annual decline of productivity growth rate	δ_a	(A.7),(A.11)	
initial growth rate of CO_2 per unit output	γ_σ	(A.10),(A.11)	
damage parameter (% loss of GDP for 3° temperature rise)	D_0	(A.8)	
cost function parameter	b_1	(A.8)	
retention rate for CO_2 emissions	β	(A.12)	
temperature sensitivity to CO_2 doubling (in °C)	$4.1/\lambda$	(A.13),(A.15)	

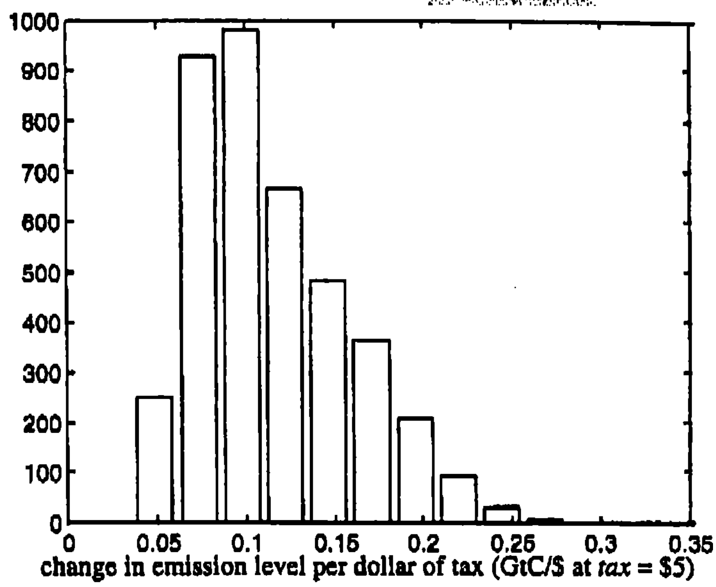
Table B.3: Description of fixed parameters[a]

parameter	symbol	equation	units	value
cost function parameter	b_2	(A.8)		2.887
decay rate of atmospheric CO_2	δ_m	(A.12)		0.00833
1/thermal capacity of atmosphere	$1/R_1$	(A.15)	°C-meter^2/watt-year	0.048
thermal conductivity b/w atmosphere and oceans	R_2/τ_{12}	(A.15),(A.16)	watt/°C-meter^2	0.44
1/thermal capacity of deep oceans	$1/R_2$	(A.16)	°C-meter^2/watt-year	$\frac{0.002}{0.44}$
1995 global population	N_0	(A.9)	millions of people	5590
initial population growth	γ_n	(A.9)		0.0124
initial rate of CO_2 emissions per unit of output	σ_0	(A.11)	billion tons CO_2 per \$1989 trillions	0.385
1995 global capital stock	K_0	(A.2),(A.3)	\$1989 trillions	79.5
1995 global output	Y_0	(A.2),(A.3),(A.10)	\$1989 trillions	24.0
1995 atmospheric concentrations of CO_2	M_0	(A.12)	billions of tons of C equivalent	763.6
1995 surface temperature[b]	T_0	(A.8),(A.15),(A.16)	°Celsius	0.763
1995 deep ocean temperature[b]	T_0^*	(A.15),(A.16)	°Celsius	0.117

[a]All fixed parameters are from Nordhaus (1994b). The parameters that do not depend on time are from Nordhaus' Table 2.4. Initial values for temperature, CO_2 concentrations, and output in 1995, as well as the initial annual growth rate for population, are based on the Nordhaus base case simulation. The 1995 capital stock is adjusted upward to reflect differences in the definition of capital as well as underlying parameter values. The decay rate of atmospheric CO_2 is divided by ten to convert from a decennial to annual rate. The annual thermal capacity of the ocean and atmosphere are from the second line of Nordhaus' Table 3.4b.

[b]Temperatures are measured as deviations from the pre-industrialization level, circa 1900.

Figure C.1: Distribution of $\frac{dQ}{d(tax)}$



In contrast, the optimal price control must be derived by taking the expectation of Δbenefit/Δtax and Δcost/Δtax, holding the tax level fixed, and finding the tax level where *these* two marginal measures are equal. This is not generally revealed by a simple diagram such as Figure 3. It is revealed, however, if the slope of the marginal cost schedule is constant and known. In that case, the condition for the optimal tax reduces to the intersection of the expected marginal cost and benefit curves:

$$
\begin{aligned}
\mathrm{E}\left[\frac{\Delta \text{benefit}}{\Delta \text{tax}}\right] &= \mathrm{E}\left[\frac{\Delta \text{cost}}{\Delta \text{tax}}\right] \\
\mathrm{E}\left[\frac{\Delta \text{benefit}}{\Delta \text{quantity}}\frac{\Delta \text{quantity}}{\Delta \text{tax}}\right] &= \mathrm{E}\left[\frac{\Delta \text{cost}}{\Delta \text{quantity}}\frac{\Delta \text{quantity}}{\Delta \text{tax}}\right] \\
\mathrm{E}\left[\frac{\Delta \text{benefit}}{\Delta \text{quantity}}\frac{1}{\text{MC slope}}\right] &= \mathrm{E}\left[\frac{\Delta \text{cost}}{\Delta \text{quantity}}\frac{1}{\text{MC slope}}\right] \\
\mathrm{E}\left[\frac{\Delta \text{benefit}}{\Delta \text{quantity}}\right]\frac{1}{\text{MC slope}} &= \mathrm{E}\left[\frac{\Delta \text{cost}}{\Delta \text{quantity}}\right]\frac{1}{\text{MC slope}} \\
\mathrm{E}\left[\frac{\Delta \text{benefit}}{\Delta \text{quantity}}\right] &= \mathrm{E}\left[\frac{\Delta \text{cost}}{\Delta \text{quantity}}\right] \\
\mathrm{E}[MB] &= \mathrm{E}[MC]
\end{aligned}
\qquad \text{(C.18)}
$$

This condition, that the slope of the marginal cost curve is constant, will be violated if the cost curve is non-linear or there are non-additive shocks. Under these conditions, the slope of the marginal cost curve cannot be factored outside the expectation, as shown in (C.18). To verify this condition, the slope of the marginal cost curve can be examined across states of nature and at different tax levels to see if it remains constant. Figure C.1 shows the distribution of slopes for a single tax level of $5/tC.[29]

Given these violations, it will not be possible to determine the optimal tax level from Figure 3 precisely, though it may still provide a rough approximation.

C.2 Correlation of Cost/Benefit Shocks

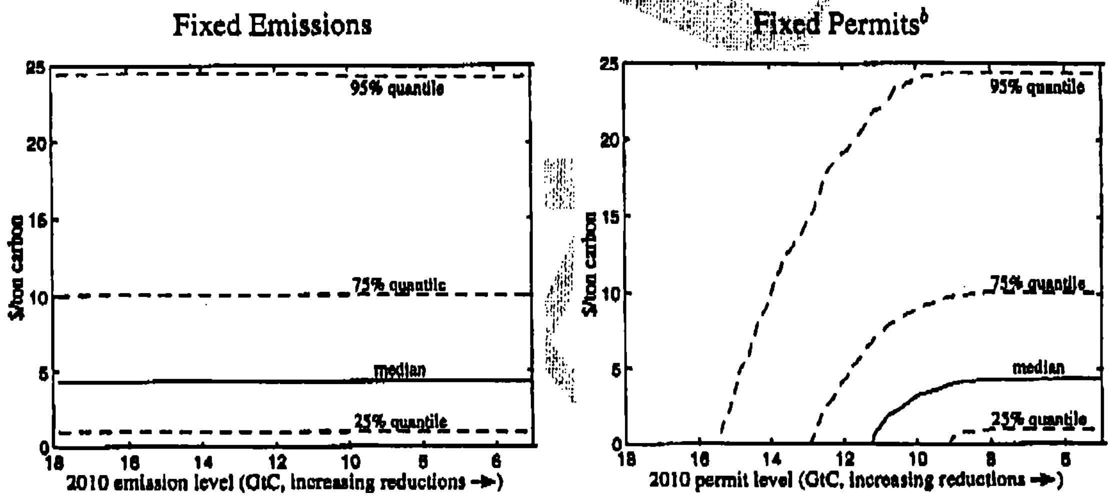
C.3 Truncation

An important point ignored by the Weitzman analysis is whether a particular quantity control is binding in every state of nature. Figure 4, for example, reveals that a quota of 12 GtC in 2010 would lie above the actual emission level roughly half the time. In these states of the world, it is inappropriate to count any benefits from the policy since the policy has no consequence. That is, in order to properly compare the expected marginal cost of a 12 GtC permit policy to its benefits, marginal benefits should only be counted when the policy is binding.

Figure C.2 shows the consequence of this calculation. The left panel (the same as Figure 2) shows the distribution of marginal benefits when emissions are fixed at – rather than limited to – different levels. This calculation ignores the actual level of emissions in 2010. In contrast, the right panel shows the marginal benefit associated with limiting emissions to the specified level (as would occur with a permit system). In those states of nature where uncontrolled emissions are below the value on the x-axis, they remain unchanged and there is no marginal benefit. Therefore at high permit levels (18 GtC) that lie above uncontrolled emission levels in every state, the marginal benefit is zero. Moving to the right, marginal benefits initially rise as additional states become contributing benefits. Eventually, the marginal benefit schedule must slope downwards as the marginal benefit in every state is declining.

[29] From Figure 3 it is clear that the slope also changes at higher permit/tax levels.

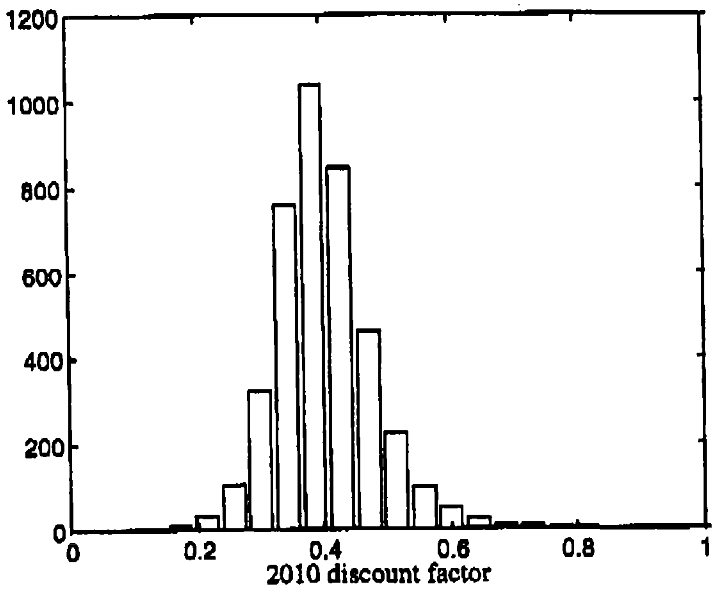
Figure C.2: Distribution of Marginal Benefits in 2010[a]



[a]These marginal benefits are based on the discounted (to 2010) value associated with emission reductions in the year 2010 only. Emissions in other periods are held at their uncontrolled levels. Values are expressed in $2010 and, due to different discount rates across states of nature, will not be weighted equally when balancing costs and benefits.

[b]The left panel indicates the range of marginal benefits obtained by varying the level of 2010 emissions as shown, ignoring the forecast level of uncontrolled emissions. The right panel indicates the range of marginal benefits when permits are used to control the level of emissions at *or below* the permit level. That is, in cases where uncontrolled emissions are below the indicated level, there is no marginal benefit since emissions are not, in fact, being reduced. As shown in Figure 4, uncontrolled emissions in 2010 are unlikely to be more than 18 GtC. The marginal benefit when the permit level is set to 18 GtC is therefore zero.

Figure C.3: Distribution of Discount Factors in 2010



C.4 Discounting

Discounting is an important issue which is ignored in the simple static case. Even when considering policy in a single period (2010), it is necessary to wonder whether costs and benefits should be measured in 2010 or 1995. This is relevant because different states of nature will involve different discount rates. Specifically, those states with higher growth involve more discounting relative to states of nature with low growth. This follows the basic intuition that extra dollars are more valuable when one is poor than when one is rich.

The static analysis in Section 3 is based on dollar welfare measures in 2010. In contrast, the dynamic analysis in Section 4 is based on dollar welfare measures in 1995. Surprisingly, there is little difference in the initial policy outcome, suggesting the descrepancy is small. Figure C.3 shows the range of discount factors observed in 2010 relative to 1995.

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Jeffrey A. Frankel
09/04/97 01:16:32 PM

Record Type: Record

To: Jon D. Haveman/CEA/EOP
cc: Randall W. Lutter/CEA/EOP, Adele C. Morris/OMB/EOP, Joseph E. Aldy/CEA/EOP
bcc:
Subject: Re: Revised memo on competitiveness

Jon,

Yes, share it with our friends in Treasury (nowhere else as of yet). BUT, first, it MUST include two sentences saying that it is important to have the developing countries participate -- for reasons other than competitiveness (especially, that: without them our sacrifice will have been largely in vain; their emissions will undo our cuts for two reasons: free-riding and leakage). This is not the point of your memo. But we can't have a document with CEA name on it that anyone could misquote as saying that CEA says that LDC participation is not important !!

JF

Jon D. Haveman

Jon D. Haveman 09/03/97 01:28:04 PM

Record Type: Record

To: Jeffrey A. Frankel/CEA/EOP

cc:
Subject: Revised memo

EMITNEXA.WP[Let me know if you'd like me to circulate this.

I've decided that looking at both high and low energy sectors is sufficient to get around the comparative advantage/net exports problem I raised before. The memo therefore contains contrasting information for high and low energy industries. The bottom line is still a lack of evidence supporting the position that the US will experience a worsened export position if the Annex 1 countries stay out....the LDCs appear to be net exporters energy-intensive products.

Jon

CEA WORK-PROGRAM ON GCC Jeff Frankel
8/20/97

WHO (and when)

Targets and timetables (TOP PRIORITY)

The importance of allowing time for capital turnover --
Case-study illustration:
Graph of replacement chronology of US power-generating plants
(make stylized assumptions on plant life if necessary).
# of plants, and cost of replacement, against year. > CS+KF

The economically-optimal path. . *JA*
In what year is peak of US emissions?
Of other Annex I?
In what year do they return to 1990 levels?

(1) Minimizing cost/benefit balance
(minus uncertainty or credibility problems).
=> no peak at all? Just slowed rise in emissions?
Need results from Integrated Assessment Models. > JS + RL
- Nordhaus, Manne-Richels?
- Edmonds (SGM)? "
- Wigley? Other EMF models?
- Cline?

(2) Minimizing cost of a given level of stabilizing concentrations at 550 ppmv
- Manne-Richels (global peak in 2050; Annex I peak in __?)
- Others (as above)?
- Any in-house models: SGM, Markal-Macro?

(3) Compare costs and benefits of "1990 by 2010"
to "peak in 2015 and return to 1990 by 2040"
and to doing nothing ("business as usual"). > JS + RL +CS
Costs are (I) price of carbon, gasoline, coal...
(ii) effects on income and consumption
(iii) likely volume of int.purchases of permits
Benefits are (I) emissions and concentration
(ii) implied effect on temperature in 2050 or 2100
(using simple linear interpolation from IPCC estimate)
- Any of the IA/EMF models >CS+QF
- Any of the IAT models (DRI, MarkalM, SGM) > Prelim. table DONE.
- Shackleton and G-cubed
- Other?

Analogies with 1970s oil shocks

Is magnitude the same? > JA + RL DONE
How much difference does it make that this would be pre-announced? (+CS)
" That there would be no transfer to OPEC?
Any bogus reasons why the IAT models did not find such adverse effects?
Did they assume that the Fed could somehow offset supply shocks?

Technology and "free lunches"

- Critique 5-Labs Study > JA
  DRAFT DONE
  Comments to EPA (coordinated with Gillingham)
- More general critique of the "technology" free lunch > RL + JA

Assumption that people ignore money-saving opportunities, that govt. Pgms. Help (e.g., can change discount rates and AEEIs), that common people are as capable as engineers, that people systematically over-consume energy but not other things, that they live in ideal homes, that energy-price uncertainty plays no role.... Double-counting pgms (in baseline and policy path).

- We're "technology optimists":
  Historical relationship between prices and EEI > JF+CS+QF

DONE

Replicate it and extend (e.g., lag structure; total energy spending) > JR

Analyze escape clause proposals

- What would be appropriate carbon prices for ceiling? > JS+RL

If 2015 emissions peak and
(e.g.) 1990 levels in 2040 (Relatively less aggressive)
If 1990 levels in 2010 (Relatively more aggressive)

- What do other agencies have in mind? > RL+JF
  (Victoria G, State Dept. Paper 8/15)
- Global price cap and sales, rather than country-by-country?

Uncertainty > *JS*
To move timetable forward: Allow for a probability of climate disaster > MT

- and apply expected welfare,
- add risk-aversion
- Allow for imperfect political credibility of promises

Domestic Implementation

- Incidence of increase in energy prices >
- Has there been a "reluctance to trade" in SO2 pgm? > JF. Answer: no
- Should revenues be used to finance soc.sec.? >
  Compute likely amount and path of revenue thru 2075 > CC + JA
- Tradeoff between stringency and flexibility > JS

LDCs

Need proposed formulas for LDC participation > *RL + JF*

- What is threshold income level for blueprint proposal?
  defined so as to include only State Dept.'s "Annex B" countries

- What is a reasonable emissions path formula for future LDC participation?
  = F(income, population, 1990 emission levels)?
  Or as reduction of emissions growth rate?

US competitiveness if LDCs don't participate > *PO+JF* memo of 8/10

- Anyone care to take on a N-factor, N-good, N-country trade model?
  N=2, or N=3 > JH

Other

Monitor incoming papers /reports from negotiations (coming via State) >

Chad Stone
(Library last CBA [illegible])

Council of Economic Advisers

Memorandum

To: Jeff Frankel — September 3, 1997

From: Jon Haveman

Subject: Net Exports data for high energy and low energy industries.

An issue has been raised regarding the participation of less developed countries in the emission reduction efforts. The issue is basically that the trade position of US industries would be adversely affected if LDCs did not participate. The argument is theoretically correct if the United States is a net exporter of products requiring relatively more energy in their production and a net importer of products requiring relatively little energy. If this were the case, unilateral emission reductions taken on by the Annex 1 countries would likely have an adverse terms of trade effect for the United States.

The following tables present net exports data for the United States, Annex 1 countries and Non-Annex 1 countries for 1992. The US aggregate net-exports numbers (column 1 in the first table) could probably be obtained relatively easily for a more recent year, but almost none of the other numbers in the table could without a great deal of effort; in particular, the division between Annex 1 and non-Annex 1 trade.

Products with High Energy Content

Turning first to industries using relatively more energy in the production process, it appears as though the US is a net-IMporter in every industry except for Chemicals and Paper (column 1). Net exports vis a vis non-Annex 1 countries in particular, are positive in these 2 industries as well (column 3). This suggests that the US does not have a particularly strong export position in energy intensive industries. This is complicated by the fact that when you aggregate over the net exports with non-annex 1 countries (add up column 3), the US is a net exporter of these products.

United States
1992 US dollars (thousands)

Industry	Net Exports	Net Exports with Annex 1	Next Exports with non-Annex 1
Chemicals	18,474,974	5,024,727	13,550,247
- Inorganic	966,300	-23,343	989,643
Paper	54,976	-4,169,457	4,224,433
Petroleum Products	-1,929,337	-1,630,863	-298,474

Stone, Clay & Glass Prod	-2,341,891	-1,701,501	-640,390
- Cement	-251,592	-192,579	-59,031
Metals	-10,133,481	-8,280,060	-1,853,421
- Aluminum	-753,690	-744,942	-8,748
- Steel	-6,206,960	-5,646,776	-560,184
Total	**4,125,241**	**-10,757,154**	**14,982,395**

The story is very different when looking at the Annex 1 countries as a group. As a group, the Annex 1 countries are net-EXporters of everything except for aluminum and petroleum products vis a vis the non-Annex 1 countries (column 1). It would appear as though the interests of the US were diametrically opposed to those of the other Annex 1 countries.

Annex 1
1992 US dollars (thousands)

Industry	Net Exports Annex 1	Total Exports to: Annex 1	non-Annex 1
Chemicals	24,544,473	223,654,539	73,138,220
- Inorganic	2,221,421	16,589,668	5,878,740
Paper	10,159,322	64,062,628	13,776,217
Metals	8,835,147	99,025,368	35,094,639
- Aluminum	-2,484,699	7,353,999	1,252,587
- Steel	15,415,120	59,348,346	25,761,998
Stone, Clay & Glass Prod	4,244,144	33,159,151	9,018,053
- Cement	514,590	1,517,392	828,095
Petroleum Products	-8,539,332	344,359,994	13,030,131
Total	**39,243,754**	**764,261,680**	**144,057,260**

Products With Little Energy Content

As the United States is a net importer in the aggregate, it is useful to contrast the above results with the same numbers for industries requiring relatively little energy in production. Here, the situation is reversed. The US is a net exporter in four of the six industries.

United States
1992 US dollars (thousands)

Industry	Net Exports	Net Exports with Annex 1	Next Exports with non-Annex 1
Industrial Machinery and Equip	9,440,638	-1,595,447	11,036,085
Instruments and Related Products	4,725,811	1,522,040	3,203,771

Tobacco Products	4,472,328	2,418,224	2,054,104
Printing and Publishing	2,282,414	1,930,052	352,362
Electronic and other Electric Equip	-7,346,192	-6,001,832	-1,344,360
Transportation Equip	-8,127,588	-33,546,236	25,418,648
Total - Low Energy Sectors	**5,447,411**	**-35,273,199**	**40,720,610**

The Annex 1 countries taken as a whole are also net exporters of these products. The trade surplus is, however, significantly larger than it was above; here, the surplus with non-Annex 1 countries represents 17% of total exports where it represented only 4% of total exports of energy intensive goods.

Annex 1
1992 US dollars (thousands)

Industry	Net Exports Annex 1	Total Exports to: Annex 1	non-Annex 1
Transportation Equip	90,608,033	352,021,896	111,526,966
Industrial Machinery and Equip	74,871,404	276,173,902	115,767,751
Electronic and other Electric Equip	29,845,127	173,616,084	85,605,095
Instruments and Related Products	16,873,294	78,029,553	27,471,780
Tobacco Products	3,320,713	7,939,942	4,068,196
Printing and Publishing	1,573,248	16,534,184	2,847,942
Total - Low Energy Sectors	**217,091,819**	**904,315,561**	**347,287,730**

The bottom line is that this data provides evidence against the view that excluding LDCs would have a substantial adverse effect on the overall US trade position. First, the Annex 1 countries as a whole rely on exports of low energy products to a greater extent than on exports of energy intensive products. Second, the US in particular is more broadly a net exporter of low energy products than it is of energy intensive products.

Note: The data in these tables were generated by aggregating up from 4-digit SITC r.2 industries. The concordance is not completely accurate in the sense that some of the included 4-digit industries are really a part of more than one industry. The industry numbers are therefore subject to a positive error. There is no reason to believe that this error is large enough to alter the above inferences.

Jeffrey A. Frankel
08/26/97 06:31:57 PM

Record Type: Record

To: Jon D. Haveman/CEA/EOP

cc:

Subject: Re: Simple international model of welfare effects of emission reductions

I had been thinking 2-factor model rather than Ricardian. But your bottom line intuition is certainly intuitive-- that the U.S. welfare effect from whetehr the LDCs go in when we go in depends on whetehr the U.S. has a comparative advantage in emissions-intensive industries. So, yes, let me know if you are able to confirm the same thing in a 2-factor (or 3-factor) model.

But it sounds like the next prioirty should be in trying to determine whether the U.S. does in reality have a comparative advantage in such goods (and whether Annex I countries in the aggregate, vs. LDCs, do). We know which six industries are most emissions intnesive (aluminum smelting, chemicals...) Perhaps to get the answer you could look into the question of our net exports in these six industries (positive or negative), and do something similar for less emissions-intensive industries. Daniel Chang or Zachary Candelario could help you.

Thanks

JF

COUNCIL OF ECONOMIC ADVISERS

MEMORANDUM

To: Jeff Frankel August 28, 1997

From: Jon Haveman

Subject: Net Exports data for high energy industries.

The following tables present a fair amount of net exports data for the United States, Annex 1 countries and Non-Annex 1 countries. In your e-mail, you only mention the US, but I thought that the aggregate Annex 1 and nonAnnex 1 data would really answer the question a little better - all the while recognizing that net-exports and comparative advantage have a somewhat tenuous link. These data are for 1992. The US aggregate net-exports numbers (column 1 in the first table) could probably be obtained relatively easily for a more recent year, but almost none of the other numbers in the table could without a great deal of difficulty.

Turning first to the US, it appears as though the US is a net-IMporter in every industry except for Chemicals and Paper (column 1). Net exports vis a vis non-Annex 1 countries in particular, are positive in these 2 industries as well (column 3). This apparently suggests that -- pollution externalities aside -- the US would rather exclude the nonAnnex 1 countries than include them. This is complicated by the fact that when you aggregate over the net exports with non-annex 1 countries (add up column 3), the US is a net exporter of these goods.

United States
1992 US dollars (thousands)

Industry	Net Exports	Net Exports with Annex 1	Net Exports with non-Annex 1
Cement	-251,592	-192,579	-59,013
Chemicals	18,474,974	5,024,727	13,550,247
- Inorganic	966,300	-23,343	989,643
Glass	-2,341,891	-1,701,501	-640,390
Metals	-10,133,481	-8,280,060	-1,853,421
- Aluminum	-753,690	-744,942	-8,748
- Steel	-6,206,960	-5,646,776	-560,184
Paper	54,976	-4,169,457	4,224,433
Total	**5,254,578**	**-9,226,291**	**15,280,869**

The story is very different when looking at the Annex 1 countries as a group. As a group, the Annex 1 countries are net-EXporters of everything except for aluminum vis a vis the nonAnnex 1 countries (column 1). It would appear as though the interests of the US were diametrically opposed to those of the other Annex 1 countries.

Annex 1
1992 US dollars (thousands)

Industry	Net Exports Annex 1	Total Exports to: Annex 1	non-Annex 1
Cement	514,590	1,517,392	828,095
Chemicals	49,454,001	223,654,539	73,138,220
- Inorganic	2,221,421	16,589,668	5,878,740
Glass	4,244,144	33,159,151	9,018,053
Metals	8,835,147	99,025,368	35,094,639
- Aluminum	-2,484,699	7,353,999	1,252,587
- Steel	15,415,120	59,348,346	25,761,998
Paper	10,159,322	64,062,628	13,776,217
Total	**72,692,614**	**419,901,686**	**131,027,129**

The bottom line, I believe, is that the US has a ready secondary source of supply for these goods should the nonAnnex 1 countries join in the agreement. That is, I believe that the terms of trade hit that the US would take from nonAnnex 1 compliance would be offset by sources within the Annex 1 group. I don't think that this superficial analysis really provides us with the basis to say that the US (from a strictly economic point of view) cares one way or another whether the nonAnnex 1 countries join in.

Note: The data in these tables were generated by aggregating up from 4-digit SITC r.2 industries. The concordance is not completely accurate in the sense that some of the included 4-digit industries are really a part of more than one industry. The industry numbers are therefore subject to a positive error. There is no reason to believe that this error is large enough to alter the above inferences.

Jeffrey A. Frankel
08/29/97 08:42:28 AM

Record Type: Record

To: Jon D. Haveman/CEA/EOP
cc: Joseph E. Aldy/CEA/EOP, Randall W. Lutter/CEA/EOP
bcc:
Subject: Re: Net Exports of energy intensive industries

Jon

Thanks for your memo. Very interesting. It confirms surprisingly strongly our suspicions that adverse "competitiveness" effects on a few energy-intensive industries might be offset in other sectors. (You mention that checking whetehr net exports are positive is not the same as comparative advantage. How seriously do you think we should we take this, in practice?) Regarding your last sentence, do you think this line of argument is too "superficial" to allow us to say "there is evidence against the view that excluding LDCs would have a substantial adverse effect on overall US "competitiveness" "? As opposed to "we can't say anything."?

Your list of energy-intensive industries overlaps almost perfectly with the list of six that we cited in a paper (author Peter Orszag, NEC) on LDC participation and US competitiveness. The only exceptions are Glass is on your list and not ours, and petroleum refining was on our list but not yours. (Obviously we import crude; but I don't know if we import or export refining services?) So you might add oil refining.

Should we correct for the fact that, these days, the US is a net importer of the average industry (i.e., we run a trade deficit)? This would be the easiest first step to generalizing the analysis to more sectors. Another possibility would be to figure out what are the LEAST energy intensive industries, and to see whether we import or export them.

Make any revisions to your memo appropriate. Include at the beginning a couple paragrpahs explaining the relevance. (The conclusion at the end shouldn't pertain to whetehr we care at all on economic grounds, but whetehr we care regarding "competitiveness", or -- if you'd rather avoid the word -- regarding trade effects. We certainly care a lot whether the LDCs are in terms of economic cost per unit reduction in GHG concentrations.) Then let's send a copy to Orszag, and Gruber at Treasury.
JF

Jon D. Haveman

Jon D. Haveman
08/28/97 08:46:51 PM

Record Type: Record

To: Jeffrey A. Frankel/CEA/EOP

cc:

Subject: Net Exports of energy intensive industries

Jeff,

I have generated some net-exports data for the following industries:

Paper and Allied Industries (SIC 26)
Chemicals and Allied Products (SIC 28)
  Inorganic Chemicals (SIC 281)
Stone, Clay, and Glass Products (SIC 32)
  Cement, Hydraulic (SIC 3241)
Primary Metal Industries (SIC 33)
  Blast Furnace and Basic Steel Products (SIC 331)
  Primary Aluminum (SIC 3334)

If these are not the industries that I should have been focusing on, please let me know. The data can very easily be altered to cover an alternative set of industries. The data are enclosed in the following WP document.

Jon

EMITNEX.WPI

Trade w/ non Annex

Non-Annex

(Untitled)

	M	X				
117100	2042338.	3652216.	12869266.	13775713.	14911604.	17427929.
		1609878.		906447.		2516325.
130120	736702.	1185373.	7431168.	10084725.	8167870.	11270098.
		448671.		2653557.		3102228.
134340	912166.	1055634.	3560915.	9887755.	4473081.	10943389.
		143468.		6326840.		6470308.
135040	2071551.	964661.	5707752.	3109011.	7779303.	4073672.
		-1106890.		-2598741.		-3705631.
137320	733.	4308.	475.	353.	1208.	4661.
		3575.		-122.		3453.
137360	234075.	198153.	555764.	165148.	789839.	363301.
		-35922.		-390616.		-426538.
137880	837365.	799113.	5539264.	3287893.	6376629.	4087006.
		-38252.		-2251371.		-2289623.
138180	2223648.	1434105.	7621674.	1668344.	9845322.	3102449.
		-789543.		-5953330.		-6742873.
141200	120079.	392714.	978699.	1604799.	1098778.	1997513.
		272635.		626100.		898735.
141400	8671.	20108.	90424.	101606.	99095.	121714.
		11437.		11182.		22619.
141480	6786.	17288.	111730.	65603.	118516.	82891.
		10502.		-46127.		-35625.
141780	126848.	57758.	531163.	1454552.	658011.	1512310.
		-69090.		923389.		854299.
142660	70930.	474064.	716753.	2147328.	787683.	2621392.
		403134.		1430575.		1833709.
160240	199109.	413627.	2110399.	3692597.	2309508.	4106224.
		214518.		1582198.		1796716.
160860	288.	285.	4530.	1605.	4818.	1890.
		-3.		-2925.		-2928.
161080	13128.	12112.	124814.	110606.	137942.	122718.
		-1016.		-14208.		-15224.
161740	20875.	3287.	81995.	28379.	102870.	31666.
		-17588.		-53616.		-71204.
161800	98501.	369056.	451740.	1285549.	550241.	1654605.
		270555.		833809.		1104364.
162040	160984.	54696.	363606.	76278.	524590.	130974.
		-106288.		-287328.		-393616.
162260	1822.	244.	54021.	40820.	55843.	41064.
		-1578.		-13201.		-14779.
162300	127710.	36198.	867019.	160161.	994729.	196359.
		-91512.		-706858.		-798370.
162620	117261.	57560.	235149.	3736.	352410.	61296.
		-59701.		-231413.		-291114.
162700	145172.	63839.	161476.	184823.	306648.	248662.
		-81333.		23347.		-57986.
162880	246624.	178496.	1024558.	865519.	1271182.	1044015.
		-68128.		-159039.		-227167.
163240	133057.	527535.	487156.	452284.	620213.	979819.
		394478.		-34872.		359606.
163840	188663.	1196423.	1495058.	2327838.	1683721.	3524261.
		1007760.		832780.		1840540.
164040	383916.	612090.	1151095.	824715.	1535011.	1436805.
		228174.		-326380.		-98206.
164300	1899711.	140287.	3394302.	735725.	5294013.	876012.
		-1759424.		-2658577.		-4418001.

164500	89297.	70406.	285178.	352122.	374475.	422528.
		-18891.		66944.		48053.
164540	76499.	64360.	215280.	402385.	291779.	466745.
		-12139.		187105.		174966.
164660	57013.	151403.	294901.	95100.	351914.	246503.
		94390.		-199801.		-105411.
164780	90067.	81881.	416820.	416659.	506887.	498540.
		-8186.		-161.		-8347.
164800	835081.	132290.	740116.	1232774.	1575197.	1365064.
		-702791.		492658.		-210133.
165080	210711.	146303.	518402.	154584.	729113.	300887.
		-64408.		-363818.		-428226.
165620	24846.	24055.	226090.	183554.	250936.	207609.
		-791.		-42536.		-43327.
165660	1754505.	2284055.	6392839.	11469252.	8147344.	13753307.
		529550.		5076413.		5605963.
166240	43437.	8244.	220073.	20175.	263510.	28419.
		-35193.		-199898.		-235091.
166380	341362.	39978.	1795119.	173691.	2136481.	213669.
		-301384.		-1621428.		-1922812.
166460	22503.	129599.	137160.	80191.	159663.	209790.
		107096.		-56969.		50127.
166540	412.	143.	22464.	7432.	22876.	7575.
		-269.		-15032.		-15301.
166860	138821.	376289.	888445.	360640.	1027266.	736929.
		237468.		-527805.		-290337.
166900	49224.	30264.	69597.	37062.	118821.	67326.
		-18960.		-32535.		-51495.
166940	21140.	10183.	147688.	373601.	168828.	383784.
		-10957.		225913.		214956.
167060	26691.	93236.	83238.	19325.	109929.	112561.
		66545.		-63913.		2632.
167160	817517.	593188.	825915.	669008.	1643432.	1262196.
		-224329.		-156907.		-381236.
167680	286719.	140338.	392621.	124700.	679340.	265038.
		-146381.		-267921.		-414302.
168000	73231.	24508.	207822.	169870.	281053.	194378.
		-48723.		-37952.		-86675.
168340	412478.	238962.	733605.	267474.	1146083.	506436.
		-173516.		-466131.		-639647.
168540	23463.	475164.	261069.	72540.	284532.	547704.
		451701.		-188529.		263172.
168940	158023.	703685.	466544.	632422.	624567.	1336107.
		545662.		165878.		711540.
168960	681362.	0.	0.	0.	681362.	0.
		-681362.		0.		-681362.
220600	198073.	26912.	874874.	550674.	1072947.	577586.
		-171161.		-324200.		-495361.
223040	6866.	9776.	370188.	321266.	377054.	331042.
		2910.		-48922.		-46012.
226660	401.	2558.	61180.	34107.	61581.	36665.
		2157.		-27073.		-24916.
330320	6517247.	7029166.	8728596.	6251727.	15245843.	13280893.
		511919.		-2476869.		-1964950.
330680	559530.	344425.	699167.	432188.	1258697.	776613.
		-215105.		-266979.		-482084.

330760	8310273.	15857679.	14862834.	23534229.	23173107.	39391908.
		7547406.		8671395.		16218801.
331520	4159231.	3782383.	6068776.	6938894.	10228007.	10721277.
		-376848.		870118.		493270.
331700	1981004.	2037748.	5871356.	5352628.	7852360.	7390376.
		56744.		-518728.		-461984.
332180	759618.	1118012.	2270477.	2197159.	3030095.	3315171.
		358394.		-73318.		285076.
334840	5252613.	3337068.	57103188.	27481161.	62355801.	30818229.
		-1915545.		-29622027.		-31537572.
336000	2767456.	438037.	2190769.	317944.	4958225.	755981.
		-2329419.		-1872825.		-4202244.
336040	1485641.	1811683.	2016064.	2265773.	3501705.	4077456.
		326042.		249709.		575751.
338580	1322252.	1023468.	856386.	757284.	2178638.	1780752.
		-298784.		-99102.		-397886.
338620	2847034.	1487768.	11286093.	2164584.	14133127.	3652352.
		-1359266.		-9121509.		-10480775.
341880	798599.	406066.	2184778.	1583162.	2983377.	1989228.
		-392533.		-601616.		-994149.
342220	510604.	317309.	1193046.	299647.	1703650.	616956.
		-193295.		-893399.		-1086694.
343200	773534.	629171.	2045719.	826487.	2819253.	1455658.
		-144363.		-1219232.		-1363595.
343400	331426.	70248.	919322.	552296.	1250748.	622544.
		-261178.		-367026.		-628204.
345580	364025.	79872.	429270.	168006.	793295.	247878.
		-284153.		-261264.		-545417.
350440	203306.	174411.	2046070.	1036342.	2249376.	1210753.
		-28895.		-1009728.		-1038623.
350520	159004.	112073.	378931.	88795.	537935.	200868.
		-46931.		-290136.		-337067.
351360	139752.	9115.	588522.	84626.	728274.	93741.
		-130637.		-503896.		-634533.
351920	501696.	570058.	803613.	669743.	1305309.	1239801.
		68362.		-133870.		-65508.
352140	647532.	265295.	2907516.	2731999.	3555048.	2997294.
		-382237.		-175517.		-557754.
353120	476006.	134045.	2758716.	291998.	3234722.	426043.
		-341961.		-2466718.		-2808679.
353320	49317.	18068.	316326.	145067.	365643.	163135.
		-31249.		-171259.		-202508.
353880	333458.	287728.	1340373.	1286348.	1673831.	1574076.
		-45730.		-54025.		-99755.
355320	913988.	699132.	1450285.	1135029.	2364273.	1834161.
		-214856.		-315256.		-530112.
356580	295382.	107824.	715308.	386899.	1010690.	494723.
		-187558.		-328409.		-515967.
357800	273679.	872765.	1130947.	1147363.	1404626.	2020128.
		599086.		16416.		615502.
357960	1463.	144.	47746.	17092.	49209.	17236.
		-1319.		-30654.		-31973.
358960	181.	0.	0.	0.	181.	0.
		-181.		0.		-181.
360840	81088.	27124.	243917.	120137.	325005.	147261.
		-53964.		-123780.		-177744.

362380	3130.	1818.	28510.	11059.	31640.	12877.
		-1312.		-17451.		-18763.
362540	95164.	44973.	1524674.	65251.	1619838.	110224.
		-50191.		-1459423.		-1509614.
363280	91485.	76014.	214695.	357746.	306180.	433760.
		-15471.		143051.		127580.
365900	3848112.	234484.	5934056.	471995.	9782168.	706479.
		-3613628.		-5462061.		-9075689.
367400	83185.	65142.	302145.	388146.	385330.	453288.
		-18043.		86001.		67958.
368960	91861.	0.	0.	0.	91861.	0.
		-91861.		0.		-91861.
413760	1985824.	2975257.	15976724.	10317222.	17962548.	13292479.
		989433.		-5659502.		-4670069.
440480	351649.	1131433.	1912973.	650953.	2264622.	1782386.
		779784.		-1262020.		-482236.
441960	908026.	532864.	3159178.	479504.	4067204.	1012368.
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443640	2886018.	5993210.	16484373.	11336020.	19370391.	17329230.
		3107192.		-5148353.		-2041161.
443680	161047.	616224.	471593.	50424.	632640.	666648.
		455177.		-421169.		34008.
444000	1437262.	1046475.	1874015.	184780.	3311277.	1231255.
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445120	1523739.	903749.	2246974.	106894.	3770713.	1010643.
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446340	219885.	1625688.	1290545.	2329433.	1510430.	3955121.
		1405803.		1038888.		2444691.
446820	6045456.	20858948.	28427326.	37650173.	34472782.	58509121.
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		493107.		-160867.		332240.
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		2382063.		2259938.		4642001.
448870	670519.	173953.	1302331.	858226.	1972850.	1032179.
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450500	1942540.	395877.	507288.	1551399.	2449828.	1947276.
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453600	10031453.	12531117.	17311951.	23844746.	27343404.	36375863.
		2499664.		6532795.		9032459.
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454180	157603.	54711.	56682.	54643.	214285.	109354.
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Joint Treasury/CEA Climate Change Agenda
August 29, 1997

I. Domestic Emissions Trading

A. EPA now is now set on presenting four options, representing the convolution of upstream/downstream and auction/allocation.

B. Strategy: Let EPA move first. They are supposed to deliver to us their version of the two upstream options today, and the two downstream options late next week.

C. Tasks (SQUITIERI):

1. Assess the upstream writeups from EPA, relative to our write-up; incorporate anything we want to from theirs into ours, and ship ours back to them as our "comments" on their draft. *(Target ship-back date is Thursday, Sept 4)*

2. Develop a clear, strong, and frank statement of why we oppose tradable credits. Key points should include the difficulty of defining "exchange rates" between sectors; the inefficiencies of CAFE-like approaches (doesn't penalize intensity of use, impacts only market for new units, not existing); should draw on empirical literature concerning the cost of the CAFE standards relative to a gasoline tax. *(Should be essentially complete by the time we receive their draft of downstream options; upon receiving such draft, modify as necessary; transmit to EPA)*

3. Comment on downstream writeups. Also, append statement to the effect that "these options are vigorously opposed by the economics agencies" *(By Monday, Sept 8)*

4. Discussion of auction mechanism with Kwerel and/or other auction experts as soon as possible.

II. Technology

A. GILLINGHAM and FRANKEL to peruse DoE's response to our comments, and give signoff (or not) to 5 labs study *(Response expected WHEN?)* Ald,

B. GILLINGHAM (and CEA collaborator?) to work on broader technology paper. *(Rough draft prepared by COB Tuesday, Sept 2?)* Ald,

Transmit to D. WILLIAMS and B. BOORSTIN for their comments

C. GILLINGHAM to check in with TJ Glauthier to see what he envisions for technology options paper - make sure that it reflects our concerns, as laid out in our broader paper.

III. Targets and Timetables

A. FRANKEL, ~~SHOGREN~~, AWG SQUITIERI, and ROBERTS to work with modellers to get runs of different paths of emissions, producing data on concentrations, temperatures, and costs to the economy. Then write up as memo. CEA to lead. *(Rough draft by WHEN?)*

B. JONES to write up a summary of the Nordhaus argument that 1990 by 2010 is worse than nothing. *(Rough draft by WHEN?)*

IV. Other Analytics

A. MULDOON to work on effects of policies on the typical family. *(Draft by WHEN?)*

B. SANTEBASAN to work on age distribution of plants, coal and nuclear (mostly done, incorporated in Frankel T&T memo). *(Draft by WHEN?)*

C. GRUBER and JONES to work on incidence (JONES is doing memo for early next week - should pass to WILCOX for review). *(Draft by WHEN?)*

D. ROBERTS to work on memo on size of financial flows. *(Draft by WHEN?)* AWG

E. MULDOON to work on political economy lessons from BTU tax and Carter oil allocation scheme. *(Draft by WHEN?)*

****

F. SCHOLZ to work on revenue recycling. How does the prescription of academic public finance theory translate into the real world? Why do simulations of empirical models suggest that deficit reduction might be a better way to go than recycling?

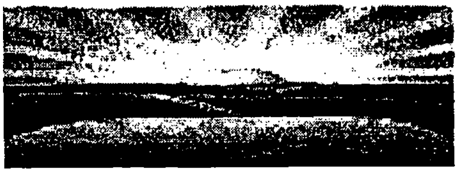
G. GILLINGHAM to work on spelling out emissions baselines for developing countries that would not involve either excessive restraint on growth nor large transfers of resources.

H. GRUBER and GILLINGHAM to work on developing principals for climate change.

I. GRUBER to write up a pithy response to 5labs: Even if you accept the report lock, stock and barrel, you get only *X* percent of the way there without raising price. To get all the way there, you have to raise price by *Y* percent. This would have the following implications for energy prices — ... — and would be roughly *Z* times as large as the BTU tax that was proposed early in the first term.

V. Papers in the Interagency process

A. Revised paper on developing country commitments — SQUITIERI and WILCOX to supply comments to State by COB 8/29.



Industries of the Future

The Industries of the Future strategy creates partnerships between industry, government, and supporting laboratories and institutions to accelerate technology research, development, and deployment. Led by the Office of Industrial Technologies within the Department of Energy's Office of Energy Efficiency and Renewable Energy, the Industries of Future strategy is being implemented in the seven energy- and waste-intensive industries listed below.

These industries use more than 80 percent of the energy consumed in all U.S. manufacturing. Two key elements of the strategy include an industry-driven document outlining the industry's vision for the future and a technology roadmap to outline the technology that will be needed in order to reach their goals. Through this process, government-funded research is brought to a sharp focus to benefit U.S. industry. To the extent that visions and technology roadmaps have been completed, OIT has outlined research needs.

Industries of the Future Overview Briefing

Aluminum - Works in the refining of alumina to the fabrication of a broad range of products from beverage cans to aircraft and construction materials.

Chemicals - Produces over 70,000 different products ranging from basic commodity chemicals, such as sulfuric acid and plastics, to mass-marketed consumer goods such as drugs, detergents, and paints.

Forest Products - Produces wood and paper products for a wide variety of consumer goods, such as stationery and paper tissues, and industrial products, such as cardboard packaging and paper for newsprint.

Glass - Produces and fabricates a diverse set of products: flat glass, largely used for windows; glass containers, such as for bottles; fiberglass for insulation and structural applications; and specialty glass, such as optical fibers.

Metalcasting - Melts and casts mostly scrap metal into literally tens of thousands of intricately shaped metal parts that are used in the assembly of over 90% of all durable goods and in virtually 100% of machine tools, manufacturing machinery, and similar capital goods.

Petroleum - Converts crude oil into fuels and feed stocks used in a wide range of products for transportation, industry, electrical generation, and heating.

Steel - Makes, shapes, and ships steel products, one of the most basic and widely used metals, to many markets such as construction, automotive, and machinery.

Agriculture - New team which is focusing on renewable bioproducts and the food processing industries

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OFFICE OF INDUSTRIAL TECHNOLOGIES
Productivity through Technology

Research Needs of Energy Intensive Industries

It is widely recognized that a critical and pervasive issue for the 21st Century will be the balancing of industrial activity and environmental stewardship, and that more knowledge is needed to make effective choices to achieve that balance. The Department of Energy has worked closely with the seven industries that consume 80 percent of the energy and produce over 90 percent of the wastes in the manufacturing sector to define their research needs. These seven are: steel, aluminum, forest products, glass, metalcasting, chemical, and petroleum refining.

DOE facilitates a process whereby the industry creates an industry-wide vision, followed by the creation of a technology roadmap which charts the research needed to achieve the vision. Through this process, government-funded research is brought to a sharp focus to benefit U.S. industry. The following list shows the research needed by the seven industries, to the extent that the visions and respective technology roadmaps have been completed.

- Forest Products Industry
- Steel Industry
- Metalcasting Industry
- Glass Industry
- Petroleum Refining Industry
- Chemicals Industry

Aluminum

Industry of the Future

DOE/Idaho Operations Office Seeks Applications for Cost-Shared Aluminum R&D Projects

Aluminum Technology Roadmap Workshop Report - PDF file

Fall/Winter 1996 Aluminum Update

Spring/Summer 1996 Aluminum Update

The U.S. aluminum industry provides raw materials for the manufacture of numerous consumer goods (e.g., automobiles, cans, structural materials, packaging). U.S. aluminum industry shipments in 1993 were 8.2 million metric tons, valued at about $31 billion, and the industry employs about 134,000 people. Through the Aluminum Industry of the Future strategy, the U.S. aluminum industry and the Department of Energy are creating a partnership to spur technological innovations that will reduce energy consumption, pollution, and production costs.

Today, the principal forces driving the industry are worldwide competition, energy costs, and compliance with domestic environmental regulations. The industry is responding by:

- Reducing primary aluminum production
- Investing in recycling facilities
- Investing in aluminum fabrication
- Developing more flexible processing technologies
- Building new primary production facilities outside the U.S.

Through the Aluminum Industry of the Future strategy the industry and the Nation can benefit significantly:

- Improved production processing technologies can significantly lower costs while improving product quality
- Higher efficiency and resource productivity can lower emissions, thus improving air and water quality while reducing the need for more costly "end-of-pipe" control technologies
- Energy consumption can decrease by 30 percent.

Ongoing Federal R&D related to the Aluminum Industry

- Industrial Projects Locator - Descriptions of on-going industrial-related research and development projects sponsored by the Department of Energy.
- Federal Agency Activities in Aluminum Related R&D

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Chemicals

Industry of the Future

The chemicals industry is one of seven energy- and waste-intensive industries that participate with the Office of Industrial Technologies' Industries of the Future initiative to maximize economic, energy and environmental benefits through research and development of innovative technologies. In December 1996, the chemicals industry -- represented by the American Chemical Society, the American Institute of Chemical Engineers, the Chemical Manufacturers Association, the Council for Chemical Research, and the Synthetic Organic Chemical Manufacturers Association -- published a report articulating its vision of the future.

Technology Vision 2020: The U.S. Chemical Industry helps establish technical priorities in areas critical to improving the chemical industry's competitiveness; develops recommendations to strengthen cooperation among industry, government, and academia; and provides direction for continuous improvement through step-change technology in four areas: new chemical science and engineering technology, supply chain management, information systems, and manufacturing and operations.

The OIT Chemical Industry Team (CIT) continues OIT's mission of creating partnerships among industry, trade groups, government agencies, and other organizations to research, develop, and deliver advanced energy efficiency, renewable energy, and pollution prevention technologies for the chemical industry. These advanced technologies will help the chemical industry to save energy and cut waste, lower operating costs, boost productivity, and prevent pollution.

To foster cooperation on *Technology Vision 2020*, the sponsors signed a Memorandum of Understanding with the U.S. Department of Energy establishing a framework for identifying appropriate areas of joint research, development, and technology demonstration. The event took place on February 26, 1997 during the 2nd Industrial Energy Efficiency Symposium and Exposition in Arlington, VA.

This page contains resources for and about the chemicals industry and the Office of Industrial Technologies' Chemical Industry Team.

What's New

- New! Solicitation for Chemical Industry to be Issued on or about July 30

Team Status - March 1997
Los Alamos and Hughes Win Award from Popular Science
Electroplating Waste Minimization wins R&D 100 Award

Industry Profile

The chemical industry is more diverse than virtually any other U.S. industry. Its products are omnipresent. Chemicals are the building blocks for products that meet our most fundamental needs for food, shelter, and health, as well as products vital to the high technology world of computing, telecommunications, and biotechnology. Chemicals are a keystone of U.S. manufacturing, essential to the entire range of industries, such as pharmaceuticals, automobiles, textiles, furniture, paint, paper, electronics, agriculture, construction, appliances, and services. More than 70,000 different products are registered. More than 9,000 corporations develop, manufacture, and market products and processes. The industry includes, but is not limited to, those identified in the U.S. government's Standard Industrial Classification 28 (SIC 28):

- industrial organic chemicals
- plastics, materials and synthetics
- drugs
- soaps, cleaners and toilet goods
- paints and allied products
- industrial organic chemicals
- agricultural chemicals
- miscellaneous chemical products

In short, a world without the chemical industry would lack modern medicine, transportation, communications, and consumer products.

[Dimensions] [Energy] [Employment] [Environmental] [Economics] [Data Sources]

Industries of the Future Process

Industries of the Future is a fundamentally different approach to the development of new industrial technologies. For the chemical industry, the process aligns federal investments in research, development, demonstration and deployment with the needs of the technology users. Technology Vision 2020: The U.S. Chemical Industry represents the dynamic impact of market, business, regulatory, and social drivers. The industry is using the vision to help it define the technology roadmaps that describe the pathways that will lead to achieving their vision. DOE helps to facilitate the process and collaborates with the industry, academia, and other governmental and non-governmental organizations. The identification of the critical technology needs enables the focusing and leveraging of scarce public and private sector R&D resources. DOE will implement R&D programs that support broad objectives of national interest, its mission, and the speci fic needs of the industry.

Advanced Technologies

- Chemical R&D; Projects in OIT

  1996 Chemicals Team Annual Report (928k Acrobat file that requires Adobe Acrobat Viewer)
  1996 Chemicals Team Annual Report (HTML version)
  1995 Chemicals Team Annual Report (HTML version)
- Federal Agencies Active in Chemicals Industry-Related R&D;
- DOE Locator of Industrial-Related Projects -- database and locator for DOE and DOE Laboratory projects related to industry
- National Technology Transfer Center Databases -- national network linking U.S. companies with federal technologies
- Annotated Bibliography -- technical reports related to the Chemicals Industry
- Full Bibliography -- technical reports related to the Chemicals Industry

For More Information

- OIT Chemicals Team Brochure (75k file that requires Adobe Acrobat Viewer)
- OIT Chemicals Team Contacts
- DOE Laboratory with Test Sites/User Facilities
  - National Renewable Energy Laboratory

- DOE Laboratories with programs relevant to the chemical industry
  - Argonne National Laboratory
  - Lawrence Berkeley National Laboratory
  - Lawrence Livermore National Laboratories
  - Oak Ridge National Laboratory
  - Pacific Northwest National Laboratory
  - Sandia National Laboratory
  - Savannah River National Laboratory

Related Industry Links

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Chemicals Industry

Reference: ***Technology Vision 2020: The U.S. Chemical Industry***

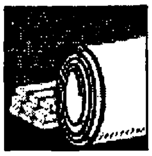
- **New Chemical Science and Engineering Technology**
  - Chemical Synthesis
    - New synthetic techniques incorporating the disciplines and approaches of biology, physics, and computational methods
    - New catalysts and reaction systems to prepare economical and environmentally safe processes with lowest life-cycle costs
    - New chemistry for use of alternative raw materials
    - New synthesis tools to efficiently create multifunctional materials that can be manufactured with attractive economics
    - Techniques for stereospecificity or precision in spatial arrangements of molecules
    - New cost-effective techniques to create a broader variety of molecular architectures in alternative reaction media
  - Bioprocesses and Biotechnology
    - Improved performance of biocatalysts
    - Improved biochemical processing
  - Materials Technology
    - Prediction of materials properties
    - Synthesis technology for precise manipulation of material structures
    - Enhanced performance in materials
    - Routes for step change improvements in performance of material systems with the use of new additive technology
    - Technology in integrated materials and processes for disassembly and reuse
  - Process Science and Engineering
    - Design principles, tools, systems, and infrastructures to accommodate a variety of improvements to meet current and emerging needs
    - Knowledge of particulate processes
    - Improved manufacturing flexibility
  - Chemical Measurement
    - Highly sensitive, precise, and accurate measurement technology needed to probe molecular processes in the laboratory
    - Robust measurement techniques for real-time, highly reliable analyses in practical environments
    - Theoretical models for guiding and optimizing chemical analysis in laboratory and plant-process environments
    - Collaboratory concepts so that scientists and engineers at one location can do experiments on the best equipment even if it is located at a physically remote site
  - Computational Technologies
    - Improvements to make computational molecular science tools more useful in modeling
    - Computational fluid dynamics programs with readily adaptable architectures that better model complex systems (coupling chemical reactions with multiphase, multidimensional, simultaneous fluid, heat, and mass transfer dynamics) and incorporate emerging advances in physical models and property databases
    - Modeling of complex, multi-site, multi-product, global environments
    - Large-scale integration of smart systems with operations, using advances in artificial intelligence to move beyond the small scale or limited scope of current advisory systems

- **Supply Chain Management**
  - Market Globalization
    - Compatibility of supply chain inventory and information systems among trading partners
  - Regulatory Restrictions

        - Consistencies in packaging materials and design and labeling
        - Testing methods for certifying materials
    - Transportation
        - Harmonization of international transportation regulation schemes
    - Information Processing
        - Efficient information flow among parties interconnected to the global supply chain

- **Information Systems**
    - Infrastructure and Open Systems
        - Improvements in hardware and software that include interfaces, gateways, data compression technologies, automated data collection/scanning devices
        - Improvements in networking, communications and data exchange
    - Business and Enterprise Management
        - Improvements in hardware and software systems that provide business information and analysis
        - Changes in networking, communications and data exchange for plant floor and production planning systems
    - Product and Process Design and Development
        - Improvements in modeling and application of information technology, e.g. simulation and modeling techniques, chemical properties prediction, reaction and separation dynamics
        - Improvements in hardware and software to integrate safety and regulatory information with design tools, to expand the use of property prediction databases, statistical analysis and neural network technology
    - Computers in Manufacturing
        - Open systems and integrated applications
        - Advanced process control technology
        - Equipment monitoring systems
        - Process modeling and advisory systems
    - Computers in Plant Engineering and Construction
        - Engineering automation
        - Robotics for plant construction
        - Advanced computer-aided design tools

- **Manufacturing and Operations**
    - Production Capability
        - Reduced manufacturing variability
        - Improved Impact of manufacturing processes on the environment
        - Agile responses to unexpected or anticipated change
        - Manufacturing reconfiguration
        - Integration of production capability
    - Information and Process Control
        - Operations of the make-and deliver system
        - Use of data and integrated systems to allow the rapid development and implementation of new product and process technology globally
        - Real-time availability of global transactional information
    - Building New Plants
        - Use of standard, prefabricated modular components
        - Design and construction processes of shorter duration
        - Centrally stored and available plant designs
        - Electronic footprints of existing plants for use in design



Forest Products

Industry of the Future

Vision

By the year 2020, the United States forest products industry envisions itself as the world's leading provider of essential wood and paper products. The industry plans to manufacture these products in leading-edge, low-cost manufacturing facilities manned by highly skilled employees, and to conduct all operations in harmony with the environment.

AGENDA 2020-- A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry - This document presents the forest, wood and paper industry's perspective of where the industry stands today, a desired state for the industry twenty-five years into the future, and the technology-related issues that must be addressed to accomplish the industry's vision of the future.

Download **Agenda 2020** from the American Forest & Paper Association in Word Perfect format

Collaborative Effort Compact - cooperative agreement between DOE and the Forest Products industry

New! **Call for Forest Products Technology Proposals** - The American Forest and Paper Association, in cooperation with the Department of Energy and the National Council for Air and Stream Improvement, issues a **request for forest products related proposals** in six key technology areas:

- Environmental Performance
- Recycling
- Sustainable Forestry
- Sensors and Controls
- Energy Performance
- Improved Capital Effectiveness

Cooperative Research Areas - projects being funded by OIT Forest Products:

- Energy Performance
- Environmental Performance
- Improved Capital Effectiveness
- Recycling
- Sensors and Control
- Sustainable Forest Management

Technology Access - OIT deployment programs and information which can improve productivity:

- NICE 3 (economic, energy, and environmental technology demonstration

grants)
- Motor Challenge(improving motor efficiency)
- Climate Wise (recognition of corporate energy efficiency, pollution prevention)
- Industrial Assessment Centers (productivity, energy, waste assessments for small manufacturing facilities)
- Inventions and Innovation (tools and services for inventors)
- Commercially Available Technologies (fact sheets on available technologies and emerging advanced technologies developed in partnership with OIT)

Team Status - Spring/Summer 1997

Ongoing Federal R&D related to Forest Products

- Industrial Projects Locator - Descriptions of on-going industrial-related research and development projects sponsored by the Department of Energy.
- Federal Agency Activities in Forest Products Related R&D

Industry Profile - energy, environment and economic data related to the Forest Products industry

Links related to the Forest Products Industry

For further information contact Valri Robinson, OIT Forest Products Team Leader.

Please send any comments, questions, or suggestions to webmaster.oit@hq.doe.gov.

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Last revision date: June 17, 1997

Forest Products Industry

- **Sustainable Forest Management**
  Valri Robinson, (202) 586-0937
  - Biotechnology Research
    - Determine and locate gene sequences for important growth traits and model
    - Manipulate genes to control: resistance to stresses; wood quality; tree growth
  - Integrated culture research
    - Characterize fiber genetics to produce needed wood structure and pulping qualities
    - Develop high yield genotypes through breeding and testing
    - Develop fertilizers, irrigation systems and pest resistance technologies for healthy tree growth
  - Long-term site productivity
    - Investigate effects of forest management practices on water quality and wildlife
    - Quantify effects of soil nutrients and water availability on plantations
    - Determine the relationships among site source availabilities, gene attributes, carbon gain, allocation and fiber production
- **Improved Capital Effectiveness**
  Charlie Sorrell, (202) 586-1514
  - Develop lower cost, safer and more efficient alternatives to the kraft chemical recovery process.
  - Develop lower cost, more energy efficient forming, pressing and drying technologies for paper and wood products.
  - Develop methods for constructing large and small facilities at lower costs .
  - Develop new materials for the industry's processing equipment which are cheaper to use, less expensive to maintain, and stand up to the harsh nature of the many chemical processes used.
- **Energy Performance**
  Stanley Blazewicz, (202) 586-4679
  - Evaluate forest, wood and paper products for life cycle energy efficiency.
  - Develop technologies that support life cycle energy efficiency assessments of wood and paper products.
  - Establish fundamental relationship between wood and paper drying and product quality and uniformity.
  - Develop combined cycle cogeneration technologies to extract the maximum useable energy from biomass, waste, and fossil fuels.
  - Demonstrate black liquor and biomass gasification technologies.
  - Evaluate new technologies that integrate the production of wood-based chemicals with current wood and paper processes.
- **Recycle**
  Simon Friedrich, (202) 586-6759
  - Establish innovative collection techniques, systems and equipment to improve the economics of recovering materials.
  - Evaluate new separation technologies to allow for more specific separations between desirable recycled components and unacceptable contaminants.
  - Determine the relationship between recycled fiber surface chemistry and product strength.
  - Develop new technologies for deinking plant sludge use and disposal.
  - Establish statistical characteristics of incoming recycled raw material streams.
  - Develop technologies for recycling of wood currently going to landfills.
- **Sensors & Control**
  Theodore Johnson, (202) 586-6937
  - Investigate the environmental implication of promising new delignification and bleaching technologies in terms of atmospheric emission, effluent quality and treatability, and solid waste generation.
  - Fiber characterization.
  - Recycle fiber quality.
  - On-line chip characteristics' determination.

- Three-dimensional mapping of fiber properties, real time, inside the digester.
- Three dimensional characterization & controls of internal tree structure and its relation to final product properties.
- Automated sorting of recycled raw material.
- Multiple species stack emission monitoring.
- Recovery boiler (100%) tubes wall integrity measurement (during operation).

- **Environmental**
  Merrill Smith, (202) 586-3646
  - New delignification and bleaching technologies to improve atmospheric emissions, effluent quality & treatability and solid waste generation.
  - Examine environmental implications of anticipated improvements in energy efficiency, reduced fossil fuel use, and reduced fresh water use.
  - Substance & source identification from effluents and emissions testing using newly developed protocols for assessments of possible human health, wildlife & aquatic community health effects.
  - Reduction of impacts of gaseous discharges
  - Removal of non-process elements in pulp and paper operations.
  - Examine atmospheric emissions and solid wastes resulting from minimization of bleach plant and pulp mill effluent discharges.
  - Study new commercially viable control technologies applicable to forest products industry emissions and discharges.
  - Investigate the environmental implications of new wood drying technologies, VOC control technologies, resin formulations, and engineered wood products manufacturing processes.
  - Develop appropriate methods for conducting life cycle analyses of forest products, including proper accounting for carbon cycling, product recycling, a use of renewable resources.
  - Characterize emissions and solid wastes resulting from black liquor gasification, non-sulfur chemical pulping processes, and improved mechanical pulping processes.
  - Evaluate environmental questions related to use of pulp mill residuals as beneficial amendments to forest soils.
  - New treatments for durability of wood products.

Glass

Industry of the Future

- Fall/Winter 1996 Glass Update
- Spring/Summer 1996 Glass Update
- Fall/Winter 1995 Glass Update

The glass industry strategy is composed of a balance of long, medium and short term research and development projects that reflect glass industry identified priorities. In the current economic environment, this competitive energy- and material-intensive industry can benefit from participation with the federal government in defining and implementing future technology advances to maintain its share in the market place. Demonstrations in oxygen-enriched air staging and cullet/batch preheating have been initiated. Current research and development efforts include work in advanced industrial materials and combustion efficiency.

- New! Partner with DOE in glass research and development (R&D). Submit an application for R&D for the Glass Industry Initiative to improve efficiencies of production, energy, environment, and innovative types or uses of glass.

- Use market data and studies to make better business decisions. See what industry impacts have resulted from OIT's technologies that assist the glass industry, (i.e. Oxy-Fuel Firing, Glass Feedstock Purification Using Advanced Optical Sortation)

- Learn about OIT's mission, strategy, organization, and budget, or get an on-line briefing of programs.

- Discover News: recent announcements, upcoming events, and highlights including:
  2nd Industrial Energy Efficiency Symposium & Expo February 25-27, 1997
  17 Firms Receive Demonstration Grants; one is a fiberglass/resin recycler.
  National Materials Advisory Board Reviews

- Learn how OIT's program Industries of the Future focuses on six other industries: forest products, steel, aluminum, metalcasting, chemicals, and petroleum refining,.

- Learn how a glass company can improve productivity by participating in one of OIT's Technology Access programs:
  - NICE3 (economic energy and environmental technology demonstration grants), 1997 Solicitation
  - Motor Challenge (improving motor efficiency),
  - Climate Wise (recognition of corporate energy efficiency, pollution prevention),
  - Industrial Assessment Centers (productivity, energy, waste assessments for small manufacturing facilities),

- Inventions and Innovations (tools and services for inventors), or
- Adopt new technologies to save money.

- Research and Development
  - Abstracts of Small Business Innovation Research (SBIR) Phase I feasibility projects for the Glass Industry
    - High temperature **forming material**,
    - Laser ultrasound on-line **viscosity sensor**, and
    - Laser Phase Doppler **fiber diameter sensor**.
  - **Ongoing Federal R&D related to the Glass Industry**
    - Industrial Projects Locator - Descriptions of on-going industrial-related research and development projects sponsored by the Department of Energy.
    - Federal Agency Activities in Forest Products Related R&D
    - Research needs - Learn about research needs of the Industries of the Future.

- Links Related to the Glass Industry

- For further information contact one of OIT's staff or one of the Glass Team Members:

  Theodore Johnson, OIT Glass Team Leader. 202-586-6937
  Rolf Butters, Technology Access, SBIR Program
  Larae Dudley, Contract Management
  Deidre Jacobs, Administrative
  Ramesh Jain, Glass/Combustion Program
  Merrill Smith, Continuous Fiber Ceramic Composites Program
  Charles Sorrell, Advanced Industrial Materials Program

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Glass Industry

Susanne Leonard (202) 586-6108

- **Production Efficiency**, including manufacturing processes and new techniques that maximize glass strength and quality.
  - Sensors for temperature and physical properties to improve fabrication.
  - Coatings to maximize glass strength.
  - Alternate glass compositions that eliminate hazardous materials.
  - Equipment that eliminates glass surface damage.
  - Improved gas and electric furnaces.
  - Computer models simulating manufacturing processes.
  - Six sigma qualities during processing.
- **Energy Efficiency and Conservation**
  - Optimize electric boosting.
  - Improving furnace design and operation to maximize efficiency.
  - Recovering and reusing waste heat from oxy fuel furnaces.
  - Producing oxygen more efficiently for oxy fuel firing.
- **Recycling**
  - Recycling of post consumer fiberglass insulation.
  - Separation of recycled glass by color.
  - Beneficiation of cullet for recycling.
  - Removal of non glass contaminants.
- **Environmental Protections**, including control of Nitrogen Oxides, sulfur oxides and particulate; solid waste reductions; and wastewater reuse.
  - Combustion processes that reduce air emissions.
  - Expanded use of 100 percent oxygen combustion.
  - Materials or furnace designs to significantly reduce particulates.
  - Manufacturing processes that generate less solid waste.
  - Refractories that do not generate hazardous materials.
  - Elimination of Halide emissions.
- **Innovative Uses for glass technology.**
  - Create new uses for glass and enhance existing materials.
  - "Smart Windows" that react to lighting and temperatures.
  - Lighter weight, impact resistant container and flat glass.
  - Fiberglass that compacts and rebounds easily.
  - New optical fiber designs and components.

Metalcasting

Industries of the Future

The DOE Metalcasting Partners

The metalcasting industry is one of seven energy- and waste-intensive industries t participate with the Office of Industrial Technologies' Industries of the Future str

The metalcasting industry--represented by the American Foundrymen's Society (American Die Casting Association (NADCA), and the Steel Founder's Society of (SFSA) has prepared a document *"Beyond 2000"* which provides a vision of what metalcasting industry could be like in the year 2020. To implement this strategy, t Metalcasting Vision Team at OIT partners with representatives of metalcasting c national laboratories, universities, and various trade/environmental/technical ass organizations to develop and implement energy efficiency technologies that will b the industry and the United States.

This page contains resources related to the metalcasting industry and the Office o Technologies' Metalcasting Team.

[Whats New!] | [Metalcasting Profile] | [Partnership Status] | [Advanced Technologies] | [Hot Links]

What's New

Collaborative effort compact signing by the Secretary of Energy and industry represent

Spring 1996 Metalcasting Update!

Metalcasting Competitiveness Research Act - 1995 Annual Report

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Industry Profile

The metalcasting industry melts and casts mostly scrap metal into literally tens of thou intricately shaped metal parts. In 1996, the U.S. metalcasting industry produced castin value exceeding $29.3 billion, and employed nearly 217,000 people which is dominate business. Of the 3,100 metalcasting establishments in this country, 79% employ fewer people.

[Dimensions] [Energy] [Employment] [Environmental] [Economics] [Data Sources]

Metalcasting Vision Process

DOE is doing business in a new way. The Industries of the Future is a fundamentally d approach to the development of new industrial technology. The process aligns federal i technology research, development, and deployment with the needs of the technology u metalcasting industry. Based on the vision document "*Beyond 2000*", American Found (AFS), Steel Founder's Society of America (SFSA) and North American Die Casting (NADCA) is leading the development of a technology roadmap that describes what is accomplish the vision. Today, some specific accomplishments include the following:

- **Vision Developed:** In September 1995, chief executive officers and presidents fr foundry, die casting, and foundry supply industries developed *Beyond 2000: A V American Metal Casting Industry*.

- **Compact Signed:** During October 1995, the American Foundrymen's Society (Founders' Society of America (SFSA), and North American Die Casting Associa (NADCA), signed a Compact establishing a voluntary collaborative effort betwe and the U.S. Department of Energy. The Compact provided the framework for id appropriate areas for joint research, development, and technology demonstration

- **Technology Roadmap:** Currently, the CMC is working toward developing a tec roadmap which sets out a strategy for pursuing and achieving the goals set out in and carrying out the cooperative agreement with the U.S. Department of Energy is working with industry and research institutions, including universities and nati laboratories to develop this roadmap.

- **Vision Implementation:** The CMC also manages R&D activities through the M Industries of the Future program. Through an Executive Board and Technical Co CMC operates with input and guidance across the metal casting industry, drawin metalcasting Industrial Advisory Board (IAB) and numerous technical committe metalcasting associations as well as relying on the input and advice from corpor academia, and government agencies. The CMC Technical Committees select can based on the goals and objectives identified in the metalcasting Vision. The CM Board, composed of representatives from the three associations, OIT, and the me IAB, work together to ensure that the candidate R&D projects correspond to the objectives and goals, and make the final project selection.

Advanced Technologies

Ongoing Federal R&D related to Metalcasting

- Industrial Projects Locator - Descriptions of on-going industrial-related research development projects sponsored by the Department of Energy.
- Federal Agency Activities in Metalcasting Products Related R&D

For More Information

- OIT Metalcasting Team Brochure
- OIT Metalcasting Team Contacts
- *"Beyond 2000:" A Vision for the American Metalcasting Industry*
- *Draft* U.S. Metalcasting "Roadmap"
- Metalcasting Competitiveness Research Act - 1995 Annual Report
- DOE Laboratories with programs relevant to the metalcasting industry:

Under Construction

Related Industry Links

Under Construction

Please send any comments, questions, or suggestions to webmaster.oit@hq.doe.gov.

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Metalcasting Industry

- **Market (Applications Development)**
  Sara Dillich (202) 586-7925
  Harvey Wong (202) 586-9235
  - Improved lost foam casting technology
  - Semi-Solid & Squeeze Casting technology
  - New Casting Alloy developments
  - Cast Metal Matrix Composites developments
  - Process Variables Control Improvement
- **Materials Technologies**
  Larry Boxall (202) 586-6436
  - Improved dimensional control of Castings.
  - Elimination of Casting defects such as porosity and inclusions.
  - Clean cast metal technology.
  - Castings with thinner walls.
  - Identification and standardization of cast metal properties.
  - New casting alloys.
- **Manufacturing Technologies**
  Doug Gish (202) 586-1741
  Bill Obenchain (202) 586-3090
  - Control and interaction of process variables.
  - Automated finishing equipment.
  - Breakthroughs in affordable automated equipment.
  - Improved core removal methods.
  - Extended diecasting die life.
  - Lead time compression.
  - Waste heat recovery and re use.
  - Cupola furnace modeling and control using neural networks.
  - Advanced sensors and process controls.
  - Melting and holding furnace optimization.
  - Solidification Modeling
  - Fluid Flow Modeling
  - Metal/Material Properties Modeling
  - Alternative Methods of Tooling
  - Rapid Prototyping
  - New Binder Substitutes
  - Casting Consistency In-Process Testing
  - Improved Refractories Lathe Design
- **Environmental Technologies**
  Bill Obenchain (202) 586-3090
  - Complete characterization of waste streams for process modification.
  - Advanced waste treatment technologies.
  - Environmentally benign sand binders and additives.
  - Improved methods of sand reclamation.
  - Beneficial re use of foundry sand and other solid waste products.
  - Alternative processes or materials for reduced waste generation.
- **Human Resources, Education, and Training**
  Gobind Jagtiani (202) 586-1826
- **Profitability and Industry Health**
  Sara Dillich (202) 586-7925
- **Partnerships and Collaborations**
  Joe Bryson (202) 586-3604

Petroleum Refining

Industry of the Future

Fall/Winter 1996 Petroleum Refining Update

The petroleum refining industry is critical to the economic stability and energy security of the U.S., meeting energy demands for more than 190 million automobiles, trucks, and buses as well as aircraft. The industry supplies 97 percent of the energy for the travel and freight needs of the nation. In 1992, the refining industry shipped products valued at over $141 billion and employed more than 74,000 people.

However, increasingly complex processes have become necessary in the last decade because of lower quality crude, volatility in the cost of crude, and environmental regulations that require higher quality and reformulated products.

The Department of Energy and the U.S. petroleum refining industry are discussing the establishment of a partnership to develop new process technologies that will improve the industry s global competitiveness while helping to achieve the government s broad national goals of energy efficiency and environmental improvement. The Refinery of the Future strategy will be based upon an industry-generated vision of the industry s future.

Cost-shared projects are concentrated in just five areas:

- Novel process development
- Process modeling, analysis, and simulation
- Fundamental catalysis
- Gaseous emissions
- Component development

Ongoing Federal R&D related to the Petroleum Refining Industry

- Industrial Projects Locator - Descriptions of on-going industrial-related research and development projects sponsored by the Department of Energy.
- Federal Agency Activities in Petroleum Refining Related R&D

Please send any comments, questions, or suggestions to webmaster.oit@hq.doe.gov.

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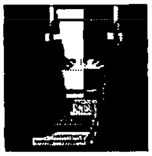
Petroleum Refining Industry

For further information in all topic areas in this industry, contact Dan Wiley at (202) 586- 2099

- Developing new approaches to refining heavy feedstocks.
- Improved energy efficiency of processes and equipment
  - New energy efficient separation technologies.
  - Alternatives to olefin alkylation process.
- New catalysts with improved selectivities, yields and lifetimes.
  - Manufacturing technology.
  - Solid acid catalysts.
- Relating chemical composition to performance of processes/equipment.
- Plant & process reliability.
  - Improved on-line non-destructive evaluation (nde) inspection technology.
  - Predicting useful remaining lifetimes of aging equipment.
  - Robotics for safety operations.
- Environmental and performance characteristics of new hydrocarbon fuel compositions.
  - Minimize particulate emissions (of particle size less than 10 micron) from conbustion source.
  - Understand the effect of multiple burner arrays on process heater efficiency and emisions.
  - Identify reasons for combustion air toxics formation and approaches to minimize toxic formation.
  - Develop low cost, real time mthods for air toxics speciation, characterization and quantification at the ppb level.
- Hydrogen production & recovery.
- Unconventional process technology.
- New materials of construction.
- Integration of environmental solutions into process and plant design.
- Advanced computational modeling of processes and reactions.
- Processing of synthetic fuels.



Steel

Industry of the Future

Fall/Winter 1996 Steel Update

The steel industry recently signed a collaborative effort compact with the U.S. Department of Energy. This compact was signed by the Secretary of Energy and representatives of the industry.

Steel is the most basic and widely used metal in industry, and is vital to the economic and national security of the U.S. The steel products industry is a $57 billion industry employing over 235,000 workers and shipping nearly 80 million tons of steel per year. The steel industry is the fourth largest energy consuming industry in the U.S. and generates 3 million tons of solid waste. To achieve greater energy efficiency, reduce pollution and wastes, and maintain the competitiveness of the U.S. steel industry, the Steel Industry of the Future strategy will build on existing government/industry collaborations to improve the steelmaking processes. The Secretary of Energy and the Chairpersons of the two leading trade groups have signed a Compact that documents the Department of Energy's and the industry's committment to the strategy.

The U.S. steel industry, with about 8 percent of worldwide steel production, competes in an environment where world capacity, some 900 million tons, exceeds actual annual production by nearly 200 million tons. Central to sustaining the industry's competitiveness are efforts to reduce costs and improve quality through fewer processing steps, better yields, greater energy efficiency, and better environmental performance.

The Steel Industry of the Future strategy benefits the industry in two ways: it helps to define and focus research, development, and deployment support as well as to streamline interactions with government agencies. The strategy is being developed by the Office of Industrial Technologies' Steel Vision team with guidance from a May 1995 document -- Steel: A National Resource for the Future produced by the American Iron and Steel Institute and the Steel Manufacturers Association.

Many of the research products that are targeted towards the steel industry are performed as part of the Metals Initiative. A Summary of Steel Projects Performed Under the Metals Initiative for FY94 provides a status report of those projects.

Ongoing Federal R&D related to the Steel Industry

- Industrial Projects Locator - Descriptions of on-going industrial-related research and development projects sponsored by the Department of Energy.
- Federal Agency Activities in Steel Related R&D

Please send any comments, questions, or suggestions to webmaster.oit@hq.doe.gov.

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Steel Industry

For further information in all topic areas in steel industry, contact Scott Richlen (202) 586-2078

- Production Efficiency
  - Develop a totally continuous steel production process to allow optimization of the overall steelmaking system, including advanced process controls.
  - Develop improved rolling/forming processes which will produce steels with superior properties.
  - Improve coating and painting technology to optimally tailor products to specific applications.
  - Commercialization of a cokemaking technology to ensure a pollution-free process.
  - Continuous improvements in environmental performance via programs with equipment suppliers to develop processes designed for pollution prevention.
  - Reducing the cost of oxygen via programs with oxygen suppliers and with the Electric Power Research Institute (EPRI) to raise the efficiency and bring down the cost of oxygen production. (With the introduction of smelters, consumption per ton of steel produced will continue to grow).
- Energy Performance
  - Improved iron units for EAF and BOF charge, and other steelmaking processes (including reducing residuals in scrap and a coal-based direct reduction process).
  - Develop new flexible steelmaking processes which can optimize sources of iron units and energy.
  - Commercialization of cleaner, energy-efficient, alternate iornmaking processes.
  - Non-intrusive furnance sensors to determine combustion/heating levels at burners when using a number of different fuels, single or combined (e.g. natural, gas, coke oven gas). Needed for heating uniformity and efficiency.
  - Novel combustion meterials to reduce air pollutants with various fuels in a simple, cost effective manners.
  - Nox generation from by-product fuels used in steel making (e.g. blast furnace gas, coke oven gas) is higher than predicted and not well understood. This area should be investigated to provide the foundation for developing lower polluting burners or operating procedures.
- Recycle
  - Commercialization of processes to recycle in-plant wastes (in particular, BF, BOF and EAF dusts).
  - Continuous improvements in waste recycling and resource recovery via research on new approaches and technologies, including biotechnology, to address process waste.
  - Research on recycling and disposal of low-level radioactive mixed waste.

check GDP growth assumptions for FSU, China

MEMORANDUM

TO: Jeff Frankel

FROM: Joe Aldy

DATE: August 27, 1997

RE: International transfers attributable to Annex I and worldwide permit trading

International trade in carbon emissions should allow for firms in the United States to purchase lower cost reductions abroad. While these reductions through international trade should reduce the costs of complying with a climate agreement, they would also result in substantial transfers of income across countries. Based on the latest round of SGM modeling runs[1], we assessed the magnitudes of these transfers by country.

Countries Buying Permits

Regardless of trading scheme (Annex I or worldwide), the U.S. is the largest buyer of permits in the year 2050 under four targets and timetables scenarios: Peak in 2015, 1990 Levels in 2010, -10% of 1990 Levels in 2010, and 1995 Levels in 2010. With the exception of the period 2010 to 2030 in the 1995 scenario with Annex I trading, the U.S. is always the largest buyer of permits in the world (see attached charts). Under these scenarios, the U.S. would buy between about $25 billion and $80 billion of permits in 2050 under Annex I trading, and between approximately $25 billion and $40 billion of permits in 2050 under worldwide trading from other countries.

Scenario	Value of Permits Purchased by U.S. in 2050, Annex I only	Value of Permits Purchased by U.S. in 2050, Worldwide
Peak in 2015	$57 billion	$25 billion
1990 in 2010	$54 billion	$24 billion
-10% of 1990 in 2010	$79 billion	$38 billion
1995 in 2010	$25 billion	$24 billion

In addition to the U.S., Western Europe and Japan are significant purchasers of international permits, ranking second and third by 2050 in all scenarios. In the 1995 Level in 2010 with Annex I trading only scenario, every Annex I country is a purchaser of permits by 2050 except for the Former Soviet Union nations and Australia.

[1] These are the runs received on 8/21/97.

Countries Selling Permits

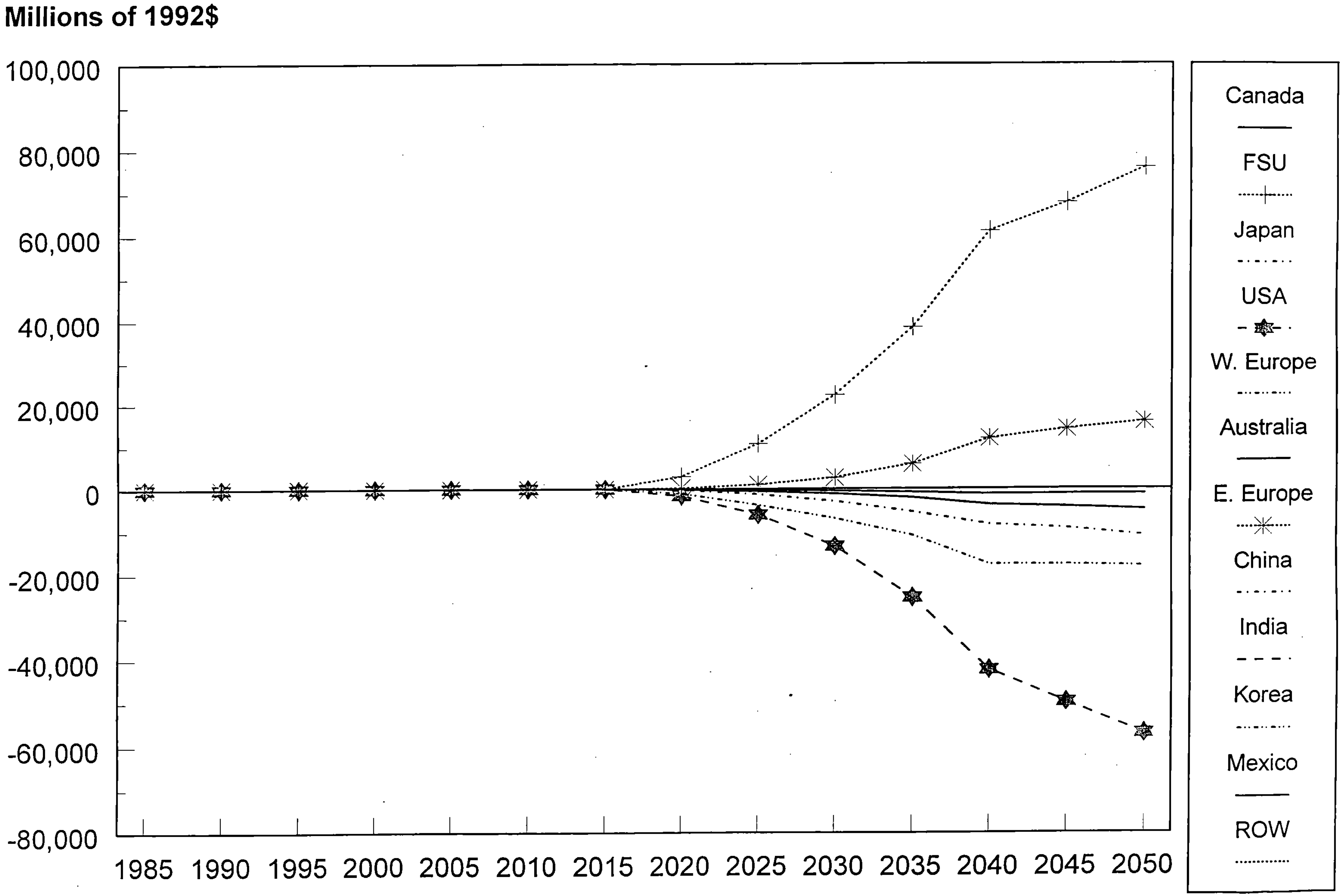
In all of the Annex I trading only scenarios, Former Soviet Union nations are the dominant sellers by 2050, with Eastern Europe second in all but the 1995 Level scenario. For worldwide trading, China is the dominant seller in all scenarios by 2050, followed by the Former Soviet Union and then the conglomeration of the Rest of the World (except for the 1995 scenario, where the Former Soviet Union countries buy permits). Eastern Europe becomes a purchaser of permits by 2050 in the worldwide trading cases. Under these trading schemes, the Former Soviet Union and China would receive substantial cash inflows for their permits.

Scenario	Value of Permits Sold by FSU in 2050, Annex I only	Value of Permits Sold by China in 2050, Worldwide
Peak in 2015	$76 billion	$22 billion
1990 in 2010	$73 billion	$21 billion
-10% of 1990 in 2010	$108 billion	$36 billion
1995 in 2010	$30 billion	$31 billion

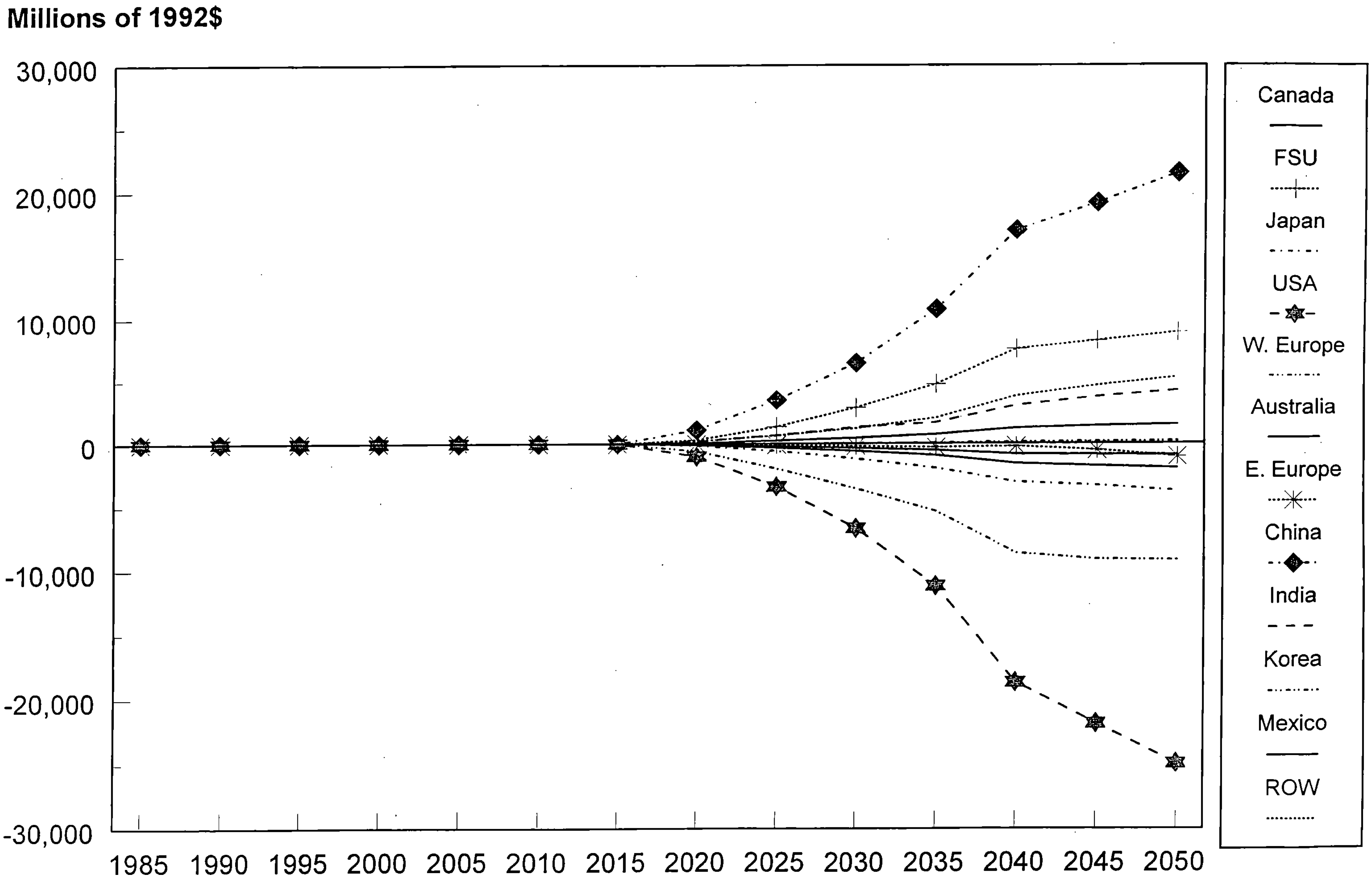
Note that SGM generates outputs for the following countries and regions:

Australia
Canada
China
Eastern Europe
Former Soviet Union
India
Korea
Mexico
Rest of the World
United States
Western Europe

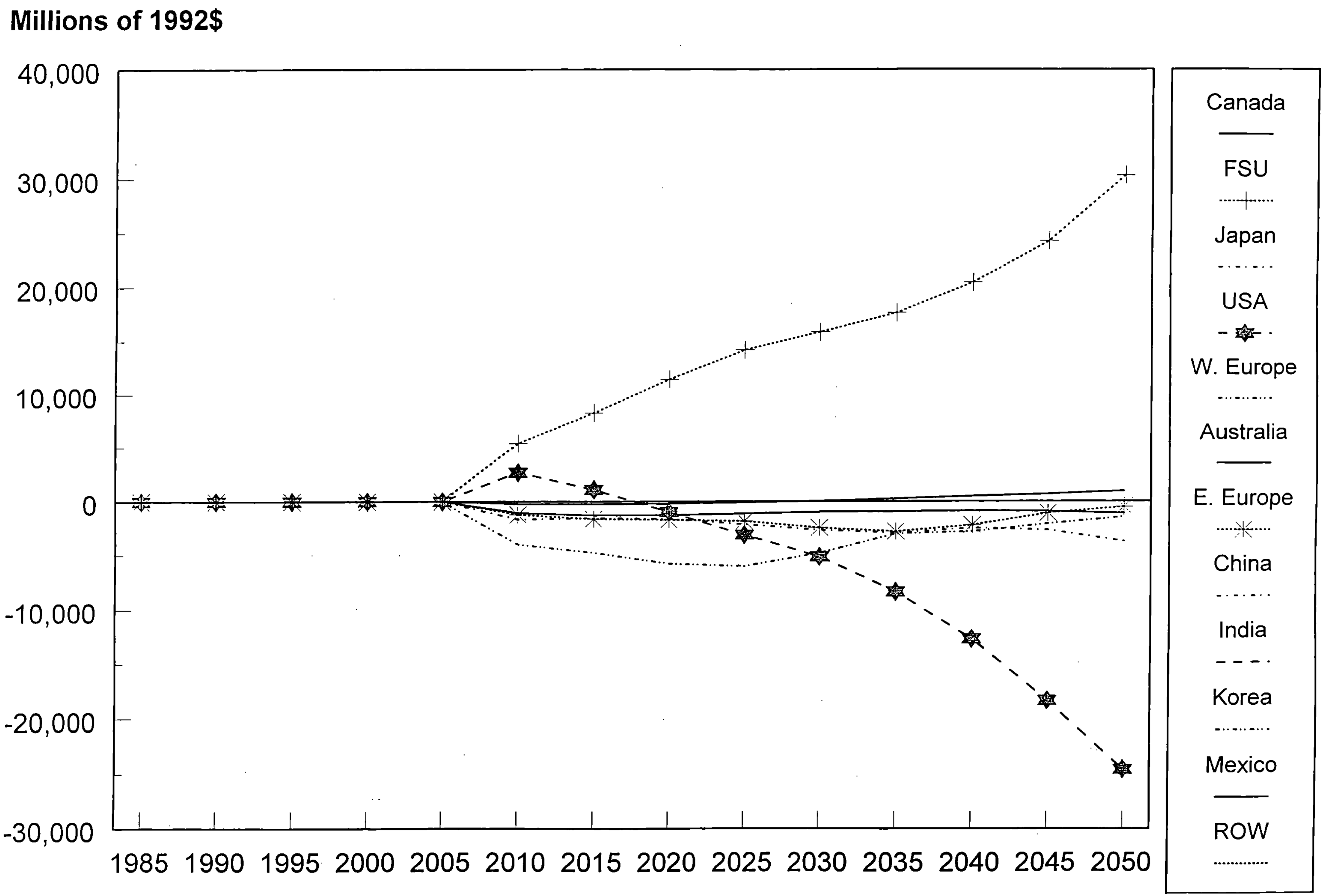
International Transfers from Permit Trading, Peak in 2015, Annex I Trading, SGM12



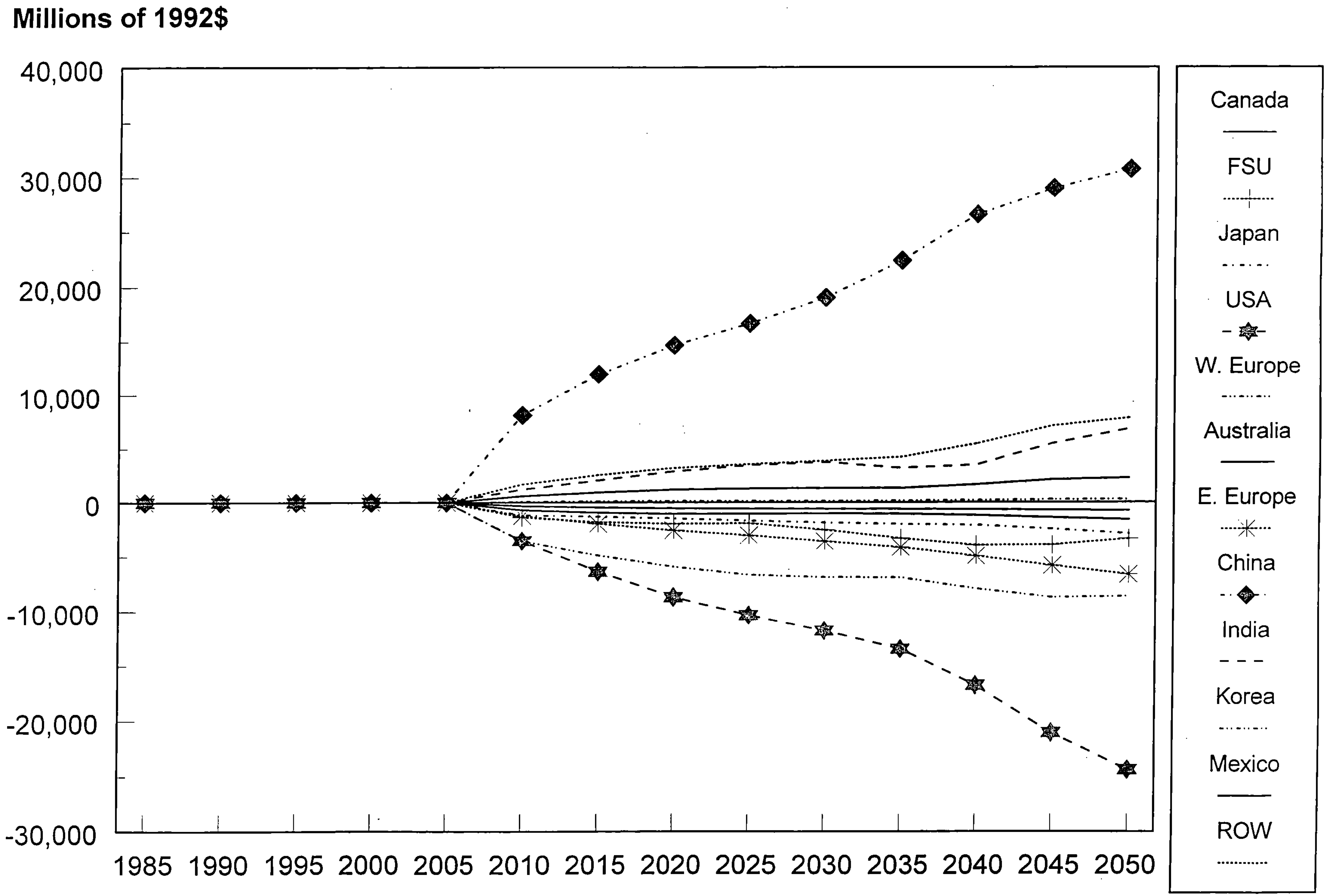
International Transfers from Permit Trading, Peak in 2015, Worldwide Trading, SGM13



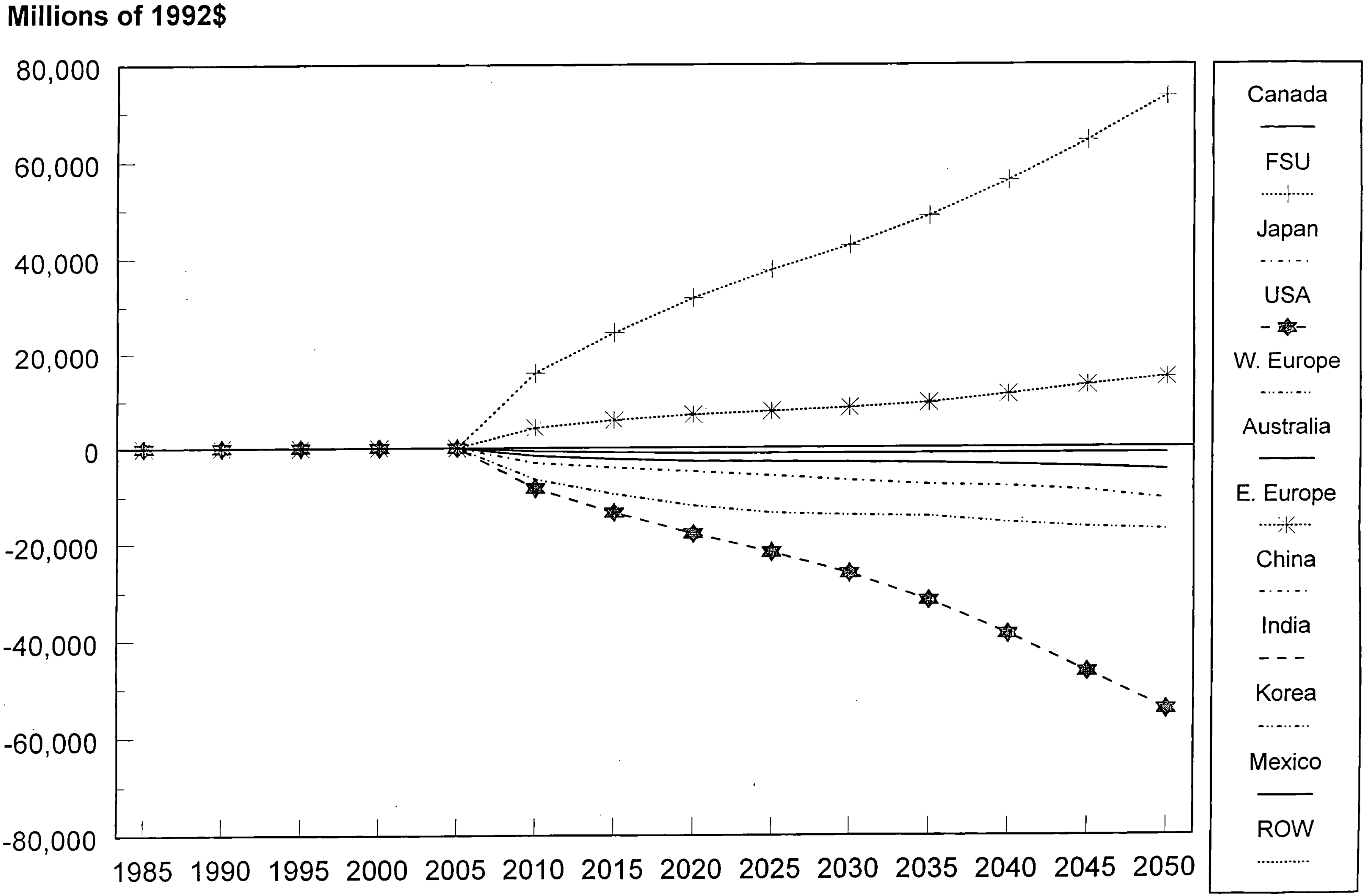
International Transfers ırom Permit Trading, 1995 in 2010, Annex I Trading, SGM6

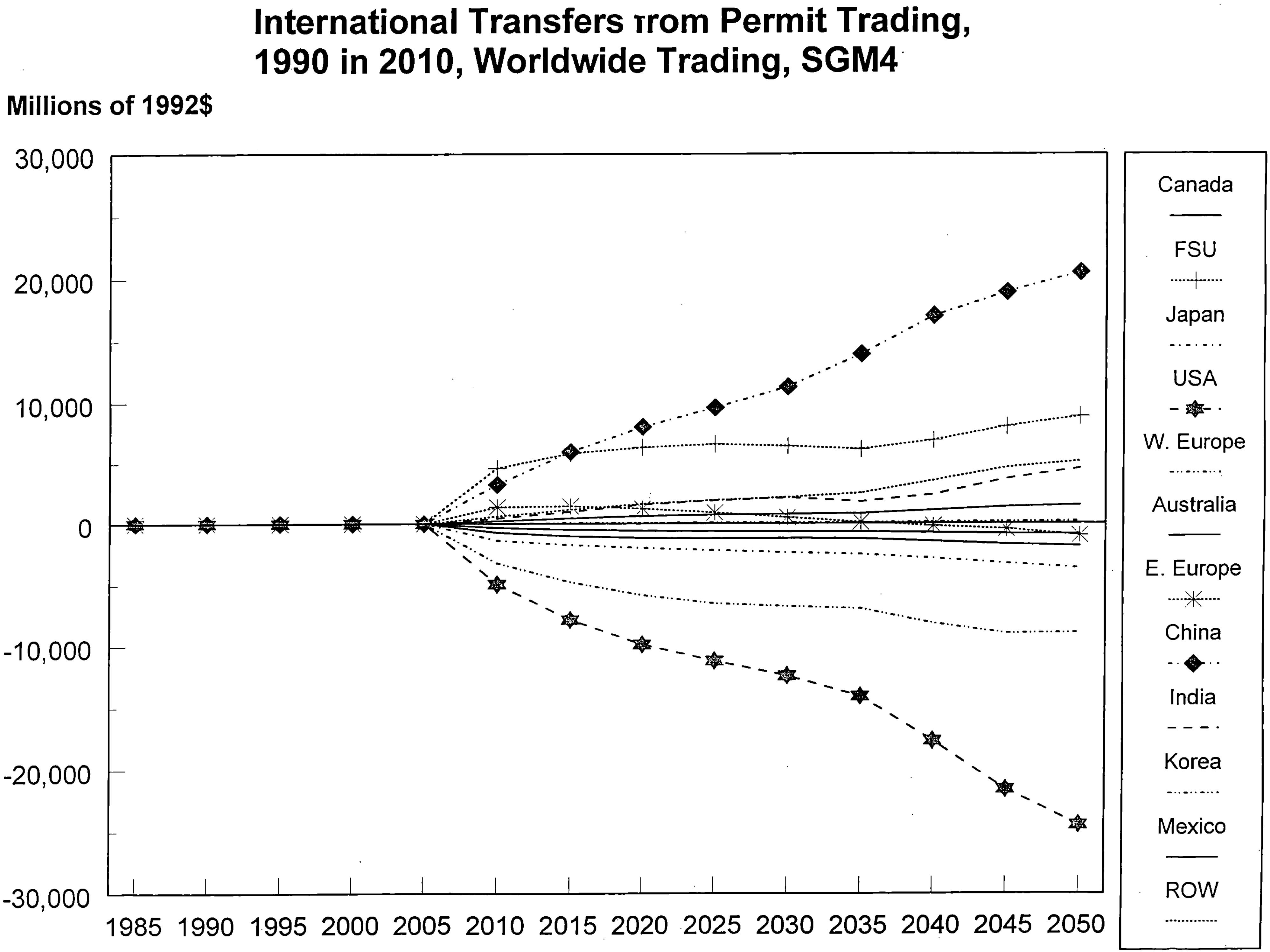


International Transfers from Permit Trading, 1995 in 2010, Worldwide Trading, SGM7



International Transfers from Permit Trading, 1990 in 2010, Annex I Trading, SGM3





International Transfers ɪrom Permit Trading,
1990 in 2010, Worldwide Trading, SGM4
Millions of 1992$
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
1985
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2005
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2015
2020
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2035
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Canada
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Japan
USA
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India
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Mexico
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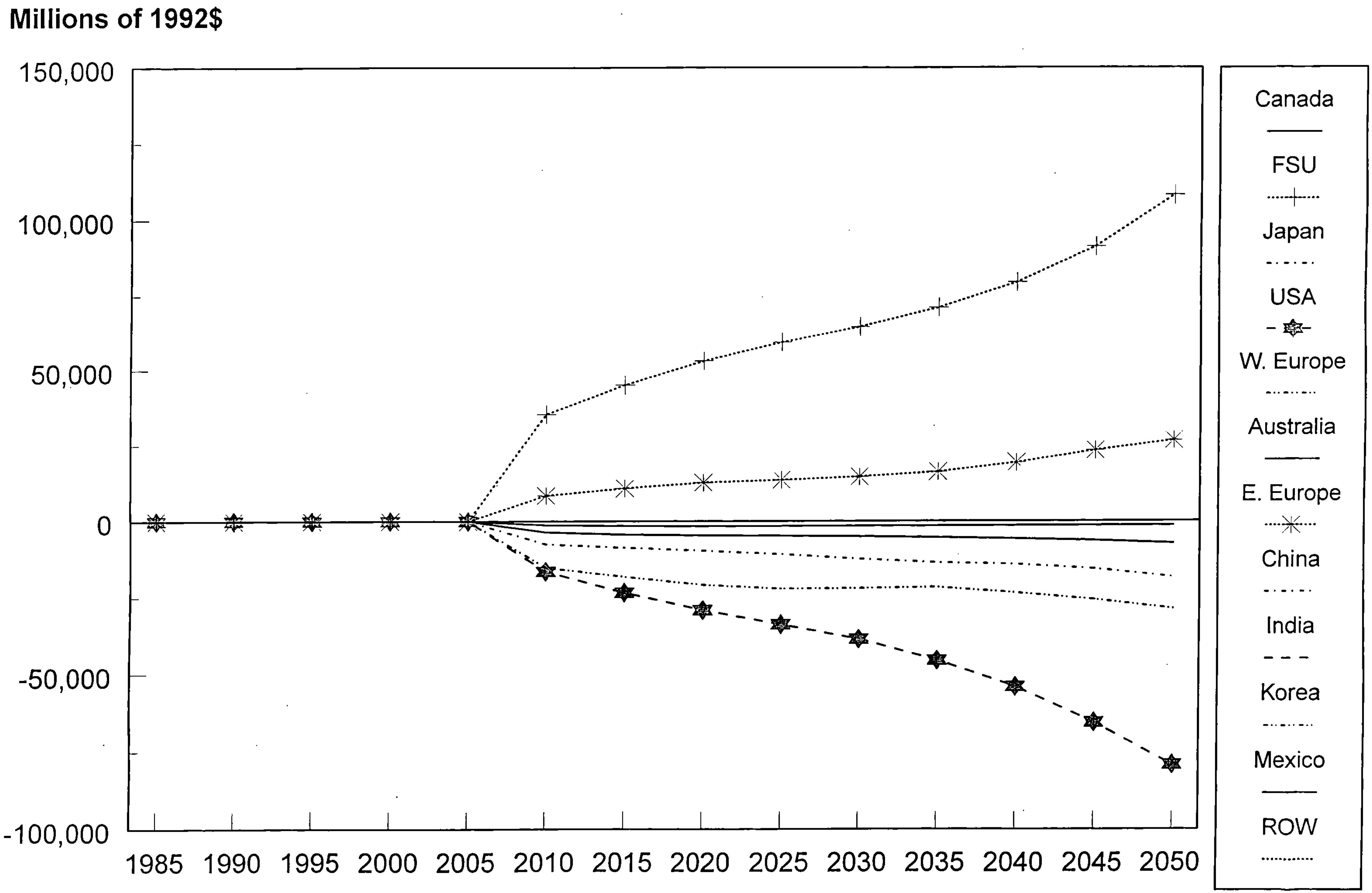
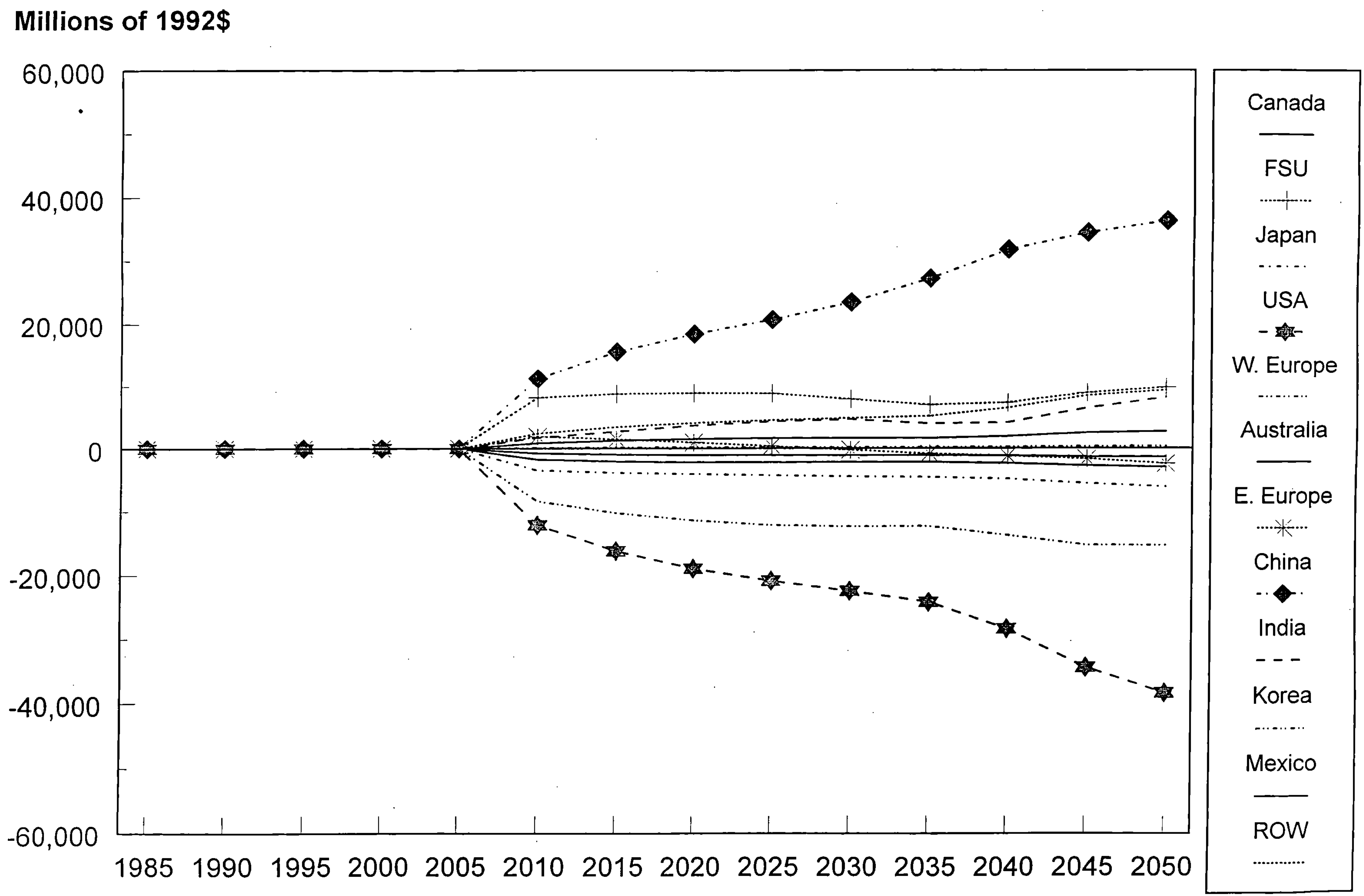
International Transfers from Permit Trading, -10% of 1990 in 2010, Annex I Trading, SGM9



International Transfers from Permit Trading, -10% of 1990 in 2010, Worldwide Trading, SGM10



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Carbon Taxes and the Global Trading System

by

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Abstract

This paper evaluates the economic impacts of two important international policy initiatives: the Uruguay Round (UR) of multilateral trade negotiations and the Framework Convention for Climate Change (FCCC). While these agreements are not directly linked, they interrelate in subtle but important ways that are the focus of our investigation.

The UR reform should result in significant global gains in efficiency and welfare, although these gains would be distributed differently across nations. Layering the emissions-reduction commitments over the UR agreements significantly affects the potential for those gains to be realized.

Carbon taxes shift some energy-intensive production to non-OECD countries and also influence the terms of trade between the OECD and non-OECD groups. We consider how lobbying by energy-intensive producers in the OECD could result in a decision to limit energy-intensive imports from non-OECD countries. Considering the market power of the OECD, it is likely that these border interventions could even be welfare-improving for the implementing nations, effectively passing some of the abatement costs onto the non-participating countries. We illustrate the relative magnitude of these effects using a 26-region, 13-commodity general equilibrium model.

Overall, our results indicate that, on its own, the carbon-tax initiative could offset a large share of gains from the UR. Offsetting "fair" trade interventions further reduce global efficiency and are particularly harmful for developing countries, but generate net gains for specific developed nations.

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1. Introduction

In this paper we develop a multi-commodity, multi-region computable general equilibrium (CGE) model of the world economy in order to analyze the potential global impacts of two important international policy initiatives. First, in Article 4 of the Framework Convention for Climate Change (FCCC), Annex I countries (largely the member nations of the Organization for Economic Cooperation and Development (OECD)) are obligated to aim to restore greenhouse gas emissions in their jurisdictions to 1990 levels by the year 2000.(1) Multilateral negotiations among these countries on actions to achieve this goal have taken place since the Berlin Mandate of 1995. Second, the comprehensive trade-liberalization agreements reached in the recent Uruguay Round (UR) of multilateral trade negotiations (MTN) began to be implemented in January, 1995. Among other things, the UR established the World Trade Organization (WTO) in addition to achieving commitments to liberalize trade in textiles and apparel, agriculture, and manufactures.

While these major agreements are not directly linked, they interrelate in subtle but important ways that are the focus of our investigation. First, the UR package should result in significant global gains in efficiency and welfare, although these gains would be distributed differently across nations. However, efficiency and welfare, although these gains would be distributed differently across nations. However, layering the emisssions-reduction commitments over the UR agreements would significantly affect the potential for those gains to be realized. For example, assuming that significant carbon taxes are employed, the taxes not only would shift some energy-intensive production to non-OECD countries but also would influence the terms of trade between the OECD and non-OECD groups.

Second, such taxes on carbon emissions, by virtue of penalizing production by energy-intensive firms in the OECD countries, almost certainly would encourage a lobbying reaction by those firms to insist on a "level playing field." If successful, such lobbying could result in a decision by the OECD to limit energy-intensive imports from non-OECD countries at their benchmark levels or to levy countervailing tariffs based on the apparent carbon content of imported commodities. Considering the market power of OECD countries, it is plausible that these border interventions could even be welfare-improving for the implementing nations, effectively passing some of the abatement costs onto the non-participating countries. Such reactions would be damaging to the trade interests of developing countries and would threaten to overturn the global gains from the Uruguay Round pact. Thus, there is an important international trade dimension to the Framework Convention.

We address these issues in the CGE model, which contains 26 regions or countries and 13 sectors, thereby allowing a flexible computation of overall industry incidence and regional impacts of carbon taxes and trade-policy responses. We initially simulate the effects of the UR agreements and its main components without any new carbon taxes. We then consider the impacts of the carbon taxes alone, without the UR, and then combine the two. The model next computes the effects of limiting energy-intensive imports from non-OECD countries at their pre-UR levels, first via import quotas and second via voluntary export restraints (VERs). Finally, we consider the impacts of countervailing duties (CVDs) imposed by the OECD countries, with the trade taxes scaled to a measure of the average carbon content of energy-intensive goods. The trade interventions we compute are proportional to "embodied carbon," which includes both the direct and indirect fuel content of the good.

Overall, our results indicate clearly that, on its own, the carbon-tax initiative would significantly offset the welfare gains from the UR, leading to much smaller net gains for both the OECD and non-OECD groups, though some particular countries would be net beneficiaries. Offsetting "fair" trade interventions further reduce global efficiency and damage the developing countries but generate net gains for specific developed nations. From these results, it is fair to conclude that there will be a strong economic interest among firms in the latter countries to lobby for environmental trade taxes.

In the next section we discuss specific policy concerns that inform our simulations, including means by which WTO rules could potentially permit such "fair tax" responses. In Section Three we discuss the CGE model and its implementation and in Section Four we present results from the Uruguay Round, the Framework Convention, and offsetting trade interventions. We offer concluding observations in Section Five.

2. Trade Policy and Environmental Taxes

To place the analysis into context, we begin with an overview of the relevant international policy institutions, including the Climate Change Convention, the Uruguay Round agreements, and multilateral rules on border tax adjustments.

2a. Climate Change Convention

The FCCC, announced at the Rio Earth Summit in 1992, has been signed by over 150 countries. As stated in Article 2, its objective is to stabilize atmospheric concentrations of greenhouse gases at a sufficiently low level to prevent "dangerous anthropogenic interference with the climate system." As noted above, it set a goal for Annex I countries of returning greenhouse gas emissions to 1990 levels by the year 2000, without specifying a mechanism for doing so. Negotiations under the Berlin Mandate to conclude such a mechanism are ongoing, with considerable controversy persisting.

The core feature of FCCC is the commitment by Annex I countries for "early action" before any (still unspecified) obligations are accepted by developing countries. This feature recognizes the fact that the developed countries are the historical source of the bulk of atmospheric gases and accepts the view that

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developed countries are the historical source of the bulk of atmospheric gases and accepts the view that they have the earliest and strongest obligation to reduce emissions. The FCCC envisioned compliance with Article 4 through each OECD country adopting national migitation strategies, but experience to date indicates the need for international coordination. The U.S. strategy of voluntary ("no regrets") measures has not moved its emissions trajectory much from its expected baseline, while proposals in the European Union for mandatory carbon taxes and efficiency standards were rejected. The issue is partly a public-good problem, in that if other nations do not also undertake mitigation, the gains to national mitigation are reduced relative to its costs and countries may be expected to choose lower-cost adaptation strategies focused on local emissions damages. Without a credible multilateral commitment to collective action, emissions reduction will be underprovided.

In this context, the outcome of the Berlin-Mandate negotiations, set to culminate in Kyoto in December 1997, might coalesce around two possibilities. The first, which we model here, is the specification of mandatory carbon taxes in the Annex One countries. Such taxes would fall largely on production of energy-intensive manufactures and services, including especially transportation services, chemicals, metals, and power generation, to the extent that these employ coal and petroleum. Because these taxes would, at least for a period, not be applied in developing countries, Annex I nations would need to consider setting sufficiently high taxes to account for the leakage of production and emissions to the former group. Presumably, any agreement reached under the Berlin Mandate would be binding, suggesting that a failure to implement the requisite taxes would result in sanctions of some kind.

Second, there may be scope for including developing countries in a collective agreement through a joint-implementation strategy in which OECD nations could meet some of their obligations by financing emissions mitigation abroad and receiving credit for doing so. While this international emissions-trading strategy bears promise for achieving low-cost compliance with the ultimate goal of the FCCC, it has met strong resistance in key developing countries. Many such governments view the proposal as a means to obligate their countries to meeting a significant portion of the compliance costs, which departs from the "early action" principle. The European Union also seems to be sympathetic with this view.

Taking the carbon-tax case to be the more likely scenario, we argue that it easily could engender a strong political reaction within the OECD countries. Indeed, energy-intensive firms in the United States strongly oppose the adoption of such taxes, claiming that they would devastate several major U.S. industries by the year 2010 without achieving significant global environmental benefits.(2) The crux of this argument is that production would be transferred to the excluded countries in favor of energy-intensive imports. Expanded production abroad would offset some amount of the abatement undertaken by OECD countries.

2b. The Uruguay Round

The Uruguay Round was the eighth MTN conducted under the auspices of the General Agreement on Trade and Tariffs (GATT), a multilateral agreement that has been folded into the new WTO. The UR was the broadest such negotiation, incorporating trade liberalization in manufactured and primary commodities, partial deregulation of domestic production supports in agriculture, clarification of disciplines on the provision of production and export subsidies, new agreements on intellectual property rights, investment regulations, and services, and an expanded and improved dispute-settlement mechanism, among other issues. These important changes bear considerable promise of raising global welfare, as demonstrated in several computational exercises (Harrison, Rutherford, and Tarr, 1996, 1997; Francois, McDonald, and Nordstrom, 1996; Brown, Deardorff, Fox, and Stern, 1996), though such gains would be unevenly distributed across countries.

For purposes of modeling the results of the Uruguay Round, our approach focuses on three policy components. The first is to incorporate the trade-liberalization commitments concluded in agricultural markets and scheduled to be phased in over 5-10 years (Hathaway and Ingco, 1996; McDougall, 1997). In addition to some tariff cuts, this liberalization was accomplished by means of tariffication of quantitative import restrictions and establishment of bound ceilings for the new tariffs. These maximum bindings should have a significant liberalizing impact, as demonstrated in Martin and Francois (1997). Further, important commitments were made to reduce both expenditure on subsidized exports and the volume of subsidized exports, though these commitments vary considerably by commodity. Finally, fairly weak commitments were reached with respect to reducing domestic support levels in agriculture.

It is evident that the effects of these changes in agricultural support policies should include higher global prices for farm goods, representing a terms-of-trade gain (deterioration) for agricultural exporters (importers). Further, there should emerge significant pressures to reallocate resources out of agriculture in inefficient nations, such as Japan, as domestic prices fall. Accordingly, our model anticipates both beneficial allocative impacts and sizeable terms-of-trade impacts with varying welfare implications across nations. These effects should grow over time, both because the policies are scheduled to be phased in gradually and because capital should flow internationally in response, thereby raising the elasticity of agricultural supply functions.

The second component is the import liberalization negotiated in non-agricultural merchandise sectors, primarily manufactures. Participants in the UR undertook a significant cut in bound tariff rates in manufactured goods, with the cuts averaging around 33% from their pre-UR levels.

The final component is the liberalization of export restraints. Most important here is the scheduled elimination of the Multi-Fiber Arrangement (MFA), a comprehensive set of export quotas in textiles and apparel. The MFA quotas are negotiated annually between the importing nations, such as the United States, EU, and Japan, and major developing-country exporters, such as China, Hong Kong, Thailand, Indonesia, Malaysia, and India. These VERs transfer the quota rents to exporting firms or governments. Accordingly, their impacts include high support prices in the importers, limited export growth but significant rents accrued by major exporters, suppressed international prices for textiles and apparel, and effective exclusion of other potential exporters from the system. Under terms of the UR, the quotas are to be phased out by the year 2005 through country-specific scheduled growth rates in allowable imports, ultimately resulting in free global trade in apparel and textiles. Therefore, as market access improves there should be significant gains in importing nations accruing from lower consumer prices and rationalized production and in exporting nations with access to larger markets. Some countries that currently benefit from rent transfers may end up worse off.

Beyond the MFA, the model takes account of the global structure of export taxes that will emerge after implementation of the UR. Further, some production subsidies and most export subsidies are to be scaled back in manufactures as a result of the agreement on allowable subsidies. Again, we anticipate efficiency gains in countries that remove their subsidies, though terms-of-trade impacts could be harmful for significant importers of subsidized merchandise.

To model the UR in the CGE context, we use explicit subsidy, tariff, and tax data across sectors or implicit price-equivalent tax wedges in agriculture, the MFA, and other NTBs that are scheduled for liberalization. These data are taken from the Global Trade and Production (GTAP) database (McDougall, 1997). These price measures are then removed or modified appropriately, using each policy component singly and all of them in a joint UR "package." Note that the full UR would have impacts that go beyond those modeled here, due to its inclusion of dispute settlement reform, intellectual property rights, and services.

2.c. The Potential for Offsetting Green Trade Restrictions

In this section we discuss the possibilities for OECD countries to employ reactive import tariffs and export subsidies to counter the impacts of self-imposed carbon taxes on the trading positions of their affected industries.

Several excellent reviews in the literature explain the institutional background for environmentally driven trade policies (Esty 1994; Low 1992; Anderson and Blackhurst 1992; Charnovitz 1992). Here we briefly discuss WTO rules that are relevant for the current issue. The question we address is whether there might be authority under the multilateral trading system for the OECD countries to erect trade restrictions against non-OECD exporters in order to offset the competitiveness impacts of carbon taxes.

Any tariffs imposed for this purpose would, in principle, contravene the fundamental WTO principle of non-discrimination. Countries are obligated to provide most-favored-nation (MFN) treatment to all WTO members. Moreover, such tariffs likely would violate commitments made by importers not to raise import taxes above bound levels. Finally, the rules and obligations of the trading system have consistently been interpreted to apply only to characteristics of products themselves, not to the processes by which they are made. Tariffs to offset cost differences, even if regulatory in nature, are discouraged because of the potentially damaging impacts they could have on trade. Regarding export subsidies, WTO procedures prohibit their use if they are provided on a sector-specific basis, which would almost certainly be the case in the present situation. Thus, basic WTO rules provide formidable obstacles to the adoption of such "green tariffs."

However, three potential avenues arise within the WTO rules to accommodate the OECD countries on this score, should they decide to pursue offsetting tariffs (Hoekman and Kostecki, 1995). These mechanisms are summarized in Table 1. First, under Article XXV of the GATT, as reaffirmed by Article IX of the WTO, OECD countries could petition for a waiver of their MFN obligations and tariff bindings, arguing that offsetting taxes on energy-intensive traded goods are necessary to correct trade difficulties associated with "exceptional circumstances," in this case the carbon taxes. However, Article XXV waivers must be approved by the majority of WTO members. Because these "green tariffs" would be imposed against a broad range of developing-country exporters, such approval is unlikely. Further, waivers must have an expiry date, which is inconsistent with the permanent imposition of carbon taxes.

A second approach would be to claim a general exception under Article XX of the GATT, folded into the WTO. Such exceptions are measures required to safeguard public health, natural resources, and the operation of domestic laws. In principle, the measures taken must not be discriminatory, nor may they be a disguised restriction on trade. Countries invoking Article XX must adopt the least trade-distorting mechanism that is feasible for achieving the objective. The OECD countries might argue that to support the operation of their carbon taxes, designed to promote public health, offsetting trade restrictions are required because international emissions leakages would otherwise frustrate the intent of the program. While such restrictions would discriminate against non-OECD nations, such discrimination is not without precedent. However, their imposition on the basis of foreign production processes is problematic in WTO terms. Nor would they be the least trade-distorting approach, in principle. Direct compensatory transers contingent on reduction in greenhouse gas emissions would be a more direct and efficient mechanism, to the extent that they are politically feasible. Ultimately, a dispute-settlement panel would need to rule on the legitimacy of the general exception claim. The history of such claims lends some credence to the use of Article XX as a safeguard against the trade effects of carbon taxes.

Finally, OECD countries may be attracted to the third approach, which is to argue that the *absence* of carbon taxes in developing countries constitutes an unfair and countervailable export subsidy. The basis of this claim must come from a new and far-reaching interpretation of the WTO Agreement on Subsidies and Countervailing Measures. The Agreement contains a secondary definition of a subsidy that includes "government revenue that is otherwise due, is foregone, or not collected." A narrow interpretation of this clause would limit claims to cases in which taxes are levied but not collected. A broad interpretation would expose the absence of environmental taxes to charges of unfair subsidization (Esty, 1994). Moreover, it could be argued that the absence of environmental taxes constitutes the provision of an environmental resource, free of charge, to producing interests. This latter argument would be particularly significant in that it could, perhaps, sustain a claim that the subsidy is sectorally biased because it would be effectively larger for energy-intensive sectors.

In our view, both the Article XX approach and the definition of lax environmental regulation as a countervailable subsidy, even if the underlying regulations are defined by the countervailing importing nations, is potentially defensible under WTO rules. Undoubtedly, non-OECD members of the WTO would resist such interpretations and, indeed, such trade restrictions would bear considerable risks for the international trading system. Our interest here, however, lies in computationally assessing their implications. Thus, in the next section we compute the effects of "green" border taxes levied on the carbon content of traded goods. We also calculate the impacts of quantitative trade restrictions (import quotas and VERs) aimed at preventing expanding imports from non-Annex I countries in response to new carbon taxes.

3. Model Structure and Parameterization

With this background, we turn now to specific features of our analytical framework.

3a. An Overview of the CGE Model and Its Implementation

The general equilibrium model we have developed for this analysis is derived from earlier analysis of the economic impacts of the Uruguay Round (Harrison, Rutherford and Tarr, 1997). A number of extensions of the early model have been undertaken to accommodate a consistent representation of energy markets in physical units. (For details of the dataset construction, see Rutherford and Babiker, 1997.)

We use a static, 26-region, 13-sector CGE model(3) of the global economy to assess the impacts of policy reform. The regional aggregation covers many individual OECD countries, including the United States, Japan, the European Union (EU12), Canada, and Australia as well as many non-OECD countries that are central to the FCCC process, such as China, Brazil, and India. Table 2 lists the specific countries and commodities that are represented in our model.

The sectors in the model have been chosen to identify as many carbon-intensive sectors for which region-specific and industry-specific data can be obtained(4). The energy goods identified in the model include coal (COL), gas (GAS), crude oil (CRU), refined oil products (OIL) and electricity (ELE). This disaggregation is essential in order to distinguish energy goods by carbon intensity and by the degree of substitutability. In addition, the model features important carbon-intensive and energy-intensive industries, which are potentially those most affected by carbon abatement policies, such as Iron and steel (ORE), chemical products (CRP), non-ferrous metals (NFM), non-metallic minerals (NMM), pulp and paper (PPP), and trade and transportation services (TRN). The remainder of the economy is divided into agricultural production (AGR) and other goods (Y).

Table 3 lists base-year gross domestic product (primary factor earnings) by sector and region. (This data set is based on GTAP statistics, which are compiled on market exchange rates, as is evident from the relative size of the US and China.)

Primary factors include labor, capital, land and fossil-fuel resources. In our calculations, we typically treat labor and capital as perfectly mobile across sectors within each region but internationally immobile. In one form of sensitivity analysis we evaluate the implications of international capital mobility as an approximation for the ultimate effect of international financial capital flows induced by uncoordinated carbon abatement policies.

The production functions assumed in each sector allow sufficient levels of nesting to permit substitution between primary energy types, as well as substitution between a primary energy composite and secondary energy (electricity). Figure 1 illustrates the nesting structure employed for production sectors other than fossil fuels. Output is produced with fixed-coefficient (Leontief) inputs of intermediate non-energy goods, and an energy-primary factor composite. The energy composite is in turn produced with a constant-elasticity-of-substitution (CES) function of a primary-energy composite and electricity. The primary-energy composite is then a function of coal, crude oil, refined oil and natural gas. The value-added composite consists of a Cobb-Douglas aggregation of labor, capital and land.

Final demand has the structure shown in Figure 2. Utility in each country is a CES function of a consumption composite and an energy good. The consumption composite is then a nested-CES function of the energy composite described above and the 12 non-energy goods in the model.

The model's equilibrium framework is based on final demands for goods and services in each region arising from a representative agent. Final demands are subject to an income balance constraint with fixed investment. Consumption within each region is financed from factor income, taxes and exogenously specified capital flows. Taxes apply to energy demand, factor income and international trade, and these finance a fixed level of public provision. The government budget is balanced through lump-sum taxes.

Energy goods and other commodities are traded in world markets. Crude oil is imported and exported as a homogeneous product, subject to tariffs and export taxes. All other goods, including energy products such as coal, electricity, and natural gas, are characterized by product differentiation with an explicit representation of bilateral trade flows calibrated to trade flows for the reference year, 1992.

Energy products (refined oil, coal, natural gas, and electricity) are sold at different prices to industrial customers and final consumers. The physical quantities of sectoral and final energy demand are calibrated to the OECD/IEA Energy Balances and Statistics.

3b. Algebraic Structure

The model includes two types of production functions, those for fossil fuels (crude oil, coal, and natural gas), and those for other goods. An index, Y_{ir}, characterizes the level of production for good i in region r, which (except for crude oil) is allocated to export and domestic markets according to a constant elasticity of transformation function:

$$Y_{ir} = \left[\theta_{ir} \left(\frac{D_{ir}}{\bar{D}_{ir}} \right)^{\eta} + (1-\theta_{ir}) \left(\frac{X_{ir}}{\bar{X}_{ir}} \right)^{\eta} \right]^{1/\eta}$$

Production of goods requires inputs of non-energy goods, energy-goods (oil, coal, gas, and electricity), and primary factors (labor, capital, and land). At the top level, non-energy goods and a constant-elasticity composite of primary factors and energy enter in fixed proportions:

$$Y_{ir} = \min \left[\min_{j} \left\{ \frac{X_{jir}}{\bar{X}_{jir}} \right\}, \left(\alpha_{ir} E_{ir}^{\rho} + (1-\alpha) V_{ir}^{\rho} \right)^{1/\rho} \right]$$

in which the exponent determines the elasticity of substitution between primary factors and energy, $\sigma = 1/(1-\rho)$. Within this function, composite energy E_{ir} is in turn a nested constant-elasticity composite of electric and non-electric energy inputs, and V_{ir} is a Cobb-Douglas composite of capital, labor, and land.

The representative consumer in region r allocates income across alternative goods to solve:

$$\max U_r(c) = \left(\alpha \prod_{i \in E} C_{ir}^{(\theta, \rho)} + (1-\alpha) \prod_{i \notin E} C_{ir}^{(\theta, \rho)} \right)^{1/\rho}$$

$$s.t. \sum_i p_{ir} C_{ir} = M_r - p_r^G \bar{G}_r - p_r^I \bar{I}_r$$

in which E is the set of energy goods entering final demand (oil, coal, gas, and electricity), and M_r is region r factor earnings and tax revenue. Final demands for goods and services exhaust income net of expenditures on public goods and final investment, both of which are held constant for our analysis.

Final and intermediate demands are nested CES composites of domestic and imported varieties:

$$C_{ir} = \bar{C}_{ir} \left(\alpha \left(\frac{c^D_{ir}}{\bar{c}^D_{ir}} \right)^{\rho} + (1-\alpha) \left[\sum_{s \neq r} \theta_s \left(\frac{c^M_{isr}}{\bar{c}^M_{isr}} \right)^{\gamma} \right]^{\rho/\gamma} \right)^{1/\rho}$$

Here, the specific choices over domestic and imported demands are made to minimize unit cost (gross of applicable taxes):

$$\min p^D_{ir} c^D_{ir} + \sum_s \left(p^X_{is}(1 + t^X_{isr}) + \phi_{isr} p^T\right)(1+t^M_{isr}) c^M_{isr}$$
$$s.t. \quad f(c^D_{ir}, c^M_{isr}) = C_{ir}$$

In this equation, t^X and t^M are export and import taxes, and p^T is the cost of international transportation services. A similar equation characterizes imports and domestic inputs into intermediate inputs, investment and public services.

3c. Base-Year Energy Statistics

Much of the work involved in constructing a general equilibrium model centers on the assembly and reconciliation of base-year data from a variety of potentially incompatible sources. Details of this work are provided in Rutherford and Babiker (1997), but we provide here a summary of the approach. We begin from a benchmark in which energy flows and prices are consistent with the energy statistics and all equilibrium conditions are reconciled through adjustment of demands for the composite non-energy good, *Y*.

Table 4 presents the implied carbon content of four energy-intensive products included in our dataset. For each of these goods (electricity, iron and steel, chemical products, and pulp and paper), the benchmark statistics specify the direct carbon content (calculated from exajoule inputs of oil, coal, and gas). These values are reported in the columns titled "DIRECT". We then use the input-output and trade statistics in the model to compute "TOTAL" embodied carbon. These values are computed by solving a large linear system of equations that incorporate direct and indirect carbon inputs in the production of goods in different regions. Given benchmark statistics for these variables:

D_r = matrix of domestic inputs per unit output

$M_{rr'}$ = matrix of region r inputs per unit output in region r'

c_r = vector of direct carbon inputs for region r

we can compute

x_r = carbon intensities for goods produced in region r as shown in Table 4.

The value of x is that which solves the following system of linear equations(5):

$$x_r = c_r + D_r^T x_r + \sum_{r'} M_{rr'}^T x_{r'}$$

Table 5 reports base-year carbon trade through fossil fuels. Crude oil, which has by far the largest trade flows in value terms, accounts for a large amount of carbon, but coal trade is also significant because of the lower price and the higher carbon content per energy unit.

Table 6 uses the calculated carbon contents, both direct and total, to evaluate the magnitude of embodied carbon trade by region and commodity type. Here, EIS is an aggregate of the energy-intensive goods identified in Table 2.) Comparing the left three columns in Tables 6 with Table 5, it is clear that energy trade flows are the dominant carbon flow in the global economy, but that carbon trade embodied in goods is important as well. Trade in energy-intensive goods takes on particular significance because it is a certainty that fossil fuel imports would be subject to a carbon tax at the border, but energy-intensive goods may not be easily taxed.

The right half of Table 6 reports embodied carbon after implementation of the UR process and a subsequent 25% abatement in carbon emissions by the OECD countries. Comparing corresponding entries on the two sides of this table provides a fairly clear insight into the specific goods and regions through which carbon leakage can take place.

4. Abatement Scenarios and Results

4.a. Basic Simulations

We begin with a set of simulations examining the economic effect of the Uruguay Round. First, AGR embodies solely the agricultural liberalization and support reduction in the UR. It includes reform of export taxes and subsidies on agricultural goods. Second, VTA considers only the import component of the UR, including tariff cuts in manufactures. Third, VER accommodates the liberalization of export barriers agreed in the UR. This case includes elimination of the export VERS within the MFA. The fourth scenario, UR, calculates total gains from the Uruguay Round. Note that the impacts in UR are not simply sums of the component reforms because there are interaction effects in these reforms. In each case, the computations refer to long-run effects after full phase-in of the trade reforms, assuming no international capital mobility. Our interest here lies in exploring the sources of gains from the UR for regions of the model.

The UR decomposition results are presented in Table 7. The first row indicates the change in global emissions of greenhouse gases, computed as a percentage of OECD emissions in the benchmark year, 1992. Emissions could rise or fall as a result of trade liberalization because of domestic scale changes and international shifts in output. Note that agricultural reform slightly lowers emissions, while a more substantial cut obtains from the removal of voluntary export restraints. On the other hand, the UR cuts in import tariffs could raise global emissions by 5.5 percent of the benchmark level. This result stems from an expansion of production in energy-intensive goods due to greater competition, with much of this output going to developing countries who will cut their tariffs by relatively larger amounts. Note further that in this scenario there is a 1.3 percent rise in the global oil price because of higher demand for petroleum. In the total UR package, emissions rise by 2.8 percent and the oil price rises by 0.8 percent. In this context, it seems that trade liberalization bears potential for raising greenhouse-gas emissions, though the relative magnitude is small.

Table 7 also reports impacts of the Uruguay Round on the terms of trade, defined as the trade-weighted change in the price of OECD exports to non-OECD countries relative to the trade-weighted price of non-OECD exports to the OECD, expressed as a percentage change from the pre-UR level. Each component of the Uruguay Round tends to lower the OECD's terms of trade, with the combined impact being a cut of 2.9 percent. Further, we compute the percentage of the OECD labor force that must adjust employment between sectors as a result of trade liberalization. Tariff reform in scenario VTA tends to place the strongest pressure on OECD labor markets, largely because significant tariff cuts in non-OECD nations generate strong international shifts in output.

The last five rows list impacts on economic welfare from trade reforms in the Uruguay Round. It is interesting to observe that aggregate welfare in the non-OECD countries declines in the cases of agricultural reform and VER cuts. In the former case this is due primarily to higher import prices of agricultural goods while in the latter case it is due to elimination of MFA export-quota rents. These results vary sharply across non-OECD countries, however, depending on each country's status as an agricultural net importer or as a participant in the MFA. Tariff cuts generate significant welfare gains for both the OECD and non-OECD countries, with the latter group enjoying a 2.3 percent rise in annual welfare, measured as equivalent variation as a percentage of initial consumption, in scenario VTA. The Uruguay Round as a whole raises annual welfare in the OECD nations by 1.2 percent overall and in the non-OECD nations by 1.7 percent overall. Again, these impacts vary by country, as is shown below in Table 9.

The effects of the full Uruguay Round are carried over to Table 8, where we present our central simulation results. These central cases assume no international capital mobility, a unitary elasticity of global oil supply, intermediate-range Armington elasticities of substitution between domestic goods and imports (8.0) and between regional import sources (16.0), and an elasticity of substitution in demand

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between energy sources of 0.5. We first calculate impacts of CTAX, or the imposition of a carbon tax alone without prior UR liberalization. In this scenario, permits are allocated to OECD countries in proportion to their 1992 emissions. The permits, which may be traded in the model among OECD countries, mandate cutbacks sufficient to reduce *global* carbon emissions by an amount equal to 25% of base-year (1992) levels in the OECD. That is, in the model, permits are endogenously issued under any policy change in order to meet this OECD-scaled goal on a global basis. We also report scenario URCT, which combines both the overall UR liberalization and carbon-tax policies. It is important to combine the programs because interaction effects mean that their impacts are not strictly additive.

The first result of note regarding CTAX is that the carbon taxes must be set to engineer a 28.9% cut in OECD omissions in order to achieve a 25% global cut. This is because the taxes generate a shift in production of energy-intensive goods to the non-OECD countries, raising emissions in those regions, and the OECD must abate by more than 25% to compensate. This carbon leakage rate of 15.5% is the increase in non-participant emissions as a percentage of target abatement by participants.[6] We also compute the implied price of carbon permits, in dollars per ton, which may also be interpreted as the required equivalent carbon tax. In the case of CTAX, this price is $223. Total trade in permits is valued at $18.9 billion. Note that the abatement program reduces the global oil price by 12.9%. Partly for this reason, it also raises raise the OECD's terms of trade by 1.8%. This price change is also due to rising prices of OECD exports and falling OECD import demand. The decline in import demand is associated with the reduction in OECD consumption of $72.4 billion per year, or 0.7% of initial consumption. Welfare in the non-OECD countries falls by relatively more, with a decline in EV of 0.9%. Thus, the OECD nations are capable of shifting a significant portion of the welfare burden of the carbon taxes onto non-participant countries. For both regions, the fall in welfare is more than half the gain from the Uruguay Round.

Scenario URCT combines the Uruguay Round and the carbon tax. It is interesting to observe that, despite the fact that the UR taken alone raises global emissions by 2.8%, it interacts with the OECD abatement program to reduce the leakage rate to 9.1% and mandate a smaller net cutback by the participants.[7] There is a higher permit price in the joint scenario and a greater value of carbon trade. The impact on the OECD terms of trade is dominated by trade liberalization, generating a net fall of 1.1%. Overall welfare rises by 0.6% in the OECD nations and by 0.4% in the non-OECD nations. However, the calculations suggest that the carbon taxes cut OECD gains from the Uruguay Round in half and the non-OECD gains by 76%.

4.b. Offsetting Environmental Trade Restrictions

In this section we study the implications of trade restrictions set by OECD countries to counter the trade effects of the carbon taxes. It should be clearly noted that each case includes URCT, so the impacts computed jointly incorporate the Uruguay Round, carbon taxes, and offsetting trade barriers. The first scenario modeled is IOT, in which import tariffs against non-OECD exports are set endogenously on a bilateral basis, in proportion to total embodied carbon in the source country and the carbon permit price in the OECD. That is, the OECD countries continue to place taxes on their own total (direct plus indirect) emissions but combine these with tariffs on the net imports from non-OECD countries of embodied carbon, calculated with input-output coefficients. Both taxes are set endogenously in order to achieve the global target in reduced emissions. Looking at Table 4, the countries with highest carbon intensities, such as China, India, and the Former Soviet Union, would face the highest tariffs to the extent they are net exporters of carbon (Table 6).

The other two trade-restrictive scenarios are simpler. In MQ, import quotas are set to maintain imports of energy-intensive goods from non-OECD countries at their pre-carbon-tax levels, with the quota rents accruing to OECD importers. In EQ, voluntary export restraints are negotiated with the non-OECD nations sufficient to return their exports to their pre-carbon-tax leves, with the VER rents accruing to the exporters.

Returning to Table 8, we find in our central case that the import tariffs (IOT) allow a substantial shift of the abatement burden to developing countries. The required OECD cutback is now only 24.9% and there is actually a negative leakage rate, meaning that emissions are reduced overall in the non-OECD regions.

There is a substantially lower permit price of $209. In this case, the OECD's terms of trade improve by 0.7%, meaning that the offseting tariffs more than compensate for the impacts of trade liberalization and carbon taxes. This policy raises the OECD's welfare gain to 0.9% of base consumption and reduces the region's gains from the Uruguay Round by just 25%. Non-OECD countries, however, absorb a net reduction in welfare of 0.6% of base consumption, meaning that the carbon taxes and tariffs more than offset their gains from trade liberalization.(8)

The quantitative trade restrictions in cases MQ and EQ result in identical OECD cutback rates and nearly identical permit prices and leakage rates. These approaches reduce both the OECD gains and the non-OECD losses from scenario IOT. It is interesting to note that the OECD countries would prefer case IOT, because it shifts some of the tax burden onto non-participants, over MQ and EQ. They would further prefer MQ over EQ because the former arrangement allows them to keep the quota rents. The opposite ranking of these policies pertains in the non-OECD countries. Policy EQ generates a slight gain over URCT, implying that the non-OECD regions might be more agreeable to such trade restrictions if they are granted the available quota rents. However, both MQ and IOT are worse than the case in which OECD imposes taxes on itself without a trade-policy reaction. These findings suggest there is scope for negotiations between the two groups over implementation strategies in the OECD countries, even if there emerge significant political pressures for offsetting trade restrictions.

Table 9 lists welfare impacts by country or region. For example, Korea enjoys a large welfare gain (10.2%) from implementation of the Uruguay Round. The OECD abatement program itself provides an additional gain of 1.1%, primarily because the lower world oil price benefits oil importers, such as Korea. The combined impact is nearly a 12% rise in EV, which is offset somewhat by tariffs on Korean energy-intensive exports in scenario IOT. Malaysia and Philippines have remarkably high gains from the Uruguay Round.(9) In Malaysia's case the gains from the UR are eroded markedly by OECD carbon taxes cum trade restrictions. China's UR gains are more than offset by CTAX alone, though the joint effect is to provide a welfare gain of 0.3%. However, the import tariffs in IOT significantly harm China's export interests and welfare. India also suffers a marked loss from IOT relative to URCT, as do the countries of the Former Soviet Union. Countries that suffer the largest welfare losses from carbon taxes and trade restrictions include Mexico, the rest of South America (including Venezuela), the Middle East and North Africa, and Sub-Saharan Africa (including Nigeria). This finding suggests that a substantial amount of the welfare costs from carbon taxes fall on oil exporters.

Turning to the OECD economies, the United States experiences a small gain from the Uruguay Round but a much larger loss from imposing carbon taxes. Offsetting tariffs in scenario IOT are sufficient to generate a net gain of 0.3%, or fully three times the gain from the UR alone. In contrast, Japan enjoys a large welfare gain from trade liberalization, though these gains are reduced somewhat by the carbon taxes. Carbon import tariffs almost fully restore the gains from the UR. Finally, carbon taxes sacrifice more than half the UR gains for the European Union, with relatively little scope for welfare changes from offsetting trade restrictions agains non-OECD regions.

In the final four tables we undertake policy analysis under varying assumptions regarding key variables and parameters. In Table 10, capital is allowed to be fully mobile across countries and regions, resulting in equalized international capital returns. In comparison with no capital mobility (Table 8), this treatment raises emissions from the UR to 3.6% of the benchmark but generates slightly larger welfare gains for both the OECD and the non-OECD groups. Capital mobility tends to raise both leakage rates and the price of emissions permits (carbon taxes). It has no noticeable effects on welfare in the OECD countries but marginally accentuates the effects in the non-OECD countries.

In Table 11 the elasticity of oil supply is reduced from 1.0 to 0.5. The impacts include a markedly larger reduction in oil prices, higher required OECD cutbacks in emissions, and higher permit prices. Welfare gains are unchanged or slightly higher for the OECD group but gains are noticeably smaller (or losses larger) for the non-OECD group. In contrast, in Table 12 the elasticity of oil supply is raised to 5.0. In this case oil prices do not fall by much and permit prices are lower. Welfare changes are more favorable for the non-OECD nations.

Finally, in Table 13 we constrain all markets to be characterized by low elasticities, again not permitting international capital flows. With limited substitution in energy demand, inelastic oil supply, and low substitution possibilities among regional import sources, welfare gains from trade liberalization are muted for both regions. When carbon taxes are introduced, oil prices fall considerably and there is a substantial increase in the implicit carbon tax, rising to levels above $400 per metric ton. In this case, the combined impacts of the Uruguay Round and the carbon taxes reduce overall welfare in both the OECD and the non-OECD groups. The former countries are able to achieve a positive net gain from imposing offsetting tariffs in scenario IOT, though this dramatically raises welfare losses experienced in the non-participant nations.

5. Concluding Remarks

In this paper we assessed the trade-related impacts of abating greenhouse-gas emissions with carbon taxes imposed by the OECD countries. We considered the prospects for border measures within the WTO rules and concluded that the adoption of border taxes is a plausible consequence of unilateral OECD abatement.

In the second half of the paper we reported on static general equilibrium calculations of the economic effects of a range of trade-policy reforms, including the recently concluded Uruguay round as a metric. We find that carbon taxes, with or without associated border measures, have substantial impacts on the global trading system, of a magnitude comparable to the UR itself. These findings leave us with some concern about the limited extent to which the trade-related effects of carbon abatement have been studied, in view of the fact that an agreement is scheduled to concluded in Kyoto by the end of 1997.

Our results point out that achieving agreement on mechanisms for reducing carbon emissions strictly within the OECD nations will continue to be elusive because there would emerge substantial outward shifts in production and trade of energy-intensive products. These shifts inevitably would raise pressures for offsetting trade restrictions against those nations that do not participate in the cutbacks. Our calculations indicate that, if enacted, these follow-on trade barriers bear considerable potential to redistribute welfare gains among countries and to overwhelm gains from global trade liberalization. Accordingly, it seems important to pursue a joint implementation strategy in which the non-OECD countries also commit to reduced emissions, with compensatory transfers made to promote compliance.

We view the analytic work in this paper to provide a starting point for these policy issues. In future work, we plan to extend our model to evaluate a range of related issues, including the design of abatement coalitions in a global context.

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Table 1. Potential WTO Provisions for Permitting Green Trade Restrictions

1. OECD petitions for a waiver of MFN obligations and tariff bindings under Article XXV of GATT and Article IX of WTO.

Logic: Required to support environmental policy and to deal with "exceptional circumstances."

Precedent: U.S. Agricultural waiver of 1955.

Difficulties: Requires majority approval of WTO members and must have expiry date; inconsistent with permanent carbon taxes.

2. OECD claims a general exception against MFN obligations and tariff bindings under Article XX of GATT, folded into WTO.

Logic: Article XX measures are those required to safeguard public health, natural resources, national security, the operation of domestic laws, and others. Could argue for an exception to support public health, given leakages, or national security.

Precedent: Many such claims have been made and countries need only claim Article XX applies, subject to dispute settlement, which generally disallows such claims.

Difficulties: - measure cannot violate national treatment;

- measure must be non-discriminatory (MFN);

- measure must be "least trade-restrictive" available;

- focuses on process of production.

3. Invoke Agreement on Subsidies and Countervailing Measures

Logic: Issue a broad interpretation of subsidy definition to include "government revenue that is otherwise due, is foregone, or not collected." Claim that absence of environmental taxes constitutes unfair and sector-specific subsidies. Also that it provides a free environmental resource to producing interests.

Precedent: None

Difficulties: - questionable interpretation of subsidy;

- would be resisted by non-OECD nations;

- implications for trading system.

Table 2: Countries, Regions, and Sectors in the General Equilibrium Model

Country or Region		Commodities	
AUS	Australia	COL	Coal
NZL	New Zealand	CRU	Crude Oil
JPN	Japan	OIL	Refined Oil Products
KOR	Republic of Korea	GAS	Natural Gas
IDN	Indonesia	ELE	Electricity
MYS	Malaysia	ORE*	Iron & Steel
PHL	Philippines	CRP*	Chem, Rubber & Plast
SGP	Singapore	NFM*	Non-ferrous Metals
THA	Thailand	NMM*	Non-metallic Mineral
CHN	China	PPP*	Pulp & Paper
HKG	Hong Kong	TRN*	Trade and Transport
TWN	Taiwan	AGR	Agricultural Goods
IDI	India	Y	Other Goods
CAN	Canada		
USA	United States		
MEX	Mexico		

*Energy-Intensive Goods

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ARG	Argentina
BRA	Brazil
CHL	Chile
RSM	Rest of South America
E_U	European Union 12
EU3	Austria, Finland, & Sweden
FSU	Former Soviet Union
MEA	Middle East & North Africa
SSA	Sub-Saharan Africa
ROW	Rest of World

Table 3: GDP by Sector

(billions 1992 US$)

	Y	CRU	COL	GAS	OIL	EGW	PPP	ORE	CRP	NFM	NMM	AGR	TRN
AUS	158.7	1.9	2.4	1.2	2.5	2.5	4.6	5.4	5.1	2.0	2.2	20.5	58.8
NZL	19.0	0.2	0.1	0.7	0.4	0.2	1.1	0.6	0.8	0.2	0.3	4.9	6.6
JPN	1922.8	0.4	0.2	1.1	17.1	23.8	63.0	118.2	111.1	16.8	38.6	186.2	816.2
KOR	141.5	0.0	0.3	0.1	3.4	3.2	3.5	10.1	11.1	1.4	5.2	40.7	47.4
IDN	61.1	5.5	0.4	2.5	0.9	0.4	1.0	1.6	2.8	0.4	0.6	30.1	18.7
MYS	22.1	2.4	0.0	3.5	0.5	0.3	0.6	0.8	1.0	0.1	0.4	10.0	10.9
PHL	14.3	0.0	0.0	0.5	0.6	0.3		0.2	0.7	0.1	0.1	15.0	11.2
SGP	12.6	0.1	1.6	0.3	0.8			0.7	1.5	0.0	0.0	1.1	13.0
THA	34.5	0.2	0.3	1.3	0.8	0.4	0.6	1.0	1.1	0.0	1.0	18.4	28.3
CHN	119.8	10.0	16.1	0.6	1.7	11.1	2.7	2.7	4.5	0.3	2.3	107.3	27.7
HKG	43.1	0.1	0.9	0.9				1.0	0.5	0.0	0.1	0.5	26.6
TWN	97.2	0.0	0.0	0.1	1.1	2.5	3.7	6.9	9.5	1.0	2.8	18.2	40.5
IDI	91.3	1.8	3.4	0.8	1.3	4.8	1.2	2.9	3.2	0.5	0.8	69.3	36.3
CAN	281.3	7.6	1.4	4.6	1.8	8.1	17.7	10.6	13.7	3.7	3.5	34.8	147.4
USA	3396.5	30.6	15.0	23.3	14.9	55.7	109.7	114.5	166.2	16.9	35.9	206.4	1184.8
MEX	133.9	10.5	0.1	0.6	3.3	1.1	3.6	5.3	10.8	1.1	4.8	45.1	84.4
ARG	103.6	2.2	0.0	0.9	0.4	0.7	4.3	10.8	12.5	1.7	3.8	37.6	24.5
BRA	205.6	2.4	0.2	0.5	2.8	6.8	5.6	7.6	13.6	0.9	3.0	45.7	63.1
CHL	15.9	0.0	0.0	0.1	0.1	0.5	0.6	0.4	0.9	1.7	0.3	5.6	7.3
RSM	102.9	13.3	0.5	1.8	2.0	2.2	1.5	1.7	5.1	0.5	1.5	45.6	49.2
E_U	3887.0	11.3	11.1	12.2	58.8	53.6	123.1	174.1	199.6	20.2	45.5	420.5	1665.1
EU3	249.2	0.3	0.2	0.2	2.0	9.0	15.3	16.4	12.6	1.9	5.5	37.0	125.9
FSU	303.1	6.4	3.8	5.8	0.1	5.3	8.3	9.4	10.2	2.8	4.9	30.6	96.1
MEA	352.9	71.3	0.0	8.1	4.9	1.8	5.3	7.1	11.8	0.6	4.1	49.3	89.7
SSA	139.8	11.7	8.1	0.8	2.1	5.5	2.8	3.5	5.1	1.4	1.6	65.8	42.5
ROW	451.4	21.2	10.1	3.4	0.4	5.5	11.9	17.9	23.7	3.8	8.2	121.5	177.6

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Table 4: Direct and Total Open Economy Carbon Intensities for Selected Energy Intensive Commodities

(grams per US$ -1992)

	ELE		ORE		CRP		PPP	
	DIRECT	TOTAL	DIRECT	TOTAL	DIRECT	TOTAL	DIRECT	TOTAL
AUS	4880	4940	190	680	110	400	40	270
NZL	1420	1460	170	520	40	240	10	170
JPN	1030	1050	90	210	80	180	20	100
E_U	1560	1590	80	250	100	290	20	160
EU3	380	430	70	210	70	230	30	160
CAN	1400	1460	160	340	300	500	70	250
USA	3200	3250	70	260	300	580	30	250
KOR	1290	1350	170	590	300	630	60	320
IDN	4020	4060	110	410	430	850	190	
MYS	1910	1950	100	440	120	370	30	260
PHL	1380	1460	130	670	130	450	100	390
SGP	1810	1870	350	260	530		150	
THA	2250	2270	70	570	60	420	50	350
CHN	4670	5070	3040	5070	1090	2590	390	1450
HKG	2390	2510	10	440	50	470	20	250
TWN	1580	1640	120	430	170	490	70	260
IDI	5280	5490	1330	2310	700	1550	260	1130
MEX	2810	2850	180	440	380	600	80	270
ARG	2030	2050	30	110	100	220	10	80
BRA	200	250	200	470	150	300	40	170
CHL	1000	1080	330	580	190	420	70	290
RSM	2040	2100	280	810	200	470	160	460
FSU	14220	14480	2730	4820	3700	6150	450	1890
MEA	3530	3560	80	400	150	440	60	340
SSA	2530	2610	600	1180	200	570	160	500
ROW	7180	7240	690	1360	430	920	120	530

Table 5: Base Year Net Fossil-Fuel Carbon Exports

(millions of metric tons)

	COL	CRU	GAS	OIL
AUS	80.8	-5.0	2.9	2.1
NZL	0.5	-2.0	0.0	0.0
JPN	-71.6	-182.1	-26.3	-35.0
KOR	-19.8	-59.2	-2.6	-0.8
IDN	9.7	28.2	15.9	4.2
MYS	-1.3	18.0	4.8	-3.1
PHL	-0.4	-10.1	-1.3	0.0
SGP	-39.4	25.3	0.0	0.0
THA	-0.3	-11.0	-6.0	0.0
CHN	10.1	8.6	-2.3	0.0
HKG	-6.3	-5.6	0.0	0.0
TWN	-14.6	-19.3	-1.2	-3.2
IDI	-3.8	-25.6	-5.1	0.0
CAN	10.4	17.7	26.9	3.7
USA	62.1	-299.7	-25.3	19.6
MEX	-0.5	60.9	-1.4	-1.9
ARG	-0.7	2.6	-1.0	3.6
BRA	-8.3	-22.4	0.5	0.0
CHL	-0.6	-5.3	-0.6	0.0
RSM	11.6	50.5	1.1	34.0
E_U	-98.3	-399.8	-55.1	16.6
EU3	-8.5	-29.2	-4.3	1.3
FSU	11.5	68.6	39.4	31.9
MEA	-5.4	589.5	20.3	75.5
SSA	34.1	95.8	0.0	0.4
ROW	9.9	169.6	5.8	-154.0

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Table 6: OECD-NonOECD Net Exports of Embodied Carbon

(millions of metric tons)

Key: ELE = Electricity,

EIS = Energy-Intensive Goods,

OTH = All other goods

Net Exports from OECD to Non-OECD countries:

	Base Year			UR + OECD Abatement		
	ELE	EIS	OTH	ELE	EIS	OTH
AUS	1.8		-2.1	-1.1		-3
CAN	-0.5		-3	-2.3		-7.2
EU3	-5.9		-7.2	-6.7		-9.2
E_U	-44.6	-14	-76	-67.1	-18.5	-77.5
JPN	-9.9		-36.5	-12.5		-28.5
NZL	-0.1		-0.3	-0.2		-0.2
USA	-4.8	-0.3	-33.7	-13.6	-0.4	-52.5

Net Exports from OECD to Non-OECD countries

	Base Year			UR + OECD Abatement		
	ELE	EIS	OTH	ELE	EIS	OTH
ARG	-0.7	-0.3	-0.9	-0.5	-0.3	-0.9
BRA	0.5	-3	0.4	0.9	-2.4	0.2
CHL	0.2		0.2	0.3		0.1
CHN	15.8	-0.4	63.4	20.2	-0.4	73.7
FSU	31.5	2	9.9	40.3	2.2	9
HKG	-1	1	4	-0.9	1.3	5.8
IDI	1.6	-0.1	6.6	1	-0.1	11
IDN	-0.2		2.3	0.3		3.6
KOR	-0.1		3.4	1.4		4
MEA	-3.7	0.3	10.2	-0.7	0.4	11.1
MEX	-3	0.2	0.6	-1.9	0.3	0.9
MYS	-0.6		4	1.7		3.6
PHL	-0.4		1.8	-0.1		3
ROW	25.6	11.3	35.3	36.4	13.9	35.3

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RSM	-1	3.2	1.2	0.2	3.6	1.9
SGP	-1.2		4.8	-0.3		3.6
SSA	2.2	0.3	4.9	3.9	0.5	4.9
THA	-0.9	-0.1	3.5	0.1	-0.1	4.8
TWN	-0.6		3.3	1.1		2.8

Table 7: Decomposition of the Uruguay Round

Key:

AGR: Agricultural tariff and subsidy reform

VTA: Import tariff reform

VER: Elimination of the multi-fiber agreement quotas and other voluntary export restraints

	AGR	VTA	VER	Total
Global Emissions	-0.1	5.5	-2.3	2.8
(% of OECD BaU)				
Oil Price (% change)	0.0	1.3	-0.7	0.8
Terms of Trade (OECD/NOECD)	-0.5	-0.8	-1.7	-2.9
Labor Adjustment Index (%)	0.3	0.6	0.3	0.7
OECD Welfare Change ($b)	20.9	84.4	32.1	136.0
Non-OECD Welfare ($b)	-2.7	75.0	-23.0	54.5
Global Welfare Change ($b)	18.3	159.3	9.1	190.5
OECD Equivalent Variation (%)	0.2	0.8	0.3	1.2
NOEC Equivalent Variation (%)	-0.1	2.3	-0.7	1.7

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Table 8: Central Simulation Results

Regional capital markets

Elasticity of oil supply = 1

Armington elasticities = 8 (DM) and 16 (MM)

Elasticity of substitution in energy demand = 0.5

Key:

UR =Uruguay Round (alone),

CTAX =Carbon taxes (alone),

URCT =Uruguay+Carbon tax

IOT =URCT+border taxes based on IO coefficients,

MQ =URCT+import quotas at base year levels for energy-intensive goods,

EQ =URCT+voluntary export quotas a base year levels for energy-intensive goods.

	UR	CTAX	URCT	IOT	MQ	EQ
Global Emissions	2.8	-25	-25	-25	-25	-25
(% of OECD Benchmark)						
OECD Cutback (%)	n/a	-28.9	-27.3	-24.9	-26.1	-26.1
Leakage Rate (%)	n/a	15.5	9.1	-0.5	4.5	4.6
Carbon Permit Price ($/ton)	n/a	223.2	229.7	208.7	220.3	220.4
Oil Price (% change)	0.8	-12.9	-13.6	-15.2	-13.6	-13.6
Terms of Trade (OECD/NOECD)	-2.9	1.8	-1.1	0.7	-0.7	-0.7
Carbon trade ($billions)	n/a	18.9	25.3	0	24.5	24.5
Labor Adjustment Index (%)	0.7	0.2	0.8	1	0.9	0.9
OECD Welfare Change ($b)	136	-72.4	69.7	95.1	79.1	71.2
Non-OECD Welfare ($b)	54.5	-30.9	13.7	-20.9	8.2	16.1

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Global Welfare Change ($b)	190.5	-103	83.3	74.2	87.3	87.3
OECD Equivalent Variation (%)	1.2	-0.7	0.6	0.9	0.7	0.6
NOEC Equivalent Variation (%)	1.7	-0.9	0.4	-0.6	0.2	0.5

Table 9: Regional Welfare Impacts in Central Simulations

Hicksian Equivalent Variations in Income (% of base year consumption)

	UR	CTAX	URCT	IOT	MQ	EQ
AUS	3.8	-0.8	1.6	1.9	1.6	1.5
NZL	0.5	-1.1	-0.6	-0.3	-0.4	-0.5
JPN	3.2	-0.6	2.7	3.0	2.9	2.8
KOR	10.2	1.1	11.7	11.1	11.5	11.7
IDN	6.6	-1.7	3.1	2.3	3.3	3.3
MYS	27.2	-0.4	27.9	21.5	22.4	23.5
PHL	16.4	0.4	17.0	16.1	17.2	17.2
SGP	5.4	-0.7	5.0	3.9	6.0	6.3
THA	9.4	0.0	9.6	8.6	9.2	9.5
CHN	0.6	-0.3	0.3	-3.6	0.2	0.3
HKG	-1.5	-0.3	-1.7	-0.4	-1.5	-1.3
TWN	-0.6	0.8	0.4	-1.3	0.1	0.5
IDI	2.3	-0.1	2.1	1.3	2.3	2.3
CAN	0.6	-1.4	-0.8	-0.2	-0.7	-0.7
USA	0.1	-0.6	-0.4	0.3	-0.3	-0.3
MEX	-0.4	-0.7	-1.1	-1.5	-1.2	-1.0
ARG	0.8	-0.2	0.6	0.8	0.6	0.6
BRA	0.9	0.1	1.1	0.7	0.9	1.0
CHL	-0.6	0.8	0.3	-0.4	0.3	0.4
RSM	0.6	-2.0	-1.8	-2.1	-2.1	-1.4
E_U	1.3	-0.7	0.6	0.5	0.7	0.5
EU3	0.7	-0.4	0.3	-0.5	0.5	0.4
FSU	5.9	-0.2	3.9	3.6	3.8	4.0
MEA	0.2	-5.9	-6.4	-7.7	-6.6	-6.4
SSA	-0.8	-1.7	-2.5	-3.4	-2.6	-2.5
ROW	-2.5	-0.5	-3.1	-4.5	-3.3	-2.9

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Table 10: Simulation Results - International Capital Mobility

Equalized return to capital in all regions.

Key: See Table 8

	UR	CTAX	URCT	IOT	MQ	EQ
Global Emissions	3.6	-25.0	-25.0	-25.0	-25.0	-25.0
(% of OECD Benchmark)						
OECD Cutback (%)	n/a	-29.6	-29.0	-24.9	-27.4	-27.5
Leakage rate (%)	n/a	18.4	16.2	-0.5	9.7	9.9
Carbon Permit Price ($/ton)	n/a	229.8	247.3	208.7	233.4	233.8
Oil Price (% change)	0.8	-13.1	-14.3	-15.0	-14.3	-14.2
Terms of Trade (OECD/NOECD)	-2.8	2.0	-0.7	0.7	-0.3	-0.3
Carbon trade ($billions)	n/a	19.9	27.3	0.0	26.0	26.0
Labor Adjustment Index (%)	0.7	0.3	0.9	1.0	0.9	0.9
OECD Welfare Change ($b)	139.9	-73.0	65.7	96.0	78.3	69.1
Non-OECD Welfare ($b)	58.9	-32.4	16.3	-15.2	9.8	19.0
Global Welfare Change ($b)	198.7	-105.4	82.0	80.7	88.1	88.1
OECD Equivalent Variation (%)	1.3	-0.7	0.6	0.9	0.7	0.6
NOECD Equivalent Variation (%)	1.8	-1.0	0.5	-0.5	0.3	0.6

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Table 11: Simulation Results
- Inelastic Oil Supply

Elasticity of oil supply = 0.5

Key: See Table 8

	UR	CTAX	URCT	IOT	MQ	EQ
Global Emissions	2.3	-25.0	-25.0	-25.0	-25.0	-25.0
(% of OECD Benchmark)						
OECD Cutback (%)	n/a	-30.2	-27.8	-25.3	-26.6	-26.6
Leakage rate (%)	n/a	20.7	11.3	1.0	6.3	6.4
Carbon Permit Price ($/ton)	n/a	246.0	241.9	218.8	231.5	231.6
Oil Price (% change)	0.5	-19.7	-20.3	-21.6	-20.3	-20.2
Terms of Trade (OECD/NOECD)	-2.9	1.8	-1.0	0.9	-0.7	-0.7
Carbon trade ($billions)	n/a	21.6	26.8	0.0	25.8	25.8
Labor Adjustment Index (%)	0.7	0.2	0.8	1.0	0.9	0.9
OECD Welfare Change ($b)	135.7	-73.5	73.2	100.7	83.8	75.4
Non-OECD Welfare ($b)	54.0	-40.7	4.3	-32.6	-1.7	6.8
Global Welfare Change ($b)	189.7	114.2	77.6	68.1	82.1	82.2
OECD Equivalent Variation (%)	1.2	-0.7	0.7	0.9	0.8	0.7
NOEC Equivalent Variation (%)	1.6	-1.2	0.1	-1.0	-0.1	0.2

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Table 12: Simulation Results - Elastic Oil Supply

Elasticity of oil supply = 5

Key: See Table 8

	UR	CTAX	URCT	IOT	MQ	EQ
Global Emissions	3.9	-25.0	-25.0	-25.0	-25.0	-25.0
(% of OECD Benchmark)						
OECD Cutback (%)	n/a	-27.1	-27.1	-24.8	-26.0	-26.0
Leakage rate (%)	n/a	8.4	8.3	-0.8	4.0	4.0
Carbon Permit Price ($/ton)	n/a	194.4	219.5	200.4	210.8	210.9
Oil Price (% change)	1.2	-4.3	-4.1	-6.2	-4.3	-4.2
Terms of Trade (OECD/NOECD)	-2.8	1.7	-1.0	0.6	-0.7	-0.7
Carbon trade ($billions)	n/a	15.7	24.2	21.8	23.4	23.4
Labor Adjustment Index (%)	0.7	0.2	0.8	1.0	0.9	0.9
OECD Welfare Change ($b)	137.4	-72.0	61.3	84.6	69.8	62.5
Non-OECD Welfare ($b)	54.8	-18.6	26.1	-5.9	21.2	28.5
Global Welfare Change ($b)	192.2	-90.5	87.5	78.7	91.0	91.0
OECD Equivalent Variation (%)	1.2	-0.6	0.6	0.8	0.6	0.6
NOEC Equivalent Variation (%)	1.7	-0.6	0.8	-0.2	0.6	0.9

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Table 13: Simulation Results - Low Elasticities

Regional capital markets

Elasticity of oil supply = 0.5

Armington elasticities = 4 (DM) and 8 (MM)

Elasticity of substitution in energy demand = 0.25

Key: See Table 8

	UR	CTAX	URCT	IOT	MQ	EQ
Global Emissions	2.0	-25.0	-25.0	-25.0	-25.0	-25.0
(% of OECD Benchmark)						
OECD Cutback (%)	n/a	-29.8	-28.8	-25.4	-27.0	-27.0
Leakage rate (%)	n/a	19.0	15.3	1.4	8.0	8.2
Carbon Permit Price ($/ton)	n/a	523.2	514.9	429.8	470.8	471.8
Oil Price (% change)	-0.3	-22.1	-22.9	-25.6	-22.8	-22.6
Terms of Trade (OECD/NOECD)	-2.7	2.5	-0.1	5.3	0.5	0.6
Carbon trade ($billions)	n/a	30.8	32.8	0.0	30.8	30.8
Labor Adjustment Index (%)	0.4	0.3	0.6	0.6	0.6	0.6
OECD Welfare Change ($b)	96.1	-146.2	-42.6	32.1	-12.7	-29.9
Non-OECD Welfare ($b)	27.2	-48.1	-27.9	-111.8	-38.2	-21.3
Global Welfare Change ($b)	123.3	-194.2	-70.5	-79.7	-51.0	-51.2
OECD Equivalent Variation (%)	0.9	-1.3	-0.4	0.3	-0.1	-0.3
NOEC Equivalent Variation (%)	0.8	-1.5	-0.8	-3.4	-1.2	-0.6

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Figure 1 Structure of Production (non-fossil fuel production)

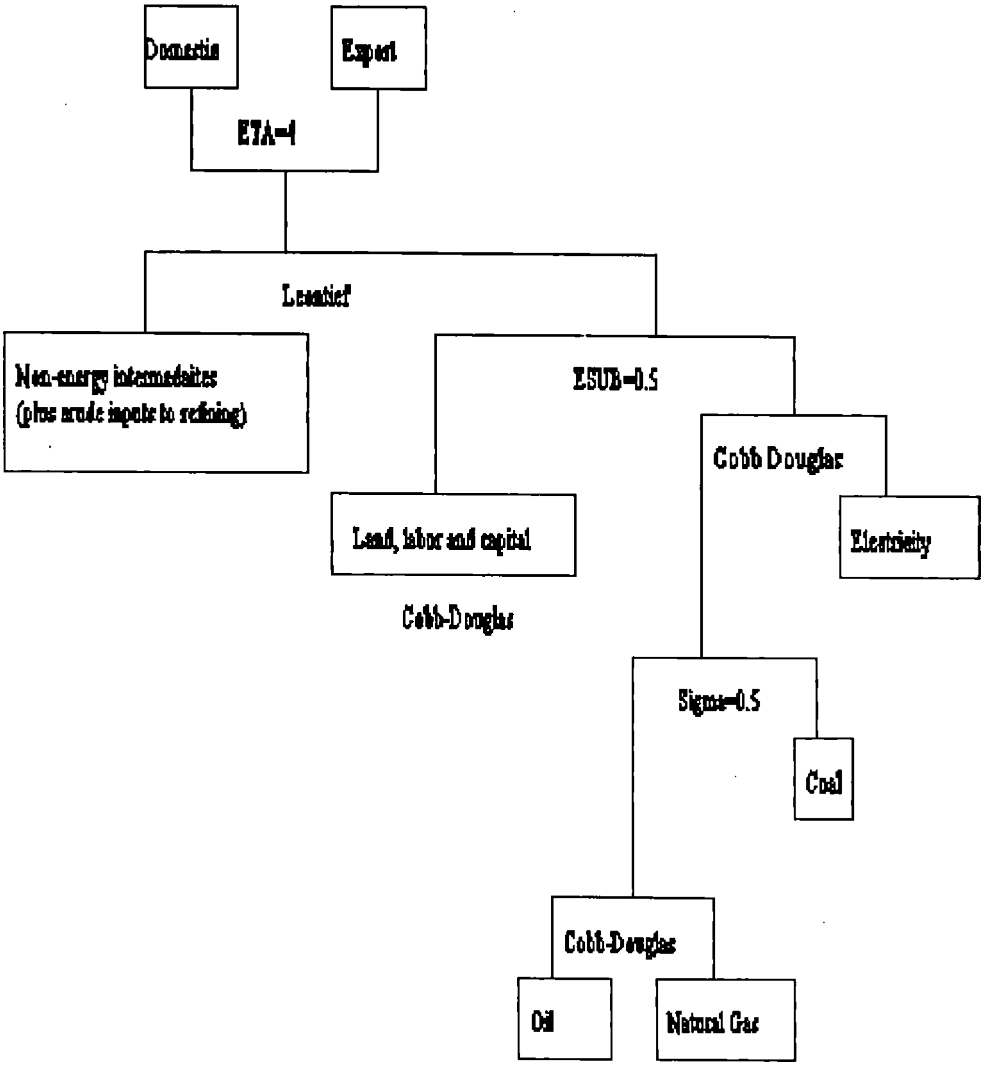

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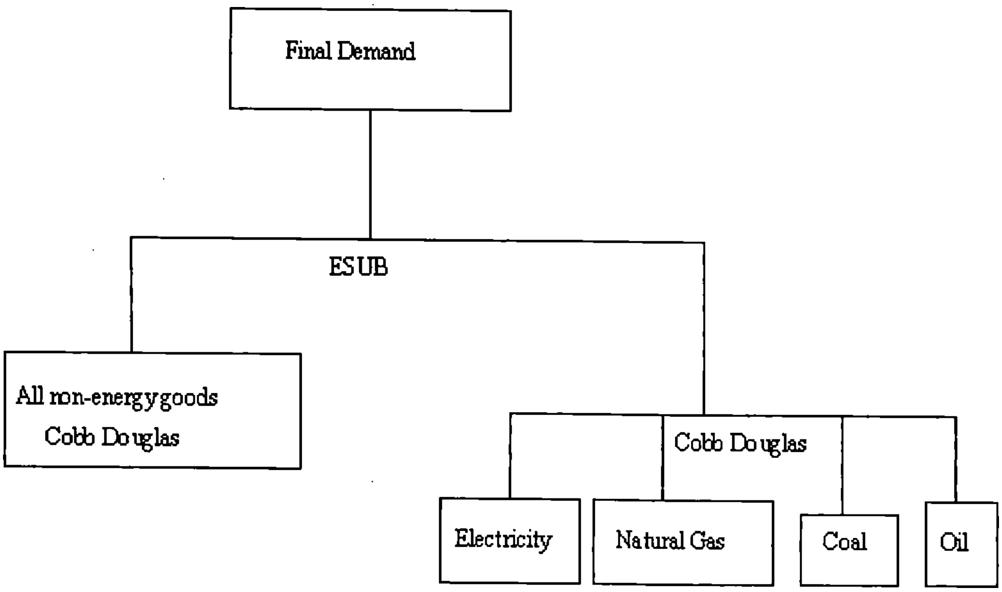
Figure 2 Nesting Structure for Final Demand



1. Annex I countries include the OECD and the countries of the Former Soviet Union. Our computations assume that only the former countries employ the carbon taxes.

2. See *Inside E.P.A.: Weekly Report*, Vol. 18, No. 16, April 18, 1997.

3. The model is formulated using the GAMS/MPSGE software and solvers described in Rutherford (1995,1997).

4. Our primary source for base year (1992) economic statistics is Global Trade Analysis Program (GTAP; see McDougall, 1997), and our primary source for energy demand, supply and price data is the OECD/IEA publications for 1992.

5. We use linear coefficients as a simplifying assumption in making this calculation. In future work we will examine the general-equilibrium issues relating to the definition of the true carbon intensity of imported goods. The marginal carbon coefficient at the border is not a constant value in our general equilibrium model, but this is not incorporated in the input-output estimate.

6. Thus, in CTAX we compute 15.5% = (28.9-25.0)/25.0.

7. This is a second-order effect that could have a variety of sources in the model, which we will explore in future work.

8. Although the effects are not strictly additive, it is a reasonable approximation that CTAX plus IOT, without UR, would lower non-OECD welfare by over 2.0% per year.

9. In fact, these may be implausibly high and raise questions about reported tariff cuts in these countries.

COUNCIL OF ECONOMIC ADVISERS

MEMORANDUM

To: Jeff Frankel August 26, 1997

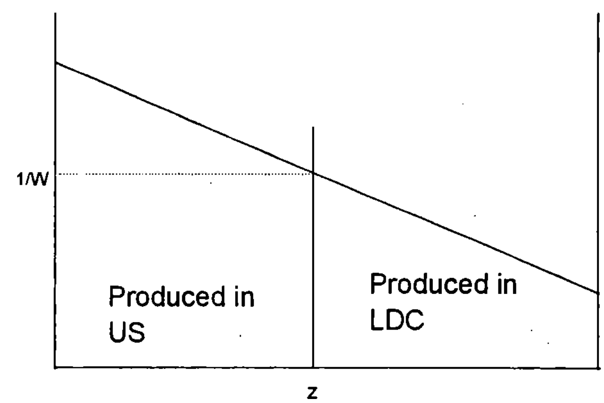
From: Jon Haveman

Subject: Simple model of the economic effects of CO_2 reductions.

I've been thinking about emission reductions as more a decline in technology, rather than as an input. Basically, I was running up against problems with resource allocation/utilization/supply. In other words, what does one do with the fact that when you tax emissions, a country is not using up its allocation of emissions. How one defines a countries allocation is another issue entirely. Also, taking the approach that emissions are an input, you get into rather more complicated models than I think are necessary. I'm not certain of the adequacy of modeling it as technology change, but until you and I have a chance to talk, that's what I'm thinking about.

The first approach is a model with perfect competition, constant returns, a continuum of goods and a single input, labor (among other assumptions). There is some technology for producing each good that differs across countries; we'll play around a bit later with the relationship between technology differences across countries and emissions. Let's just assume 2 countries for the time being, I presume Annex 1 and non-Annex 1 countries. I'll call them the US and LDC, resp.

Figure 1

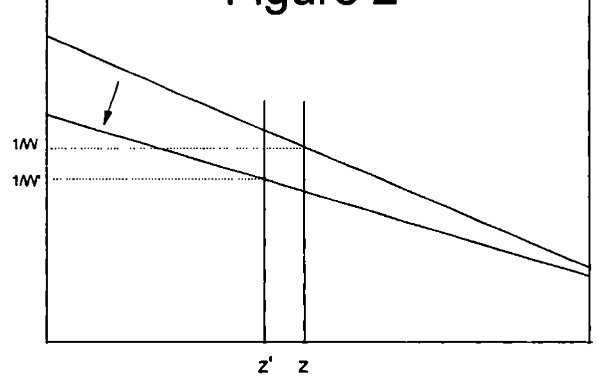


Taking the point of view of the US, rank all goods according to the labor required to produce one unit in the LDC relative to the labor required in the US. Going from left to right in figure 1, the US then has a comparative advantage in the goods on the left and the LDC has a comparative advantage in the goods on the right; there will be one good (z) somewhere in the middle that is produced by both countries. Assuming that US wages are equal to one, the wage in LDC is determined by the inverse of the labor requirements ratio for of good z.

We can now ask of the simple model, what is the impact of a unilateral emission reduction on the part of the US. We want to think about this in several different situations: a) the rate of emissions declines as US comparative advantage declines(from left to right), b) the rate of emissions expands as US comparative advantage declines, and c) the rate of industry emissions is essentially random. This final option is a challenge to model as it will imply a reordering of industries if the rate of emissions is non-monotonic around the jointly produced good. Therefore, instead of random, consider uniform emissions across goods, or, a uniform cost of emission reduction.

A) The US has a comparative advantage in high emission goods. Consider Figure 2. The way to represent a unilateral reduction of emissions in the US is by shifting down the line representing the productivity ratios in a way that is bigger for goods on the left (goods produced in the US) and smaller for goods on the right (goods produced in the LDC). If we hold wages in the US constant, we can make several inferences regarding prices and wages in the LDC. First, prices of goods produced in the US will rise; essentially labor requirements have risen in each industry. Second, wages in the LDC will rise. This second effect is due to a leftward shift in the jointly produced good and a reduction in the productivity ratio for that good. Wages in LDC rise because in order to get labor for production in the new industries, they must be bid away from the old industries. Finally, prices of goods initially produced in LDC will now rise; this being a consequence of the higher wages.

Figure 2

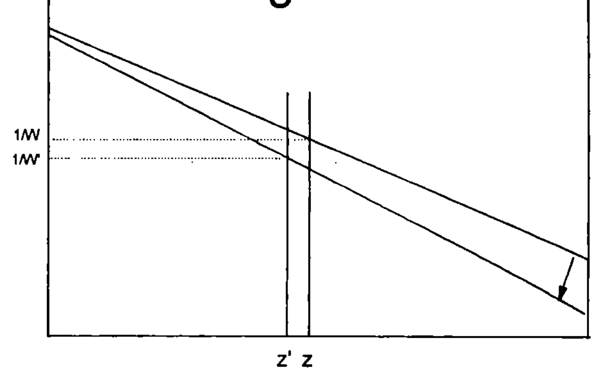


In terms of welfare consequences, prices of all goods have risen relative to US wages. The standard of living(SOL) in the US is therefore reduced. Note that LDC wages need not rise and prices of initially produced LDC goods need also not rise; in this case, the SOL in LDC has also fallen.

B) US comparative advantage in Low emission goods. Consider figure 3. Shift the productivity ratio in a fashion opposite that in figure 2; down more on the right and less on the left. The consequences of this shift are similar, but slightly different from (a). First, prices in US rise, although by less than in (a). Second, wages in LDC rise. Third, prices of initially produced LDC goods rise.

The welfare consequences in this case again represent a loss for US (smaller than in a), but potentially a gain for LDC. This gain comes about from the likely event that wages in LDC rise by more than prices of initially produced US goods.

Figure 3



C) The third case is similar to both A and B, except that the ambiguity surrounding welfare in LDC is greater. It is less clear whether wages in LDC rise by more than prices in US. The US again suffers a decline in welfare.

The second question we might ask of the model is: suppose the US has already limited emissions, what are the welfare consequences of LDC reducing its emissions? The answer is simply the reverse of the above. If the US has a comparative advantage in high emissions industries, then the US will likely gain, if the US has a comparative advantage in low emissions industries, then the US will likely lose. If there is no particular pattern of emissions relative to comparative advantage, then the impact on the US is ambiguous.

I'll turn my efforts towards producing results from a 2-factor model, but I'll be surprised if the intuition turns out to be entirely different. I'm thinking that the only difference will be presence of distributional issues, but we'll see.